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Impact Evaluation of the MCA Jordan Compact Baseline Results of Component 2 – Water Balance Analysis & Farm Surveys

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Prepared by Social Impact, Inc.
for the Millennium Challenge Corporation
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Marc Jeuland[1], Jenny Orgill[1], Amani Al-Farra[2], Karen Azeez[3]

[1] Duke University, Durham, NC USA
[2] Independent consultant, Rome Italy
[3] Social Impact, Arlington, VA USA. www.socialimpact.com. Please address communication for Social Impact to Daniel Hudner at dhudner@socialimpact.com.

List of Acronyms

AEP	As Samra Expansion Project
AS	As Samra
CI	Confidence Interval
DA	Development Area
DiD	Difference-in-Differences
DoS	Jordanian Department of Statistics
ERR	Economic Rate of Return
FGD	Focus Group Discussion
GIS	Geographic Information System
GOJ	Government of Jordan
IE	Impact Evaluation
IRB	Institutional Review Board
JVA	Jordan Valley Authority
KAC	King Abdullah Canal
KTD	King Talal Dam
KTR	King Talal Reservoir
M&E	Monitoring and Evaluation
MCA	Millennium Challenge Account
MCA-J	Millennium Challenge Account – Jordan
MCC	Millennium Challenge Corporation
MWI	Ministry of Water and Irrigation
NRW	Non-Revenue Water
PSU	Primary Sampling Unit
SES	Socio-Economic Status
SI	Social Impact
SOW	Scope of Work
WAJ	Water Authority of Jordan
WHO	World Health Organization
WNP	Water Network Project
WTP	Willingness to pay
WWNP	Wastewater Network Project
WWTP	Wastewater Treatment Plant

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1 Introduction

The Hashemite Kingdom of Jordan is one of the four driest countries in the world, and is currently facing severe water scarcity with declining per capita water resources as a result of population growth (including from new refugees), economic development, and decreasing water availability (Hashemite Kingdom of Jordan 2016). The scarcity of water in Jordan has been called the single most important constraint inhibiting the country's future growth and poverty alleviation. Water constraints not only affect economic development, but also have consequences for food production, health, social and human development. According to the Ministry of Water and Irrigation (MWI) and the Food and Agriculture Organization, renewable water availability in Jordan declined from 3600m^3/capita-year in 1946 to less than 100 m^3/capita-year in 2016, well below the international water poverty line of 500m^3/year (Hashemite Kingdom of Jordan 2009, FAO 2015). Moreover, water sector costs represent a major drain on the Government of Jordan (GOJ)'s fiscal resources, accounting for about 5% of the 2010 national budget and 17% of the 2010-2013 capital investment program (USAID 2011).

The challenges of water scarcity and its consequences for economic activity and poverty are amplified in Zarqa Governorate, a populous, dry, and mostly urban governorate west of the capital Amman. Nearly three in ten households in Zarqa consume less than the minimum amount of water considered essential for personal hygiene and food safety by the World Health Organization (WHO) (MCC 2009). This is mainly due to irregular water availability: many households receive piped water only for a limited number of hours, one or two days per week.

Against this backdrop, the MCC has been working with the GOJ to implement an investment Compact that is aimed at addressing water challenges in Zarqa. Social Impact (SI) was contracted by the MCC to measure the impacts of the Compact activities on economic and social outcomes. The Impact Evaluation (IE) aims to establish a *causal* relationship between program interventions and observed changes in household availability and consumption of different sources of water, income, expenditure, and health indicators. The IE also aims to measure potential impacts on other sectors (agriculture, utility financial performance, and local enterprises) should these occur in parallel to, or instead of, the expected impacts on households. This IE is, to our knowledge, the first attempt to conduct a rigorous IE design of a large infrastructure project in Jordan. It provides a unique opportunity for the MCC, the GOJ, and the broader development community to understand the impact of a large water investment on income and poverty of urban households and others who are affected by it. The IE design as a whole attempts to measure a diverse set of impacts that are differentially related to the three Compact projects, in order for the MCC to better understand which specific component(s) led to the observed changes in outcomes. A comparison of these different impacts will further allow for conclusions about the relative cost-effectiveness of each intervention.

This report details the results of baseline data collection activities conducted in association with the second of three IE components. Component 2 of the IE has two specific aims:

1. To quantify the amount of water involved in the **primary substitution effect** that is expected to result from the Compact, that is, the volume of water that is collected and treated in the As Samra (AS) Wastewater Treatment Plant (WWTP), and then reused for productive irrigation in the Jordan Valley and elsewhere, and the implications of that reuse for substitution of freshwater to urban areas in Jordan; and
2. To measure the impacts of the Water Network Project (WNP) and Wastewater Network Project (WWNP) on irrigators affected by these new flows of treated wastewater.

To achieve these aims, Component 2 of the IE involves two distinct and complementary data collection activities, each of which is accompanied by a set of statistical and modeling analyses. The first, associated with aim 1, consists of collection of system indicators related to water availability and water allocation, for use in construction of a water balance model that clearly identifies flows of water into Zarqa and Amman, wastewater collection from those urban areas and into the As Samra Treatment facility, discharges of recycled wastewater into the Zarqa River,[4] and allocations of water to irrigators both upstream and downstream of the King Talal Reservoir (KTR). The second data collection effort comprises a set of annual agricultural surveys – to measure farm characteristics and farming behaviors; crop choices and productivity; water use and expenses; and farm revenues and costs – with farmers located upstream and downstream of the KTR, who may be affected by the increased flows of recycled wastewater. The baseline agriculture surveys were conducted in the summer of 2015 (June to September), by teams from the Jordanian Department of Statistics (DoS) working with SI.

The structure of the report is as follows. Section 2 provides a very brief summary of the Jordan Compact, and describes the main features of the IE. Section 3 then reviews specific details related to Component 2. In Section 4, we describe prior literature that informs understanding of the water system dynamics in Jordan, focusing particularly on flows of water to urban areas and to irrigators in the Jordan Valley. Section 5 summarizes data sources and outcomes. Section 6 describes the Water Evaluation and Planning (WEAP)[5] tool that we have been working to develop in order to better understand the water balance and the extent of water substitution enabled by the Compact, and discusses the status of the water balance modeling (*work in progress*). Baseline results from the farm surveys are presented in Section 7. Finally, Section 8 discusses administration of the activities conducted under Component 2 of the IE.

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[4] Throughout this report, we refer to **recycled wastewater** as **treated wastewater** (i.e. wastewater treated to discharge standards governing wastewater releases in a particular location, which itself need not be reused) that is reused for any purpose. **Blended water** is a water supply that combines both runoff (from precipitation) and discharges of treated wastewater.

[5] WEAP is particularly suitable for the intended purpose because it easily accommodates the extensive primary and secondary data sets we are assembling, and because it allows the simulation of various water supply and demand scenarios (including a modeled counterfactual). Prior work has shown operating rules specified in WEAP can reproduce historical observations with accuracy that is sufficient for the purpose of policy analyses.

2 Overview of the Compact and the Impact Evaluation Design

2.1 *Summary of Compact Activities*

The Millennium Challenge Corporation (MCC)'s five-year, $275 million Compact aims to reduce poverty and increase income in Zarqa Governorate through improvements to the water network, the extension of wastewater collection and the expansion of wastewater treatment. The combined Compact projects should theoretically improve the efficiency of water delivery in Zarqa. The MCC Compact investment was motivated in large part by the **primary substitution effect**, through which increases in the use of recycled wastewater in agriculture enables increases in conventional freshwater availability for higher-value municipal uses. The entity charged with implementing the Compact in Jordan is the Millennium Challenge Account – Jordan (MCA-J).

The MCC Jordan Compact includes three inter-linked projects in the water sector in Zarqa Governorate:

(i) The Water Network Project (WNP) consists of two activities, a) the rehabilitation and restructuring of water supply transmission and distribution infrastructure, and replacement of domestic water meters, with the aim of improving the overall water system efficiency, reducing water losses and facilitating the transition from periodic distribution under high pressure to more consistent, gravity-fed distribution; and b) the Water Smart Homes (WSH) activity, a household-level intervention aimed at improving in-house water storage and sanitation that consists of a general outreach campaign, as well as delivery of infrastructure subsidies and technical assistance to poor households.

(ii) The Wastewater Network Project (WWNP) encompasses the expansion, rehabilitation and reinforcement of the wastewater network in West and East Zarqa, as well as West Ruseifa, aimed at improving the overall wastewater system efficiency and expanding the capture of municipal wastewater for reuse in agriculture downstream, possibly making additional freshwater available to the population of Zarqa Governorate through future wastewater substitutions for conventional freshwater.

(iii) The As-Samra Expansion Project (AEP) is designed to raise the capacity of the existing treatment plant with the aim of providing proper handling of increased volumes and loads of both oxygen-demanding material and suspended solids, allowing treatment of the additional wastewater volumes resulting from the WNP and WWNP investments.

2.2 *Rationale for this Impact Evaluation*

As with all Impact Evaluations (IEs) funded by MCC, the Jordan Water IE is designed to meet the dual goals of learning and accountability. The research questions, evaluation methodology, and outcomes of interest are selected to maximize the utility of evaluation findings. In addition to answering programmatic questions about the effectiveness of the intervention and how benefits accrue to population sub-groups (e.g., women), the evaluation seeks to inform future MCC programming, and to improve the effectiveness and efficiency of investment decisions. By documenting and substantiating

lessons learned with rigorous research methodology, the evaluation will provide useful and actionable information to MCC and the MCA-J senior management, project managers, beneficiaries, implementing partners, evaluators, and other evaluation stakeholders, most notably the Government of Jordan (GOJ). Lastly, with MCC's emphasis on transparency, the findings and data will be shared with the broader donor and development community, supplementing the global knowledge pool and amplifying the utility of the Jordan Water IE.

The IE will also help MCC to recalculate the Economic Rate of Return (ERR) of the Compact investment in Jordan following the investments. The SI team has, in close collaboration with the MCC and MCA-J technical teams, reviewed assumptions behind the original ERR calculation and identified areas in which the IE will provide MCC with new inputs to update this calculation in the future. In the same vein, the IE design has been developed in a manner that allows for accurate determination of the most appropriate and necessary inputs to the ERR calculations in order to maximize the utility of the IE. It is important to note, however, that not all inputs to the final ERR are to be supplied by the IE as some of these indicators are not impact estimates.

This IE also has the potential to contribute in meaningful ways to the existing literature on economic development and poverty reduction. Given the scale and anticipated impact of the Jordan Water interventions, MCC and the broader donor community have much to learn about which intervention or combination of interventions can be most effective and efficient in increasing available income through reduced water expenditures. In particular, there remains relatively little rigorous evidence on the impact of urban infrastructure interventions on household level outcomes, and even less on the private (enterprise) sector.

This IE is, to our knowledge, the first attempt to conduct a rigorous counterfactual IE design of a large infrastructure project in Jordan and will provide a unique opportunity for the MCC, the GOJ, and the broader development community to understand the true impacts of a large urban water investment. Finally, this IE will provide a unique and new dataset that can be used by other researchers to look at questions related to the effect of improved water and wastewater supply and systems on a series of household level outcomes. Following end line data collection, the team will synthesize the data into a report that will also be submitted for publication in the form of one or more articles in a peer-reviewed journal. As with all evaluations conducted by MCC, anonymized data will be made available for public use. This transparency will further facilitate the MCC goal of promoting learning.

2.3 Logic of the Impact Evaluation

As emphasized in pre-project feasibility studies and economic analyses of the Compact investments, the economic case for the MCC investments rests on a complex and interrelated set of hypothesized changes that flow from projects to outputs, then to outcomes and finally overarching goals. The linkages between the various components and these intermediate and final changes, respectively, are depicted in the IE logic (Figure 2.1). Importantly, as described in greater detail in the Evaluation Design Report (EDR), this diagram does not directly follow the categorization of impacts promulgated in other prior descriptions

of Compact impacts (e.g., in those accompanying the MCC's economic rate of return analysis), for the following main reasons:

1) The impacts included in those analyses were admittedly non-exhaustive, due to data limitations (for example, effects on enterprises and/or on property values were omitted from the analyses); and
2) The purposes of the IE logic are a) to trace out the *hypothesized* relationships between projects and intermediate outputs (grouped by color), and final outcomes and goals, b) to illustrate the overlapping relationships between project activities and desired outcomes, and c) to draw attention to some of the key assumptions underlying the case for the investment (as shown in annotations to Figure 2.1).

The IE logic aims to identify the set of final outcomes (and to a lesser extent the intermediate outputs) we intend to measure and track through the evaluation. Importantly, the so-called **primary substitution effect** (the increased use of blended KTR water in irrigation in the place of freshwater) is not and cannot be measured or shown as a single outcome. Rather, the quantification of this possible benefit stems from analysis that integrates several outcomes and outputs – to be carried out at the conclusion of the IE using data we proposed to collect – that flow through the following connections: a) reduced physical losses (WNP) and b) increased wastewater capture (WNP and WWNP); which lead to c) increased wastewater use in agriculture and d) substitution of KTR water for King Abdullah Canal (KAC) water in the Jordan Valley; which together e) change per-capita use of utility water and lead to f) end-user time savings; g) consumer cost savings; h) aesthetic and health benefits; and i) are capitalized in land values. Similarly, understanding the net value of the **secondary substitution effect**, or the increased use of network water in place of tanker and/or vended water, flows through a complex chain that includes (not in order of importance), a) improved water quality at the point of delivery and b) changes in per capita use of utility water (due to the factors listed above as well as these quality improvements) which are embedded in reduced purchase of c) tanker water and d) vended water; both of which should ultimately appear as consumer e) cost and f) time savings, but may also result in reduced sales and/or profits in the water tanker and vended water industries. In addition, the extent of these primary and secondary substitution effects will likely be mediated (positively or negatively) by changes in utility performance, itself a function of the delivery of improved services.

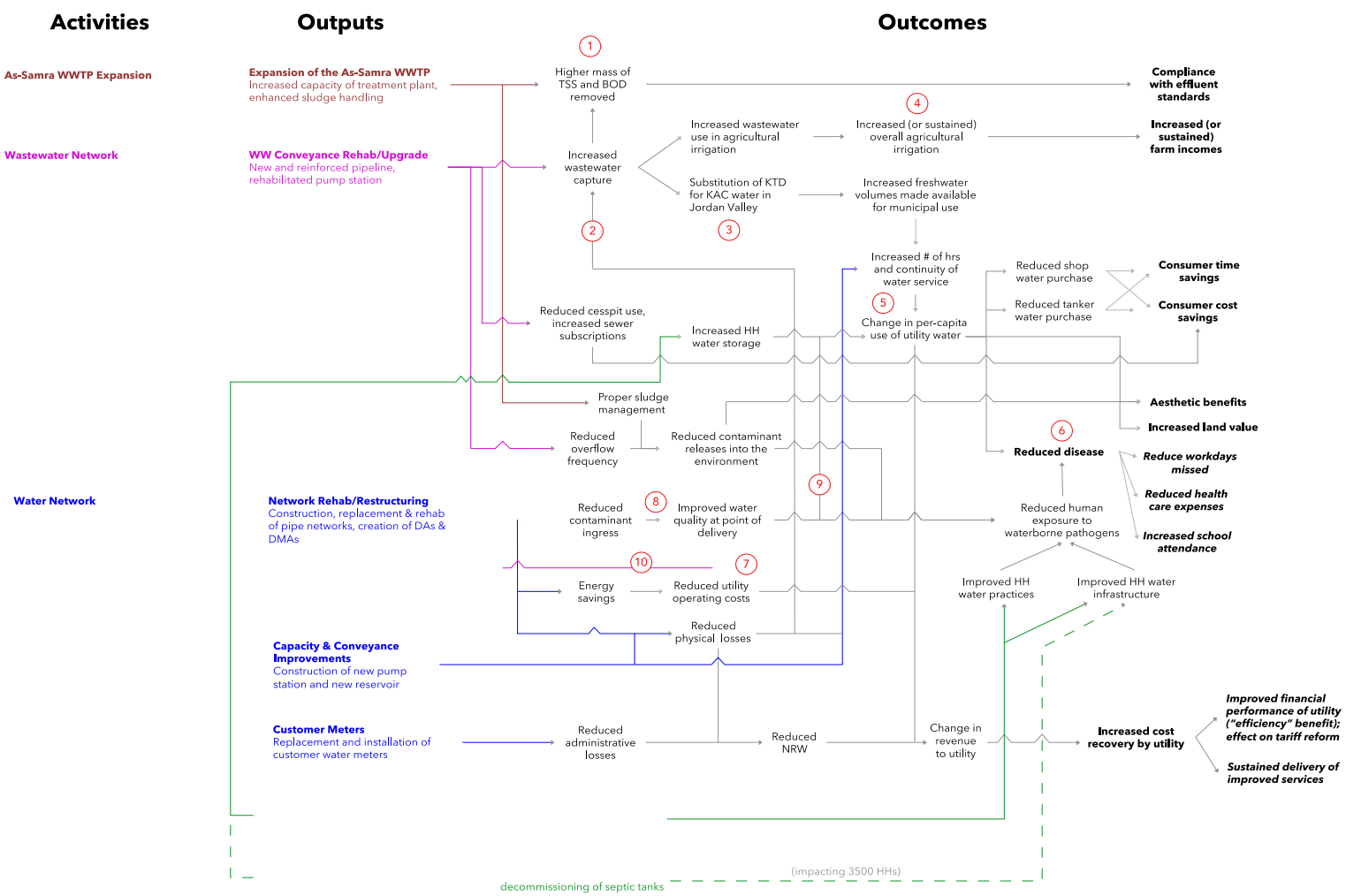
Thus, we emphasize that measurement of these effects, as well as several others mentioned in the previous analyses of MCC Compact's economic feasibility (see Table 2.1 for a complete list), does not stem from any of the three individual data collection components described in this report, but rather from analysis and integration of their specific results. These components are:

1. Component 1: Household and enterprise surveys conducted in both intervention and control areas of the Zarqa/Ruseifa conurbation (and similar control areas selected from the Amman Governorate);
2. Component 2: Detailed longitudinal water balance analysis for the system spanning the Zarqa and Amman water and wastewater networks, the King Talal Reservoir, and the complex irrigation network of the Jordan Valley; as well as farm surveys in the Jordan Valley to estimate

the magnitude and economic impacts of changes in the availability and utilization of water from different sources;

3. Component 3: Detailed monitoring of District Metering Area (DMA) and utility-level data on water delivery and wastewater collection in Zarqa, as well as indicators of financial and technical performance of the WAJ-Zarqa.

