Analysis of the Potential for Treated Wastewater Reuse from the MCC Jordan Compact Investment and Implications for the Compact's Economic Benefits

by

Lina Kelpsaite

Dr. Marc Jeuland, Adviser

April, 2016

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment of Duke University

Table of Contents

Tables and Figures

EXECUTIVE SUMMARY

Population growth, widening gap between available water supply and demand, and increasing variability in precipitation patterns create a challenge for many countries to have a reliable water supply for all the human and environmental needs. The Hashemite Kingdom of Jordan, which is one of the most water poor countries globally, is faced with the same challenges. This has resulted in greater competition among municipal and agricultural sectors, as well as groundwater over abstraction and its significant depletion. Water scarcity acts as an important constraint impeding Jordan's growth and development not only in food production but it is also a crucial factor of health, and social and economic development.

As the agriculture is the largest water consumer in Jordan, reuse of treated wastewater for irrigation, especially in Jordan Valley, receives a lot of attention. It is seen as a way to reduce the water shortage gap and to free freshwater for the higher value municipal and industrial uses. Thus, the U.S. Government acting through the Millennium Challenge Corporation (MCC) and the Government of Jordan signed an agreement for 275 million USD Compact investment to address the infrastructure inefficiencies, to increase the income and reduce the poverty in Zarqa Governorate through improving the supply of water for households and businesses. In addition to improvements in municipal water networks, the expanded wastewater collection system and As-Samra Waste Water Treatment Plant upgrade are predicted to generate additional wastewater flows used for agricultural irrigation in Jordan Valley. The logic of the substitution principle is that these new additional wastewater flows can be transferred to farmers in the Jordan Valley, such that equivalent amounts of freshwater can subsequently be diverted to Amman and Zarqa for higher value domestic uses.

This study attempted to estimate the economic benefits associated with reuse of wastewater in field irrigation in Jordan Valley due to MCC Compact investment. Two step approach was employed: Jordan Valley water balance model development and cost-benefit analysis. The goal of the water balance model was to characterize the water resources, water supply and demand in Jordan Valley and Amman and Zarqa municipalities. The model, developed for period 2000-2014, indicated that 21.3 MCM of additional wastewater would be made available for irrigation and 9.5 MCM for substitution for year 2014. These flows were larger than the ones predicted by MCC ERR analysis in 2011. The subsequent cost-benefit analysis estimated that Net PV Benefits associated with the investment were JD 51.9 million, and investment ERR – 14 percent. Both estimates were smaller than MCC economic analysis estimates of JD 63.8 million for Net PV Benefits and 19.5 percent and 13.5 percent ERR for water and wastewater sectors, respectively. The majority of the parameters for cost-benefit step were obtained from the MCC economic analysis, but many were adjusted, when possible, based on most recent data.

The value of high-value crop cultivation revenue was the largest benefit category, JD 111.4 million. Value of water to municipal sector of JD 1.1 per cubic meter from household survey in Zarqa was used for the analysis, which was smaller than estimate of JD 3.1 per cubic meter used in MCC economic analysis. Thus, the estimated substitution PV benefits were much smaller as compared to MCC analysis. Some of the cost and benefit categories were evaluated only qualitatively due to inability to monetize them. Effects from soil salinization such as crop yield reduction were incorporated in sensitivity analysis, which showed that salinity can have significant negative effects.

Despite the limitations such as lack of reliable data, the analysis shows that MCC Compact Investment not only provides the benefits to municipal and agricultural water users, but potentially contributes to reduction of the gap between Jordan's water demand and supply.

ABBREVIATIONS AND ACRONYMS

ERR	Economic Rate of Return
GDP	Gross Domestic Product
GOJ	Government of Jordan
IE	Impact Evaluation
JV	Jordan Valley
JVA	Jordan Valley Authority
KAD	King Talal Dam
KAC	King Abdullah Canal
WAJ	Water Authority of Jordan
MWI	Ministry of Water and Irrigation
MCC	Millennium Challenge Corporation
NRW	Non-Revenue Water
O&M	Operation and Maintenance
RCP	Representative Concentration Pathways
SO	Stage Office
WEAP	Water Evaluation and Planning
WSH	Water Smart Homes activity
WWTP	Wastewater Treatment Plant

1. INTRODUCTION

1.1. Evaluation Context

Growing world population, widening gap between available water supply and demand, and increasing variability in precipitation patterns create a challenge for many countries to provide a reliable water supply for all human and environmental needs. Inefficient water allocations and physical water losses within water supply networks result in wasted large volumes of potable water, which further exacerbates the problem. Addressing this issue through improved infrastructure and water allocations, water conservation and pricing mechanisms, as well as wastewater reuse could significantly benefit the populations in water scarce countries and reduce water deficit.

The Hashemite Kingdom of Jordan[1] is one of the most water scarce countries globally. Limited resources coupled with rapidly growing population further exacerbates the problem especially in the face of climate change. Water scarcity acts as an important constraint impeding Jordan's growth and development not only in food production but it is also essential for health, and social and economic development. Agriculture is the largest water consumer in the country and the Government of Jordan aims to increase the reuse of the wastewater in agricultural irrigation in order to reduce the water shortage gap and to free the freshwater for the higher value urban and industrial uses. Jordan is not the only country worldwide utilizing the non-conventional water sources for irrigation. Mexico, Egypt, China, Spain, USA and Israel are the largest wastewater re-users (World Bank, 2010, p. 8).

With aim to reduce the water shortage gap and poverty in Zarqa Governorate in Jordan, 275 million USD Compact[2] investment was made by the Government of the United States of America through the Millennium Challenge Corporation (MCC) in agreement with the Government of Jordan (GOJ). This is achieved through improving municipal water supply for households and businesses and increase the collection and reuse of wastewater for agricultural irrigation.

1.2. Evaluation Scope and Objectives

The scope of this project is limited to the water balance modeling for Jordan Valley and detailed economic analysis of impacts primarily to the agricultural sector in Jordan Valley and municipal water users in Amman and Zarqa governorates. The evaluation of impacts to other than the previously indicated beneficiaries as well as the environmental impacts are not a part of this study.

Initial economic analysis for the Compact investment was done by MCC in 2011 prior to the project, which started in 2013. This study focuses on economic evaluation of three Compact project components:

1. The Water Network Project (WNP),
2. The Wastewater Network Project (WWNP),
3. The As-Samra Expansion Project (AEP).

---

[1] In the remainder of the report The Hashemite Kingdom of Jordan is abbreviated to Jordan.

[2] Compact is a large five-year grants for countries that pass MCC's eligibility criteria (MWI, 2010, pp. 1-2).

It also incorporates the most recent data and the developments in water sector such as Disi water supply. An attempt is made to attribute the specific cost and benefits of the investment to either water or wastewater sectors.

Specifically, the study intends to answer the following questions:

- What are additional wastewater flows from As-Samra Wastewater Treatment Plant to Zarqa River and available for irrigation in Jordan Valley that are associated with Compact Investment?
- What are the associated benefits for agriculture sector in Jordan Valley and municipal water users in Amman and Zarqa Governorates associated with increased wastewater generation due to Compact Investment?

The report consists of the following sections: Section 2 discusses background of the study; Section 3 discusses the Compact Investment scheme; Section 4 summarizes relevant key studies; Section 5 discusses Water Balance Model and Section 6 – Cost-Benefit Analysis; and the report is concluded with Section 7, Discussion and Section 8 that includes Policy Recommendations.

2. BACKGROUND

2.1. Water Sector Overview

2.1.1. Geography and Climate

Jordan has three main climatic regions: the Ghor region or lowlands, Highlands, and the Badia and Desert region (GoJ, 2014, p. 30). The Ghor region extends from north to south along west border of Jordan (GoJ, 2014, p. 30). Jordan Valley (JV), which is highly productive agricultural region in Jordan, is located in northern part of Ghor, Figure 1. The Highlands extend to the east of Ghor region (Ababsa, 2013). Jordan's natural forest is located in Highlands and covers below 1 percent of total land area, (Ababsa, 2013). The Badia and Desert region extends eastwards from the Highlands and covers about 80 percent of total area of the Kingdom (GoJ, 2014, p. 37; World Bank, 2014; IPCCC, 2014, p. 15).

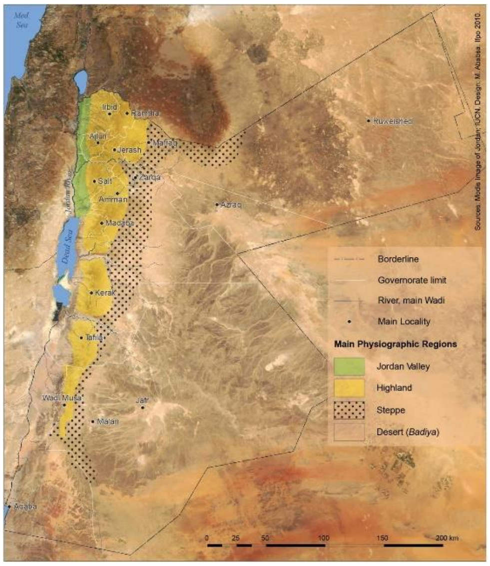
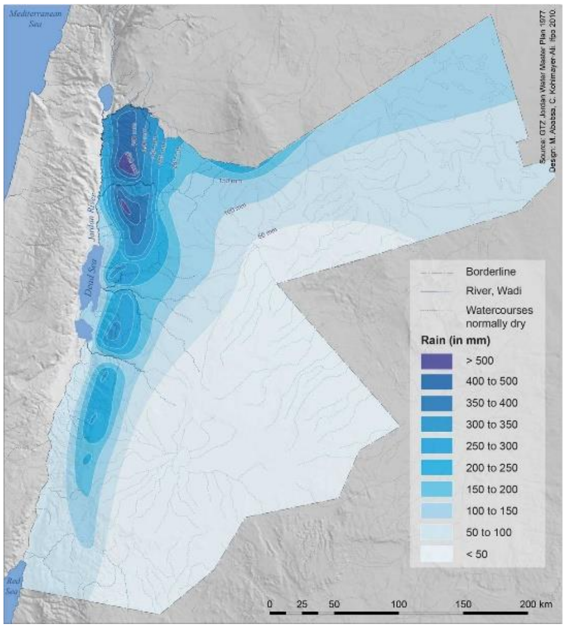


Figure 1. Physiographic regions of Jordan (Ababsa, 2013)



Source: GTZ, Jordan Water Master Plan 1977
Design: M. Ababsa, C. Kohlmayer-Ali. Ifpo 2010

Figure 2. Average Precipitation in Jordan (Ababsa, 2013)

Jordan's total annual precipitation can fluctuate drastically between 3,000 and 11,000 million cubic meters and it also varies geographically between 50 and 500 mm, Figure 2 (MWI, 2013; Ababsa, 2013). The majority of the rainfall falls in the norther part of Ghor region, 300-500 mm. Rainfall drops to 100-200mm in the Ghor region north of Dead Sea. The amount of rainfall significantly decreases to 100-200mm in the Highlands and to less than 100mm in the desert region. Due to the high temperatures nearly 95 percent of rainfall evaporates, which does not allow much recharge of surface and groundwater resources (MWI, 2013). The rainy season extends from October to May with about 80 percent of rainfall occurring during the months of December through March (GoJ, 2014, p. 37).

2.1.2. Water Resources and Supply

In 2010 estimated per capita renewable water availability in Jordan was 125 cubic meters per capita, which is way below the international water poverty threshold of 1,000 cubic meters per capita (IPCCC, 2014, p. 15). In 2015 total available renewable water resources was around 700 million cubic meters (MCM), which includes safe yield from renewable groundwater of 275 MCM (MWI, 2013). Same year groundwater over abstraction stood at 173 MCM and 160 MCM of non-renewable groundwater was extracted, thus, further depleting the groundwater resources, Table 1.

To address the water shortage Jordan utilizes non-traditional water sources such as treated wastewater reuse for irrigation, desalination and SWAP[3] program shown in Table 1. Disi Water Conveyance Project, which was completed in 2013, brings water from Disi aquifer in Southern Jordan to capital city, Amman. In 2014 it diverted nearly 100 MCM to Amman and surrounding urban areas. Another controversial project, Red-Dead Sea Pipeline, is currently under review. The project would bring water from Red to Dead Sea for consumption in Jordan, Israel and Palestinian territories as well for electricity generation.

---

[3] Signed agreement between Jordan and Israel allows to share water produced by planned desalination plant in Aqaba: Israel will be able to buy annually 35 MCM of fresh water for its desert south and Jordan, in return, will be able to buy an additional 50 MCM a year of water from Lake Kinneret.

Table 1. Water resources currently and future projection (MWI, 2015a, p. 14)

Year	2014	2015	2020	2025	2030
Groundwater safe yield	275	275	275	275	275
Groundwater over abstraction	173	173	156	130	104
Surface water (local & Tiberius lake)	250	250	260	270	280
Non-renewable groundwater	160	160	169	224*	224
Sub-total fresh water resources	**858**	**858**	**860**	**899**	**883**
Treated wastewater	137	140	180	200	220
Additional resources (desalination & SWAP)	10	10	90**	90	240**
Total resources	**995**	**1008**	**1130**	**1189**	**1343**
*40 MCM from Sheideah and 15 MCM from Azraq deep ground water **Red - Dead Sea Project (Phase I & II)					

The primary surface water sources are Yarmouk, Jordan and Zarqa Rivers, and Tiberius Lake. King Abdullah Canal (KAC) redirects water from Yarmouk River and Tiberius Lake to Jordan Valley for agricultural irrigation and domestic uses in Amman governorate. Zarqa River discharges to KAC south of Deir Alla Diversion. KAC receives additional flows from wadis[4] which have relative low water flows.

Most of the dams are built on rivers and wadis in Jordan Valley to supply water for agricultural irrigation. Table 2 lists dams that are relevant to this study, their location, capacity, year build and the purpose (Hadadin, 2015, p. 3287).

Table 2. Dams with their location, capacities and purpose

Dam	Location	River/Wadi	Capacity (MCM)	Year Build	Purpose
King Talal Dam	Eastern Heights	Zarqa River	86	1977, raised in 1987	Irrigation & electricity
Wadi Arab Dam	Jordan Valley	Wadi Arab	20	1986	Irrigation, municipal, industrial and electricity
Kafrein Dam	Jordan Valley	Wadi Al-Kafrein	8.2	1967, raised in 1997	Irrigation
Shuaib Dam	Jordan Valley	Wadi Shauib	2.3	1969	Irrigation
Ziglab Dam	Jordan Valley	Wadi Ziglab	4.3	1967	Irrigation, municipal and industrial
Karameh Dam	Jordan Valley	Wadi Al-Mallahah	52	1997	Irrigation, desalination and recreation
Mujib Dam	Karak Governorate	Wadi Mujib	31.2	2003	Irrigation, municipal and industrial
Al Wehda Dam	Yarmouk District	Yarmouk River	110	2006	Irrigation, municipal and industrial

---

[4] Wadi is a small stream.

2.1.3. Water Demand, Consumption and Scarcity

In 2015 water demand for all sectors was 1,417 MCM while the supply was only 1,008 MCM, Table 3 (MWI, 2015a, p. 14). Water deficit with groundwater over abstraction was 409 MCM and without – 582 MCM. According to the Government of Jordan, if current water usage trends continue, by 2030 water demand will increase to 1,600 MCM per year, which is 700 MCM above the currently available supply (MWI, 2015a, p. 14).

Table 3. Current water demand and future projection (MWI, 2015a, p. 14)

Water demand and supply	2014	2015	2020	2025	2030
Municipal, industrial and tourism demands	714	717	727	751	810
Irrigation demand	678	700	700	700	700
Oil shale and nuclear power demand	0	0	57	72	90
Total demand	1392	1417	1484	1523	1600
Total resources	995	1008	1130	1189	1343
Deficit (with over abstraction)	**-397**	**-409**	**-354**	**-334**	**-257**
Sustainable resources	832	835	974	1059	1221
Deficit (without over abstraction)	**-560**	**-582**	**-510**	**-464**	**-379**

Jordan's agriculture sector is the largest water consumer. In 2015 it received nearly 52 percent of total annual water supply. The amount is only a fraction, 505 MCM (Table 4), and nearly 200 MCM short of its water needs of 700 MCM. Same year municipal water users consumed 44 percent of water, and the rest 4 percent were equally shared by industrial and other users such as tourism sector (MWI, 2015a, p. 17).

Table 4. National Water supply and use by sector in 2015 (MWI, 2015a, p. 17)

Source	Domestic	Industrial	Irrigation	Total	Share
Surface	103.8	4.8	150	259	**27%**
Groundwater	325	32.2	231.3	589	**61%**
Treater wastewater	0	1.7	123.3	125	**13%**
Total Used	429	39	505	972	**100%**
Sector share	**44%**	**4%**	**52%**	with treated wastewater	
Sector share	**51%**	**4%**	**45%**	without treated wastewater	

Jordan is experiencing water scarcity across all the sectors as it is not able to meet water demand with available water supply (MWI, 2015a, p. 12). Water supply for municipal uses has been steadily increasing since 2000 whereas for agricultural irrigation it has decreased from peaking around 600 MCM in 2005-2007 to around 500 MGM in recent years (MWI, 2013). Growing population, especially in urban areas, caused the reduction in available water for farming activities and increasing competition over scarce water supplies. As water has a low value in agriculture[5], current water sector strategies focus primarily on higher value water supply for municipal and industrial uses. Thus, to address the deficit gap wastewater is increasingly reused for irrigation in the valley. Table 4 shows that in 2015 it accounted for about 7 percent of all water consumed in agriculture sector (Table 4).

2.1.4. Other Factors Contributing to Water Scarcity

Transboundary Waters. Water resource scarcity in the country is also closely linked to the regional geopolitics. About 40 percent of fresh water comes from transboundary rivers, Jordan and Yarmouk, that are shared with Israel and Syria (MWI, 2013). Two agreements were signed 1953 and 1987 between Jordan and Syria on the use of Yarmouk River including the construction and establishment of joint commission for implementation of provisions for Wahdah Dam (UN-ESCWA & BGR, 2013, p. 172). The 1994 Treaty of Peace between Jordan and Israel included the Annex II that discusses the water allocation and storage of Jordan and Yarmouk Rivers including the establishment of a Joint Water Committee (Ibid.). Despite the existence of the agreements Jordan, a downstream state, does not receive its fair share of river water as it lacks economic and political power in the region (Farber & et al, 2005, p. 138).

***Population Growth*.** Due to high population growth of 2.2 percent per year, and a large influx of refugees from neighboring countries in conflict, the population of Jordan increased from 4.6 million to 6.6 million in last 15 years (Sabah, 2011; Government of Jordan, 1997; World Bank, 2014). UNHCR reports that in 2015 Jordan provided asylum to nearly 1 million refugees from Syria (UNHCR, 2015). Growing urban population, which reached 83 percent in 2014, intensifies the competition between agricultural, municipal and environmental water uses (UN DESA, 2015; Haddadin, 2006, p. 68).

2.1.5. Climate Change

Jordan's Third National Communication on Climate Change (Communication) reports that "based on long historical data obtained from Jordan Metrology Department climatic variables are changing significantly at both national and station level, indicating that climate change is becoming more apparent" (IPCCC, 2014, p. 20). The country level climate projections were developed using two selected models, Representative Concentration Pathways (RCP) 4.5 (based on GCAM model) and 8.5 (based on MESSAGE model) (IPCCC, 2014, p. 120). The predicted mean temperature rise throughout Jordan is from 3.1°C (RCP 4.5) up to 5.1°C (RCP 8.5) (GoJ, 2014, p. 122). The Communication also reports the precipitation decrease by 20-21 percent by 2055 and large variability between dry and wet years (GoJ, 2014, p. 128). The potential evapotranspiration (PET) is predicted to increase on average by 70-100 mm by 2050 (GoJ, 2014, p. 137). Such climate changes will further exacerbate existing water scarcity in Jordan effecting the agriculture sector the most, forcing the country to rely more on non-conventional water sources.

2.1.6. Institutional Framework and Policies

Ministry of Water and Irrigation (MWI), which was established in 1988, is an official institution with mandate to overseer water sector including national water strategy and policies, construction,

---

[5] The price of water for agricultural irrigation is much lower as compared to the other uses.

operation and maintenance, data collection and processing (MWI, 2010, pp. 3-6). Under its umbrella it has Jordan Valley Authority (JVA), established in 1978, and Water Authority of Jordan (WAJ), established in 1983.

JVA is an independent public agency with mandate to promote the socio-economic development of Jordan Valley that includes water and land resources management, operation of the irrigation and some water supply systems. The agency has an autonomous status and freedom in planning, policy implementation, and finance management (Van Aken et al., 2007, p. 70). WAJ has a centralized oversight of the water sector and is mainly responsible for management of water and wastewater services (MWI, 2015a, p. 20). The capital and operational cost recovery for the irrigation and municipal water systems has been a long-time battle for the Government of Jordan. Both agencies are not able to collect enough revenue from tariffs to cover their expenses and depend heavily on government subsidies, which results in public expenditure on the water sector between 2 and 4 percent of GDP (Hübschen, 2011, p. 139; MWI, 2015a, p. 8).

In 2002 the Government of Jordan published Jordan's Water Policy and Strategy emphasizing the priority of surface and groundwater use for basic human needs clearly stating that municipal water uses supersede the agricultural uses (Haddadin, 2006, p. 92). The goals were set to maximize the efficiency and conservation in transmission, distribution and the use of water, as well as augment the fresh water supplies with reclaimed wastewater and desalinated brackish water. The Irrigation Water Policy addresses the sustainable use of irrigation water and "farm water management, irrigation water quality, management and administration, water pricing, regulation and control among others" (IUCN).

In 2008 Royal Commission for Water published "Water for Life", National Water Strategy 2008-2022, focusing on water management, fair distribution, alternative water sources and wastewater management (Hübschen, 2011, p. 135). In 2015 MWI introduced an updated National Water Strategy 2016- 2030 recognizing the need to ensure that national goals and priorities are reevaluated to meet the country's changing needs and to incorporate the new SDGs (MWI, 2015a, p. 7). The new strategy addresses the changes in the regional geopolitical situation, the growing population and expanding economy, and the risks related to renewable water resources. The key strategy areas are: Integrated Water Resources Management; water, sewage and sanitary services; irrigation water, energy and other uses; institutional reform; and sector information management and monitoring (MWI, 2015a, p. 9). National Reallocation Policy which was also introduced in 2015 intends to maximize treated wastewater use for irrigation in the valley by promoting the action plans "for redistributing water flexibly between sectors and governorates" (MWI, 2015a, p. 35). According to the reallocation policy the future irrigated agriculture expansion will only occur in the areas where treated wastewater is available and in Jordan Valley it will increase only when a subject to improvements in reclaiming non-revenue water or increased availability of treated wastewater (MWI, 2015a, p. 15).

2.2. Agriculture in Jordan Valley

2.2.1. Agricultural Production in Jordan Valley

Jordan Valley is one of the two main regions for agricultural production. Jordan Valley represents less than 5 percent of total country's land of which almost 83 percent, or 288,000 dunums[6], is irrigated (MWI, 2015a, p. 37). The valley is divided in three cultivation areas: North, Middle and South JV.

Table 5. Total agricultural and irrigated areas in Jordan Valley (Alfarra A. , 2009, p. 19)

Region	Total Area (dunums)	Irrigable area (dunums)	% of Irrigable Area
North JV	97.7	82.8	84.7
Middle JV	127.4	91.1	71.5
South JV	124	114.3	92.2
Jordan Valley	**349.1**	**288.2**	**82.6**

Modern irrigation technology to transfer water from the outside sources played a key role in development of agriculture sector in Jordan Valley (Van Aken et al., 2007, p. 57). In 1959 the East Ghor Canal Authority carried land re-distribution program aimed to create a community of "land owners-operators" each farmer owning 3-4 hectares of irrigated land plot (Haddadin, 2006, p. 35). The policy did not have expected results as the owner-operator ownership increased only by 8 percent (Van Aken et al., 2007, pp. 64-65). By late 1990s the leases were the most important way to manage the land, and small and medium farms successfully transformed the agriculture into investment linked to "access to technology and capital" and cheap manpower mainly from Egypt (Van Aken et al., 2007, p. 75).

Currently the farms are usually managed by the owner, renter or sharecropping, which is a shared responsibility between the owner and renter (Alfarra A. , 2009, p. 15). For the latter arrangement the sharecropper provides the labor including labor by family members and hired manpower. In 2012 the agriculture and forestry sectors employed less than 2 percent of Jordanians, about 69 percent of agricultural workforce are non-Jordanian workers (GoJ, 2014, p. 47; USAID, 2012a, p. 12).

The agriculture in Jordan Valley contributes to 70 percent of country's agricultural output, and consumes only 35 percent of total irrigation water, which is an indicator of high productivity as compared with other agriculture production areas in Jordan (MWI, 2015b, p. 8). One of the primary challenges in the valley, as indicated by National Water Strategy 2016-2030, is to increase irrigation efficiency through reduction of losses, unproductive water use and shifting cropping patterns to include higher-value crops (MWI, 2015a, p. 38).

Agriculture sector in Jordan is essential in providing fruits, vegetables and dairy products for domestic consumption and exports. In 2011 Jordan Valley contributed to about 44 percent in gross output or 227.8 million JD (USAID, 2012, p. 53). Irrigated agriculture contributed about 90 percent of total gross output value (USAID, 2012a, p. 1). Even though the overall agriculture contribution to GDP is

---

[6] 1 dunum=0.1 hectare

small, only 2.9 percent, the agricultural sector contribution expanded from 276 million JD in 2006 to 598 million JD in 2012. (USAID, 2012, p. 11). In 2012 sector contributed 17 percent to total national exports, which is equal to JD 795 million with over half of it coming from the exports of vegetables and fruits (GoJ, 2014, p. 46).

2.2.2. Cropping Patterns

Nearly 59 percent of irrigated area in Jordan Valley are planted with summer and winter vegetables, 32 percent are covered with tree crops and 9 percent – with field crops (USAID, 2012). Tomatoes, eggplants, potatoes and Jew's mallow are main vegetables grown in the valley; citrus, banana and dates are main crop trees; and the maize is the main field crop (USAID, 2012a, pp. 12-14). Vegetables are main crop in southern part of North JV and in Middle JV (USAID, 2012a, p. 63). Warm winters allow off-season production, thus, vegetable farming has two cropping seasons, - October through January for winter vegetables, and February through May – for summer. Citrus (lemon, orange, mandarin, and clementine) orchards are primarily located in North part of JV, but due to limited availability of water and overproduction the profitability of orchards has been low in recent years (Van Aken et al., 2007, p. 146).

2.2.3. Water Supply and Demand in Jordan Valley

In 2014 total available fresh water in JV was 180 MCM out of which about 110 MCM was delivered to urban areas for domestic uses leaving about 70 MCM for agricultural irrigation in the valley (MWI, 2015b, p. 11). This is significantly less than annual irrigation water demand estimated at 320 MCM, thus, the valley obtains water from outside sources, which differ for each region (Alfarra & et al., 2012, p. 2; Abbas & et al., 2015, p. 1178). In North JV the irrigation water mainly comes from Yarmouk and Jordan Rivers, whereas in Middle and South JV the irrigation primarily uses blended water, a mixture of wastewater and surface water, which has a lower quality than freshwater (USAID, 2012, p. 2).

In Jordan the total amount of water used in agriculture has decreased from 80 percent in 1970s to about 52 percent in 2015 due to competition among the sectors, new irrigation technologies and improved efficiencies (MWI, 2015b, p. 7). In 1980s the gravitational water distribution system in the valley was replaced by pressurized network of pipes. The efficiencies in irrigation and reuse of the wastewater allowed 30 percent increase in irrigated land during period between 1994 and 2013 (MWI, 2015b, p. 9). Irrigation technologies used in JV are drip irrigation, surface irrigation and sprinkler irrigation. Drip irrigation is the most common one having low water losses in the system. In 2015 water use efficiency in irrigation was estimated at 75 percent for North Jordan Valley and 81 percent - for Middle and South JV (Abbas & et al., 2015, p. 1182).

JVA, which oversees of irrigation systems, collection and distribution of surface water to the farmers in the valley, uses the system of crop-based water quotas to allocate the irrigation water (Van Aken et al., 2007, p. 137). To overcome water shortage of about 100 MCM (or 34 percent of the demand) annually the agency reduces the quantities of water delivered to the farmers proportionally to water availability (Alfarra A. , 2009, p. 19). In 1977 the Government of Jordan formally endorsed reuse of wastewater in agricultural irrigation as one of the solutions to increase water availability, and currently about 123 MCM of irrigation water, mostly consumed in the valley, is reclaimed water (Alfarra & et al., 2012, p. 2). As-Samra Wastewater Treatment Plant (WWTP) is the largest treatment plant in the country serving Amman and Zarqa areas treating about 100 MCM annually, of which about 70 MCM is used for agriculture in the valley and the rest – in the farms near the treatment plant (MWI, 2015b, p. 11). In 2015 total wastewater discharged into waterways in Jordan was about 125 MCM and by 2025 the treated wastewater is projected to increase to 240 MCM (MWI, 2015b, p. 5).

The substitution principle is applied by MWI to exchange for wastewater the same amount of freshwater. Usually in March of each year WAJ and JVA agrees on the quantities for water substitution: freshwater delivered from JV to Amman for domestic uses and in exchange JV receives the same amount of treated wastewater (MWI, 2015b, p. 12). WAJ and JVA signed an agreement to monitor the use of water between the As-Samra WWTP and King Talal Dam to maximize the amount of treated wastewater available for agriculture in the valley (MWI, 2015b, p. 11).

2.2.4. Value of Water in Irrigation

Even though the modern water conserving irrigation technologies such drip irrigation systems have been adopted and implemented by the farmers, the overuse of water is still prominent due to large governmental subsidies (Denny et al., 2008, p. 4). Therefore, the farmers in JV pay low tariffs, on average JD 0.012/m^3, for irrigation water, while the weighted average value of water[7] used to produce crops in the valley is nearly 50 times more - JD 0.85/m^3 (USAID, 2012a, p. 22). Water has the highest value in winter vegetable production, JD 1.55/m^3, followed by summer vegetable – JD 0.72m^3, Table 6.

Table 6. Water value of different type of crops in the Jordan Valley (USAID, 2012)

Crop	Area (dunums)	Water use ('000 m^3)	Water use (% total JV)	Value (JD/m^3)
Field Crops	29,946	17,082	10%	0.31
Winter Vegetables	138,245	45,058	26%	1.55
Summer Vegetables	43,507	18,246	10%	0.72
Tree crops	90,877	79,374	46%	0.58

The values of water depend on climate zones, crop production, soils, water qualities and other factors, thus, it also varies for different regions in the valley (USAID, 2012, p. 4). Ministry of Agriculture (2015) estimated the value of water in North Jordan Valley at JD 0.86/m^3 (mainly surface water), the value of blended water primarily used in Middle and South Valley is JD 0.84/m^3, and groundwater water value, which is mainly used in highlands, stands at JD 0.4/m^3 (MWI, 2015b, p. 10). USAID study (2012) provided higher value of water estimates for regions: in the North Jordan Valley values estimated at about JD 0.79/m^3, in Middle Jordan Valley - at about JD 1.1/m^3, similar values are also for South JV.

2.3. Water and Sanitation in Amman and Zarqa

2.3.1. Socio-Economic Context of Amman and Zarqa

Zarqa Governorate is the third largest governorate by population, after Amman and Irbid, representing almost 15 per cent of the total Jordanian population (MCA-J, 2012, p. 12). The estimated growth rate is 3 percent. The majority, 94.5 percent, of the population reside in urban areas with

---

[7] The value of water is estimated from crop value minus all other inputs required for growing the crop.

population density of 191.3 people per square kilometer (MCA-J, 2012, p. 12). MCC ERR (2011) study estimated that about 6 percent of residents lives on less than USD 2 a day, 31.6 percent – on USD 2- USD 4 and over 60 percent - on more than USD 4 a day. Most of the residents live in apartment type housing with the average household size of 5.68 persons, which is greater than national average of 5.4 persons (MWI, 2010, pp. 4-5). In 2008 on average the household in Zarqa spent 0.74 percent of the income on water and wastewater services, which is slightly less than country's average, 0.88 percent (MCA-J, 2012, p. 13).