The present report focuses only on the sampling procedure and baseline data collected as part of Component 2. For details on the other components, readers can refer to the EDR.



Key:
- Colors correspond to Activity
- Normal text corresponds to intermediate outcomes
- **Bold** corresponds to longer term outcomes
- ***Bold italic*** corresponds to secondary or derivative long term outcomes
- Numbers correspond to relationships that include caveats included below

Figure 2.1. IE Logic Diagram

Figure 2.2. Annotation List.

1. The As-Samra Facility expansion will enable removals of suspended matter and oxygen-demanding materials from increased volumes of wastewater that would not be treated in the absence of the expansion, as well as potentially facilitating the proper management of sewage sludge. In other words, it will not affect the volume of wastewater production from Zarqa, but it will ensure that increased effluent volumes will continue to meet internationally recognized wastewater treatment standards.
2. Wastewater volume increases will result from increased wastewater capture, a product of the wastewater network rehab/upgrade. It could also result from reductions in physical losses from the water network, assuming that the reduction of those losses lead in turn to increased municipal water usage.
3. Measuring the specific amount of replacement of freshwater by blended and/or treated wastewater (blended = treated effluent plus freshwater from the Zarqa watershed) in the Jordan Valley or elsewhere downstream of the As-Samra Plant will require careful construction of a water balance for the system.
4. Depending on the degree of substitution taking place, the amount of water used for irrigation downstream of the As-Samra facility may remain static or actually increase. Alternatively, freshwater allocation to farmers may decline at a rate higher than the increase in blended KTR water that is made available, in which case overall irrigation may actually decline, and the Compact benefit will be in slowing the decline of irrigation.
5. Changes in per-capita water use will be influenced by 1) increased # of hours and continuity of municipal water service, 2) improved water quality at the tap, if perceived by consumers, and 3) increased HH storage infrastructure resulting from WaterSmart Homes - though this will be only from a small number of homes. However, increases in usage could be modulated by increased metering, which will change household water use behavior. (We have not indicated this modulating factor in the diagram).
6. We include multiple possible causal relationships between Compact activities and disease. The first is the result of increasing per-capita water usage, and we emphasize that the relationship between water quantity interventions and health indicators such as diarrhea are not supported by the current literature. The second is by reducing disease transmission pathways resulting from urban wastewater overflows as well as those from land application of sewage sludge at As-Samra. Finally, the Water Smart Homes activity could result in reduced pathogen exposure via improvements in hygiene behaviors as well as reduced contamination in household storage.
7. We have not made a distinction here between overall energy savings for the utility and energy savings per unit volume of water delivered. We expect unit costs to decline, but overall system utilization - and thus, energy consumed, and operating cost incurred - could actually increase.
8. Though we have not seen significant and consistent data, we anticipate that the changes in water quality at the tap will be minimal, since there appear to be few documented instances of fecal contamination exceeding the WHO standard in the Zarqa system.
9. Improved water quality at the tap will result in increased per-capita use of utility water only if user perceptions of utility water improve in tandem. We note that the water quality benefits are likely to be difficult to detect (since pathogen detection in utility water is already so low), so a corresponding change in customer perceptions is also of low probability.
10. We note that the expansion of the As-Samra WWTP and the rehabilitation of the Wastewater Network may add to utility operating costs considerably, perhaps more than the associated increase in wastewater treatment revenues.

Table 2.1. Relationship between IE design components and the main expected economic benefits of the Compact (questions that are at least partly related to Component 2 are shaded in gray)

Economic impact question	Data collection components required
1. What is the economic value of increases in water consumption and reliability due to the intervention?	Components 1 (household/enterprise surveys) and 3 (utility monitoring)
2. What is the economic value of consumer savings from reduced vendor and tanker water consumption? (**secondary substitution effect**)	Component 1 (household/enterprise surveys; water vendor surveys)
3. What are the health benefits stemming from changes in water quality and consumption?	Component 1 (household surveys)
4. What is the value of avoided contamination of irrigated areas stemming from wastewater investments?	Component 2 (water balance, farm survey)
5. What are the net cost savings (in terms of expenditures on wastewater management) to consumers without sewerage of connecting to the wastewater network?	Component 1 (household/enterprise surveys)
6. What is the value of land reclaimed from septic / latrine for newly-connected wastewater network consumers?	Component 1 (household/enterprise surveys; land survey)
7. Are there utility cost savings from reduced maintenance of network infrastructure?	Component 3 (utility monitoring)
8. What is the economic value of substitution of additional blended KTR water for freshwater in irrigation? (**primary substitution effect**)	Components 1 (household/enterprise surveys), 2 (water balance, farm survey) and 3 (utility monitoring)
9. What is the value of new irrigation stemming from Compact investments?	Component 2 (water balance, farm survey and remote sensed data)
10. What is the value of citrus and other high value crops that are preserved due to increased water availability for irrigation?	Component 2 (water balance, farm survey and remote sensed data)
11. What are the time savings and productivity gains from improved urban water supply in Zarqa?	Component 1 (household/enterprise surveys)
12. What are the non-health aesthetic (quantity) benefits of improved urban water supply in Zarqa?	Component 1 (household/enterprise surveys)
13. What are the impacts on utility performance (namely cost recovery)?	Component 3 (utility monitoring)
14. Are there increases in property values in Zarqa separate from the value of reclaimed land?	Component 1 (household/enterprise surveys; land survey)

3 Design of IE Component 2: Water Balance and Impacts of Farmers

3.1 General description and rationale

A significant part of the economic case for the Compact investments is an assumed water efficiency improvement that would stem from substitution of conventional freshwater currently used in irrigated areas in the Jordan Valley with an expanded supply of treated wastewater collected in Zarqa. Specifically, it was expected that freshwater saved by this substitution would be redirected to higher value uses by municipal and industrial users, thereby improving economic outcomes. The full extent of this assumed substitution effect relies on both the water and wastewater network investments, because it requires both reduction of losses from the existing water delivery network, and subsequent collection and recycling of increased quantities of wastewater from Zarqa. This so-called **primary substitution effect** of the Jordan Compact fits within a larger vision of increased reuse of water for irrigation that is consistent with water policy objectives of the GOJ (MWI 2015). The general idea is to convert wastewater from a nuisance that must be managed into a resource that improves economic productivity.

The measurement of the economics of the primary substitution effect provides much of the motivation for Component 2 of SI's Impact Evaluation, which consists of water balance analysis conducted through enhanced data collection of longitudinal inflows to and outflows from the Zarqa and Amman water networks, the As-Samra WWTP, the KTR, and the complex irrigation network of the Jordan Valley (a map showing the geographic extent of these connections is provided in Figure 3.1). In parallel, Component 2 includes farmer surveys in the Jordan Valley to estimate the magnitude and economic impacts of changes in the availability and utilization of conventional freshwater and blended KTR water. This blended water is a mixture of natural runoff and recycled wastewater that is reused for any purpose following treatment to discharge standards.

Establishment of the primary substitution effect is extremely important for understanding the impacts of the Jordan Compact. At the time of the design of Component 2 of the IE, however, a number of challenges associated with measuring it and its economic impacts were described (Albert et al. 2013). These included: 1) the difficulty in separately identifying the contributions of individual project activities to the amount of substitution; 2) problems with differentiating this Compact-enabled substitution from natural flow variability and contributions from other sources providing water to agricultural end-users in the Jordan Valley; 3) extensive data requirements for creation of a water balance model of the hydrological behavior of this highly integrated system; and 4) the lack of a real comparison group that could be used to approximate the no Compact counterfactual. These challenges, elaborated further in the Evaluation Design Report (Albert et al. 2013), should be kept in mind by readers of this baseline report.

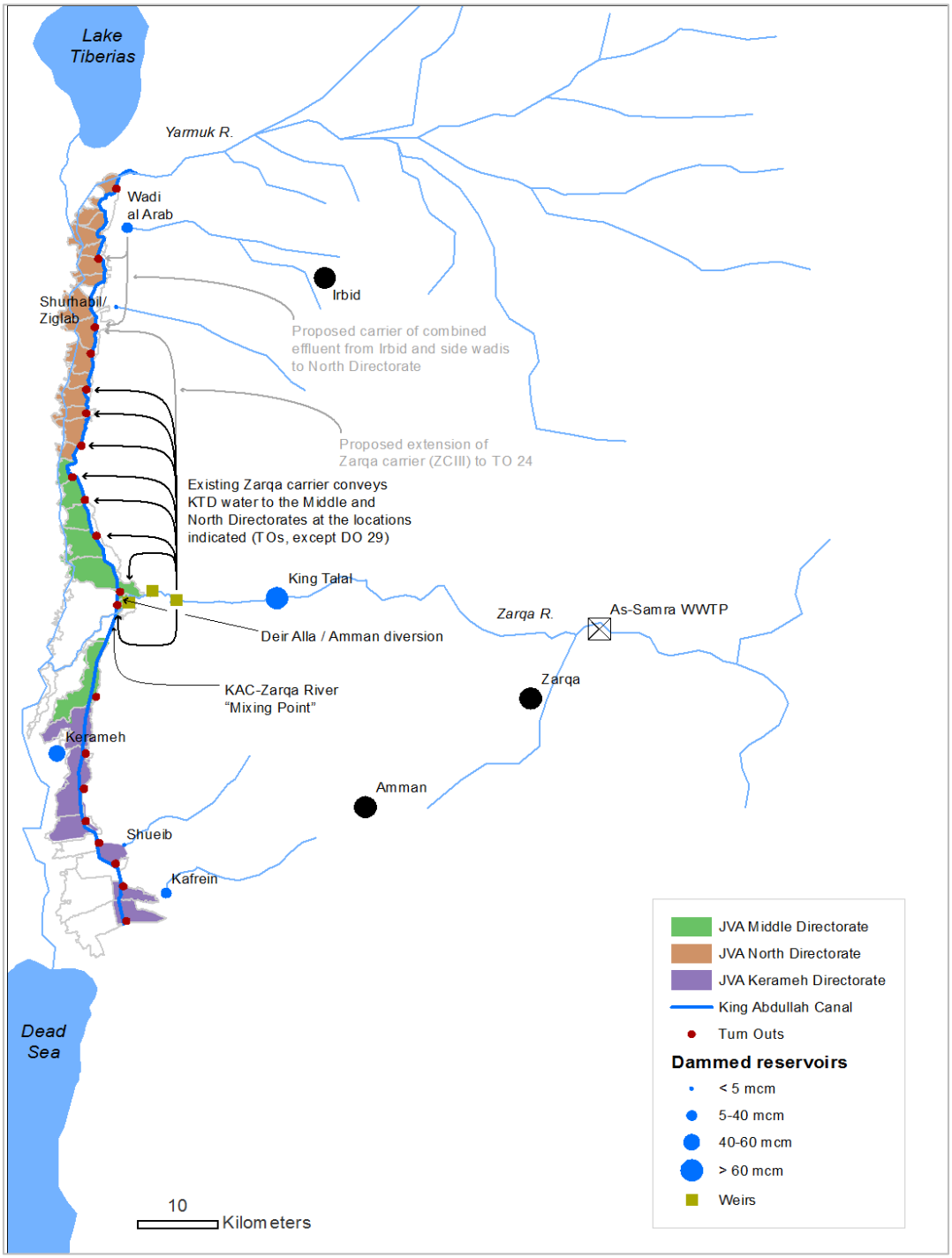


Figure 3.1. General schematic of wastewater irrigation conveyance to the JV from Zarqa/Amman. Existing / planned wastewater delivery systems from reservoirs into the JV are illustrative; other elements of the map are nominally accurate in geographic terms.

3.2 Component 2 evaluation questions

The main evaluation questions related to component 2 of the IE, that is, to the changes faced by irrigators located downstream of Zarqa and the As-Samra treatment plant, and to the magnitude of the primary substitution effect, are the following:

1. Impacts on water sourcing: Does the combined WNP/WWNP/AEP result in increased irrigation with addition blended KTR water? Does the volume of irrigation using KAC freshwater correspondingly decrease?
2. Impacts on farming costs: Does the combined WNP / WWNP / AEP lead to changes in farm input costs?
3. Impacts on farm output: Does the combined WNP / WWNP / AEP lead to changes in the value of farm output in affected areas?
4. Impacts on asset value: Are farm values affected by the WNP / WWNP / AEP investments?
5. Overall impacts on farm welfare: What is the net economic value of changes in irrigation?
6. Impacts on compliance: Does the AEP result in increases in the quantity of wastewater that meets effluent standards prior to discharge into the environment? (Note: This is not really an impact evaluation question, but it does seem to be the only specific impact that can be attributed to the AEP alone).

Besides considering each of these evaluation questions, we will aim to study the mechanisms by which they are produced, by tracking as many intermediate impacts or contributing factors to them as possible (in collaboration with the M&E activities of the MCA-J), as shown in the IE logic. A more elaborate list of the measures to be tracked is presented in Section 5 of this report.

The EDR describes the two critical and complementary design elements of Component 2, which together will allow consideration of the full set of IE questions presented above. The first is detailed water balance modeling, and the second consists of a quasi-experimental design aimed at measuring the farm-level impacts of water source substitution. These elements will together inform on alterations in the water balance and resulting changes in agricultural production in affected areas downstream of Zarqa and in the Jordan Valley.

3.3 Basic design of water balance element

The potential substitution of reclaimed wastewater for conventional freshwater in agriculture constitutes an important part of the ERR calculation justifying MCC's investment. Attributing changes in agricultural water use to Compact activities is impossible without producing a detailed water balance supported by a detailed and comprehensive dataset. The assembly and systems analysis of these data, which are detailed later in this report, allow for defensible estimation of incremental changes in flows, due to the Compact, into the As-Samra-bound sewer network as well as into the Zarqa River upstream of the KTR.

As noted in the EDR, proxies for several of the variables required for understanding the effects of primary substitution are being tracked through the ITT elaborated in the M&E plan. Unfortunately, those indicators do not allow attribution, for a variety of reasons detailed in that document. It is with these considerations in mind that the water balance element is being undertaken as part of the Compact IE.

3.4 Agriculture survey element

3.4.1 Review of basic design

Developing a rigorous experimental design for evaluation of the impacts of expanded wastewater availability on farmers is not practical in this case, given that increased flows of mixed KTD water will affect all farms within areas receiving such supplies, with areas outside of the receiving zones almost certainly being systematically different with regards to soil fertility, climate, access to markets, and other less readily observed factors. However, the change in allocations of mixed water over time across large swathes of the Jordan Valley does provide a natural experiment through which differences in productivity and net agricultural returns over time can be compared for areas that already use KTD water but may receive more, areas that do not yet rely on KTD water but will now receive some, and areas that do not and will not receive KTD water. At present, reclaimed effluent is used in varying proportions by farmers near the As-Samra WWTP, along the Zarqa River above the KTD, and by farmers in the Middle and Southern portions of the North Directorate of the Jordan Valley. There are currently many areas in the North Directorate that are unconnected to the distribution network for mixed effluent distribution, and it is unlikely these areas will all be connected during the period of the IE (see Figure 3.1).