The city of Amman is the capital of Jordan with the population of 2.38 million (2013) representing 36.4 percent of total Jordan's population (Klassert & et al., 2015, p. 3644). In the same year more than 100,000 refugees from Syria settled in Amman (Klassert & et al., 2015, p. 3644). Capital's population density is 286.7 people per square kilometer (Makhamreha & Almanasyeha , 2011, p. 256). On average the household in Amman spends about 1 percent to 1.5 percent of income on piped water supply and wastewater (Klassert & et al., 2015, p. 3649).

2.3.2. Water Supply and Demand in Zarqa and Amman

The main water supply sources for Zarqa Governorate are wells and water import from Amman. Annual water supply is about 50-60 MCM (MWI). In 2010 about 35 percent of Zarqa's households received water delivered by network once a week and another 30 percent – no more than twice a week (MCA-J, 2012, p. 13). The water scarcity is exacerbated by the inefficiencies on demand management side such as large physical and administrative losses. In 2013 physical network water losses were estimated at 59 percent, which reduced the average water consumption to 75 liters per person per day, Table 7 (MWI, 2013). In 2009 there were 130,948 water service subscribers (MWI, 2010, pp. 2-6).

Amman's annual water supply is estimated at approximately 130-180 MCM (MWI). The main water supply sources for Amman are KAC (through Deir Alla Diversion), Disi water pipeline, Zara-Mujib desalination plant and wells. Disi water pipeline, which started to convey water from Aqaba's Disi aquifer to Amman in 2013, contributed nearly 100 MCM to Amman's water supply in 2014 (MWI). The water supply from KAC varies between 37 MCM (2000) to about 54 MCM (2008) (Abbas & et al., 2015, p. 1178). Physical water losses in the network are estimated at nearly 40 percent resulting in average water use of 91 liters per person per day, Table 7, which is higher than water use rate in Zarqa (USAID, 2006, p. 16; MWI, 2013). About 98 percent of households in Amman are connected to piped water system (Klassert & et al., 2015, p. 3644). Similarly to Zarqa Governorate households in Amman receive water for several days per week depending on their location. In 2010 weekly supply duration on average was 36 hours (Klassert & et al., 2015, p. 3644). Water supply is even more reduced during the summer months.

Table 7. Average water supply and consumption per governorate 2013 (MWI, 2013)

Governorate	Population (2013)	Supply (L/cap/day)	Consumption (L/cap/day)
Zarqa	965,000	185	75
Amman	2,380,000	154	91

Common factor reducing the value of piped water on household level is frequent supply intermittences, which lead to network damages and incorrect meter readings (Klassert & et al., 2015, p. 3644). The majority of households collect water and store it in-house, in storage tanks on the roof-tops, or sometimes in the basement. Many residents resent using network water for drinking because of the perceived health risks. Alternative drinking water sources include buying water from private tanker operators; or 10-20 liter bottles of filtered water or 1-2 liter water bottles from the shops (Klassert & et al., 2015, p. 3644). Survey conducted in Zarqa by Jordan's Department of Statistics revealed that nearly 30 percent of poor households consume shop water with an average monthly cost of JD 10-15[8] (MCA-J, 2012, p. 13).

Water related policies for municipal water uses primarily focuses on the supply side, but on the domestic level water conservation practices are also underutilized. The Government of Jordan attempted to introduce policies on water demand management side, but with varied success and mostly focused on reducing illegal water use (Klassert & et al., 2015, p. 3644). Moreover, the collected tariffs for piped water are not able to cover capital, operational and maintenance cost of water networks. Water sector deficit which currently stands at 0.4 percent of Jordan's GDP is subsidized by the Government of Jordan (Klassert & et al., 2015, p. 3649).

2.3.3. Sewerage Services and On-site Sanitation in Zarqa

In 2009 there were 94,265 wastewater service subscribers in Zarqa Governorate, which represents about 72 percent of households with sewer connections (MWI, 2010, pp. 2-6). The existing wastewater collection system is supported by three pumping stations, East Zarqa (EZPS), West Zarqa (WZPS) and Hitteen Camp (MWI, 2010, pp. 2-5). West Zarqa pump station also receives some wastewater from Northeastern Amman areas (Tariq, Marka and part of Shafa Badran, Jubaiha and Naser) (MWI, 2010, pp. 2-5). All wastewater from East Zarqa and West Zarqa stations is pumped to As-Samra Wastewater treatment plant. The capacity of pumping stations are 85,000 cubic meters per day.

Study prior to the project implementation showed that most of flat sewers were blocked by sand, silt and grease. Several segments got overloaded during the rain events flooding streets and wadis (MWI, 2010, pp. 2-6). This projection for the wastewater generation rates for the Zarqa Governorate based on population forecasts, water consumption rates and the wastewater return value is estimated at 34.3 MCM per month by 2035 (Hübschen, 2011, pp. 2-11).

Cesspits collect some of the wastewater on household level. Because they are unregulated, there is high probability that the wastewater in cesspits leaks to the water table or is just discharged through a pipe. Some of the cesspit wastewater is pumped out by service providers. It is also not guaranteed that service providers bring collected wastewater to the wastewater treatment plant with some potentially discharging it in ditches or areas outside the city.

2.3.4. Value of Water for Domestic Uses

The household survey conducted in Zarqa and nearby areas of Amman as part of MCC Compact investment impact evaluation showed that willingness to pay (WTP) for an improved additional 24 hours per week water supply service is only 1.8 JD per month, which indicates household reluctance to pay more for network water (Orgill & et al., 2016). On the other hand, due to unreliable water supply the

---

[8] Equal to about $14.40-21.60

average coping costs[9] for the surveyed households are 10 times greater than the average WTP (Orgill & et al., 2016). The average survey household coping costs are 33 JD per month equating to about 8.6 percent of total average monthly expenditures of which 7 percent are non-network coping cost (Orgill & et al., 2016). Mean coping costs for only water related expenses are 14.4 JD or 3 percent of total monthly expenditures (Orgill & et al., 2016). Also households that are not connected to the water network spend about 1.5 times more on water related coping behaviors than the households that are connected to piped water, which on average pay 24 JD for utility for water utility services (Orgill & et al., 2016).

3. BACKGROUND ON COMPACT INVESTMENT PROGRAMS

The Government of the United States of America through the MCC and the Government of Jordan signed an agreement for 275 million USD Compact investment to increase the income and reduce poverty in Zarqa Governorate through improving the supply of water for households and businesses. In addition to improvements of municipal water networks, the expanded wastewater collection system and its reuse for irrigation in Jordan Valley is seen as a way to free up freshwater for domestic uses in Amman and Zarqa. The project has three components, Figure 3, that are projected to increase the treated wastewater available for agricultural irrigation: 1. *The Water Network Project* (WNP), 2. *The Wastewater Network Project* (WWNP), 3. *The As-Samra Expansion Project* (AEP).

3.1. Zarqa Water Rehabilitation Project

The goal of Water Network Project (WNP) Project is to improve the efficiency of water supply system in key areas, Zarqa and Ruseifa, in Zarqa Governorate through reduced physical water losses and improved continuity of water service (MCA-J, 2012, p. 10). The project is expected to reduce physical losses by 19 percent, which are currently at 59 percent. The additional water will be available for domestic consumption and the transition of water supply system “from periodic distribution under high pressure to more frequent, gravity-fed distribution” will lead to more reliable network water supply (MCA-J, 2012, p. 10). This can potentially allow to extend water delivery time and increase the reliability making more water available for the households, which is expected to increase human productivity through health benefits and reduced illness (Ibid.). The assumption is made that Zarqa residents will switch from more expensive tanker and shop water to cheaper network water used for domestic consumption, which will also reduce total household expenses for the water (MCA-J, 2012, p. 13)[10]. MCC estimated number of households that will benefit from project over twenty year period is about 302,000 or approximately 1,634,000 residents (MCA-J, 2012, p. 15).

Second part of WNP is Water Smart Homes (WSH) Activity through which direct assistance is provided for poor households in Zarqa governorate to improve their household water and sanitation infrastructure and enhance the project benefits. The two activities include WSH Outreach Campaign to disseminate about best water storage and maintenance practices, and WSH Direct Assistance Program

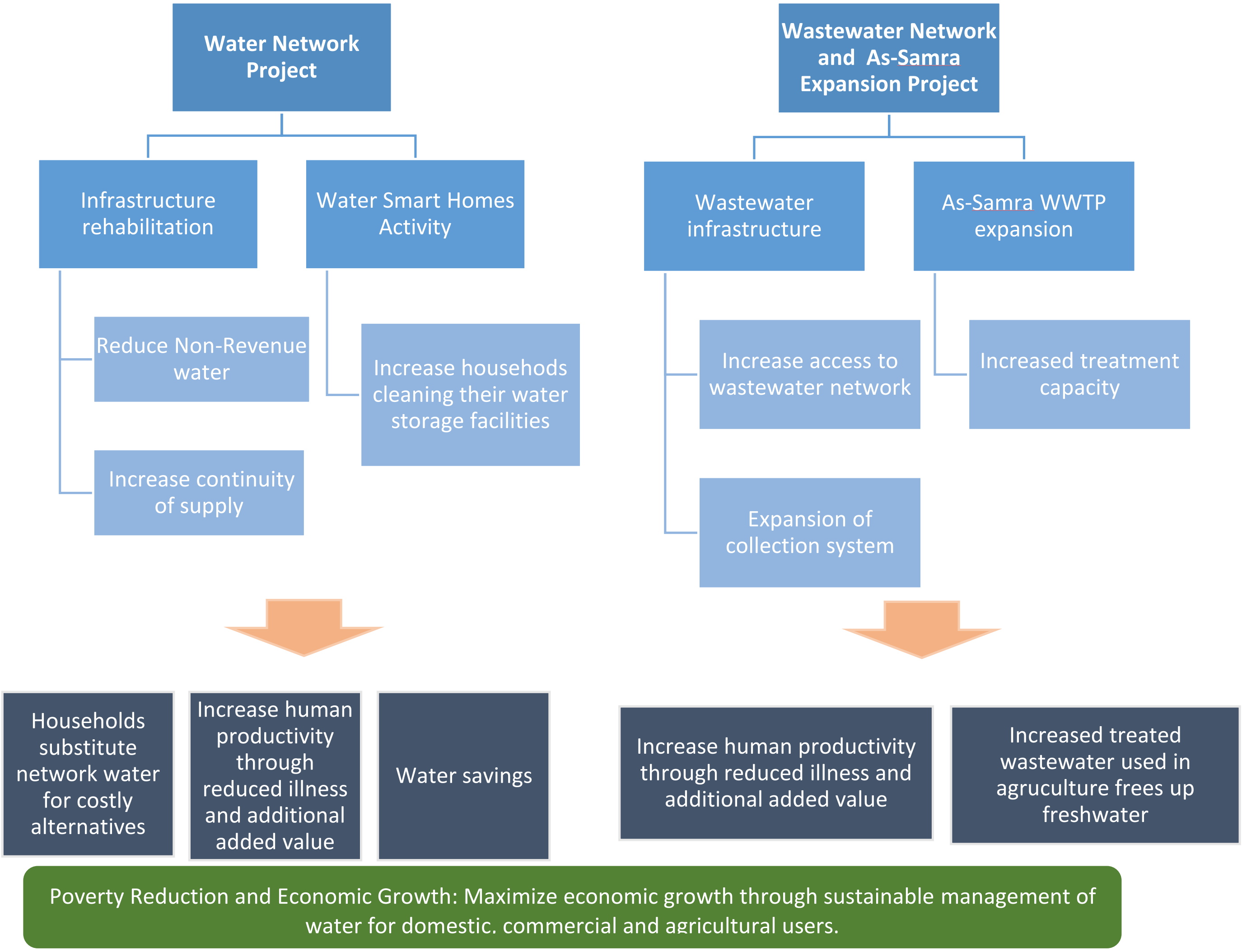
---

[9] “monetized coping behaviors in which households engage when faced with unreliable water supply” (Orgill et al., 2016)

[10] Benefits for industrial and commercial users are not considered as their operations do not depend significantly on water supply.

to assist poor households with the technical and infrastructure needs in Zarqa Governorate (MCA-J, 2012, p. 7).

Figure 3. Compact Investment Logic (MCA-J, 2012, p. 6)



3.2. Zarqa Wastewater Network Expansion Project

The Wastewater Network Project (WWNP) is expected to expand, rehabilitate and reinforce the wastewater network to reach additional 10 percent of households to total of 82 percent in West and East Zarqa, which will benefit about 19,000 households (or about 100,000 residents) (MCA-J, 2012, p. 9). The wastewater collection system expansion will allow to capture more wastewater and also reduce the incidents of wastewater overflow at the pumping stations. The primary benefit of this project component is the additional wastewater volume available for agricultural irrigation in Jordan Valley. Additional benefits include potential reduction of risk of illnesses, which can be caused by the the on-site septic systems or lack of any wastewater collection system at some households.

3.3. As-Samra Wastewater Treatment Plant Expansion Project

As-Samra Wastewater Treatment Plant (WWTP) treats wastewater from Amman and Zarqa Governorates and it is approaching its capacity. The wastewater generation in both urban areas has increased primary due to additional water supply from Disi aquifer.

The treated wastewater from As-Samra WWTP is discharged to the Zarqa River where it mixes with the river flow. This blended water is then used for irrigation primarily in Middle and South Jordan Valley. Main objective of As-Samra Expansion Project (AEP) is to increase the hydraulic capacity from 267,000 cubic meters per day to 365,000 cubic meters per day and provide an adequate treatment of wastewater improving its quality for suspended solids, biological materials and other critical pollutants (MCA-J, 2012, p. 9). Thus the additional higher quality treated wastewater will be available as a substitute for freshwater in Jordan Valley and in exchange the freshwater from the valley will be transferred to Amman and Zarqa for domestic uses and then returned back to wastewater collection system. High-quality treated wastewater will have other benefits such as reduced risk of bacterial and heavy metal pollution of cultivated land (MCA-J, 2012, p. 9).

Both wastewater project components complement each other and their benefits overlap. WWNP and AEP together are projected to benefit approximately 375,000 households or about 2,020,000 people in Zarqa and Amman municipalities (MCA-J, 2012, p. 16). The initial MCC ERR estimated that both projects may generate up to 10 MCM of additional wastewater annually available for substitution.

4. Literature review of previous studies

4.1. Water Balance Modeling

Some studies attempted to analyze Jordan’s water demand and deficit on local or basin levels. Several different Water Evaluation and Planning (WEAP) models were developed to assess water deficit and analyze different future scenarios. Alfara’s (2009) WEAP water balance model for Jordan Valley for period 1990-2006 indicates large agricultural demand for wastewater, which subsequently can reduce stress on water resources for domestic uses in urban areas. The study by Al-Omar et al. (2015) investigates the deficit in irrigation demand for period 2009-2050. WEAP model results show that even taking measures such as improving irrigation efficiency, NRW reductions and including Disi pipeline supply, only Red-Dead Sea canal project scenario show deficit reduction mainly due to increased availability of treated wastewater from increased domestic water use in Amman and Zarqa (Abbas & et al., 2015, p. 1176). Hoff et al. (2011) included transboundary component in Jordan basin wide WEAP model to provide the framework for addressing “environmental, technical, socio-economic, institutional and political aspects of water management”. Study’s preliminary findings list socio-economic factors and climate change as future water scarcity drivers (Hoff & et al., 2011, p. 732).

Some different models include Zarqa River Basin model that was developed by Shatanawi and Shammout (2011) analyzing and optimizing water supply and demand within the basin. Developed baseline scenario is recommended for use by the policy makers for best conservation practices (Shatanawi & Shammout, 2011). The water management model developed by Abu Rumman et al. (2009) for Integrated Southern Ghor Project for period of 1977-1999 uses dynamic programming. It predicts that with the increased water demand new and unconventional water sources such as reclaimed water should be considered (Abu Rumman & et al., 2009).

Comair et al. (2013) indicates that the variability in data and lack of sufficient climate and water data is a challenge for the region as discussed in the study on water resource management in Lower Jordan River Basin. The developed WEAP model studied water resources vulnerability in the basin when facing climate change (Comair & et al., 2013).

4.2. Cost-Benefit Analysis

MCC Compact investment Economic Rate of Return (ERR) analysis was completed by MCC in 2011 prior to the project implementation to evaluate all three project components by quantifying monetary and non-monetary benefits that the projects will provide. Analysis results show that ERR for the investment in water sector rehabilitation will be 19 percent and for the investment in expansion of wastewater network and As-Samra WWTP upgrade will be 13.5 percent.

There is very limited number of studies on evaluating the costs and benefits associated with investment in water and wastewater sectors and also wastewater reuse for irrigation, especially in Jordan and other regions reusing the reclaimed wastewater. Lienhoop et al. (2014) in their study monetized and incorporated the non-market health, environment and irrigation in agriculture benefits to assess the decentralized wastewater treatment and reuse at two remote locations in Jordan. Study results suggest that decentralized wastewater treatment technologies in remote areas are worthwhile (Lienhoop & et al., 2014). Fan et al. (2015) study on cost-benefit analysis of wastewater reclamation and reuse for agricultural, industrial, municipal and environmental purposes in Beijing show that benefits are 1.7 greater than the costs. Intangible benefits such as "environmental improvements, public health impacts, groundwater recharge and pollution" and reduced wastewater recharges are evaluated employing opportunity cost approach (Fan & et al., 2015). Similarly Haruvy et al (1997) wastewater reclamation and reuse alternative economic analysis for Israel estimated benefits included groundwater recharge, agricultural output and decreased fertilization costs. The costs associated with health risks and nitrogen pollution are included in the analysis, nevertheless, the agricultural irrigation option produced the higher benefits than other options (Haruvy, 1997). Alcon et al. (2013) incorporated non-market benefits in cost-benefit analysis of reclaimed wastewater use for mandarin crops in southern Spain. Even though monetization of intangible benefits is complex the study claims that such approach provides a more balanced assessment of wastewater reuse impacts (Alcon & et al., 2013).

The paper by Tabieh et al. (2012) analyzed household water demand in Amman-Zarqa basin showing that the estimated residential water demand elasticity of -0.47 (-0.62 for Amman and -0.004 for Zarqa) for the basin is negative and only little responds to price change (Tabieh & et al., 2012). Low price elasticity of water demand indicate that the price of water is not an appropriate mechanism for water conservation in Amman and Zarqa (Tabieh & et al., 2012). On the other hand, Al-Ansari et al. (2014) reports that water demand management measures can effectively ensure reduction of water use and water loses in water network, improve water quality and enforce a real cost of water supply (Al-Ansari & et al., 2014).

5. JORDAN VALLEY WATER BALANCE MODEL

5.1. Methodology

The methodology to develop water balance model for Jordan Valley is described in this section. It comprises of four main steps: data gathering and compilation, Jordan Valley water system schematics development, Jordan Valley water balance model, and scenario development.

5.1.1. Data Gathering and Compilation

This study uses data from primary and secondary sources. The primary cleaned raw data was obtained from Impact Evaluation project team that conducted Farm Surveys in Jordan Valley in 2014-2015 on investment impacts on the irrigators downstream of As-Samra WWTP.

The secondary data on water supply, storage, demand and stream flows were obtained from the Ministry of Agriculture and the Ministry of Water and Irrigation. Relevant data from the Water Evaluation and Planning (WEAP) model developed by Dr. Amani Alfarra in 2009 for her PhD Dissertation were also used for the water balance model. Additional secondary data were obtained from the international organizations', such as Word Bank and United Nations, databases as well as published and peer-reviewed reports and studies.

Gathered data were then complied and reviewed to assess the suitability and missing data gaps.

5.1.2. Demand-Supply Water Allocations for Jordan Valley Schematics Development

The aim of the schematics is to show the sources of water, storage facilities, water treatment facilities, major transmission and distribution lines, main agriculture and municipal use points within Jordan Valley. Only water flows in Jordan Valley, and Amman-Zarqa municipal areas are of interest for this study. Thus, the assumption is made that the flows outside this water system do not affect or interact with the system.

The schematics is an integral part of water balance model and is generated based on demand-supply water allocation diagrams previously developed by Dr. A. Alfarra, U.S. Aid for International Development (USAID) and International Water Management Institute (IWMI). Additionally the schematics incorporate recent water-related developments: Disi water pipeline and Zarqa carrier III, which delivers blended water from King Talal Dam (KTD) to Stage Office (SO) 2 in North Jordan Valley.

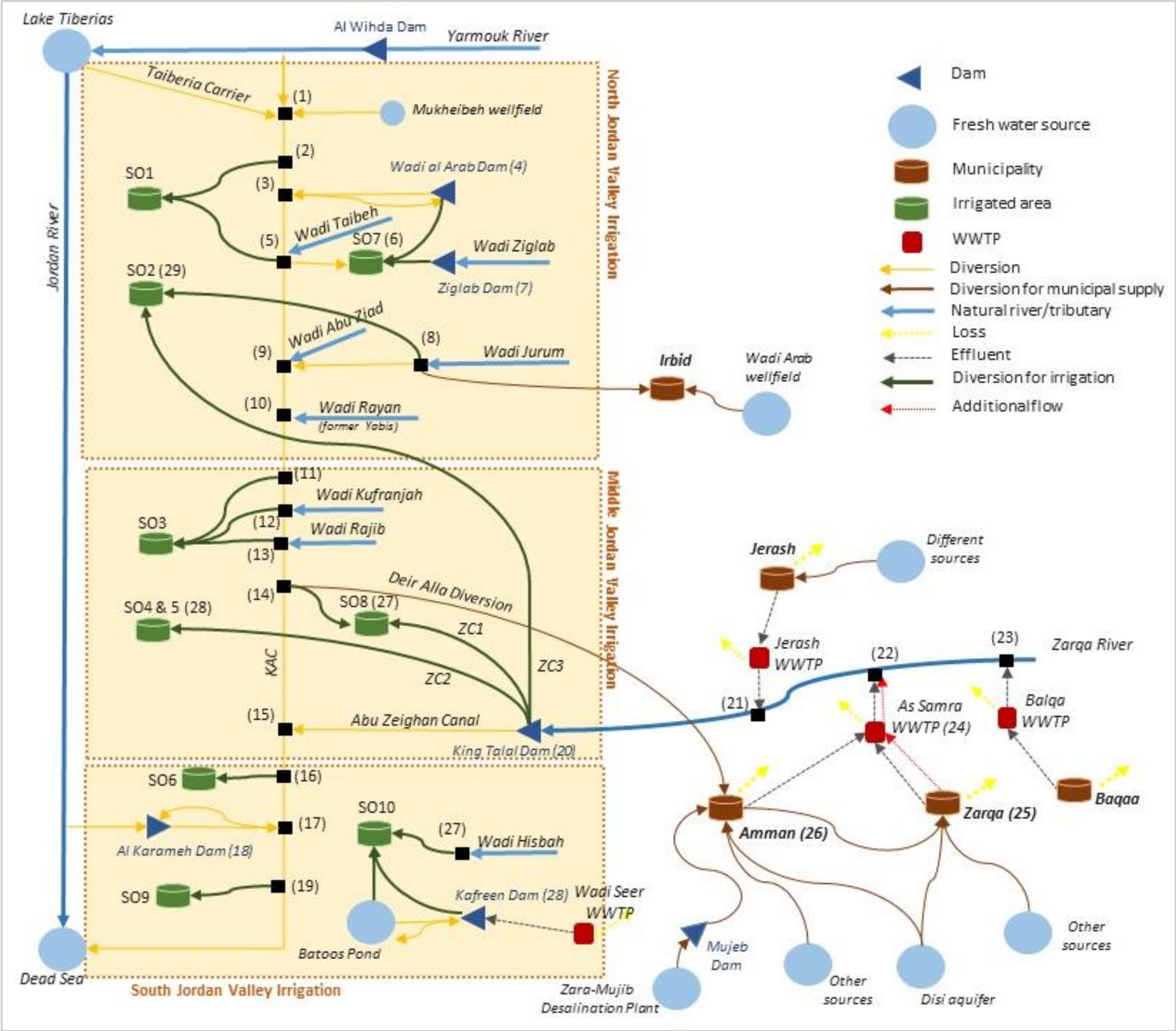
The major features of the schematics, Figure 4, are water supply, storage and use points, as well as transmission and distribution lines. Main transmission line is King Abdullah Canal (KAC), which transports water from Yarmouk River, Lake Tiberias and Mukheiba Wells to Jordan Valley and serves as primary irrigation water source for North Jordan Valley. Middle and South Jordan Valley receives irrigation water from KTD either directly through Zarqa carriers I and II or after discharging through Abu Zeighan Canal to KAC and mixing with upstream water. Zarqa carrier III which started to operate only in 2010 delivers blended water to North JV. Arab, Ziglab, Al Karameh, Kafreen and King Talal dams are important part of water balance as they store and supply irrigation water. Several small wadis discharge to KAC throughout JV and Deir Alla diversion diverts KAC water to Amman for municipal water uses, Figure 4.

Primary water use points are:

- Urban areas: Amman and Zarqa.

- Agricultural production areas indicated by Stage Offices (SOs):
    - SO1, SO2 and SO7 in North Jordan Valley,
    - SO3, SO4, SO5 and SO8 in Middle Jordan Valley,
    - SO6, SO9 and SO10 in South Jordan Valley.

Figure 4. Water demand and supply allocation for Jordan Valley



Although the schematics was developed using several reliable sources, some presumed flow diversions might be missing due to inability to confirm them, which is one of the limitations of this study. For example, there might be structures diverting some water from the Zarqa River to the nearby farms between As-Samra WWTP and KTD but due to lack of evidence such structures were not included in the schematics. Despite this limiting factor the schematics incorporate major water system components and is the basis for JV water balance model development.

5.1.3. Jordan Valley Water Balance Model Development

The purpose of water balance model is to characterize water resources supply and demand allocations within the Jordan Valley and Amman-Zarqa governorates connected by the water transfer lines. The developed model is used to model water and wastewater system changes due to Compact investment and estimate the additionally generated wastewater flows.

The water balance model is built in Excel software package based on previously discussed schematics.

The following water balance equation is a building block for the model:

$$\Delta S = I - O,$$

where: ΔS- change in storage
I – inflow
O – outflow

Model is developed for a period of 14 years, 2000-2014, to represent the variation over a longer time interval. Due to significant lack of data for years before 2000, they were not included in the model. To address the missing data issue in the model the approach of replicating the data from the closest years to fill the missing data gaps. Keeping in mind that such approach introduces inaccuracy, it was selected as most appropriate one for this study. Month was used as a modeling time step to show the greater flow variation.

Each balance point depicted by the node in the schematics, Figure 4, has separate worksheet in the model representing the water balance at that point. Balance points that do not provide water storage have change in storage equal to zero with inflow equating to outflow. Moreover, this model does not explicitly model the changes in storage as they are not relevant to this study. Thus, reservoir water losses to evaporation and groundwater seepage are implicitly included in measured reservoir in- and outflow data. The water losses within the municipal water networks are estimated based on water supply and wastewater flow data.

The developed model does not have a priority system to allocate water from the dammed reservoirs to SOs and solves the allocation problem proportionally, based on the historical trends. The priority system is only used to allocate the additional wastewater flows due to MCC Compact Investment from KTD to Zarqa Canal I, II, III and Abu Zeighan Canal. This was done to overcome the limitations of the Excel.

Key assumptions and elements of incorporating water supply and demand data into the model are discussed next.

Water Supply. Water flow data for KAC, Yarmouk River and Tiberius Lake used in the model was available for all, 2000-2014, period, but flow data for wadis – only for years 2000-2009. Thus, the 2009 data were replicated for missing years, 2010-2014.

The Zarqa River monthly flow distribution was modeled based on the median annual flow of 53 MCM upstream of As-Samra WWTP measured at the New Jerash stream gauge (EXACT Program of the US Geological Survey).

The assumption was made that all additionally generated wastewater flows from As-Samra WWTP are used in agricultural irrigation in Jordan Valley. The outflow from KTD to each Zarqa Carrier was modeled to increase/decrease proportionally with changes in water inflow to KTD. The monthly outflows were modeled based on the monthly water flow distribution.

Municipal Water Demand. Municipal water demand was estimated from available water supply data for Amman, Zarqa and Jerash for period 2009-2014 and wastewater inflows to As-Samra WWTP. 2009 data was replicated for missing data years 2000-2008. The estimates for non-revenue water losses, household connectivity to water and wastewater networks were used to estimate the network water losses in Amman and Zarqa urban areas. The following assumptions associated with municipal water demand were made in the model:

- Annual Jarash water supply estimated at 5MCM divided equally over the twelve months (Alfarra A. , 2009);
- Deir Alla diversion transports 9-14 MCM annually to Amman;
- Baqa'a urban area water use was estimated based on the population of 344,985 residents (2004), population growth of 2.5 percent and estimated wastewater production per person and available data on effluent inflow into Balqa WWTP.

Agriculture Water Demand. Agricultural water demand was estimated from crop water demand for main crop types, and cropping patterns for three different regions - North, Middle and South JV[11] (Table 8). Each Stage Office (SO) node in the schematics and the model had associated water demand. The modeled SO water demand was compared to the recorded annual water supply for each SO for years 2000-2014. The recorded annual flow was transformed to monthly flow using Jordan Valley WEAP model water demand curve for each region, Figure 5. The same demand curves were used to estimate monthly diversions by Zarqa Carriers[12] I, II and III from KTD. The additional blended water flows associated with Compact investment are assumed to be diverted from KTD to JV through ZCI, ZCII, ZCIII, and Abu Zeighan canal. This additional flow from KTD was modeled based on the priority system: ZCI – highest priority, ZCII- one step lower, followed by ZQIII, and Abu Zeighan receiving the remaining additional flows.

No data were available for water diversions from Zarqa River between As-Samra WWTP and KTD. Thus, based on the water balance for the preceding and following nodes in the model monthly water losses and diversion to nearby farms were estimated between 15 and 25 MCM. The same issue was encountered between KTD and KAC, where, based on the available water flow data for KTD and KAC, about 30 percent of KTD outflow was not accounted for in the model. In order to balance out the water flows it was assumed that 30 percent of flow in Abu Zeighan Canal is diverted for irrigation and other uses and is lost to the evaporation and seepage. I recommend to investigate these assumptions in the future studies.

Water losses in agricultural irrigation is estimated to be 25 percent to account for not only physical but also administrative losses.

---

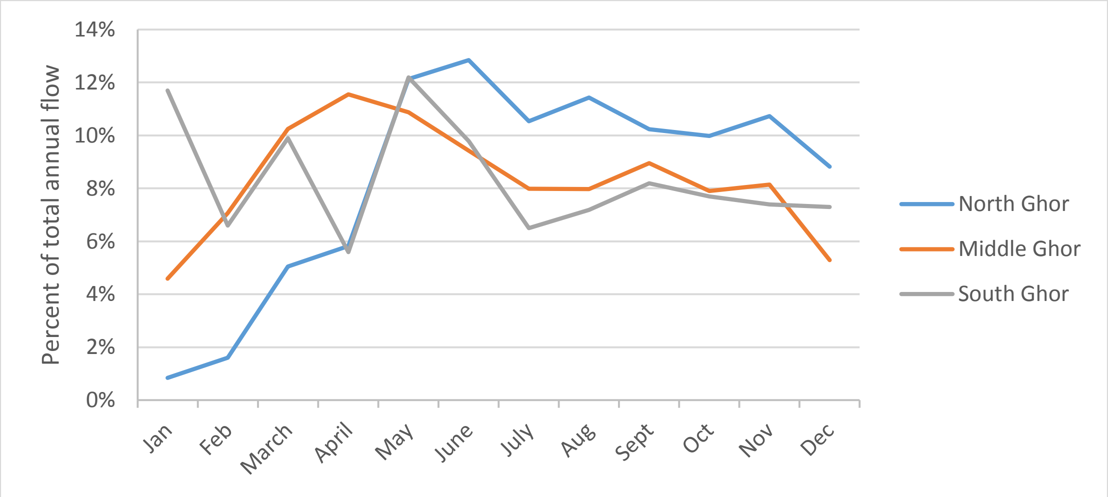
[11] Analysis of rained agriculture is not part of this scope.