We therefore proposed to use a difference-in-differences (DiD) methodology to isolate the effects of changes in the quantities of KAC and KTD water supplied to a representative sample of farms extending over these various regions, using the model shown in equation 1:

$$Y_{ijt} = \alpha + \gamma Q^{KTD}{}_{ijt} + \delta Q^{KAC}{}_{ijt} + \beta X_{ijt} + \upsilon_i + \delta_{ijt}, \qquad (1)$$

where Y_{ijt} is the outcome of interest for farm i in zone j at time t, $Q^{KTD}{}_{ijt}$ and $Q^{KAC}{}_{ijt}$ indicate the quantity of KTD and KAC water delivered to the farm i in zone j at time t, X_{ijt} is a vector of time-varying variables (farm inputs, weather, crop prices, etc.) that affect the outcome for unit i in zone j at time t, υ_i is a farm fixed effect, and δ_{ijt} is a time-varying error term. Within this framework, the coefficient γ measures the "treatment effect" of an additional unit of KTD water, and δ measures the treatment effect of an additional unit of KAC water. This estimate will be unbiased so long as the error term δ_{ijt} is not correlated with assignment to different water sources, a risk which is considerably reduced through the use of fixed effects panel estimation. The outcomes of interest will be yields for different crops grown in farm i, as well as overall net agricultural returns.

For the purposes of baseline data collection, we planned to survey roughly 550 farmers (110 farmers in each of five differentially affected areas) to determine crop production and returns for the previous year, along with measures of water supply from different sources. Using the data from these 550 farms, we conduct more detailed power calculations at the end of this report to determine the effect sizes needed to observe differences across groups.

3.4.2 Selection of locations for farm surveys: Stratification by source of water and relative geography

The sample was stratified to include farms located in five distinct areas, as detailed below, and depicted on an illustrative schematic (Figure 3.2).

Area 1: North Jordan Valley 1 (between pump stations / turnouts 02 and 24, area spanning from development area (DA) 1-9/10 and 33-39). This is North of plans to extend the ZC-III and where use of treated wastewater is possible (from other sources than the KTD) but more limited than further south. It

appears that the farms in several DAs are somewhat smaller in this zone, so to minimize the possibility of confounding based on farm size and scale of operations, we suggested random (representative) sampling of farms from the following DAs: 2 and 5-9. According to the sampling frame, this comprises just over 700 potential farms.

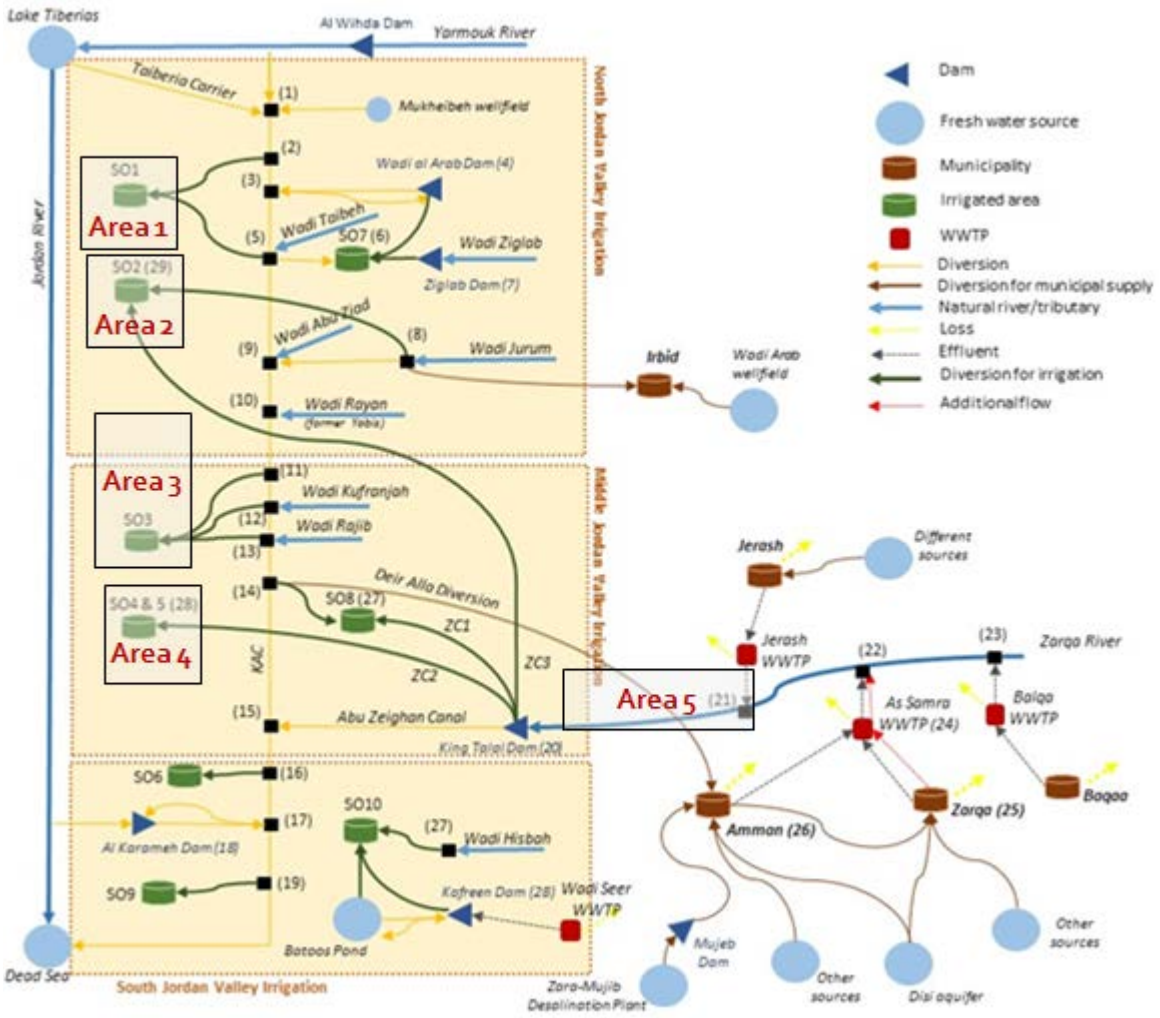


Figure 3.2. Schematic representation of the irrigation water system; showing the locations included in the agriculture survey

Area 2: North Jordan Valley 2 (between pump stations / turnouts 24 and 33; area spanning from DAs 11-12). This is where there are plans to extend the ZC-III and where use of more treated wastewater is possible or likely in the future. DA 10 is not likely to be reached by the extension of ZC-III but is likely to be similar to DAs 11-13 in many ways, while DA 13 is already receiving some blended water. We suggested random (representative) sampling of farms from DAs 10-13. According to the DoS sampling frame, this zone comprises nearly 1,000 farms.

Area 3: Middle Jordan Valley 1 (between pump stations / turnouts 33 and 65; area spanning DAs 13-22 and 29); this is where KAC and KTD water are currently mixed through the ZC-I, -II, and –III. We suggested

random (representative) sampling of farms from DAs 14-22. According to the sampling frame, this zone comprises 1,500 potential farms.

Area 4: Middle Jordan Valley 2 and Karameh (between pump stations / turnouts 70 and 96; area spanning DAs 23-28, 30, 53 and 54); this is after the diversion of KAC water to Amman, where KAC water is likely more scarce (and thus more treated wastewater). Water use is a bit different in this zone as is soil quality. Therefore, we suggested random (representative) sampling of farms from DAs at the northern end of this zone: 23-25, 30, 53 and 54. According to the sampling frame, this zone comprises over 1,600 potential farms.

Area 5: Highlands area, between As Samra and King Talal Dam: This is the zone for which DoS completed an initial enumeration (with the help of the MoA) that identified 370 farms, specifically for use in the IE. We suggested random (representative) sampling of farms from this zone, following the detailed listing.

3.4.3 Agriculture survey sample construction

In the EDR, we proposed inclusion of 500 + 10% (due to potential attrition) farms at baseline, for a total of 550 farms, stratified across 5 zones that were differentially exposed to varying sources of irrigation water. The idea was to test for differences in crop production patterns and returns, along with perceptions of the adequacy of both water supply and quality for agricultural production. We proposed that we would then use the baseline data to assess the size of the treatment effect that could be observed under standard assumptions about power, given changes in water sourcing over time (those calculations appear towards the end of this report).[6]

In each selected area, the Government of Jordan's Department of Statistics (DoS), the data collection firm for this evaluation, randomly sampled 200 farms from its listing of farms, and then proceeded to attempt interviews with the first 110 farms selected. In case of refusals, DoS then continued down the list of remaining 90 farms in each zone, using the extras as replacements until the target of 110 complete surveys was reached (In practice, only one farm that was selected in the first round refused). The final target sample sizes for each arm are summarized in Table 3.1.

3.4.4 Development and testing of instruments

The agriculture surveys were developed to collect information on basic farm characteristics (soils, canal location, etc.); inputs and costs; outputs and revenues; advantages and constraints; assets and equipment; animal husbandry; irrigation water situation and management; willingness to pay (WTP) for more dependable irrigation water supply (of blended, not freshwater); and socio-economic status and characteristics of the farmer. The agriculture survey instrument (see Annex A) included 13 modules and took approximately 1.5 hours to complete. A slightly modified version was fielded in the highlands, owing

[6] We could not use previous agriculture survey data from DoS for this purpose because it did not clearly record the source of water, nor was its representative sample of Jordan Valley farms relevant to the strategically selected sample constructed to facilitate our IE design.

to the differences in farming practices in that region. All pre-tests and surveys employed computer-assisted personal interviewing (CAPI) using tablets.

Table 3.1. Proposed and targeted distribution of households across the five sample arms

	Source of irrigation water	*Final target distribution of households*	
		DAs	Farms
Area 1: North JV1	Primarily freshwater	2; 5-9	110
Area 2: North JV2	Primarily freshwater, switching to blended fresh & Zarqa River	10-13	110
Area 3: Middle JV1	Blended fresh & Zarqa River	14-22	110
Area 4: Middle JV2	Primarily Zarqa River	23-25; 30; 53; 54	110
Area 5: Highlands	All Zarqa River	N.A.	110
Total			550

Prior to developing the surveys, three focus groups were held with groups of irrigators in the Jordan Valley, in order to obtain information on the nature of water allocation, perceptions of water quality and quantity, and implications of water sources for cropping decisions. The agriculture survey instruments were then developed working from the information collected in the focus groups and based on well-tested existing instruments previously applied by members of the SI team in studies in other countries. The draft instrument underwent forward and backward translation to ensure the accuracy and precision of survey language. Meanwhile, MCC, MCA-J, and DoS provided formal and informal feedback on the questionnaire, leading to its further revision and refinement. The survey was then programmed by DoS using the programming language, Java. Finally, pre-tests were conducted in non-sample areas of the Jordan Valley prior to launch of the survey. These pre-tests (conducted in June and July 2015) helped the team to identify and troubleshoot a range of programming glitches and to identify problems with the understanding of the WTP scenario. To correct the latter problem, the team worked closely with MCA-J and DoS enumerators to refine the survey language and to make the payment implications for irrigation water more relevant and understandable to respondents. This process took several weeks, and delayed the launch of the survey work until August 2015.

3.4.5 Risks and mitigation strategies

The primary risks to attribution in Component 2, and our mitigation strategy for addressing them, are discussed in detail in the EDR (and summarized in Table 3.2). The main challenge that we foresee is in attributing agricultural and farm welfare changes to Compact activities, given the multitude of dynamic natural (climatic and hydrological) and policy confounders that are influencing irrigated agriculture in Jordan.

At the time of the writing of the EDR, our central concern was that relevant present and historical data either did not exist or would not be readily shared with the evaluation team. At this point, many of our fears about data sharing have been mitigated (and the monitoring and evaluation (M&E) team at MCA-J has been a key and critical collaborator in obtaining information from relevant departments in the JVA

and MWI), but data quality remains a challenge, as will be highlighted later in this report. Below we discuss briefly the issues that appear most serious as of the time of writing of this report.

The issues of moderate concerns relate to water being provided from the Disi aquifer project – a large contemporaneous water supply enhancement investment in Jordan that brings water from a deep aquifer in southern Jordan to Zarqa and Amman – and to water allocations at sub-governorate or at a disaggregated level in the Jordan Valley. While the overall water flow from Disi is known, it has proven difficult to determine how much of this water is being sent to Zarqa, due to the lack of metering in the system (although we hear that this problem has recently been remedied). Similarly, we do not at this time know how the specific water allocations to DMAs are evolving in time; we only know what a) Component 1 survey households are consuming; and b) Overall system supply in Zarqa. Finally, we are reviewing and integrating disaggregated stage office water allocations into our water balance model, but these data suffer from two problems: a) They represent planned allocations that may or may not actually be delivered in reality; and b) They remain highly aggregated and could be unevenly distributed over development areas within a stage office (one stage office typically includes a half a dozen or so development areas).

Table 3.2. Categorization of threats to identification of impacts on the water balance and irrigators, and mitigation strategy

Description	Type of Risk	Mitigation strategy	Current level of concern
Inflows of Disi water into Amman and Zarqa drinking water distribution networks cannot be determined directly or with sufficient precision	Confounder	Produce estimate based on influent volume trend at AS and estimates from MWI and Miyahuna (Zarqa & Amman)	Moderate
Drinking water metering data at DMA level cannot be determined directly or with sufficient precision	Confounder	Produce estimate based on influent volume trend at AS and estimates from MWI and Miyahuna (Zarqa & Amman)	Moderate
Wastewater production resulting from WWNP cannot be determined directly or with sufficient precision	Confounder	Produce estimate based on influent volume trend at AS and estimates from MWI and Miyahuna (Zarqa & Amman)	Low; AS data are available
Zarqa River withdrawals in the vicinity of As-Samra (downstream of the treatment plant) cannot be determined directly or with sufficient precision	Confounder	Estimate using combination of: publicly available satellite image time series, interviews with JVA personnel, and field visits	Low; surveys and satellite images provide information
Natural inflows of Zarqa River water into the KTR cannot be determined directly or with sufficient precision	Confounder	Locate streamflow proxy data from precipitation data from the Jordan Meteorological Department and/or other publicly available weather or climate models for the Jordan basin	Low; data are available
Releases from the KTR into the Jordan Valley through the Zarqa Connectors and the Abu Zeighan Canal cannot be determined directly or with sufficient precision	Confounder	Direct measurement of inflows, outflows, and elevation of the reservoir surface on a bi-weekly basis	Low; data are available
Inflows of Jordan-Yarmuk water into the KAC cannot be determined directly or with sufficient precision	Confounder	Unknown at this point	Low; data are available
Specific volumetric allocations of the KAC and KTR water to Jordan Valley farmers cannot be determined directly or with sufficient precision	Confounder	Produce estimates based on contact with JVA personnel and farmer surveys	Moderate

3.4.6 Timeframe and implementation of Component 2

The timing of relevant Compact activities and data collection for Component 2 is summarized in Figure 3.3. The baseline surveys were conducted in the summer of 2015 (in May/June for the JV areas, and in September for the highlands).

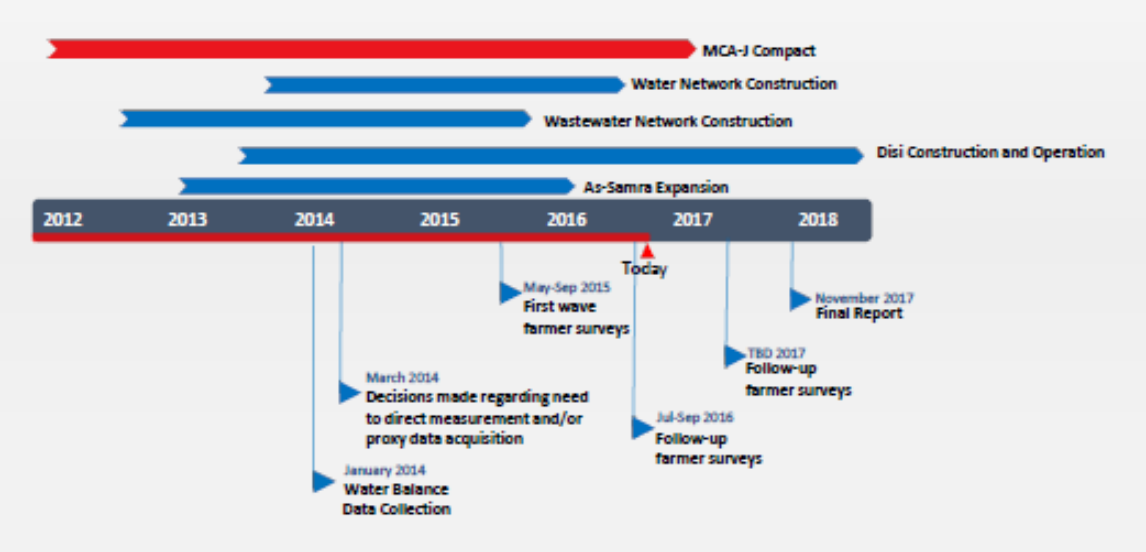


Figure 3.3. Component 2 Timeline

4 Background: Water balance in Jordan and prior literature

4.1 Water resources in Jordan and supply to the Jordan Valley

Jordan, an extremely water scarce country, has estimated renewable water resources of 125 m^3 per capita per year (FAO 2016). Water scarcity in the country is driven primarily by the combination of an arid to semi-arid climatic regime, a large (and expanding) irrigated agricultural sector, and recent population growth driven by high rates of fertility (UN 2016) and the recent immigration/refugee influx from crises in Iraq and Syria. The JV, with its distinct climate that acts as a "natural greenhouse" (MWI 2015), has traditionally been the "food basket" for Jordan, but the Jordan River is also the major source of drinking water for Amman and other municipalities. Seventy three percent of the Jordanian population now lives in such urban centers (Klinger et al. 2015), compared to less than 6% in the JV. Managing these multiple pressures, as well as industrial and ecosystem demands, require careful planning and balancing of sectors and objectives.