[12] Monthly supply variations for Zarqa Carriers I, II and III were not provided by MWI.

Table 8. Annual crop water demand and cropping patterns for three regions

Crop	NORTH JV		MIDDLE JV		SOUTH JV	
	Annual water demand (m^3/dunum)	Share of area (%)	Annual water demand (m^3/dunum)	Share of area (%)	Annual water demand (m^3/dunum)	Share of area (%)
Greenhouse vegetables	360	1%	358.7	6%	439.5	2%
Summer vegetables	443.6	14%	446.8	20%	453.7	15%
Winter vegetables	314.5	20%	327.5	35%	343.7	43%
Winter cereals	621.8	29%	626	24%	675.6	20%
Citrus trees	1177	31%	1187	11%	1243	5%
Banana trees	1752	2%	1790	1%	1854	12%
Olive trees	688	0%	688	0%	688	0%
Other trees	1177	3%	1187	2%	1243	3%

Figure 5. Water demand curves for North, Middle and South JV

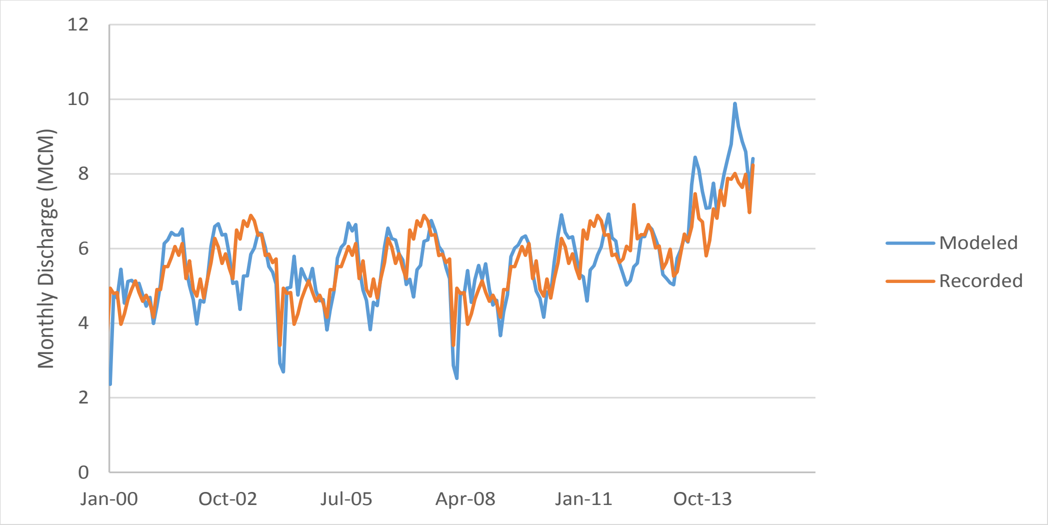


Model Calibration. The model was calibrated with the recorded data at the following points (refer to Figure 4):

- Stage Offices: SO2 (Node 29), SO4&5 (Node 28), SO7 (Node 6) and SO8 (Node 27)
- Amman (Node 26) and Zarqa (Node 25)
- As-Samra WWTP (Node 24)
- KTD (Node 20)

Figure 6 shows a comparison of modeled and provided by the MWI monthly effluent discharge data for As-Samra WWTP.

Figure 6. As-Samra WWTP effluent outflow – modeled and recoded



After the calibration of the model I assessed water shortage for each Stage Office, which assumed to be reduced by the generated additional flows by the Compact investment scheme.

5.1.4. Scenario Development

I built two scenarios within the model to generate the additional flows and determine the impact distribution among the water users in the water balance system:

- **Baseline**. This scenario does not have any major investments associated with it. Its goal is to provide a reference point for the study. Main features of this scenario are:
  - Non-revenue water losses in Zarqa are 59 percent
  - Population connected to wastewater network in Zarqa is 72 percent
- **Compact Investment Scenario**. This scenario incorporates the additional flows that are generated by the Compact Investment. This mainly occurs through the following changes within the water and wastewater networks:
  - Non-revenue water losses in Zarqa are reduced from 59 percent to 35 percent;
  - Population connected to wastewater network in Zarqa increased from 72 to 82 percent;
  - As-Samra WWTP capacity increase by 37 percent;
  - Assuming there is a mechanism in place for substitution the JV received additional wastewater flows generated by the project and in exchange Amman receives the same amount of freshwater from JV.

The main objective of the scenarios is to allow to measure the impact of the investment. The results for both scenarios are summarized in the next section and incorporated in subsequent Compact investment economic analysis.

5.2. Scenario Analysis and Results

5.2.1. Baseline Scenario

Baseline Scenario reflects the historical conditions of the Jordan Valley water system. Table A-1 in Appendix A shows water demand for each SO. Because the data for actual SO water demand were not available, the repeated numbers indicate that the modeled agricultural water demand is the same for every year during the study period, 2000-2014. Following table A-2 in Appendix A shows modeled water shortages at each stage office during the period 2000-2014. Again the repetition of same numbers for the SOs during 2000-2009 period indicates missing data. Total annual water shortage for Jordan Valley varies between 24-65 MCM. The model shows greatest water shortages for SO2 and SO6. The latter has a sharp increase of over 5 MCM between years 2010-2012 and then a sharp drop. This was due to decreased water supply to the Stage offices, Table A-2 in Appendix A. SO4&5 shows the water shortage nearly doubles for the last 7 years, from around 3-5 MCM to over 9-11 MCM. This is due to decreased water supply through Zarqa Carrier II, Figure 7. North JV region has the most significant water shortage, Figure 8, which is in agreement with actual data.

Figure 7. Monthly flows to Zarqa Carriers and KAC, 2000-2014

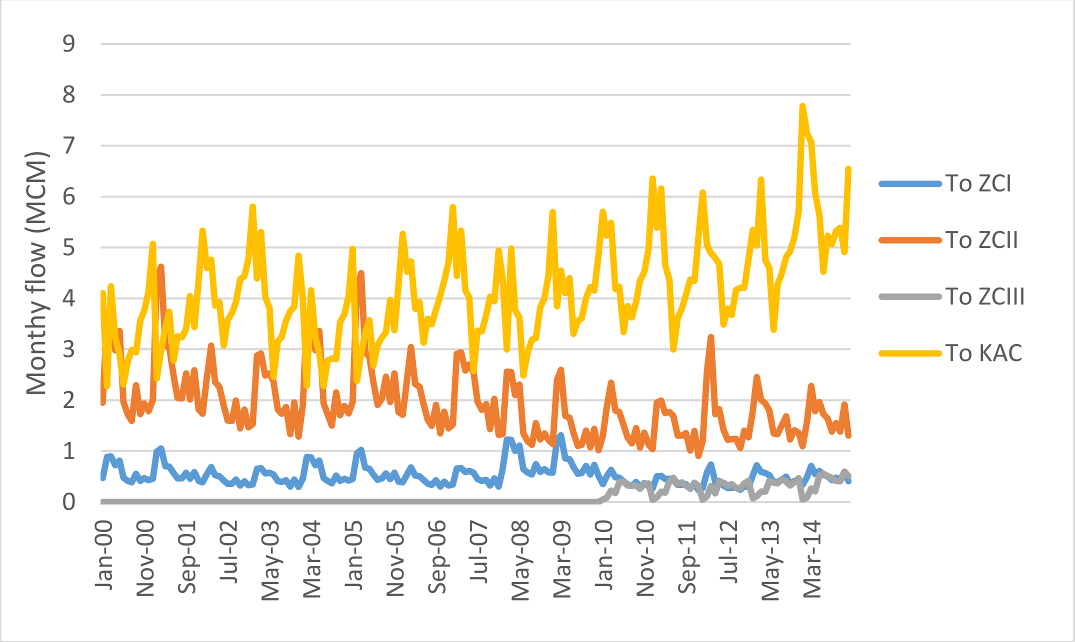
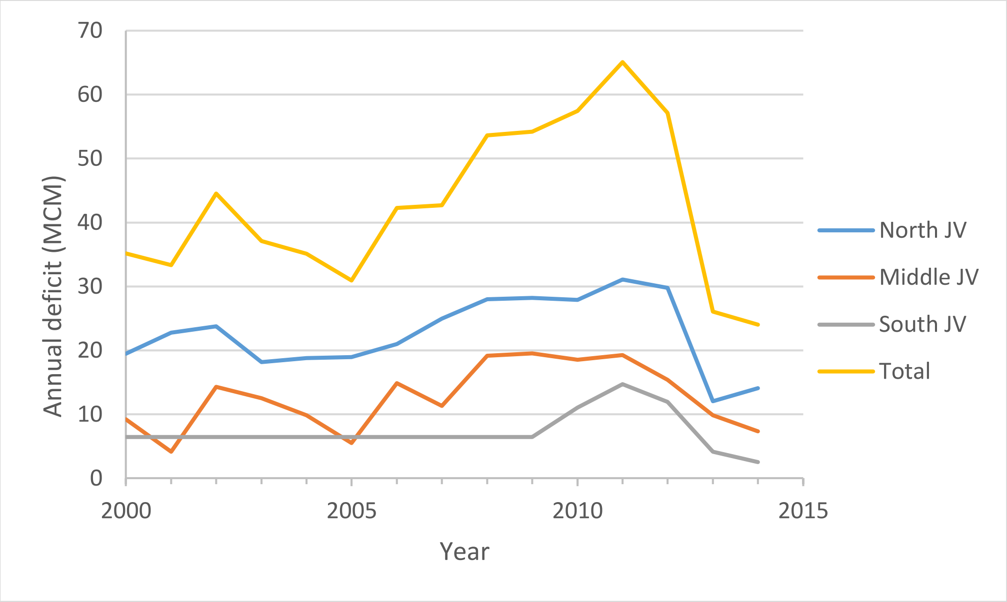
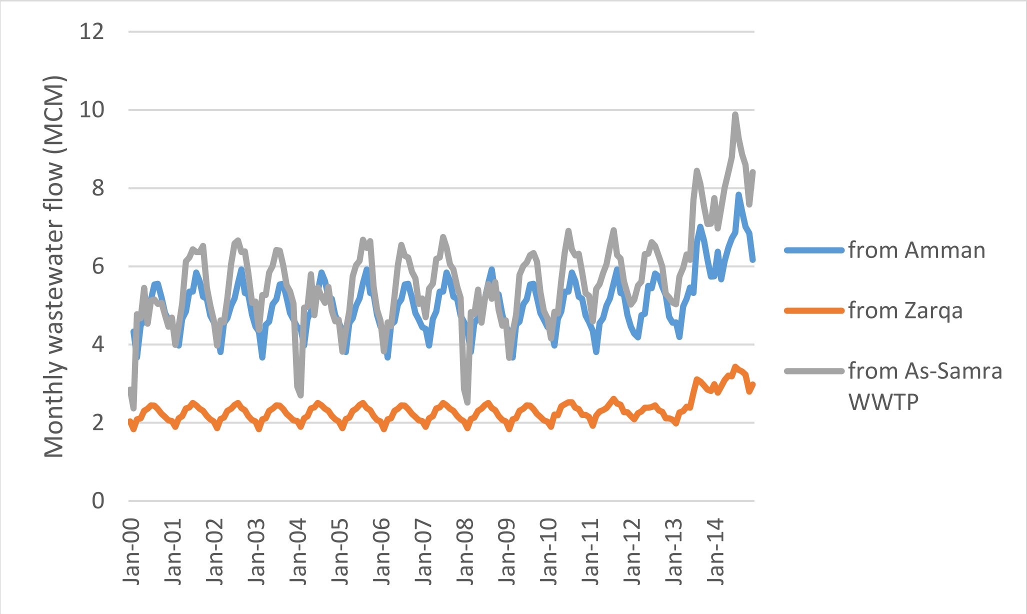


Figure 8. Modeled water deficits for North, Middle and south Jordan Valley regions (Baseline scenario)



Monthly wastewater flows from Amman and Zarqa, Figure 9, indicate the increased wastewater flows in 2013 due to start of Disi Pipeline operation, which in 2014 transferred projected 100 MCM to Amman. Subsequently treated wastewater discharge from As-Samra WWTP have increased by about 4 MCM in 2014, which was made available for irrigation. However, the gap between agricultural supply and demand the valley is still significant, Table A-2, Appendix A.

Figure 9. Modeled monthly wastewater flow from Amman, Zarqa and As-Samra WWTP, 2000-2014



5.2.2. Compact Investment Scenario

The model predicts that Compact Investment can generate between 14.6-21.3 MCM annually, Figure 11. The scenario was modeled for the analyzed period which shows that for years 2000-2012 the additional annual flows are just around 14-15 MCM and with increased water consumption during 2013-2014 in Amman the additional flows increase to 21.3 MCM for 2014, Table 9.

Table 9. Additional flows generated by Compact Investment Scenario

Year	ZCI (SO8)	ZCII (SO4&5)	ZCIII (SO2)	Abu Zeighan Canal	Total
	(MCM)				
2000	3.45	3.78	0.00	7.40	14.62
2001	2.53	1.56	0.00	10.77	14.85
2002	3.39	4.35	0.00	7.02	14.77
2003	2.67	3.52	0.00	8.43	14.62
2004	3.57	4.09	0.00	7.19	14.85
2005	2.71	2.25	0.00	9.80	14.77
2006	3.49	3.70	0.00	7.43	14.62
2007	2.45	4.40	0.00	8.00	14.85
2008	4.63	1.58	0.00	8.56	14.77
2009	3.38	2.02	0.00	9.22	14.62
2010	1.98	4.49	1.20	7.56	15.23
2011	1.50	6.04	0.97	7.05	15.55
2012	1.62	3.54	0.66	9.27	15.09
2013	0.00	5.87	5.07	6.49	17.43
2014	0.00	9.44	8.94	2.93	21.31

The additional wastewater from As-Samra WWTP is discharged to Zarqa River, which flows to King Talal Dam. The model redistributed additional flows among Zarqa Carriers and Abu Zeighan Canal based on the priority system discussed in Methodology section. Table 9 summarizes distribution of additional flows among the three carriers and Abu Zeighan Canal as well as additional water received by SOs.

The additional flows can be separated by the investment component:

- Generated by water network improvement 6.7-10.5 MCM,
- Generated by investment in wastewater sector 7.9-11 MCM.

6. COST-BENEFIT ANALYSIS OF COMPACT INVESTMENT

6.1. Methodology

The methodology for cost-benefit analysis component of the study is described in this section. It comprise of three main steps: data and information collection, typology of costs and benefits, and cost-benefit analysis (including the sensitivity analysis).

6.1.1. Data and Information Collection

This study uses data from secondary sources. The main data source for cost-benefit analysis parameters was economic rate of return (ERR) analysis completed by MCC in 2011, which were re-evaluated and updated with most recent data as needed. Additionally, the secondary data was obtained from the Ministry of Water and Irrigation, USAID reports and peer reviewed papers. The flows generated by water balance model for year 2014 were incorporated in cost-benefit analysis.

6.1.2. Typology of Costs and Benefits

This section discusses the impacts in greater detail that are associated with the Compact Investment. Table 10 below summarizes costs and benefits for the agricultural sector in Jordan Valley and municipal water users in Amman and Zarqa.