Given its disproportionate role in water use compared to its share in GDP (over 60% of water consumption for 3% of GDP), the agricultural sector based primarily in the JV has long been the target of efforts to reduce water demand (MWI 2013, Fileccia et al. 2015). Nonetheless, there is increasing pressure to reduce this water use even more significantly to free up water for high-value urban use, and JV irrigators are increasingly faced with the possibility that their water supply may be severely curtailed in the near to medium term. Concerns over the effects of climate change in the region (increased temperature and evaporative loss, and a projected decline in precipitation in the eastern Mediterranean region exacerbate these worries (Zachariadis 2016). Meanwhile, urban areas – which consume about 290 million m^3/yr (over 42% of which goes to Amman) – face increasing stress and water rationing, and only about 60% of households in Jordan are connected to sewers, which limits significantly the ability to reuse urban wastewater (Jeuland 2015).

It is important to understand that there is also significant variation in agricultural practices in the JV that arises from both climatic and water supply differences. The Jordan Valley Authority (JVA) identifies the region as a long rift valley running from the Yarmouk River and Lake Tiberius in the north to the Red Sea in the south--over a total length of 380- kilometres. The northern and semi-arid part (precipitation of 350 mm/year) reaches from the Yarmouk River to the Dead Sea and is divided into eastern and western parts by the Jordan River. Bordered by a steep escarpment on both eastern and western sides, the JV reaches a maximum width of twenty-two kilometres. (GOJ 1998), and its altitude varies from 200 m (in the north) to 400 m (in the south) below sea level—the deepest place on earth. The climate is arid in the south (precipitation of 50 mm/year near the Dead Sea). Temperatures are moderate during the winter (averaging between 15°C and 22°C between November and March), and reach extremely high levels during summer, commonly exceeding 45°C during the day between June and August. The warm winters allow for the production of off-season crops.

The river basin receives most of its freshwater inflows from the Yarmouk and Zarqa Rivers that flow towards the Dead Sea, and smaller inflows from side wadis or seasonal streams. Treated wastewater also already plays a dominant role as a source of irrigation water in the Jordan Valley, primarily through the blending that occurs in the Zarqa River upstream of the King Talal Dam (KTD). This blended water,

utilized for agriculture sector from the middle to the southern JV (and now beginning also in the northern JV), consists primarily of the effluents of the As-Samra treatment plant that serves Amman and Zarqa and from the highly variable natural flows in the Zarqa River (as shown in Figure 4.1). Depending upon winter rains, the KTR can enter the dry irrigation season with volumes varying by more than 40-50 Mm^3.

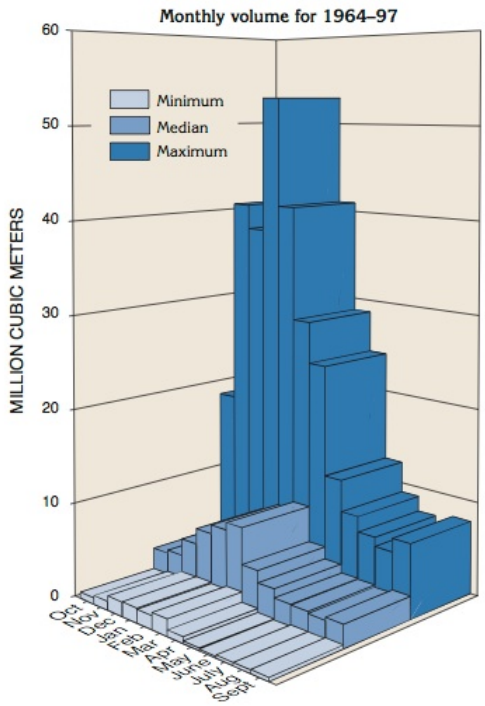


Figure 4.1. Minimum, median, and maximum monthly discharge of the Zarqa River measured at the New Jerash stream gauge, 1964-1997. Source: EXACT Program of the US Geological Survey.

The Jordan River itself flows in a 30 m to 60 m deep gorge through a narrow alluvial, fertile plain locally called "Al Zhor" that ranges between 200 m to 2 km wide (Figure 4.2). The rest of the valley, called "Al Ghor[7]" in Arabic, is a fertile area formed by colluviums coming from neighbouring mountains and alluvial fans lying on the lacustrine sediments of Lake Lisan, which covered the area 14,000 years ago. Gently sloping (1.5 to 2.5%) from the mountains, the "Al Ghor" valley is 20 km wide in the south, narrows down to 4 km in the middle, and again widens to 10 km in the north. In these two areas, soils are deep and of good quality but, because of the climate, only steppe and grassland existed prior to the installation of widespread irrigation in the valley, with the notable exception of small areas that were seasonally irrigated by side-wadis[8] and springs (Courcier et al. 2005).

The rift valley on the southern side of the Dead Sea is known as the Southern Ghor and the Wad al Araba. The Southern Ghor runs from Wadi al Hammah, on the south side of the Dead Sea, to Ghor Fifa, about twenty-five kilometers south of the Dead Sea. Wadi al Araba is 180 kilometers long, from the southern shore of the Dead Sea to Al Aqabah in the south (Metz 1989).

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[7] The northern part of the valley is known as the *Ghor*, and it includes the Jordan River. Several degrees warmer than adjacent areas, its year-round agricultural climate, fertile soils and water supply have made the Ghor a key agricultural area.

[8] A **wadi** (Arabic: وادي) is a narrow valley with a dry riverbed that contains water only during times of heavy rain (flash flood events).

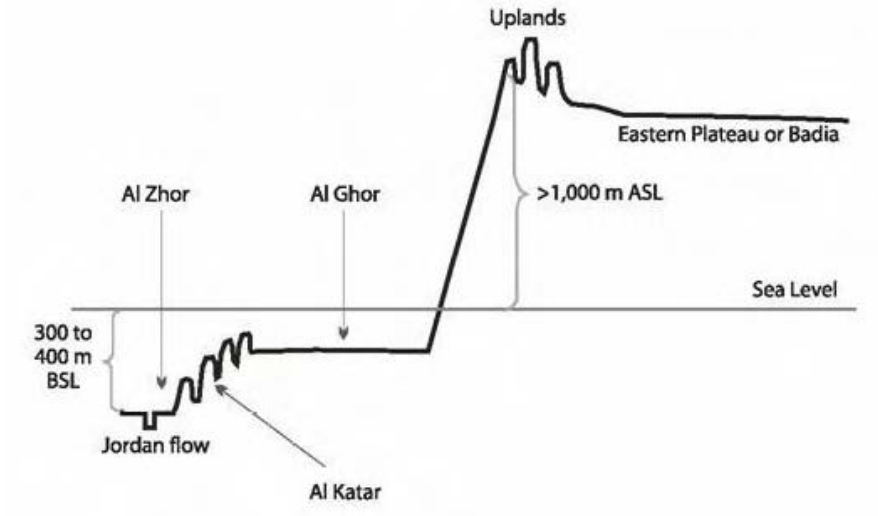

Figure 4.2. Topography of the Jordan River Basin in Jordan (Van Aken et al. 2009)

4.2 *Agriculture in the Jordan Valley and elsewhere in Jordan*

As mentioned above, variations in climate – namely temperature, humidity, and rainfall – produce distinct agro-climatic zones in the JV. The three main regions as defined by the JVA and the Ministry of Agriculture are the Northern JV, Middle JV and Southern JV. The total area and irrigable area of each of these regions is summarized in Table 4.1.

The farming system in the Northern JV is generally homogeneous within specific zones. One zone consists of lands irrigated with water from the northern part of the King Abdullah Canal—a freshwater source. Recently, there is a move to increase use of treated wastewater (from 3 plants at Shalaha, Irbid and Wadi Arab in the north of Jordan) as another source of water for irrigating this zone. These effluents are collected in a pond prior to conveyance to irrigators. The second zone in the far north is a citrus zone, where most of the lands has been cultivated with various varieties of citrus by established farming families for many decades (Venot 2004). The citrus zone has been shrinking over time due to regulation and water shortages. Finally, a few areas located around the villages of Wadi Ryan and Kreymeh focus on growing open field and greenhouse vegetables.

Table 4.1. Geographical and irrigated areas in the JV

Zone	Total Area	Irrigable area	% of Irrigable Area
	Dunum	Dunum	
Northern JV	97.7	82.8	84.7
Middle JV	127.4	91.1	71.5
Southern JV	124	114.3	92.2
Jordan Valley	349.1	288.2	82.6

1 square kilometre = 1 000 dunum

The Middle JV is situated between the villages of Kraymeh and Dah-Rat Al Ramel. Irrigation water in the zone consists of a mixture of the blended wastewater in the King Talal Dam and freshwater from the northern part of the King Abdullah Canal. In this zone, the main cultivated crops are vegetables (which cover 70%). Greenhouse cultivation is preferred for crops such as tomatoes, paprika and cucumbers, while open field cultivation (for eggplant and potatoes) is considered to be of secondary importance. The zone also consists of fruit orchards, palm trees, and a small amount of citrus. Small farms with open fields are more common in the south, while large farms with greenhouses lie in the north between Kraymeh and Al Muaddi.

Finally, the more arid Southern JV lies between Dah-Rat Al-Ramel and Swaemeh (north of the Dead Sea); irrigation in this zone uses a variety of water sources. The Southern JV stretches along an 18 km extension project of the King Abdullah Canal, the Hisban-Kafrien irrigation project supplied by the Wadi Shuaib Dam,[9] and a 14.5 km additional canal extension that is not presently in operation due to limited water supply. Some farmers in the zone depend on ground water (from deep tube wells) and pay fees to the Water Authority of Jordan (WAJ) for their use. The JVA delivers limited amounts of water up to Karameh via the canal system to help farmers to cope with high groundwater salinity (EC exceeds 2,000 ppm). More than 35 farmers in the South JV also operate small desalination plants for cultivating cash crops. Finally, other parts of the South JV depend on water (for which they pay) from the Kafrein Dam and Wadi Hisban. The main crops that are grown are open field and greenhouse vegetables (tomatoes, eggplants, squash, parsley and mint) and bananas in the South Shouneh area.

The annual available water in the whole of the JV is around 250-300 MCM, while the annual demand for irrigation exceeds 500 MCM (Table 4.2). Around 50 MCM of water is pumped up to the Amman city and 20 MCM to Irbid for domestic uses from ground water sources and through the King Abdullah Canal (KAC) (GOJ 2004, JVA 2004). The JVA overcomes the gap between demand and supply by reducing the quantities delivered to farmers, with a percentage that varies depending upon the availability of water each year.

Table 4.2. Water demand for the various sectors, all in MCM (MWI 2014)

Water Source	Sector			Total
	Municipal	Industrial	Agriculture	
Ground water	325	32.2	231	589
Surface water	103.8	4.8	150	259
Treated Wastewater	0	1.7	123	125
Total	429	39	505	972
Percentage of total	44.1%	4%	51.9%	100%

Notes: Rain-fed agriculture consumes around 100 MCM per year.

About 60% of agriculture in Jordan depends on rainwater and 40% is irrigated agriculture located in the highlands and the JV. This irrigated share is much more productive than rainfed land and produces 90% of all agricultural products. Agriculture in the JV alone produces 70% of total agricultural products while consuming an estimated 35% of irrigation water. This demonstrates the greater productivity of lands

[9] This project provides water to farmers free of charge.

cultivated with irrigation water and the significance of irrigation in the JV. Table 4.3 shows the agriculture by type and value.

Table 4.3. Irrigated Areas in Jordan (MOA 2012)

Type of agriculture	Area		Value	
	Million Dunum	Percentage	JD Million	Percentage
Rain fed	1.6	60	49	10
Irrigated	1.0	40	461	90
Total	2.6	100	510	100

The irrigated areas located in the highlands are on the order of 441,000 dunums. Some 4,000,000 highland dunums are fit for dry land farming, but such farming is only practiced on half of this area because of lack of sufficient rainfall and other constraints on farming. In comparison with the JV, rainfall in the highlands is higher, temperatures are lower, and crops (field crops, vegetables and fruits) are less water-intensive (Fileccia et al. 2015). Nonetheless, the light regulation of irrigated agriculture in the highlands meanwhile is contributing to a steady depletion of aquifers, raising concerns about exhaustion or salinization of these groundwater reservoirs. Highland users of both ground and surface water sources do not pay a resource use fee, and there is limited effort to restrict or rationalize use via other mechanisms (e.g., licensing or use of quotas and metering).

Indeed, over the past 20 years, the pattern of water use in irrigation has begun to change as water scarcity has increased. A mix of policies and supply constraints have resulted in greater tapping of groundwater sources in the highlands (representing 77% of water use in 2010), and a significant decline in freshwater in the JV. This has led to an increasing share of irrigated agriculture for water-intensive (and low value) crops in the highlands. In addition, cost recovery for water delivery to agricultural users is low.

4.3 Previous water balance work pertaining to management of water resources in Jordan

Previous efforts to generate a water balance of Jordan's resources have utilized a range of modeling tools to evaluate the present situation and predict future scenarios. This work includes descriptions of the natural hydrology of both regional and country-level systems, as well as analyses of various sectors including industrial and domestic use and emphasizing agriculture. Prediction studies have focused on understanding the potential effects of climate change and development trends on the water deficit, in addition to hypothetical impacts of political efforts to change water pricing or add new water sources. In general, the literature pertaining to Jordan's water balance places an emphasis on the agricultural sector, with a number of studies also addressing the economic factors that can influence water demand and allocation.

A range of models using assorted datasets and algorithms have successfully been applied to the Amman-Zarqa Basin to understand the current state of its water resources and demands. A study by Shammout et al. (2014) compared an HEC-1 model and a Water Resources Model (WRM). The HEC-1 model simulates how surface runoff responds to precipitation within the framework of a single storm event while the WRM model calculates flood and base flow to describe a daily demand and supply balance.

Although the philosophies of the two models differed, both were considered efficient in predicting flow in the Zarqa River Basin. Abdulla and Al-Omari used a Surface-Infiltration Baseflow model to understand long-term runoff and evaporation in the Amman-Zarqa Basin by calibrating with a lengthy historical data set of rainfall and potential evapotranspiration data. This achieved a coefficient of determination of 0.78, and an overall 18% error between observed and simulated streamflow. Al-Abed and Al-Sharif (2008) and Al-Abed et al. (2005) also achieved coefficients of determination in the range of 0.7-0.8 for the Zarqa River Basin using data from the 1990s. The former applied the Hydrological Simulation Program – FORTRAN model and the latter applied a Spatial Water Budget Model, and both studies integrated GIS data. A study by Al-Omari et al. (2009) calibrated the WEAP model using 2005 data of the same area, and found good agreement between calculated and measured inflows. Schulz et al. (2013) used the water balance model J2000 to calculate the amount and spatial distribution of groundwater recharge, which was found to be impacted by the distribution of the river network and to have a non-linear relationship with precipitation. Additional description studies have focused on the Lower Jordan River, an area controlled by shallow groundwater flow according to water balance calculations (Farber et al. 2005, Holtzman et al. 2005). Many of the hydrological studies of Jordan's water balance focus solely on natural processes, incorporating water and hydrogeology but disregarding irrigation or domestic return. Meteorological data is also an integral aspect of many of these studies, as the wide variability in precipitation, both seasonally and geographically, greatly affects the water supply and deficit (Schulz et al. 2013).

Most of the previous research in this field has placed the greatest emphasis on the agricultural sector, as it accounts for 50-70% of water demand and consumption (Shahateet 2008, Al-Omari et al. 2009, Al-Bakri et al. 2013). In the Zarqa River watershed, this usage is concentrated in the Zarqa River watershed and the highlands (Al-Omari et al. 2009). Groundwater resources are the source of irrigation water in the highlands, where vegetable growth is the primary cause of exceeding safe extraction rates (Salman and Al-Karablieh 2004). The agricultural sector overall has the highest unmet water demand, which was at a calculated 186.67 MCM in 2005 (Al-Omari et al. 2009), and a slightly higher 195 MCM in 2015 (MWI 2015). A dynamic econometric model showed the agricultural water supply is determined predominantly by the level of production (Shahateet 2008). Efforts to optimize water allocation in the agricultural sector, therefore, must take into account seasonal and monthly production cycles, the value and water requirements of crops, and the amount of cultivated area (Doppler et al. 2002).