Table 10. The impacts associated with the investment

Costs	**Evaluation**
Water Network Rehabilitation Project	
• Associated Investment Costs	Quantitative
• Water Smart House Activity	Quantitative
Wastewater Network Project and As-Samra WWTP Expansion Project	
• Investment in WWNP and AEP	Quantitative
• Reoccurring costs	Quantitative
• Clogging of irrigation equipment	Quantitative
• Reduced agriculture land value	Qualitative
• Reduced crop yields and soil productivity due to salinity	Qualitative
• Groundwater contamination through excess nutrients and heavy metals	Qualitative
Benefits	**Evaluation**
Water Network Rehabilitation Project	
• Water supply cost savings	Quantitative
• Total savings associated with switching from shop and tanker water to network water	Quantitative
• Health gains associated with increased water consumption	Qualitative
Wastewater Network Project and As-Samra WWTP Expansion Project	
• Retention of irrigated land for citrus	Quantitative
• Value of water substitution	Quantitative
• Additional water available for existing irrigation (high value cultivation)	Quantitative
• Irrigation added value	Quantitative
• Reduced use of fertilizers N and P	Qualitative
• Avoided downstream agricultural contamination	Quantitative
• Benefits for domestic water users due to wastewater network expansion	Quantitative
• The recharge of the groundwater	Qualitative

In order to fully utilize the available treated wastewater from As-Samra WWTP the following assumptions were made:

- The infrastructure exists for diversion of wastewater to the agriculture fields in Jordan Valley;
- All treated wastewater released from As-Samra WWTP is available for irrigation;
- There is no negative perception of the wastewater reuse for irrigating the agricultural crops.

6.1.3. Cost Categories

Water Network Rehabilitation Project

Compact Investment Costs. The Compact investment is made in water delivery infrastructure in Zarqa as part of Water Network Rehabilitation Project to reduce the non-revenue water from 59 percent to 35 percent. The investment is 77.5 million JD, which is spread over 5 year of project implementation, 2014-2018 (1st year – 6 percent of total investment, 2nd – 17 percent, 3rd – 15 percent, 4th – 15 percent and 5th – 18 percent), and subsequent 9 years following the completion of the project: for first 4 years – 4 percent and rest 5 years – 2 percent.

Water Smart House (WSH) activity. This category includes the costs associated with the investment in Water Smart Homes activity, which is a household-level intervention that aims to improve water storage and sanitation in poor households. The main components of this intervention are general outreach campaign, delivery of infrastructure subsidies and technical assistance (Albert & et al., 2013, p. 2). The investment is 2.86 million JD which is spread over 5 years, 2014-2018, of project implementation as follows: 1st year – 7 percent of total investment, 2nd – 26 percent, 3rd – 23 percent, 4th – 22 percent and 5th – 21 percent.

Wastewater Network Expansion Project and As-Samra WWTP Expansion Project

Compact Investment costs. The 5-year Compact investment is made in Wastewater Network Project to expand wastewater collection system and to the As-Samra Expansion Project to expand the plant's capacity to treat wastewater from Amman and Zarqa. The investment is 138 million JD (193 million in 2011 USD), which is spread over 5 years, 2014-2018, of project implementation as follows: 1st year – 27 percent of total investment, 2nd – 32 percent, 3rd – 60 percent, 4th – 16 percent and 5th – 2 percent.

Recurring costs include the operation and maintenance costs (O&M) to maintain the expanded wastewater collection network and upgraded pumping stations, and to operate the As-Samra WWTP. In the MCC economic analysis the wastewater collection system O&M costs are projected to decrease by 1 million JD annually due to rehabilitation of pumping stations (Albert & et al., 2013, p. 13). Since the reduction is greater than the increased pumping costs, then it provides overall net benefit of cost reduction, which is indicated as a negative cost. These costs are taken "as is" from the MCC ERR analysis. The wastewater O&M costs depend on the volume of water treated. The cost to treat a cubic meter of wastewater is 0.08 JD which stays the same after the project implementation. There is a projected national increase in treatment charges by 25 percent as indicated by MCC which is applied for cost estimates. The following equation is used to estimate As-Samra O&M costs:

*Recurring costs=inflow volume*water treatment O&M cost**
**projected national increase in O&M charges*

Clogging of irrigation equipment. The clogging of drip emitters is a concern among the farmers in JV. Studies show that 75 percent of farmers experience the plugging problems as early as in the second year of irrigation equipment use (Ammary, 2007, p. 171). The primary causes are the algae, high total suspended solids (TSS) and water pH (Ibid.). The increased algae presence in irrigation water is caused by elevated nitrogen and potassium levels in King Talal Reservoir (KTR) water (Ibid.). Chlorination can be applied as one of the means to reduce the algae and clogging of the equipment. As-Samra WWTP is efficient in removing TSS from treated wastewater thus high TSS is not much of concern for farmers using water from KTR, especially as the KTR also provides efficient TSS removal through long water stay in the reservoir (Ammary, 2007, p. 171). This cost is evaluated using the cost of agricultural irrigation development per hectare provided by MCC. The assumption is made that the cost to provide additional treatment for irrigation water to avoid the damages or replace the damaged equipment will be equal to 2 percent of agricultural irrigation development after project implementation and 1 percent currently. The following equation is used:

*Clogging irrigation equipment=Cost of agricultural irrigation development**
*Affected agricultural area*percent*

6.1.4. Other Cost Categories

Crop yield and soil productivity loss due to soil salinization. The increase use of reclaimed water in irrigation can have negative effects on long-term soil productivity and crop yields. In Indo-Ganges Basin in India the reported crop yield losses for wheat are up to 40 percent and in Indus Basin in Pakistan the average loss is 32 percent (UNU-INWEH, 2014). The studies indicate that salt accumulates at the soil surface when drip irrigation is used. The concentration of salts in area irrigated by water from KTR can be twice the concentration as compared to area irrigated with water from Yarmouk River (Al-Zu'bi, 2007, p. 75). The evaluation of the long-term effects on the agriculture land is complex and accurate data for the region is lacking. Thus for this analysis this cost category is only evaluated in sensitivity analysis using 2 percent annual production loss in the following equation:

*Cost of soil salinization=Value added for high value cultivation*Affected agricultural area*2%*

Agricultural land value. The land price in Jordan Valley depends on the quantity and quality of water available for the agricultural irrigation. Greater water availability increase the value and the lower quality of the water – decrease it (Haddadin, 2006, p. 111). In case of increased wastewater reuse in the irrigation it is difficult to isolate the impacts of these water characteristics. Thus the assumption is made that increased effluent volume from As-Samra for irrigation offset the decrease of quality in irrigation water due to higher ratio of wastewater used. Negative attitudes towards use of reclaimed water can further negatively affect the value of the land. This cost category is not evaluated separately and can potentially be captured in other categories such as costs of soil salinization.

Groundwater contamination. The risk of groundwater contamination can occur through excess nutrients and heavy metals, but the literature is scarce for quantifying such costs. The study done by Al-Zu'bi on soil contamination in JV concluded that As-Samra is efficient in removing the pollutants and the irrigation water has heavy metals present within accepted limits (Al-Zu'bi, 2007, p. 75). The costs of this category are not quantified.

6.1.5. Benefit Categories

Water Network Rehabilitation Project

Water supply cost savings. Network rehabilitation project will reduce the NRW from 59 percent to 35 percent in Zarqa. Assuming that the O&M costs stay constant during the identified project life time, the increased volume of water delivered to households will reduce the water cost delivery per unit of water by about 28 percent on average. Since the collected tariff for water services does not fully cover O&M costs, the revenue generated from this additional water supply will reduce the subsidies provided by the Government of Jordan. Subsidy reduction approach was used to estimate this benefit category. Projected tariff increase is estimated for 2015 to JD 0.246 (from JD 0.23) per cubic meter and in 2019 to JD 0.295/m^3. The associated total water deliver cost includes estimated Disi water delivery cost which is JD 1/m^3.

*Water supply cost savings=(with project authorized water consumption- No Investment authorized water consumption)*Average consumer price for piped water*

Total Savings associated with switching from shop and tanker water to network water

Additional substituted water from Jordan Valley of 9.5 MCM annually is available for domestic uses in Amman. It will reduce the burden of the households to buy expensive shop and tanker water. Poor network water quality and water shortages forces the households in urban areas to buy more expensive water from tankers and shops. Tanker water is primary used to cope with the limited network water and short delivery times, and used for domestic consumption. Shop water is primary purchased for drinking. The assumption is made that the residents are willing to substitute network water for tanker water that is primary used for domestic consumption, which will generate savings for the households. Cost of network water is JD 0.23/m^3, tanker water cost is - around JD 4/m^3, and shop water up to - JD 52.8/m^3. The water network improvements are likely to improve water quality by limiting the time network is under no pressure which allows contaminated water seep through the pipes (Albert & et al., 2013, p. 17). The analysis values additionally supplied network water at marginal cost of water supply (Albert & et al., 2013, p. 14). In the analysis the substitution priority is given for tanker water and then the same principal is applied for the remaining water available for substitution with shop water:

Savings associated reduced tanker water purchase=additional water supplied[13]**(tanker water cost-network water cost)*

*Savings associated reduced shop water purchase=(additional water supplied-water substituted for tanker water) *(shop water cost-network water cost)*

---

[13] Condition is set that additional water supplied cannot exceed the existing purchased tanker water quantity.

Health gains associated with increased water consumption. Poor health and disease incidences are associated with limited water supply for domestic uses. Thus increasing water supply can result in gained health benefits in terms of avoided diseases, increased productivity and prevented sickness days. The study conducted by WHO Health and Environment Linkages Initiative (HELI) in 2004-05 in Jordan concluded that reducing leakage in water delivery system by 5 percent (from 30 to 25 percent) can lower the incidence of diarrhea by 38 percent (WHO, 2006, p. 9). This is achieved by making available additional 10 L/cap/day (WHO, 2006, p. 9). Reducing the incidence of diarrhea from 45 percent to 23 percent in 10 year span can result in potential health benefits up to JD 59.6 million with 1.84 return of investment in the health and environmental benefits (WHO, 2006, p. 15). However, this study restrains to quantify health benefits due to difficulty to make those estimates and lack of relevant data. It is also unclear whether the additionally available water will reach the poor households consuming less than 50 L/cap/day, who could gain greatest health benefits due to this Investment. Moreover, many households employ measures such as water storage infrastructure and purchasing water from tankers and shops to reduce the gap between intermittent water supply and the household water demand.

Wastewater Network Expansion Project and As-Samra WWTP Expansion Project

Retention of irrigated land for citrus. The citrus farms most of which are located in North Jordan Valley receive water from KTD. This benefit is related to retention of the existing citrus farm area, which otherwise can shrink because of reduced future water supply. It is assumed that without the project the water supply for the area will be short of 1.8 MCM annually, which corresponds to 143 ha loss for 4 years, after which the loss stays at 572 ha annually. Some studies indicate that citrus trees are very sensitive to elevated salinity in irrigation water. However, as there is no available information about such losses in JV, it is assumed that there is no negative effect on citrus trees from increased use of wastewater for irrigation. The parameters from USAID report are used for this category as they are based on more recent data. Thus, the difference in estimated water supply for citrus, is 89 percent of requirement. The following equations are applied:

*Retention of Irrigated Land for Citrus=Retained citrus area*Added value for citrus*

Retained citrus area=annual area loss# of years*

Water substitution benefit. The primary benefit of this economic evaluation is the benefit that comes from the substituted wastewater for fresh water in agricultural irrigation. It is assumed that the substituted freshwater is transported to Amman for higher value domestic uses, which is a lower cost alternative as compared to the shop water in Zarqa and Amman (Albert & et al., 2013, p. 14). Thus, the wastewater reuse in agriculture could benefit the consumers in Zarqa and Amman who are willing to pay more for the freshwater. Substituted water is forecasted to be up to 9.5 MCM annually, - water balance model estimate for year 2014. The value of water of 1.55[14] JD/m^3 for municipal uses estimated from Household Surveys (Orgill & et al., 2016) and 0.6 JD/m^3 transport costs, provided by MCC, are used to evaluate this benefit. The following equation is used:

---

[14] The related coping costs are estimated at $11.5 per month and household average monthly water use – 7.6 m^3. Thus coping costs per cubic meter are $11.5/7.6 m^3=$1.55/m^3 or JD 1.1/m^3.

*Water substitution benefit=(value of water for municipal uses-transport costs)*Substituted volume*

Irrigation added value. The additional water available for the irrigation that was made possible by the Compact Investment is estimated at 0.33 JD/m^3 as marginal value for production (from MCC ERR analysis). The value is based on estimating the difference between the potential added value per hectare and high value cultivation.

*Irrigation added value=remained water for irrigation*marginal value of adding water*

$$Marginal\ value\ of\ adding\ water =$$

$$= \frac{(potential\ added\ value - high\ value\ cultivation\ added\ value)}{agricultural\ water\ deficit}$$

Value of existing irrigation. This benefit is based on the assumption that all available cultivation area will be used for high value crops, which means that due to water availability the farmers will make a rational choice to switch to more profitable crops. In comparison an assumption is made that currently 90 percent of land is used for high value crop cultivation and the rest for low. Without the investment with the decreasing water supply increasingly the land will be used for low value cultivation and in year 8 and the subsequent years reaching 100 percent of low value cultivation. Below is the equation for estimating this benefit:

*Value of existing irrigation=affected agricultural area**
*(low value cultivation*percent of cultivated land with low value crop+*
*+high value cultivation*percent of cultivated land with high value crop)*

Avoided contamination benefits. According to Jordan's reclaimed domestic wastewater Standard 893/2002 the E.coli microorganism count in wastewater used for the irrigation should not exceed 100 microorganisms (MPN) per 100 mL for water used to irrigate vegetables used for cooking (Ulimat, 2012, p. 12). In 2011 the reported E.Coli concentration for As-Samra effluent was 18MPN/100ml, which is below the requirement (Ulimat, 2012, p. 15). In Jordan it is not allowed to use wastewater to irrigate vegetables that are consumed raw, such as tomatoes and lettuce. The Standard 893/2002 for fecal coliforms is 200 MPN/100ml. In 2014, the highest monthly average fecal coliform concentration in effluent from As-Samra WWTP was 590 MPN/100 mL, which is three times more than the recommended maximum concentration (MWI, 2014). The microorganism count exceeds the standard and the main concern is the health of farm employees, who can get infected through the contact with polluted water. However, effluent that is used for irrigation in JV is mixed with Zarqa river water. Moreover, most of the irrigation systems in Jordan Valley are piped networks and 96 percent of the farms use drip irrigation. Thus, the risk is minimized as the workers have only minimal contact with water (Al-Zu'bi, 2007, p. 74; Haddadin, 2006, p. 110). Thus expansion of As-Samra WWTP will likely improve the water quality, especially in As-Samra vicinity, reducing the health risks. Avoided contamination benefits are calculated under assumption that alternative investments would be made to avoid the contamination, which are valued at JD 0.16 million per million cubic meters as provided by MCC (Albert & et al., 2013, p. 12). The equation for benefit estimation is:

*Avoided contamination benefits=excess overflow*alternative wastewater treatment investment*

6.1.6. Other Benefit Categories

Reduced fertilizer consumption. The effluent from the wastewater plant have elevated levels of nutrients such as nitrogen and phosphorus. From As-Samra WWTP the average total nitrogen value for effluent in 2011 was about 20 mg/L and for potassium (in form of PO_4) – nearly 16 mg/L (Ulimat, 2012, p. 15). The concentrations are reduced after the effluent mixes with the Zarqa River flows. However, the benefits of reduced fertilizer use at the farms can be predicted if the farmers are well informed about the nutrients and their quantities in irrigation water. Quantifying the benefits of this category is complicated and actual data is needed, thus, they are evaluated in sensitivity analysis only to understand the sensitivity of net benefits to its fluctuations. The lower and upper bounds for these benefits are estimated at 5 percent and 15 percent, respectively.

Net benefits to households due to expansion of wastewater collection network. These benefits are transferred directly from initial MCC economic analysis for a complete investment analysis. The benefits include the avoided cesspit construction and maintenance costs and value of land reclaimed, and the costs to the household include network connection costs and annual wastewater tariff.

6.1.7. Cost-Benefit Analysis

The goal of this analysis is to estimate the impacts generated by the Compact Investment in wastewater sector. The life of the project is estimated to be 20 years, which includes 5-year implementation period. It is assumed that there are no alternative investment planned for next 20 years, and O&M costs are constant throughout the lifespan of the projects.