Domestic and municipal water use is modeled primarily using population and hypothetical per capita usage (Shahateet 2008, Hoff et al. 2011). Instrumental variables techniques have shown residential demand is positively correlated with household size, welfare level, education, and number of bathrooms (Tabieh et al. 2012). There is also a temporal component, with domestic water balances of the cities Amman and Zarqa showing increases in summer months due to more people and higher consumption (Al-Omari et al. 2009). Overall, a study of Balqa, Zarqa, Amman, and the greater Jordan Valley estimated a municipal water deficit of 6 liters per person per day (Wildman 2013). Potter et al. (2010) quantified the current consumption to be 94 liters per person per day, a relatively low average that is dependent on household income. The issue of water scarcity in domestic and urban contexts disproportionately impacts those in lower economic classes. The deficit and unreliable rationing system forces people to complement the water supply network with other sources. Rooftop or underground storage units, bottled water, or purchases from private water vendors or water tankers can be regularly necessary but

potentially cost-prohibitive (Potter et al. 2010, Wildman 2013). Tanker water in particular is, along with piped water, the most quantitatively significant urban residential source. Klassert et al. (2015) used an agent-based model to quantify an upper bound estimate of this tanker water for the city of Amman at 38,451 m^3 per day, heterogeneously distributed across districts and income groups. The domestic water deficit and demand are projected to continue to increase, due to expected population growth and improvement in quality of life standards (Al-Bakri et al. 2013). Wildman et al. (2013) particularly notes the increasing challenge to meet the needs of the growing influx of Syrian refugees, who may not be connected to the water supply system and may not be able to afford or store trucked water without financial assistance. In order to meet growing demand, urban conservation actions may be helpful. An optimum mix of actions, such as encouraging customers to install water efficient appliances and offering rebates to those who adopt conservation technology, could help Amman gain an estimated 10.7-30.0 MCM/year, though households differ in their individual ability save domestic water (Rosenberg 2009, Rosenberg and Lund 2009).

The demands of industrial and tourism sectors have also been studied and are expected to increase with current development trends, while "unaccounted for" or non-revenue water is expected to decrease due to upgrades in maintenance (Al-Omari et al. 2009). A WEAP mass balance approach used by Al-Omari (2013) notes that this non-revenue water (NRW), defined as the difference between the annual volume input into the water supply and the billed authorized consumption, is currently higher in Jordan than in other developing countries. In Amman, the percentage of NRW from 2001 to 2006 was in the range of 43-49%, and somewhat lower in Zarqa at 24-30%. Decker (2006) developed a global top-down flow balance model to study the impact of rationing in Amman on the NRW. The model, and a confirming pilot field study, found that the best strategy to progressively reduce NRW is to move limited areas to continuous supply, as this removes the issue of surges and allows for for traditional leakage control tools. The alternative of maintaining rationing but extending supply time stresses the network, allowing for longer leaks and increasing non-revenue water. This conclusion supports an argument for introducing any new resources in a progressive fashion rather than all of a sudden in order to minimize non-revenue water. It is important to note that the ongoing reductions in real loss NRW is itself equivalent to making new water resources available (Al-Omari 2013).

Among models of future water balance scenarios in Jordan, there is a general consensus that the "business as usual" scenario, both with and without climate change, will bring greater water deficits than what is currently being experienced. This will be due to a combination of natural phenomena, economic growth and development, increases in population and refugee arrival, and improvements to quality of life (Shahateet 2008, Al-Bakri et al. 2013). Using the WEAP model, Al-Omari et al. (2009) predicted a total deficit of 240 MCM in the Amman Zarqa Basin by 2025. Using a different water requirement model and regression analysis, Al-Bakri et al. (2013) predicted a comparable deficit, of 215 MCM by 2030 and 248 MCM by 2050, but for the entirety of Jordan. This difference could potentially be explained by the thoroughness of the former study in addressing per capita usage increases, the tourism sector, and additional areas of increasing demand as well as the latter's inclusion of expanded wastewater reuse in its business as usual scenario. Expected reductions in water loss by improved municipal management and network rehabilitation will not be sufficient to prevent the expected deficits included in most predictive models (Al-Omari et al. 2009, Hoff et al. 2011).

A number of predictive frameworks have been used for modeling future water and land use in regards to the agricultural sector. Some authors note there will be a decrease in irrigation water demand in the Amman-Zarqa Basin and Jordan River Basin as a result of improved management (Al-Omari et al. 2009, Hoff et al. 2011). Others emphasize an increase in cultivated area in the country, specifically up to 5-10% per year in the Jordan Valley alone, due to an increased demand for food (Shahateet 2008, Alfarra et al. 2012). Al-Bakri et al. (2013) contests this claim by anticipating a decrease in irrigated areas through 2030 and 2050 by several percentage points. However, despite the conversion of agricultural land to urban land, the authors of this particular study predict there will still be an indirect increase in agricultural water demand and crop production. Due to these different theories of the future water usage in the agricultural sector, further analysis is necessary to develop more thorough and agreed upon scenarios.

Climate change models are in agreement that future temperature increases will exacerbate the current water scarcity in Jordan. The WEAP model applied by Alfarra et al. (2012) took into account a temperature increase of up to 4.5˚C, which can result in a 25% reduction in precipitation and a 23% reduction in runoff and inflow in the Jordan Valley. Abdulla and Al-Omari (2008) ran twelve climate change scenarios – general circulation models as well as incremental temperature and precipitation changes – using the Surface-Infiltration Baseflow Model to predict the effects in 2040 in the Zarqa River System. All scenarios showed a decrease in monthly runoff, with the harshest model of a 4˚C increase and 20% precipitation decrease resulting in an inflow decrease of 70%. The study revealed the most serious effects occurring in basins with already low precipitation. Al-Bakri et al. (2013) claims the most probable climate change scenario includes a temperature increase of 1˚C by 2030 and 2˚C by 2050 and decreased rainfall of 10-20% in most of Jordan's surface water basins. According to their water requirement model and regression analysis, this will lead to a 25-40% reduction in runoff, primarily impacting groundwater sources. These climate change water balances have been useful in quantifying the degree of intervention needed to minimize Jordan's future water deficits.

To combat the effects of population growth and development, potential agricultural increases, and climate change, water balance models have been used to assess how various new sources and policies can increase Jordan's water supply. The Disi aquifer project, which has been included in many models as an aspect of "business as usual" scenarios, is expected to provide 100 to 125 MCM per year for 50 to 100 years (Al-Omari et al. 2009, Hoff et al. 2011, Al-Bakri et al. 2013). The Red-Sea Dead-Sea Channel project, with the potential to bring in between 570 and 600 MCM per year into Jordan, would take water from the Red Sea in Aqaba to be desalinated near the Dead Sea and ultimately transported to Amman (Al-Omari et al. 2009, Hoff et al. 2011, Al-Bakri et al. 2013). Additional sources, including the expansion of desalination plants, could bring further water increases (Rosenberg 2009, Al-Bakri et al. 2013).

As an additional source, models have been used to explore the effects of expanding wastewater reuse efforts. A WEAP model of the Jordan Valley by Alfarra et al. (2012) demonstrated 114 MCM can be provided through treated wastewater if the wastewater reuse index (WRI) is increased to 70% of generated wastewater is reused. Using a WEAP model of the Amman-Zarqa Basin, Al-Omari et al. (2009) showed that 76 MCM were available for reuse in 2005, but that this is expected to double by 2025. A broader study of all of Jordan describes the trend as increasing to 256 MCM by 2030 and 400 MCM by 2050 (Al-Bakri et al. 2013). The increase in use of wastewater for agriculture will help free water for allocation for domestic uses (Alfarra et al. 2012). In various predictive configurations used in water

balance models of Jordan, increased volumes of treated wastewater and the incorporation of additional sources have been successful in eliminating expected water deficits.

According to some models that take into account economic policies, water pricing can also play an important role in water usage. Ramirez et al. (2011) used an econometric model to understand water use in the Mafraq Basin and determined that low water prices discourage conservation. Specifically, a reduction in 360 mm depth of water was seen for each addition one JD per cubic meter increase in water price. The water price itself was more of a determining factor for conservation in comparison to other encouraging or discouraging factors. A mathematical model by Doppler et al. (2002) found a similar trend that higher prices lead to lower water demands and that water pricing can be used as a control to hypothetically prevent otherwise growing water deficits. The impact of water pricing can also be applied to urban settings. The elasticity of urban water demand with increasing price is negative and weak in Zarqa at -0.004, and higher in the wealthier city of Amman at -0.621 (Tabieh et al. 2012).

The applicability and accuracy of models created to research Jordan's water resources are somewhat limited by the quality and existence of necessary data. In particular, data on exact inflows is difficult to measure, especially in dry months (Farber et al. 2005, Abdulla and Al-Omari 2008), and existing data is often heterogeneous (Hoff et al. 2011). As with any prediction models, there is uncertainty associated with any climate or development trends, both of which have strong effects on most water balance models (Hoff et al. 2011). There is space in the spread of current literature for further modeling of water balance in urban settings, especially in regards to the effects of reallocating water from the agricultural sector to cities. Additionally, more research must be done to take into account transboundary impacts on present and future water resources. Hoff et al. (2011) created one of the seemingly few models that specifically incorporated data from Israel and Palestine. The researchers noted, however, the political challenges and barriers when collaborating with nearby partners. Future research on the water balance of Jordan would benefit from using the highest quality available relevant data, explore a wide range of variability for future scenarios, and addressing the less frequently emphasized issues of urban settings and transboundary issues.

5 Data sources and outcome definitions

The primary data sources discussed in this report are from the Component 2 Water Balance and Agricultural Survey elements (Table 5.1). Data for the first of these come from secondary sources, mostly at the MWI or JVA. The second come from the surveys conducted by the Jordanian Department of Statistics (DoS) on behalf of Social Impact (SI). These surveys serve as the baseline for the longitudinal panel study of farms in the five sample zones described in Section 3 of this report. The agricultural survey was programmed directly by DoS using Java software.

Table 5.1. Data Sources

Data source	Population of interest and unit of analysis	Temporality (cross-sectional, time-series, panel)	Coverage (representative, non-representative)	Type (Qualitative, quantitative)	Target Sample size
Water balance data	System flow quantity and quality	Time-series, secondary data	n.a.	Quantitative	n.a.
Agriculture survey	Farms using different sources of irrigation water	Panel (only baseline collected so far)	Non-representative	Quantitative	550 farms

5.1 Water balance

Attributing changes in agricultural water use, and in resulting re-allocation of freshwater to urban areas, to Compact activities is impossible without producing a detailed water balance calculation supported by a comprehensive dataset. This dataset must include measures and/or defensible estimation of flows into the AS-bound sewer network as well as inflows to and outflows from the Zarqa River upstream from the dam. Improved monitoring of both mixed effluent and conventional freshwater flows within the Jordan Valley irrigation network is also helpful in piecing together the complicated dynamic of water substitution. A summary of the key indicators is provided in Table 5.2; these encompass new contributions to wastewater flows into the AS WWTP; water quality measures; water flows into and out of the Zarqa River upstream of the KTD; water allocations to the Jordan Valley irrigation system; and water allocations from the KAC to urban areas.

Table 5.2. Variables required for analysis of the role of Compact investments in allowing primary substitution of water away from Jordan Valley irrigation (water balance analysis)

Variable	Source or institution(s)
New contributions to the AS-bound wastewater network	
Volume of Disi or other new imports (e.g., due to national substitution policy, or new water supply development)	MWI, WAJ, PMU
Δ in wastewater production due to population/demand growth and non-Compact sewer expansion	MWI, WAJ, PMU
Δ in wastewater capture from Compact in already sewered areas (from reduced physical network losses)	WAJ, PMC
Δ in wastewater capture from Compact in newly-sewered areas	WAJ, PMC
Water quality of wastewater effluents	
TSS, BOD, and bacteria levels in AS effluent	MWI, MoH, PMC
TDS, TSS, bacteria, and chlorophyll-A in KTD water	JVA, MoH
Water balance between AS and the KTD	
Δ in withdrawals of treated effluent from the Zarqa River in the vicinity of AS	JVA
Δ in withdrawals of treated effluent from the Zarqa River downstream of AS	JVA
Inflows to the Zarqa River from the Jerash and Ba'qa WWTPs	WAJ
Precipitation-based inflows into the Zarqa River	MWI
Releases from the KTD Releases	JVA
Water allocations to JV irrigation systems and to urban areas	
KTD water allocations to irrigated areas, by turnout	JVA
KAC water allocations to irrigated areas, by turnout	JVA
Water flows into the KAC (from wastewater and freshwater sources)	JVA
Weekly water allocations to individual farm units	JVA
KAC flows to Amman (through the Deir Alla Diversion)	MWI

Note: The SI team recognizes that proxies for several of these variables are included in the MCA-J's ITT.

5.2 Agricultural surveys

Baseline data collection for the agriculture survey was initiated in late July 2015, and completed for the Jordan Valley areas in late August. Highland surveys were then conducted in late September. Ultimately, DoS reported that enumerators visited a total of 551 farms from the sample (Table 5.3). Questionnaires were recorded as complete by DoS for 550 of these farms (>99%), with only a single farm refusing consent. These high completion rates give us confidence that we have a highly representative sample of the selected zones.

Table 5.3. Agricultural Survey Outcomes

	From final datasets			From DoS reporting		
Province	**# of farms visited**	**# completed questionnaires**	**% completed questionnaires**	**Closed** (from DoS)	**Empty** (from DoS)	**Refused** (from DoS)
Area 1: North JV1	114	114	100%	0	0	0
Area 2: North JV2	108	108	100%	0	0	0
Area 3: Middle JV1	108	108	100%	0	0	0
Area 4: Middle JV2	110	110	100%	0	0	0
Area 5: Highlands	111	110	>99%	0	0	1
Total	**551**	**550**	**>99%**	**0**	**0**	**1**

The major variables of interest from the agricultural surveys are summarized in Table 5.4 below. These pertain to water use and changes arising from alteration of irrigation water sourcing; farm-level physical measures and outputs; changes in net profits; and changes in farm values.

Table 5.4. Key intermediate and final economic outcomes measured through the agricultural survey

Outcome	Indicators
Intermediate outcomes	
Farm-level water use and changes due to water source modification	-Balance of blended KTR water and freshwater use in irrigation -Perceptions of water quality suitability -Modification of cropping choices
Farm-level production	-Irrigated area -Farm selection of non-water inputs -Farm output (quantities and yields)
Economic outcomes	
Change in net profits from irrigated agriculture	-Farm input costs -Farm revenues -Farm profits
Change in farm value	-Farm assets -Farm land value

6 Water Balance Element: Methodology and progress to date

6.1 General overview

To effectively understand the complex system dynamics that influence water availability in the Jordan Valley and in Zarqa, the SI evaluation team has begun to develop a water resources model using the Water Evaluation and Planning System (WEAP) tool (Johnson et al. 1995, Yates et al. 2005). WEAP is a software program that is designed to assist policymakers in evaluating water supply policies and developing sustainable water resource plans. It operates on the basic principle of water balance accounting, and allows integration of watershed-scale hydrologic processes with a water management model driven by water demands and environmental requirements as constrained by natural watershed and physical infrastructure characteristics. It has been widely applied by practitioners as well as researchers seeking to better understand water flows and how these are influenced by infrastructure development, increased demand, changes in water management institutions, and changes in water supply (Lévite et al. 2003, Rosenzweig et al. 2004, Mounir et al. 2011). The model has also previously been applied to the Jordan Valley system by several researchers (Al-Omari et al. 2009, Alfarra et al. 2011, Hoff et al. 2011).

In this section of the report, we first describe the basic structure of WEAP as it is applied in this work, and discuss progress so far on model development.

6.2 Model features of WEAP and use in this application

WEAP allows for various types of system components – demand sites; wastewater treatment plants that receive and discharge return flow from demand sites; local supplies; and rivers and their nodes. The software package has recently been enhanced to more easily link to other modeling systems and applications (e.g., MODFLOW groundwater models and QUAL2K water quality models). WEAP also offers spreadsheet-like capabilities for reading in data and for implementing complex algorithms. As discussed further below, most of the calculations in WEAP are carried out automatically within a water allocation framework.

WEAP Structure consists of five main views:

1. **Schematic -** GIS tools allow the user to easily and quickly configure a system, including "drag and drop" capability to create and position system elements. Users can add ArcView and other standard GIS vector or raster files as background layers. They can also quickly access data and results for any element in the system.
2. **Data -** Model-building tools help users to create variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel for data importing and exporting.
3. **Results -** Detailed and flexible display of all model outputs can be viewed in graphs, tables and on a map. The graph and map formats allow for animated viewing of results through time.
4. **Scenario Explorer** – Users can design summary graphs to highlight key system indicators for quick review. These allow efficient exploration of the effects of changes in data on results.