The cost-benefit components does not use scenario approach but estimates the Compact investment benefits relative to *No Compact investment* (baseline) assumption meaning WAJ would continue to operate water and wastewater networks and As-Samra WWTP on “as-is” basis with possibly minor investments to maintain the networks without major improvements. As-Samra WWTP already operates at full capacity and the excess wastewater would be directly discharged to the Zarqa River without treatment, which could pose increased health risks to downstream populations and the environment. Blended water used for irrigation would be of a lower quality but the increased volume of water due to some improvements would benefits in preventing the decline of some of existing agricultural areas.

Compact investment in three project components provide greater benefits. Water distribution network in Zarqa would be rehabilitated to reduce physical water losses, the wastewater collection network would be expanded in Zarqa to capture additional wastewater that is currently collected in cesspits. As-Samra WWTP upgrade would result in larger quantities of higher quality treater wastewater discharged to Zarqa River for irrigation in Jordan Valley reducing health risks. Moreover, this additional wastewater would replace the freshwater used for irrigation, which would be transported to Amman for high value residential and commercial uses (Albert & et al., 2013, p. 14). It is projected that Compact investment could generate annually up to 21.3 MCM of additional wastewater for irrigation of which about 9.5 MCM would be available for substitution.

6.2. Results and Discussion

6.2.1. Net Present Value Discussion

The monetary estimates are in 2011 Jordanian Dinars (JD). The monetary values of parameters for other years than 2011 are adjusted to 2011 JDs. Table 11 lists the present value of costs and benefits for the Compact Investment, showing that project PV benefits exceeds PV costs resulting in JD 51.9 million of Net PV benefits. The greatest benefits are associated with the value of existing irrigation.

Table 11. Present Value cost and benefits for Compact investment

Category	Compact Investment
Water supply cost savings (million JD)	6.9
Total savings from switching from shop and tanker water (million JD)	41.1
Value of retaining the existing citrus area (million JD)	22.6
Value of water substitution (million JD)	25.9
Incremental irrigation added value (million JD)	11.5
Value of existing irrigation (million JD)	111.4
Avoided downstream agricultural contamination (million JD)	21.5
Total Benefits (million JD)	**240.9**
WRRP investment costs (million JD)	45.3
WWNP & AEP investment costs (million JD)	136.6
Recurring costs (million JD)	-5.3
Other agricultural costs (million JD)	17.7
Total Costs (million JD)	**189.0**
Total Net Benefits (million JD)	**51.9**

Initial project analysis used the 10 percent discount rate, which is appropriate to use for the projects in developing (mid- to low- income) countries. World Bank uses 10-12 percent rate to evaluate the development projects (Mejia, 2013). For comparison purposes 7 percent discount rate (used by U.S. Office of Management and Budget), 12 percent (rate used by International Development Bank) and 15 percent (upper bound used for developing countries) are applied. There is a significant difference in Net benefits for different discount rates as shown in Table 12.

Table 12.Project evaluation under different discount rates

	10%	7%	12%	15%
PV Total Benefits (million JD)	240.9	322.0	191.0	143.7
PV Total Costs (million JD)	189.0	212.1	175.3	157.8
PV Net Benefits (million JD)	51.9	109.9	15.7	-14.1
Benefit-Cost Ratio	**1.27**	**1.52**	**1.09**	**0.91**
ERR	**14%**			

The Benefit-Cost Ratio (BCA) is positive for all selected discount rates varying between 1.52 and 0.91. The discount rate of 10 percent would be a preferred option with Economic Rate of Return (ERR) of 14 percent. Notice that with 15 percent discount rate the Net PV Benefits of the investment are negative, meaning that with greater discount rate the project does not seem to be beneficial.

The distributional impacts of the project are to be mentioned. Besides the direct costs associated with the investment and O&M, the negative impacts are borne by the farmers such as clogging of the equipment and loss of yields and contamination. The benefits are reaped by the farmers and the municipal water users, who gain the benefits from increased water supply. The impacts to the environmental and losses due to environmental degradation are not evaluated in this effort.

The initial MCC ERR analysis completed in 2011 estimated the ERR of 19.4 percent for WRRP project and 13.5 percent for WWNP and AEP projects. The net benefits for water sector investment and wastewater sector investments were JD 28.9 million and JD 34.9 million, respectively. The difference between this and MCC ERR analysis is mainly due to reduced value of substituted water for municipal sector used for this analysis. Additionally, the associated additional flows generated by Water Balance Model are larger than the flows estimated in MCC ERR analysis.

6.2.2. Sensitivity Analysis

The benefits of this project highly depend on selected parameters that are used to assess costs and benefits. Thus the sensitivity analysis is important to determine how sensitive overall benefits are to parameter fluctuations. For example, crop yields and associated farm profits in Jordan Valley depend greatly on the crops cultivated, soil productivity, irrigation equipment used, water allocations and quality, fertilizer and other inputs used in the production. Therefore, it is difficult to estimate the accurate values for overall added value of water to the cultivation. Sensitivity analysis can help to identify the magnitude of the impact by varying the added value of water parameter.

In this cost-benefit analysis the benefits associated with maintaining the existing irrigation provide the largest benefits, Table 11. Thus, the parameter used in the estimates of these benefits were explored, Table B-1 in Appendix B. Additionally, the discount rate, water value to municipal sector, and the variability of water supply for Amman were also included in the analysis. The reasoning was that they can significantly increase or reduce the treated wastewater flow estimates. Moreover, crop yield loss due to salinity and benefits due to reduced fertilizer use were also investigated in the sensitivity analysis to determine how significant the affect Net PV benefits. The sensitivity analysis was prepared using Crystal Ball in Excel. Note that some of the selected parameters for sensitivity analysis were used in equations for cost and benefit categories. Net PV benefits were selected as an output variable.

Tornado Analysis, Figure B-1 in Appendix B show that Net PV benefits were very sensitive to changes in discount rate. Other two significant contributors were value of water to municipal sector and high-value crop cultivation revenue, which had greater positive effect than negative. These parameters used in the estimation of the cost and benefit categories must be selected with caution. The substitution was predicted to be one of the greatest project benefits, but using the value of water for municipal sector from *Household surveys,* which was estimated JD 1.10 per cubic meter, reduced the associated benefits significantly as compared with the value used by MCC in the initial economic analysis. For another category, the analysis estimates that due to increased water availability all the areas will be transformed to high value crop cultivation, which might not be an accurate assumption. Thus, for future analysis a more accurate estimation of high-value crop cultivation revenues obtained from the farm surveys is crucial. Other parameters selected for sensitivity analysis have smaller effects on Net PV benefits.

The distribution chart, Figure B-2 in Appendix B, shows the greatest likelihood of Net PV Benefits is concentrated around 30-80 million JD with a long positive tail. There is some chance that the project can generate negative benefits (part of left tail), but the likelihood is greater for the project to exceed the relative to baseline Net PV Benefits.

The sensitivity of Net PV Benefits to salinity parameters was explored in separate analysis, Figure B-3, Appendix B. It indicates that the costs associated with the reduced annual crop yields due to soil salinization have a significant effect on the estimated benefits resulting in greater probability to have the negative Net PV Benefits. Thus, it is recommended in future economic analyses to make an attempt to monetize costs associated with salinity effects on the soil fertility and crop productions.

7. DISCUSSION

Jordan is one of the most water poor countries in the world. Water scarcity in Jordan is exaggerated by rapidly increasing population, especially in urban areas, which results in greater competition among different sectors, mainly municipal and agricultural. Other contributors to increasing water shortage are groundwater over abstraction and climate change. Available water resources are limited, and the only source that can have significantly increase water supply is Red-Dead Water Conveyance Project, which is currently under review.

The Government of Jordan identified municipal sector having the priority over the agricultural sector for freshwater use. However, water conservation practices in municipal water sector and related policies have not been fully utilized. Non-revenue water estimates for urban areas are significant: in Zarqa more than half of water is lost in the water delivery networks, and in Amman - just over 40 percent. These are significant water losses especially in water scarce country such as Jordan. Additionally, WAJ, which cannot fully recover the costs associated with water delivery loses large portion of the revenue.

Jordan Valley is primary area in Jordan that produces crops, vegetables and fruits for domestic market and for export. Most of cultivated land in the valley is irrigated. Increasing competition over limited water resources has resulted in increasing gap between the irrigation water demand and available supply. Water deficit has negative impact on agricultural output, livelihoods of farmers and the future of Jordan’s agriculture sector. The Government of Jordan focus its efforts on recovering treated wastewater as an alternative water source to irrigate crops in Jordan Valley. The substitution principle is also applied, which means that the wastewater is substituted for freshwater in Jordan Valley, which is then transferred for higher value municipal uses in Amman and Zarqa.

MCC Compact Investment in Zarqa Governorate water and wastewater sectors aimed to benefit both, agricultural and municipal users, by increasing available treated wastewater for the irrigation and water substitution. This study used two-step approach, development of water balance and cost-benefit analysis, to estimate the net economic benefits associated with the Compact Investment. Water balance model was developed to simulate water system in Jordan Valley indicating the allocations for different municipal users and agricultural production areas as well as existing water supply. Such model provides more accurate flow estimates that were incorporated in cost-benefit analysis. The model was developed for period 2000-2014, and generated 21.3 MCM of additional wastewater available for irrigation and 9.45 MCM for substitution for year 2014. These flows were larger than the ones predicted by MCC ERR analysis in 2011.

The costs-benefit analysis estimated that Net PV Benefits associated with the investment are JD 51.9 million, and investment ERR – 14 percent. Both estimates are greater than MCC ERR estimates of JD 63.8 million for Net PV Benefits and 19.5 percent and 13.5 percent ERR for water and wastewater sectors, respectively. The majority of the parameters for cost-benefit step were obtained from MCC ERR, but adjusted, when possible, based on most recent data.

Some impacts were evaluated only qualitatively such as negative impacts from increased salinity and heavy metal pollution as it is difficult to quantify them. However, such pollution can have a long term negative implications on crop yields and reduced soil fertility and I recommend in the future, if data is available, to monetize them. Effects from soil salinization such as crop yield reduction were incorporated in sensitivity analysis, which showed that salinity can have significant negative effects. Figure B-3, Appendix B. Health benefits associated with increased water availability for domestic uses, which was quantified in MCC ERR analysis, was also difficult to estimate since there is no clear causal relationship. The other negative impacts that were not feasible to monetize include food safety risks and the loss of markets for agricultural goods.

The substitution was predicted to be one of the greatest project benefits, but using the value of water for municipal sector from *Household surveys,* which was estimated at JD 1.10 per cubic meter, reduced the associated benefits significantly as compared with the value of JD 2.35 per cubic meter used by MCC in the initial economic analysis. The value of water from household surveys was based on the estimated coping costs. Even with the reduced benefits the substitution is still justifiable providing the municipal water users with additional network water.

The value of high-value crop cultivation revenue was the largest benefit categories, JD 111.4 million. Revenue from high-value crop cultivation portrayed that such cultivation can provide significantly larger benefits for agricultural sector as compared to lower-value crop cultivation. Thus, subsidy reduction for agriculture coupled with improvements in crop post-production and marketing sectors can improve competitiveness of agricultural sector for water, and, at the same time, increase efficiency in irrigation and spur shift to higher-value crop production.

Lack of and limited available data were main study limitations. As sufficient and reliable data for water balance model was a challenge, thus, data from various sources such as MWI, WEAP model, reports and peer reviewed papers were used for the model. Some of the data were conflicting, thus, I used best judgement to select the most appropriate source. Reliable data were also a challenge in quantifying associated project costs and benefits.

8. POLICY RECOMMENDATIONS

The Government of Jordan utilizes unconventional water sources, such treated wastewater reuse for agricultural irrigation, to address the water shortage in the country. The advantages as well as negative impacts due to such practice have been studied, but there is limited literature on the negative effects of wastewater reuse for irrigation in Jordan Valley. Thus, to minimize the potential negative impacts the following recommendations associated with such practice are proposed:

- Maintain high quality of treated wastewater in order to reduce the contamination of soil, groundwater and reduce health risks.

- Focus on providing a high quality network water for municipal water users.
- Increase irrigation efficiency in JV and design programs to switch cultivation from low- to high-value crops; improve post-production sector to reduce the post-harvest losses and increase farm revenues.
- Invest in conservation practices on demand management side to reduce NRW and promote water conservation on household level.
- Adjust the price for water across all the sectors to better reflect its value, as well as reduction of subsidies.

The implementation of above recommended policies can be difficult and even not possible. However, I recommend for the Government of Jordan to take the action to address the increasing water scarcity especially with rapidly growing population and climate change. The Compact Investment is an important step towards more efficient utilization and conservation of precious water resources.

REFERENCES

Ababsa, M. (2013). *Atlas of Jordan.* Beyrouth: Presses de l'Ifpo, Institut français du Proche-Orient.

Abbas, A.O. S. & et al. (2015). Irrigation Water Management in The Jordan Valley Under Water Scarcity. *Fresnius Environmental Bulletin, 24*(4), 1176-1188.

Abu Rumman, M. & et al. (2009). A surface water management model for the Integrated Southern Ghor Project, Jordan. *Construction Innovation, 9*(3), 298-322.

Al Abed , O. (2004). *Palestinian refugees in Jordan.* Forced Migratin Online. Retrieved October 9, 2015, from http://www.forcedmigration.org/research-resources/expert-guides/palestinian-refugees-in-jordan/fmo025.pdf

Al-Ansari, N., & et al. (2014). Water Demand Management in Jordan. *Engineering, 6*, 19-26.

Albert, J., & et al. (2013). Impact Evaluation Design Report (Jordan Compact - Water Sector).

Alcon, F., & et al. (2013). Incorporating Non-market Benefits of Reclaimed Water into Cost-Benefit Analysis: A Case Study of Irrigated Mandarin Crops in southern Spain. *Water Resour Management, 27*, 1809–1820.

Alfarra, A. (2009). Treated Wastewater for Irrigated Agriculture in the Jordan Valley. Disertation.

Alfarra, A., & et al. (2012). Modeling Water Supply and Demand for Effective. *Journal of Agricultural Science and Applications (JASA), 1*(1), 1-7.

Al-Zu'bi, Y. (2007). Effect of irrigation water on agricultural soil in Jordan valley: An example from arid area conditions. *Journal of Arid Environments, 70*(1), 63–79.

Ammary, B. (2007). Wastewater reuse in Jordan: Present status and future plans. *Desalination, 211*, 164–176.

Comair, G., & et al. (2013). Water resources management in the Jordan River Basin. *Water and Environment Journal, 27*(4), 495-504.

Denny, E. & et al. (2008). *Sustainable Water Strategies for Jordan.* Ann Arbor: University of Michigan.

Dinar, A., & Albiac, J. (2009). *Policy and Strategic Behaviour in Water Resource Management.* London: Earthscan.

Fan, Y., & et al. (2015). Cost-benefit analysis of reclaimed wastewater reuses in Beijing. *Desalination and Water Treatment, 53*(5), 1224-1233.

Farber, E., & et al. (2005). Management Scenarios for the Jordan river salinity crisis. *Applied Geochemistry, 20*, 2138-2153.

Government of Jordan (GOJ). (1997). Human Resources: the Demographic Challenge. Retrieved September 6, 2015, from http://www.kinghussein.gov.jo/resources2.html

Government of Jordan (GOJ). (2014). Jordan's Third National Communication on Climate Change. Amman, Jordan.

Hadadin, N. (2015). Dams in Jordan Curent and Future Perspective. *Canadian Journal of Pure and Applied Sciences, 9*(1), 3279-3290.

Haddadin, J. M. (2006). *Water Resources in Jordan.* Washington D.C.: Resources for the Future.

Haruvy, N. (1997). Agricultural reuse of wastewater: nation-wide cost-benefit analysis. *Agriculture, Ecosystems and Environment, 66*, 113-119.

Hoehn, J., & Krieger, D. (2000). An Economic Analysis of Water and Wastewater Investments in Cairo, Egypt. *Evaluation Review, 24*(6), 579-608.

Hoff, H., & et al. (2011). A Water Resources Planning Tool for the Jordan River Basin. *Water*(3), 718-736.