5. **Notes –** Users can easily document data and assumptions by annotating their models.

WEAP is an appropriate tool for the present study for several reasons. First, it is available at no charge for institutions in developing countries and at an affordable price for developed countries and private companies. Second, the scenario features of WEAP support the exploration of how non-traditional water sources could change water availability and use in the targeted area; this makes it ideal for constructing a modeled counterfactual to the situation including the MCC project. Finally, because WEAP models are easily extendible, the model that is built could be used as the basis for a larger model that includes the whole of Jordan. In addition, Jordan's MWI could integrate groundwater models and water quality variables into the WEAP model if necessary and as appropriate.

At the same time, there are limitations to WEAP that should be kept in mind. First, WEAP represents spatial relations through the length of river reaches. The built-in hydrologic model is a lumped-parameter model that does not represent spatial variation across a catchment. Second, some aspects of the water distribution system in the JV are challenging to represent using the model features. Specifically, there is a two-way flow between the King Abdallah Canal and the Wadi Arab Reservoir. There are no built-in rules within WEAP for representing such a two-way flow, and so the actual net flow must be approximated using WEAP's existing modelling capabilities.

For setting water allocation rules, we use WEAP's framework for analysis of constrained water resources distribution. Water allocation at each point in time is carried out according to user-specified priorities for different demand sites and sources. At each time step, the model aims to maximize coverage of demands in sequential order, starting with the highest priority and moving down until constraints on water availability or other constraints that limit specific demands bind. To achieve this prioritized allocation, the WEAP algorithm is implemented as a series of linear programming (LP) problems, iterated over demand and supply priorities.

The algorithm can be written in the following way (we suppress the time label except when necessary for clarity although all variables are allowed to vary over time). Suppose that there are N demand sites and M sources. Denote the maximum demand at site i with priority p by $D_i^{(p)}$. The amount of water actually supplied to the demand site from source r is $x_{i,r}^{(p)}$, while the total amount of water available from source r is S_r. Note that a source can also have a demand; for example, a reservoir accepts inflows and may have storage targets to meet.

The model solution starts with priority $p = 1$, and loops over supply preferences to demand sites at that priority, to solve the following linear program (LP):

Maximize coverage $C^{(p)}$ at priority p, subject to

$$S_{r,t} - \left(\sum_{i=1}^{N} x_{i,r}^{(p)} - \sum_{s=1}^{M} x_{r,s}^{(p)} \right) = S_{r,t-1}; \text{ Mass balance constraint for storage}$$

$$\sum_{r=1}^{M} x_{i,r}^{(p)} = c_i^{(p)} D_i^{(p)} \qquad \text{Coverage constraint for demands}$$

Where either

$c_i^{(p)} = C^{(p)}$; Equity constraint for demand sites

or

$c_i^{(p)} \geq C^{(p)}$. Equity constraint for reservoirs and in stream flow

Additionally,

$0 \leq C^{(p)} \leq 1$; Bound on coverage

$x_{i,r}^{(p)} \geq 0$; Non-negativity for demand priority *p* from supply *r*

$x_{i,r}^{(>p)} = 0$; and For lower priorities (that is, with values greater than *p*)

$x_{i,r}^{(p)} = 0$. If supply priority exceeds the one being evaluated.

The LP is solved, yielding shadow prices for each equity constraint. If the shadow prices are positive, $x_{i,r}^{(p)}$ is set to the corresponding optimal values. The routine is then repeated for the next lowest supply priority for the demands at priority *p*. The entire routine is then repeated at *p*+1, until all demand priorities have been considered.

To be able to reproduce this process, we first formulated a set of basic operating rules for system reservoirs as a starting point. Then we set demand priorities in the WEAP application. These priorities were informed by discussions with the JVA and others knowledgeable about the system, where a priority of 1 denotes the highest priority, as follows:

Priority 1: KAC headflow, Wadi Arab backpump, North JV agriculture
Priority 2: Ziglab reservoir level, Amman city
Priority 3: Wadi Arab reservoir level
Priority 4: Middle JV agriculture, South JV agriculture
Priority 5: King Talal reservoir level, KAC tailflow
Priority 6: Shueib reservoir level, Kafrein reservoir level

As shown above in priority 4, the flow in the King Abdallah Canal as it exits the study area (the tailflow) is modeled as an instream flow requirement that is tied to the volume of water in the King Talal Reservoir. This requirement is specified in the following way: When live storage behind the KTD is less than 25% of the reservoir capacity, the tailflow requirement is set to zero. When live storage is 100% of capacity, the tailflow requirement is set to 1.5 m^3/ second. Between those two limits, the tailflow requirement increases linearly with the volume in the KTD reservoir.

In addition to the priorities listed above, the Wadi Arab, Ziglab, Shueib, and Kafrein reservoirs have "buffering" rules that slow down releases as the reservoirs empty. The rate of release from the buffer zone is set by a buffer coefficient. The levels of the buffers and the coefficients were specified to lie between minimum and maximum values, as shown in Table 6.1.

6.3 Schematic for the Jordan model

Our WEAP water schematic is based on a simplified representation of the Jordanian water supply system that is depicted in Figure 6.1 (the geographic projection from WEAP is shown in Figure 6.2). At the northern end, the Yarmouk River originates in Syria and flows along the Syria-Jordan border until it meets the Lower Jordan River. The historic inflow to Jordan since the Jordanian-Israeli Peace Treaty of 1994 has been about 110 MCM. Half (55 MCM) of this comes from the Yarmouk and 55 is provided from the Upper Jordan via the Tiberias Carrier (Alfarra 2010). The Upper Jordan River itself has tributaries that originate in the Golan Heights and in Lebanon, and then run through Israel to the Sea of Galilee (Lake Tiberias).

Table 6.1. Reservoir calibration parameters

Parameter	Minimum	Maximum	Initial Value	Run 1 Calibration	Run 2 Calibration
Top of Buffer (million m³)					
Wadi Arab	3.1	20	9.1	16.2	16.4
Ziglab	0.4	4.3	2.4	3.2	3.2
Shuieb	1.43	2.3	2.12	2.3	1.93
Top of Buffer as fraction of storage capacity (dimensionless)					
Kafrein	0	1	0.25	1	0.58
Buffer Coefficient (dimensionless)					
Wadi Arab	0.1	1	0.2	0.1	0.13
Ziglab	0.1	1	0.75	0.1	0.1
Kafrein	0.1	1	1	0.67	0.1
Shuieb	0.1	1	0.5	0.1	0.1

Downstream of the confluence with the Yarmouk, most of the remaining flow in the Lower Jordan (and in the wadies that previously converged with it) is fed into the KAC that runs parallel to the river. The Jordan River's historic flow downstream is therefore now less than 20-30 MCM (Suleiman 2003, Courcier et al. 2005), while the KAC receives most of this upstream flow plus about 25 Mm³/year from the Mukheiba wells and 8 Mm³/year from seasonal side wadies.

The other major inflows into the KAC system come from storage dams that hold water – freshwater from the Al-Arab Dam (14 MCM) and Ziglab Dam (4 MCM), and blended freshwater and treated wastewater from the KTD, Shueib and Kafrein Dams (90 MCM). Outflows from the KAC are then conveyed primarily to JV irrigators, Amman (45 MCM), Irbid (17 MCM) and to the Karameh reservoir (25 MCM) (Alfarra 2010).

The concrete KAC – shown in green in Figure 3.1 and in red in Figure 3.2 – was built in several waves from the 1960s to the 1980s and now runs the length of the JV for some 110 kilometers. It serves as the major water supplier for irrigated agriculture in the JV (and more recently sends increasing volumes to Amman for municipal use via the Dear Alla diversion). Roughly 110 MCM of water is pumped from the Yarmouk River and nearby wells (Mukheiba) into the canal each year, which has a capacity that starts at 20 m³/s in the north and ends at 3.2 m³/s at its southern end. A number of other seasonal wadis (the main ones are the Wadi Arab, Wadi Ziglab, Wadi al Jurum, and Wadi Yabis) join the KAC in the Northern JV, and

diversions to fields occur at various distribution points that supply stage offices 1 and 2 in this zone.[10] Demands at these sites are partitioned by crop type based on existing cultivated area and water demand for each crop. Importantly, water flows in both directions from the Wadi Arab to the KAC and from the KAC to Wadi Arab. To account for this, the KAC-to-Wadi Arab backpump is represented in WEAP as a diversion with a minimum flow requirement that is set to the historical flow amounts. Treated wastewater effluents are also now being supplied to farmers from the Wadi Arab, Irbid, and Shalalah wastewater treatment plants (WWTPs).

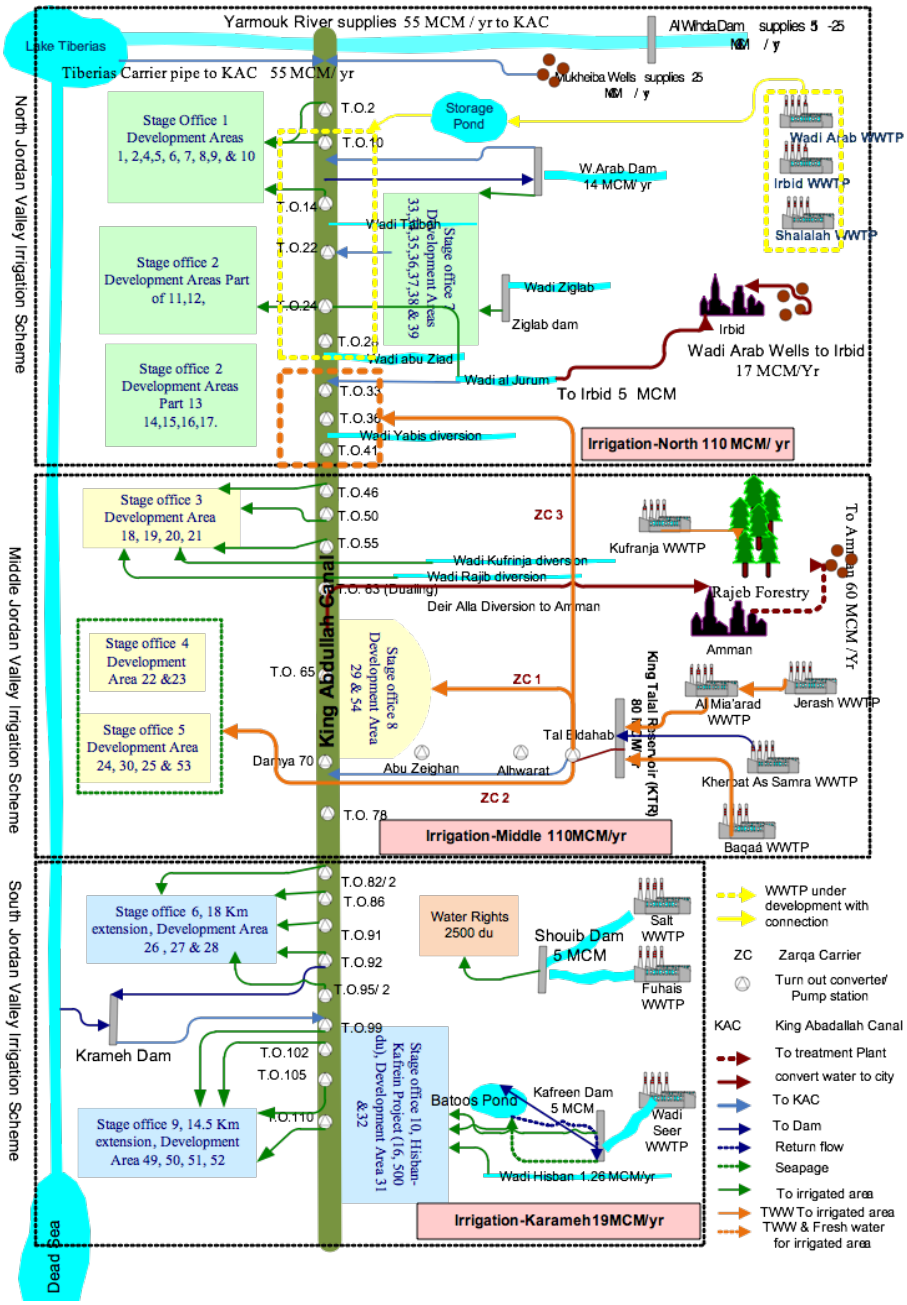

Figure 6.1. Simplified representation of the water allocation system for the Jordan Valley

[10] The JVA is the institution responsible for development of the water system and irrigation system in the JV. It distributes water from the KAC to farmers via the stage offices. The JVA operates under the Ministry of Water Irrigation, along with the Water Authority of Jordan (WAJ).

Further to the South, in the Middle JV, the major inflow of water is from the Zarqa River, which holds seasonal rainfall as well as treated wastewater from a number of WWTPs (mainly As Samra, but also Jerash, Baqaa, and Al Mia'arad). Due to the Zarqa River's proximity to the major population centers in and around Amman, the river suffers from severe pollution. In addition, the Water Authority of Jordan (WAJ) in the past has issued user-licenses to farmers to reuse TWW in the vicinity of the As Samra WWTP. Water diversions from the KAC in this zone go to Amman (through Deir Alla), and to JV irrigators attached to stage offices 3, 4, 5 and 8. Two seasonal wadis – Wadi Kufrinja and Wadi Rajib – directly supply stage office 3 with supplementary water.

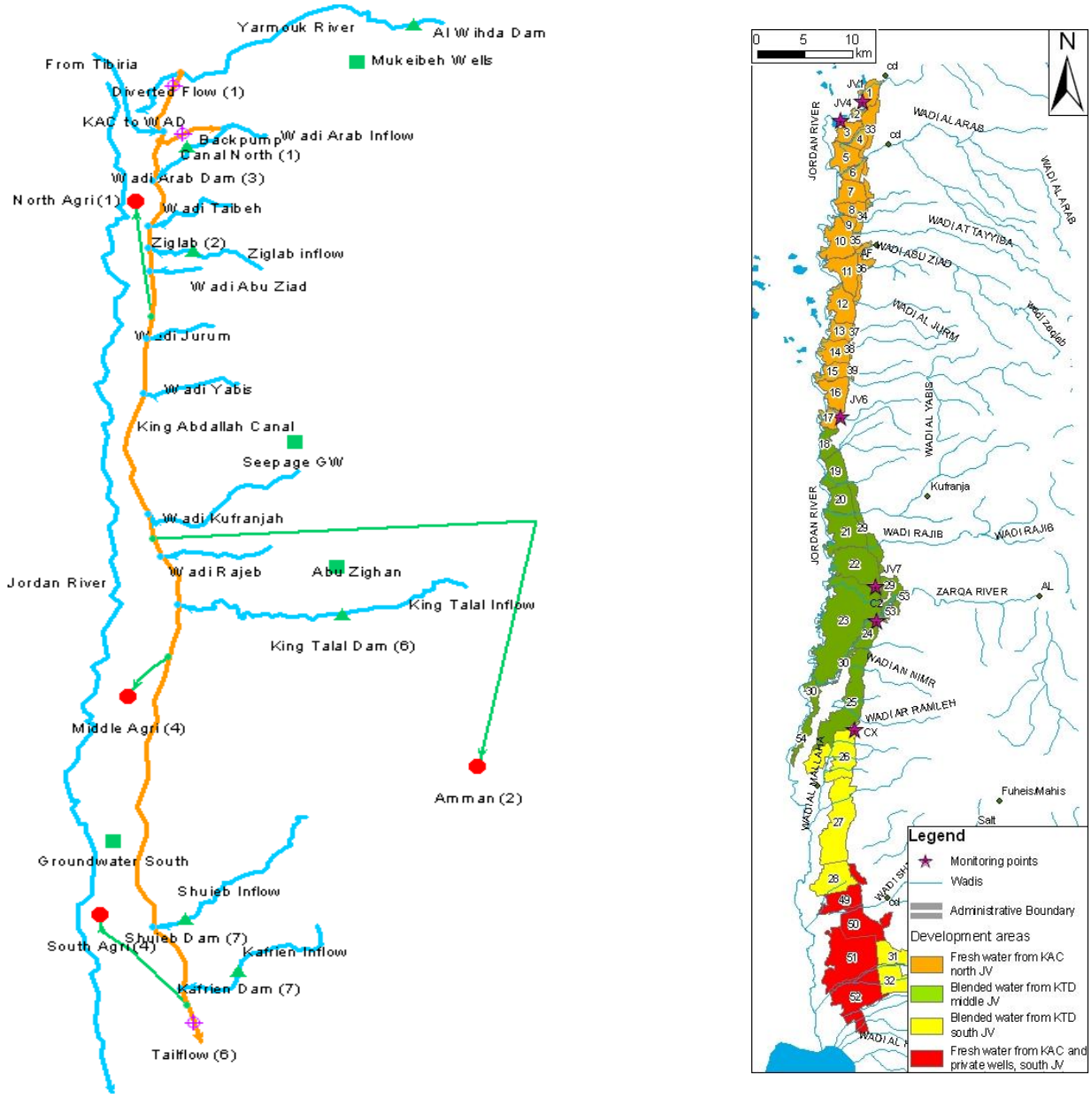

Figure 6.2. Geographic projection of the water supply system as represented in WEAP.

Finally, in the Southern JV, there are few inflows into the KAC, except through the Krameh Dam that receives water from the Jordan River. Diversions from the KAC reach stage offices 6 and 9, while stage office 10 recieves its water from the Wadi Hisban and Kafreen Dam. The latter infrastructure stores blended water from seasonal flows and the Wadi Seer WWTP. Finally the Salt and Fuhais WWTPs similarly supply the Shueib Dam that is used for dedicated water rights in the southern Jordan Valley.

In WEAP the water demands in urban centers (e.g., Amman and Zarqa) are aggregated together, as are the wastewater return flows (which country-wide equal about 40% of water supplied to urban zones). Estimates of the annual network water consumption vary between 55 and 90 m^3 per person per year in these cities (Nicholas O'Dwyer 2010, MWI 2013). However, these figures do not match supply statistics of 140 m^3 per person per year (MWI 2013). In other words, not all water supplies reach households (non-revenue water is considerable). Within the WEAP simulation it is therefore assumed that 50% of the supplied water does not reach users, and the annual rate of consumption is assumed to be 60 m^3 per person per year.

6.4 Data requirements

Use of the WEAP model requires a significant effort in data collection, to obtain the following parameters:

- Temporal pattern of inflows of water from various surface and groundwater sources;
- Spatially and temporally-explicit water demands for various purposes (agriculture, municipal, industrial, ecosystems);
- Factors influencing water demands (climatic variation, population projections, crop water requirements)
- Institutional constraints (e.g., water rights, water use prioritization);
- Infrastructure characteristics (e.g., location, capacities, wastewater collection and treatment percentages, operating rules); and
- Estimation of losses in the system (evaporation, infiltration, etc.).

We prepared and relayed a detailed data request to a number of Ministries and partners in Jordan through the Millennium Challenge Account – Jordan (MCA-J) (Table 3.2). The table also indicates where we stand on the data collected relative to the full request. We note that the data request is challenging because data even within the MWI are located in different departments. Its collection therefore necessitates a great deal of cooperation between departments.

Table 6.2 shows a number of critical data gaps that remain at this point. The most critical needs are for the creation of a direct communication link, to be moderated by MCA-J and MCC, between the evaluation team (and notably Amani Alfarra) and key data contacts at the Ministry of Water and Irrigation.

6.5 Model calibration results

Using existing data obtained from previous work and through the MCA-J, the JV model was developed and calibrated to analysis of changes in the supply and management of water resources in the Jordan Valley. Besides development of the schematic and model structure, a major focus of the set-up work for

the model was to develop a realistic representation of reservoir and infrastructure operating rules in the JV. The goal was to specify demand priorities consistent with water allocation practice in Jordan.

Table 6.2. Data required for the water balance model

Parameter	Source	Status	Description
Dam storage, inflow, outflow	JVA	Complete (through 2015)	Some years of data were missing; several methods were explored to address this. First, we fit the data to various statistical distributions (normal, log normal and Gumbel), but found that these models tend to overestimate missing values. As such, the editing tool in WEAP was used to interpolate missing values from data before and after.
Wadi flow	JVA	Complete (through 2015)	Some years of data were missing; the interpolation method described above was again used to address this. Years from 2006 to 2009 were missing from the records, those years were filled with the monthly average flows over the period 1960 to 2000.
Deliveries and irrigated areas	JVA	Complete, but highly aggregated	Monthly data for irrigated areas in the Jordan valley were available from 1960 till 2006; these data were updated to 2015. Data aggregation was based on the location of the agricultural land in the Jordan valley (North, Middle and South).
Water distribution to urban areas	WAJ and MWI	In progress	We have received considerable data on distributions, and are working to integrate this into the model. We need to work closely with WAJ to better understand the distribution of water sources to urban demands, and to close the loop between TWW at different locations and inflows to the stage offices in the JV.
Wastewater treatment	WAJ and MWI	As Samra data acquired; other WWTPs missing	We have yet to receive data from most of the countries WWTPs, and also need to work with MWI to better understand if and where the treated wastewater is being re-used.
Wastewater reuse	JVA	Incomplete	We do not yet have information on the active WW reuse project in the North, including how much water is going to the JV and the capacity of storage in the new pond / reservoir built for this.

Here we focus on the agricultural system, since the data supplied thus far for urban demands are insufficient for their inclusion in the calibration. The calibration exercise relied on a software-based calibration tune operating rules to replicate the observed historical release patterns and delivery of water to the demand system from 1990-2006, the period for which we had data.[11] This procedure was used because the decision processes carried out by the MWI are somewhat ad-hoc, and so cannot easily be hard-coded as specific rules in the model.

In general, two linked allocation questions are answered by the MWI on an annual basis:

- How much potential irrigation and municipal water demand will actually be supplied?
- How much water will be released from each reservoir to meet this required demand?

Once the priorities and a set of basic rules had been specified, the model was calibrated in a two-step process. In the first calibration step, observed reservoir levels for the total storage system were compared with their modeled values to assess goodness of fit. In the second run, the calibrated values from the first

[11] For this calibration, we used a two-step PEST parameter estimation software version 1.1 (Watermark Numerical Computing 2004).

run were set as new initial values, and observed reservoir levels for all reservoirs except for KTR were compared to their modeled values. This second step was deemed necessary because the volume in the KTR is very large such that its simulation dominates the results (see Figure 6.3). The second calibration thus ensured a good fit for the smaller reservoirs.

The measured and estimated reservoir volumes for three important reservoirs (King Talal, Wadi Arab, and Kafrein) are shown in Figures 6.4, 6.5 and 6.6, respectively. As can be seen on the figures, the calibrated operating rules and priorities reproduce the historical reservoir levels reasonably well. Some deviation during low storage periods, but the bias is not consistently high or low during such periods (perhaps because the JVA deviates more substantially from standard practices during unusual flow periods).

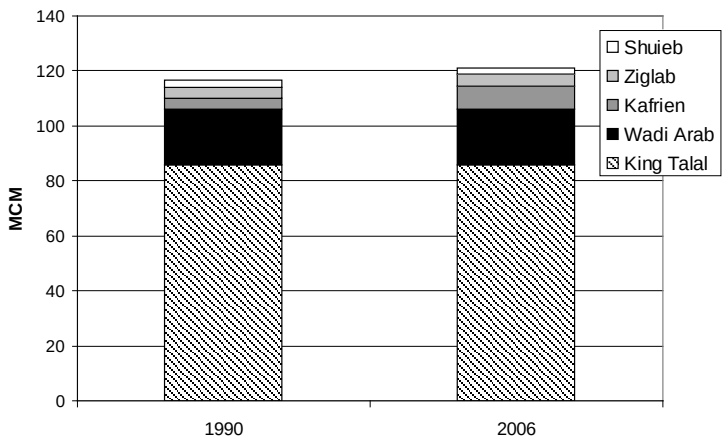

Figure 6.3. Gross storage capacity of JV reservoirs (Mm³); the change in 2006 corresponds to the increase in capacity of the Kafrein Dam.

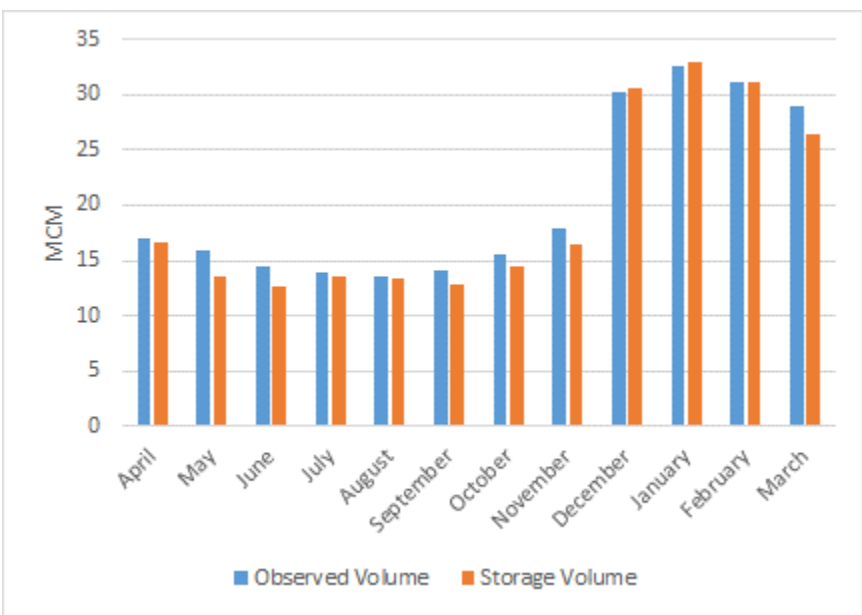

Figure 6.4. King Talal Storage (historical and WEAP calibration)

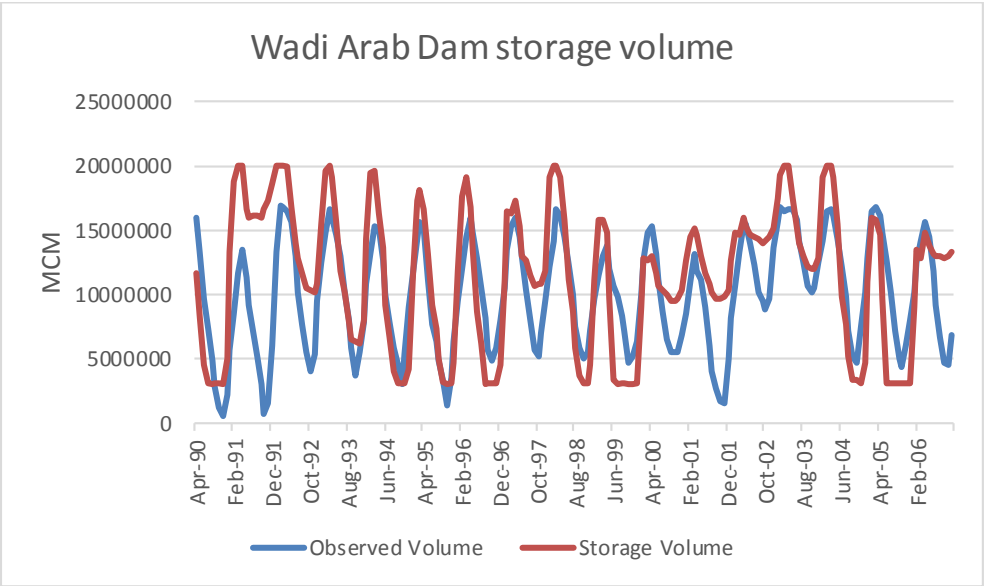

Figure 6.5. Wadi Arab Reservoir storage (historical and WEAP calibration)

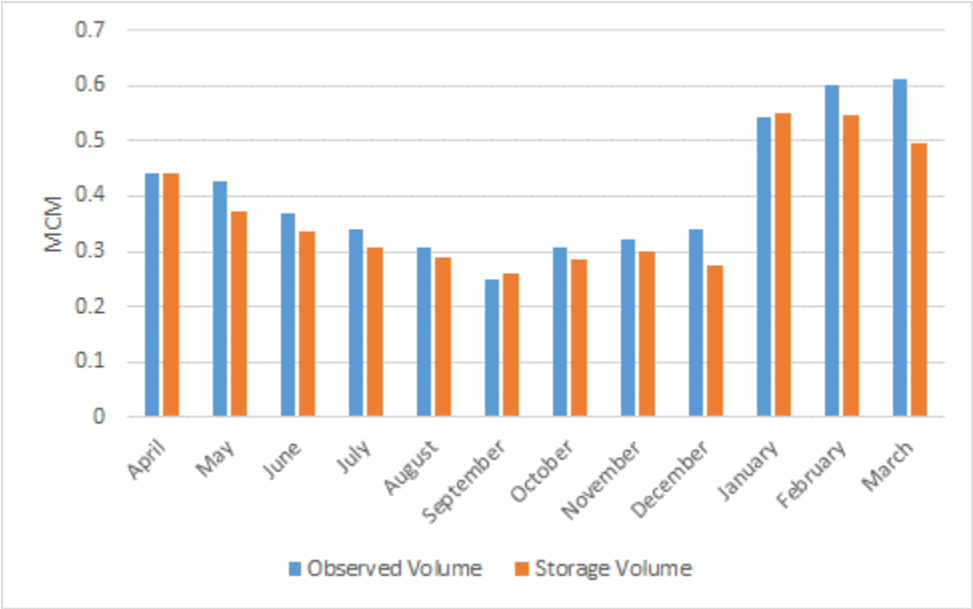

Figure 6.6. Ziglab Reservoir storage (historical and WEAP calibration)

6.6 Specific assumptions / planned scenarios

As a planning tool, WEAP supports scenario analysis as part of its core features. Our use of WEAP aims to describe how the MCC-funded investments may contribute to the policy of water substitution of TWW for freshwater in the JV, thereby improving the overall efficiency of the water allocation system in Jordan. To answer this question, we envision two scenarios:

Scenario 1. Business as usual (no MCC/MCA-J investment). In this scenario, the water network and sewerage project investments are not made, and the wastewater contribution from Zarqa and other locations to the As-Samra WWTP continues to evolve as it did during the pre-project period (due to

population increases, normal investments, etc.). The Government of Jordan slowly continues to encourage use of TWW in the JV in line with this no-project evolution.

Scenario 2. MCC/MCA-J investment scenario. In this scenario, the water network and sewerage project investments occur, and the wastewater contribution from Zarqa to the As-Samra WWTP increases substantially as a result, in accordance with the increases in water consumption and sewerage rates in Zarqa measured through household surveys (and implied reductions in water losses). The Government of Jordan sends this additional TWW to the JV, allowing for greater substitution than in scenario 1.

We will compare the additional amount of water made available for urban areas as a result of this reallocation of additional flows of TWW to the JV.

6.7 Next steps

The next step in the Component 2 water balance work is for Dr. Jeuland and Dr. Alfarra to continue to specify key aspects of the model, based on data acquired after September 2016.

7 Results from baseline agriculture surveys

As noted in the sampling section of this report, baseline data collection with farmers yielded useable survey data for 550 farms (this was the target sample size) spread across 5 distinct areas (100 farms per area). In this section, we provide a description of the demographic and socio-economic make-up of the farm survey sample, and discuss farm characteristics and farming behaviors; crop choices and productivity; water use and expenses; and farm revenues and costs in this population.

7.1 Baseline descriptive statistics

All of the farmers in our sample were male, with an average age of 52.1 (Table 7.1). Most farmers (95%) were Jordanian (94%), married, and lived in households of an average of 5 people. Most of the farmers were literate (93%), while very few had received formal farmer training (3%).

Half of the farmers in our sample owned the farm, and farms had an average size of 38 dunums, with 32 dunums being cultivated. The average farm in our sample was reported to be worth about 166,700 JD. Most farms did not have buildings (residence, storage facilities, or livestock buildings) on their land, with the number of average buildings per farm being 0.84. 80% of farmers grew crops in the winter, and 40% grew crops in the summer. The average self-perceived wealth in the sample was 3.32 (on a scale between 1-6), which is close to the median level for the scale and consistent with expectations. Enumerators similarly ranked the average farmer 3.13 on a scale between 1-5. Very few farmers were NAF recipients (0.01), and reported average monthly incomes and consumption were 1297 JD and 892 JD, respectively. The average farm had about 22,400 JD in assets, with 7,190 JD of this asset wealth being in water-related assets. Meanwhile, very few farmers reported taking loans in the past year (3%), and only 15% reported having saved money in the past year.

On average, farmers cultivating during the winter season (n=441) spend about 13,400 JD in agricultural inputs (Table 7.2), with most of those costs being spent on vegetables (9,630 JD) and trees (3,250 JD). Field crops and flowers have considerably lower input costs, 380 and 200 JD, respectively, partly because of the smaller area and lower number of farmers growing such crops. In the summer, input costs among farmers growing crops (n=220) were slightly higher for trees (3,230 JD) than for vegetables (2,840 JD). The majority of farms (0.64) had at least one permanent worker, and the average number of permanent workers per farm was 1.55. The average total pay for permanent workers is 4,120 JD/year. Farms, on average, also have roughly 4 unpaid employees.

Consistent with the lower costs observed in summer, the average area of land used for farming was larger in winter than summer, though in both seasons, trees took the largest area (13.8 and 14.5 dunum, in winter and summer, respectively), followed by vegetables (12.2, and 6.97), field crops (4.56 and 3.06), and lastly, flowers (0.18 and 0.09). The average overall area used for farming was 30.8 dunum in the winter and 24.6 dunum in the summer during the prior year. Correspondingly, farmers reported leaving an average of 1.5 dunum fallow in the prior winter and 7.7 dunum fallow in the prior summer. In winter, vegetables produce the highest output of 76 tons, followed by, trees (28.5 tons), and field crops (26.5 tons). In summer, the order is different with trees producing the greatest output (34.0 tons, followed by

vegetables (16.1 tons), and then field crops (7.85 tons). On average, farms generate revenues of 23600 JD in the winter and 8860 JD in the summer. Most farmers thought that their yields in the last year were normal (Figure 7.1), though 15% felt that the winter yield had been lower than normal and 16% felt that the summer yield had been lower than normal.