Hübschen, K. (2011). *Integrated Water Resources Management as a Governance Challenge for Countries of the Middle East with Special Focus on Yemen, Jordan and Syria.* Berlin: Logos Verlag Berlin GmbH.

IFAD. (n.d.). *Country fact sheet. Jordan.* IFAD Aquastat.

IPCCC. (2014). *Scenarion Process for AR5*. Retrieved February 16, 2016, from IPCCC Data Distribution Center: http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

Klassert, C., & et al. (2015). Modeling Residential Water Consumption in Amman: The Role of Intermittency, Storage, and Pricing for Piped and Tanker Water. *Water, 7*, 3643-3670.

Lienhoop , N., & et al. (2014). Environmental cost–benefit analysis of decentralised wastewater treatment and re-use: a case study of rural Jordan. *Water Policy*(16), 323-339.

Makhamreha, Z., & Almanasyeha , N. (2011). Analyzing the State and Pattern of Urban Growth and City Planning in Amman Using Satellite Images and GIS. *European Journal of Social Sciences, 24*(2), 252-264.

Mandri-Perrott, C. (n.d.). *Jordan: From water service provision to planning and management in the Jordan valley authority (#161).* Global Water Partnership.

Millennium Challenge Account – Jordan (MCA-J). (2012). Monitoring and Evaluation Plan*.*

Mejia, F. (2013). *In the long run we are all dead*. Retrieved December 2, 2015, from IDB: http://blogs.iadb.org/desarrolloefectivo_en/2013/05/31/in-the-long-run-we-are-all-dead/

Ministry of Water and Irrigatio (MWI). (2010). *Feasibility Study, Environmental and Social impact Assessment and Detailed Designs and Biddign Documents for Zarqa Governorate Wastewater System Reinforcement and Expansion Project.*

Ministry of Water and Irrigatio (MWI). (2013). *Jordan Water Sector Facts and Figures.* Amman: Government of Jordan, Ministry of Water and Irrigation.

Ministry of Water and Irrigatio (MWI). (2015a). *National Water Strategy 2016-2030.* Amman, Jordan. Retrieved February 16, 2016, from http://www.mwi.gov.jo/sites/en-us/Hot%20Issues/Water%20Sector%20Strategy%202016-2030.pdf

Ministry of Water and Irrigatio (MWI). (2015b). *Water Substitution Policy.* Amman, Jordan.

Ministry of Water and Irrigatio (MWI). (n.d.). Water Supply Data for Amman and Zarqa Governorates: 2009-2014.

Orgill, J., & et al. (2016). Coping with irregular water supplies: A comparison of contingent valuation and averting expenditure estimates (Working Paper).

Philippe, V. J. (2003). *Farming Systems in the Jordan River Basin in Jordan: agronomical and economic description.*

Rosenberg, D., & Lund, J. (2009). Modeling Integrated Decisions for a Municipal Water System with Recourse and Uncertainties: Amman, Jordan. *Water Resour Management, 23*, 85–115.

Sabah, A. (2011). Water in Jordan: Water security and protection. Retrieved September 6, 2015, from http://www.envirosecurity.org/essmed/june2012/presentations/II-B_Jordan_Ali_Subah.pdf

Shatanawi, M. R., & Shammout, M. W. (2011). Supply-Demand Modeling of Water Resources in Zarqa River Basin in Jordan. *International Journal of Applied Environmental Sciences, 6*(3), 261-278.

Sidahmed, A. E., Rabboh, W., Khresat, S., & Karablieh, E. (2012). Assessment of the Agricultural Sector in Jordan. Volume I. European Union.

Tabieh, M., & et al. (2012). The Residental Water Demand Function in Amman-Zarka Basin in Jordan. *Wulfenia Journal, 19*(11).

Ulimat, A. (2012). Wastewater Production, Treatment, and Use in Jordan. *Second Regional Workshop "Safe Use of Wastewater in Agriculture".* MWI.

UN DESA. (2015). *World Urbanization Report.* Retrieved September 11, 2015, from http://esa.un.org/unpd/wup/FinalReport/WUP2014-Report.pdf

UN-ESCWA, & BGR. (2013). Chapter 6: Jordan River Basin. In U.-E. a. Western, & B. f. Rohstoffe, *Inventory of Shared Water Resources in Western Asia.* Beirut.

UNHCR. (2015). ***Jordan*.** Retrieved October 9, 2015, from 2015 UNHCR country operations profile - Jordan: http://www.unhcr.org/pages/49e486566.html

UNU-INWEH. (2014). World Losing Farm Soil Daily To Salt-Induced Degradation. Retrieved November 25, 2015, from http://inweh.unu.edu/world-losing-farm-soil-daily-salt-induced-degradation/

USAID. (2006). Amman Water Management/Commercialization Assessment. USAID.

USAID. (2012). *I*SSP Water Valuation Study: Disaggregated Economic Value of Water in Industry and Irrigated Agriculture in Jordan. USAID*.*

USAID. (2012a). Water Valuation Study - Summary Report. Disaggregated Economic Value of Water in Industry and Irrigated Agriculture in Jordan. USAID.

Van Aken et al., M. (2007). Historical Trajectory of a River Basin in the Middle East: The Lower Jordan River Basin (in Jordan). Amman: International Water Management Institute and French Regional Mission for Water and Agriculture.

WHO. (2006). Report on the Regional Consulation on Health and Environment Linkages Initiative (HELI) and Chilrden's Environmental Health Indicators (CEHI). Amman, Jordan: WHO.

World Bank. (2010). Improving Wastewater Use in Agriculture: an Emerging Priority. World Bank.

World Bank. (2014). Jordan: indicators. Retrieved October 9, 2015, from http://www.worldbank.org/en/country/jordan

APPENDIX A

Table A-1. Modeled demand for each Stage Office in Jordan Valley

Year	SO1	SO2	SO7	SO3	SO4&5	SO8	SO6	Total
	North JV			Middle JV			South JV	
2000	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2001	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2002	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2003	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2004	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2005	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2006	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2007	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2008	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2009	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2010	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2011	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2012	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2013	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148
2014	9.7	25.8	31.0	11.3	29.0	14.3	27.0	148

Table A-2. Annual deficit for each Stage Office for No Investment *Scenario, 2000-2014 (MCM)*

Year	SO1	SO2	SO7	SO3	SO4&5	SO8	SO6	Total
	North JV			Middle JV			South JV	
2000	-1.99	-15.34	-2.15	-5.59	-0.37	-3.29	-6.44	-35.17
2001	-1.99	-15.34	-5.42	-5.59	3.55	-2.12	-6.44	-33.36
2002	-1.99	-15.34	-6.44	-5.55	-5.34	-3.39	-6.44	-44.50
2003	-1.99	-15.34	-0.81	-5.59	-4.33	-2.60	-6.44	-37.12
2004	-1.99	-15.34	-1.48	-5.59	-0.85	-3.40	-6.44	-35.10
2005	-1.99	-15.34	-1.60	-5.59	2.43	-2.38	-6.44	-30.92
2006	-1.99	-15.34	-3.66	-5.59	-5.77	-3.49	-6.44	-42.29
2007	-1.99	-15.34	-7.61	-5.59	-3.34	-2.37	-6.44	-42.70
2008	-1.99	-15.34	-10.69	-5.59	-9.16	-4.39	-6.44	-53.61
2009	-1.99	-15.34	-10.89	-5.59	-11.04	-2.91	-6.44	-54.21
2010	-2.75	-14.97	-10.18	-5.56	-11.04	-1.92	-11.05	-57.46
2011	-3.93	-16.48	-10.69	-6.29	-11.56	-1.41	-14.71	-65.08
2012	-2.89	-17.99	-8.93	-4.52	-9.61	-1.26	-11.96	-57.16
2013	-0.18	-14.78	2.91	-3.10	-9.17	2.44	-4.17	-26.05
2014	-1.44	-13.80	1.14	-1.65	-9.44	3.74	-2.55	-24.00

Table A-3. Annual deficit for each Stage Office for Compact Investment Scenario, 2000-2014 (MCM)

Year	**SO1**	**SO2**	**SO7**	**SO3**	**SO4&5**	**SO8**	**SO6**	**Total**
	North JV			**Middle JV**			**South JV**	
2000	-1.99	-15.34	-2.15	-5.59	3.41	0.16	-6.44	-27.95
2001	-1.99	-15.34	-5.42	-5.59	5.11	0.41	-6.44	-29.27
2002	-1.99	-15.34	-6.44	-5.55	0.90	0.00	-6.44	-34.87
2003	-1.99	-15.34	-0.81	-5.59	1.01	0.07	-6.44	-29.10
2004	-1.99	-15.34	-1.48	-5.59	3.24	0.16	-6.44	-27.44
2005	-1.99	-15.34	-1.60	-5.59	4.69	0.34	-6.44	-25.95
2006	-1.99	-15.34	-3.66	-5.59	0.81	0.00	-6.44	-32.23
2007	-1.99	-15.34	-7.61	-5.59	1.05	0.08	-6.44	-35.85
2008	-1.99	-15.34	-10.69	-5.59	-2.14	0.24	-6.44	-41.96
2009	-1.99	-15.34	-10.89	-5.59	-4.19	0.47	-6.44	-43.97
2010	-2.75	-9.14	-10.18	-5.56	-1.56	0.06	-11.05	-40.18
2011	-3.93	-10.58	-10.69	-6.29	-1.60	0.09	-14.71	-47.73
2012	-2.89	-12.41	-8.93	-4.52	-0.83	0.35	-11.96	-41.19
2013	-0.18	-4.46	2.91	-3.10	0.86	2.44	-4.17	-5.70
2014	-1.44	-0.90	1.14	-1.65	0.00	3.74	-2.55	-1.66

APPENDIX B

Table B-1. Parameters used in Sensitivity Analysis

Parameter	Value	Low bound	High bound
Discount rate (%)	10%	5%	15%
Value of water to municipal sector (JD/m3)	1.10	0.16	3.1
Water transport efficiency for agricultural irrigation (%)	70%	65%	90%
Affected Agricultural Area (ha)	11500	8000	14000
High-Value crop cultivation revenue (USD*/ha)	2285	1800	3500
Amman water supply (MCM)	179.19	150	240
Annual production loss due to saline soils (%)	2%	1%	5%

*This was converted to Jordanian Dinars for the analysis.

Figure B-1. PV Net Benefits sensitivity to parameter changes (Tornado Analysis)

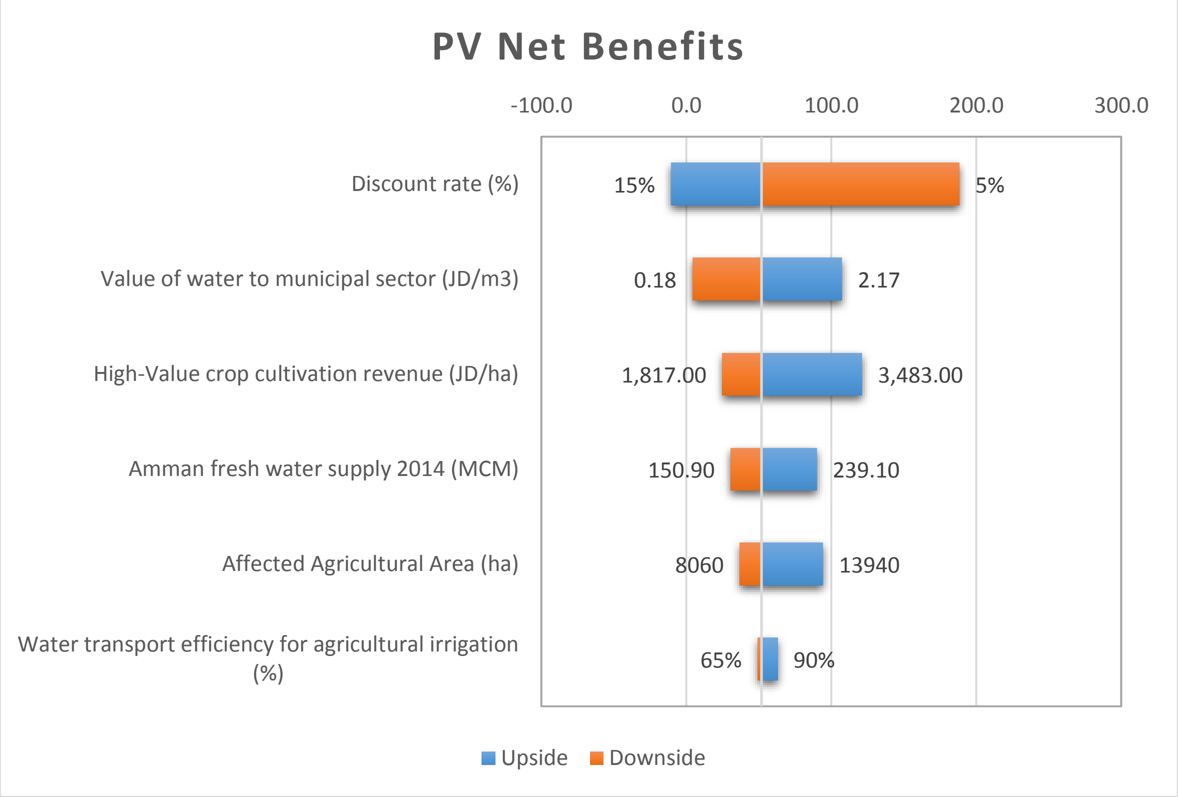


Figure B-2. PV Net Benefits of Compact Investment

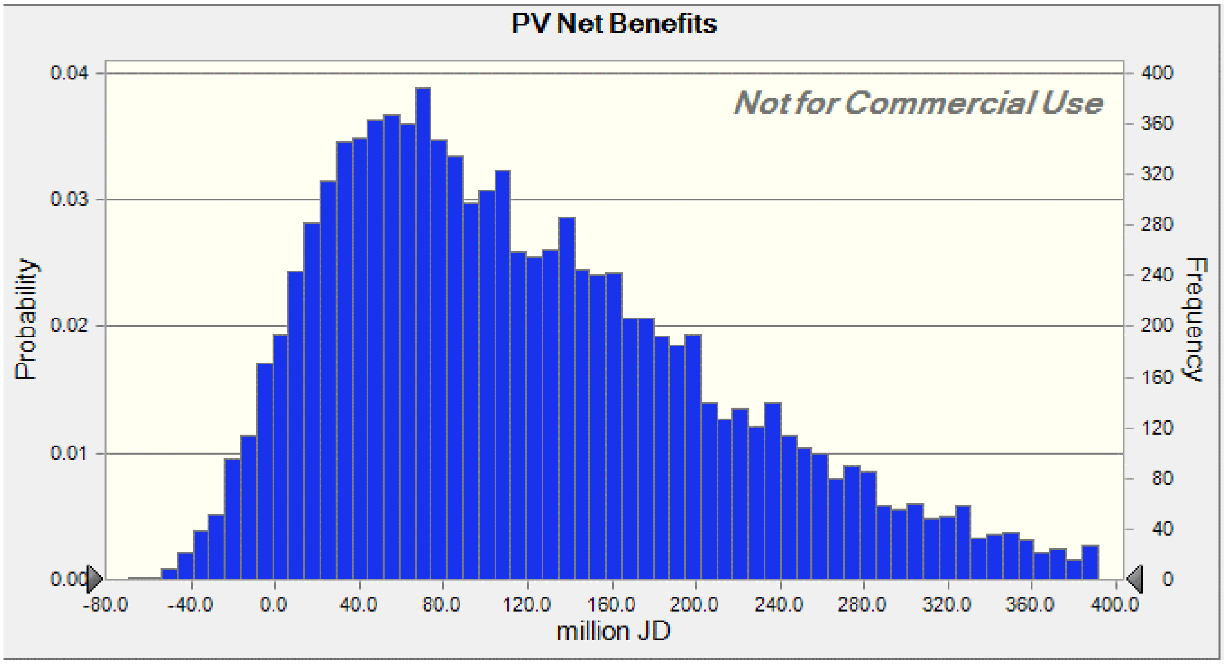


Figure B-3. PV Net Benefits sensitivity to parameter changes (Tornado Analysis) including salinity effects