Table 7.1. Farmer survey descriptive statistics (Demographics, farm and socioeconomic characteristics)

Variable	N	Mean	SD
Demographic variables			
Age	548	52.1	12.7
Gender	550	1.00	0.06
Married	550	0.95	0.21
Children in hh	550	1.69	2.02
Adults in hh	550	3.52	2.99
Literate	550	0.93	0.25
Farmer training	550	0.03	0.18
Jordanian	550	0.94	0.23
Basic Farm information			
Area of land	550	37.6	34.7
Area cultivated	550	32.3	27.1
Market value of land (thousands of JD)	469	166.7	125.3
Own farm	550	0.50	0.50
Manage farm for others	550	0.06	0.24
# of buildings on farm	550	0.84	0.92
Grow crops in winter	550	0.80	0.40
Grow crops in summer	550	0.40	0.49
Socioeconomics			
Wealth stairway (1=poorest; 6=richest)	537	3.32	1.06
Wealth stairway in 4 years (1=poorest; 6=richest)	508	3.41	1.11
Total HH consumption/month (JD)	550	892	750
Total HH income/month (JD)	550	1297	1577
NAF recipient	550	0.01	0.09
Took loan in past year	550	0.03	0.16
Saved in past year	550	0.15	0.36
Total value of assets ('000 JD)	550	22.4	29.3
Value of water-related assets ('000 JD)	550	7.19	7.32
Have greenhouse	550	0.20	0.40
Own tractor	550	0.14	0.34
Own transport vehicle	550	0.32	0.47
Own cooling equipment	550	0.01	0.10
Own plough	550	0.11	0.31
Enumerator opinion of wealth (1=very poor; 5=rich)	550	3.13	0.90

Table 7.2. Farming Inputs, Outputs and Constraints

Variable	N	Mean	SD	N	Mean	SD
Inputs[‡]		*Winter*			*Summer*	
Vegetables: Total ('000 JD)	441	9.63	15.0	221	2.84	8.17
Field crops: Total ('000 JD)	441	0.38	1.52	221	0.30	1.53
Trees: Total ('000 JD)	441	3.25	7.00	221	3.23	9.11
Flowers: Total ('000 JD)	441	0.20	2.63	221	0.22	1.31
Overall: Total ('000 JD)	441	13.4	14.6	221	6.59	11.4
Have permanent workers	550	0.64	0.48			
Number of permanent workers	550	1.55	2.42			
Total pay for permanent workers ('000 JD/year)	550	4.12	5.62			
Number of workers without pay	550	4.01	15.0			
Outputs/revenues[‡]		*Winter*			*Summer*	
Vegetables: Area (dunum)	441	12.2	14.9	221	6.97	11.2
Field crops: Area (dunum)	441	4.56	14.8	221	3.06	11.5
Trees: Area (dunum)	441	13.8	29.6	221	14.5	21.1
Flowers: Area (dunum)	441	0.18	1.94	221	0.09	0.95
Overall: Area (dunum)	441	30.8	16.7	221	24.6	13.3
Vegetables: Output (tons)	441	76.0	139	221	16.1	44.5
Field crops: Output (tons)	441	26.5	341	221	7.85	37.0
Trees: Output (tons)	441	28.5	102	221	34.0	53.8
Flowers: Output (tons)	441	0.00	0.048	221	0.00	0.00
Total revenue (calculated, in '000 JD)	441	23.6	52.3	221	8.86	27.8
Other farming[‡]		*Winter*			*Summer*	
Last year yield=normal	441	0.80	0.40	222	0.83	0.38
Land area left fallow last year	441	4.92	14.3	222	7.85	14.8
Livestock		*Both Seasons*				
Have livestock	550	0.04	0.20			
# of animals	550	2.21	17.6			
Purchases of animals last year (JD)	550	10.5	138.6			
Sales of animals last year (JD)	550	38.9	400.1			
Cost of inputs for animals last year (JD)	550	255	2147			
Constraints (1=excellent; 5=very poor)		*Both Seasons*				
Soil fertility	550	2.29	0.79			
Irrigation water amount	550	3.05	1.06			
Irrigation water quality	550	2.81	1.09			
Canal position	550	2.87	1.02			
Drainage	550	2.69	0.74			
Input costs	550	3.52	0.91			
Access to capital	550	3.00	0.84			
Access to markets	550	2.92	0.96			
Volatility in crop prices	550	3.71	0.92			
Taxes and licensing fees	550	3.21	0.96			

[‡] Inputs and revenues are only reported for farms with activity in that season, hence the smaller sample sizes for these statistics.

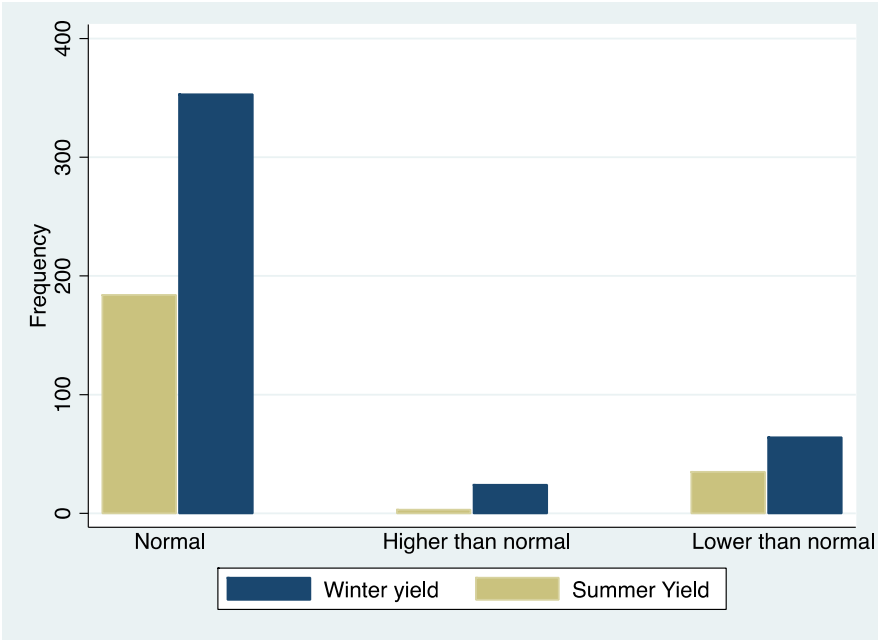

Figure 7.1. Farmer perceptions of yield during the prior year, by season

Regarding livestock inputs and outputs, very few farmers (0.04) reported having any livestock. On average in the past year, farmers had 2.21 animals, made purchases of animals of 10.5 JD (only 5 famers made any purchase of animals), earned 38.9 JD from selling animals (only 10 farmers made any sale of an animal), and spent 255 JD on inputs for animals.

Farmers did not report feeling very constrained by water-related issues on their farm. Their biggest reported constraint was with the irrigation water amount (ranked on average of 3.05 on a scale of 1 being excellent and 5 being very poor). Farmers ranked canal position, irrigation water quality, drainage and soil fertility as 2.87, 2.81, 2.69, and 2.29, respectively.

For both last winter and last summer, farmers reported receiving more water (17,600 m^3 and 6,850 m^3, respectively) than they had planned on (13,900 m^3 and 5,050 m^3), on average (Table 7.3). Most farmers (83% in winter and 85% in summer) reported that amount of water they received last season was normal. On average, water quality was not viewed as a major constraint (ranked 2.89 in winter and 2.78 in summer on a scale of 1 being excellent and 5 being very poor). Few farmers found the level of water they received to be sufficient (0.36), but very few (0.07) adjusted their crop mix because of water shortages. About half of the farmers reported having water quality problems. On a subjective scale of 0 (completely unusable for irrigation) to 10 (completely usable), farmers ranked their water quality as 5.38, on average.

A quarter of farms use water pumps, and on average, a farm spends 318 JD/year on these pumps and 450 JD/year on network water repairs. Only 3% of farmers use groundwater. 83% of farms pay for water, and on average, the total payment for water is 479 JD/year. 19% of farmers reported that other farmers in the area tried to evade water payments in some way. While 20% of farms were located where water user associations (WUAs) existed, only 5% of farmers were member of WUAs, and 4% made payments to WUAs. On average, farmers in areas with WUAs ranked their effectiveness as 2.55 (1=very effective, 5=very ineffective).

As expected, we see that farm characteristics and activities do vary across sample zones (Table 7.4). While the total average farm area is smallest in the North Jordan Valley, more of the land in that zone is used, and there is a gradient in intensity of farming from North to South (Figure 7.2). Reported land values, meanwhile, are highest in the middle Jordan Valley and in the highlands (Figure 7.3). More farms are owned (rather than rented) in the north Jordan Valley and highlands.

Table 7.3. Farm irrigation

Variable	N	Mean	SD	N	Mean	SD
		Winter			*Summer*	
Planned water (m^3)	441	13893	20503	221	5052	7482
Actual water (m^3)	441	17559	25854	221	6846	9647
Average water quality (1=excellent, 5=very poor)	441	2.95	0.95	221	2.58	0.85
Water amount last season=normal	441	0.83	0.37	222	0.85	0.36
		Both seasons				
Water sufficiency	550	0.36	0.48			
Have spray irrigation	550	0.05	0.21			
Have drip irrigation	550	0.76	0.43			
Have water storage tank	550	0.25	0.43			
Use pumps	550	0.25	0.43			
Spending on pumps	550	318	795			
Spending on network	550	450	633			
Use groundwater	550	0.03	0.18			
Changed crop mix because of water shortage	550	0.07	0.26			
Have water quality problems	550	0.49	0.50			
Water quality rating	550	5.38	2.03			
Pay for water	550	0.83	0.38			
Amount paid for water each year	550	479	1249			
Farmers in area try to avoid payment	462	0.19	0.39			
Water user association exists	550	0.20	0.40			
Pay WUA (yes/no)	550	0.04	0.20			
Effectiveness of WUA	110	2.55	0.88			
Member of WUA	550	0.05	0.23			

Farming is much more labor intensive in the South and Middle Jordan Valley; this likely reflects the greater production of vegetables and flowers in those regions. Trees, meanwhile, are hardly grown in the southern zones. Interestingly, total revenues are highest in the South and Central Jordan Valley, where agriculture is more focused on vegetables and field crops. In terms of farming constraints, water quantity and canal position are slightly more severe constraints among farmers in the North Valley (compared to water quality and soil fertility). In the South Valley, water quality and quantity are most severe and roughly equal in severity, while canal position and drainage are most serious in the highlands. Farmers in the North Jordan Valley receive more water than those in the South and highlands but pay less for it. Nonetheless, all farmers reported receiving more than their scheduled (planned) amount in the prior year. Pumps and spending on water and water-related assets are highest in the South Jordan Valley. Finally, only farmers in the South and South Central Jordan Valley report changing their crop mix due to water quantity problems (Figure 7.4).

Table 7.4. Selected farm survey descriptive statistics, differentiated by zone

Variable	Jordan Valley 1 (North) (n=114)		Jordan Valley 2 (North/Middle) (n=108)		Jordan Valley 3 (Middle) (n=108)		Jordan Valley 4 (Middle/South) (n=110)		Highlands (n=110)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Demographic variables										
Age	52.9	9.77	56.4	12.8	52.1	14.1	46.9	12.1	52.3	12.8
Children in hh	1.94	2.25	1.32	1.80	1.73	2.02	1.86	2.07	1.56	1.88
Adults in hh	3.34	2.90	3.48	3.48	3.64	3.15	2.90	2.33	4.25	2.88
Farmer training	0.12	0.33	0.02	0.14	0.00	0.00	0.01	0.10	0.02	0.13
Jordanian	0.98	0.13	0.97	0.17	1.00	0.00	0.79	0.41	0.97	0.16
Basic farm information										
Area of land (dunum)	34.1	8.54	37.9	11.5	37.8	13.9	36.5	11.5	41.7	74.2
Area cultivated (dunum)	32.2	8.60	35.2	10.8	32.1	13.1	28.3	12.3	33.8	56.1
Market value of land ('000 JD) ‡	146.9	57.5	179.2	88.7	189.6	94.0	131.1	108.5	189.3	229.1
Own farm	0.59	0.49	0.56	0.50	0.46	0.50	0.23	0.42	0.64	0.48
Manage farm for others	0.00	0.00	0.21	0.41	0.01	0.10	0.08	0.28	0.02	0.13
# of buildings on farm	0.81	0.83	0.80	0.93	1.04	0.86	0.85	0.81	0.72	1.13
Grow crops in winter	0.61	0.49	0.71	0.45	0.95	0.21	0.98	0.13	0.75	0.43
Grow crops in summer	0.50	0.50	0.51	0.50	0.25	0.44	0.32	0.47	0.43	0.50
Socioeconomic status										
Wealth stairway (1 to 6; 6=richest)	3.16	1.12	3.71	1.24	3.11	0.93	3.33	0.94	3.31	0.96
Wealth stairway in 4 years ‡	2.82	1.13	3.56	1.07	3.68	1.03	3.73	1.09	3.29	0.99
Total HH consumption (JD/mo)	648	414	1303	1293	898	643	872	458	754	390
Total HH income (JD/mo)	987	1052	2379	2805	1105	986	1149	912	893	621
Total value of assets ('000 JD)	8.39	9.35	12.7	12.6	40.6	41.5	39.7	33.5	11.5	15.2
Value of water assets ('000 JD)	4.88	4.50	7.68	8.36	7.89	6.41	9.57	6.88	6.05	8.91
Have greenhouse	0.02	0.13	0.03	0.17	0.50	0.50	0.43	0.50	0.04	0.19
Own tractor	0.08	0.27	0.23	0.42	0.15	0.14	0.15	0.35	0.08	0.28
Own transport vehicle	0.24	0.43	0.17	0.37	0.36	0.48	0.54	0.50	0.31	0.46
Own cooling equipment	0.00	0.00	0.03	0.17	0.01	0.10	0.01	0.10	0.01	0.10
Own plough	0.09	0.28	0.06	0.23	0.08	0.28	0.18	0.39	0.13	0.33
Saved in past year	0.25	0.43	0.17	0.37	0.02	0.14	0.18	0.39	0.13	0.33
Enumerator opinion of wealth (1=very poor; 5=rich)	2.92	0.90	3.48	1.07	3.11	0.81	3.16	0.92	3.00	0.68
Farm inputs										
Overall winter: Total ('000 JD)	3.85	2.46	6.72	5.70	22.8	16.5	22.1	16.1	4.92	5.47
Overall summer: Total ('000 JD)	3.97	2.59	4.84	3.20	18.8	26.6	6.13	9.31	5.15	5.54
Have permanent workers	0.57	0.50	0.58	0.50	0.82	0.38	0.69	0.46	0.53	0.50
Number of permanent workers	0.72	0.86	0.79	1.15	3.06	3.87	2.14	2.50	1.07	1.54
Total JD/year; permanent workers	2342	2635	2396	3511	7503	8055	5417	5913	3053	4532
# of workers without pay	3.60	5.10	1.28	2.25	2.50	5.40	4.77	15.0	7.85	28.6
Outputs/revenues—winter										
Overall: Area (dunum)	30.9	15.7	32.7	19.4	30.2	18.8	27.2	15.0	34.2	57.1
Vegetables: Yield	3.17	12.6	3.66	12.0	136.2	155.2	153.7	146.2	28.8	148
Field crops: Yield	7.72	23.0	1.19	4.46	0.14	1.20	65.8	673.5	47.5	163
Trees: Yield	56.7	47.6	67.3	201.5	16.8	67.6	0.33	3.09	19.7	84.3
Flowers: Yield	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.10	0.0	0.0
Last winter yield=normal ‡	0.86	0.35	0.81	0.40	0.64	0.48	0.78	0.42	0.98	0.15
Total crop value ('000 JD) ‡	11.9	9.85	7.72	48.8	46.0	64.0	56.3	63.1	62.1	128.8

Outputs/revenues—summer										
Overall: Area (dunum)	28.1	15.3	26.5	16.5	24.7	18.7	17.4	12.9	23.3	29.6
Vegetables: Yield	3.22	9.23	3.02	9.25	52.0	96.8	32.5	46.9	14.1	30.9
Field crops: Yield	1.23	6.70	1.84	8.89	0.67	2.92	5.37	14.7	28.9	75.2
Trees: Yield	60.0	46.2	57.6	53.5	7.93	24.3	0.60	3.55	14.7	66.5
Flowers: Yield	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Last summer yield=normal ‡	0.89	0.31	0.87	0.34	0.52	0.51	0.74	0.44	0.94	0.24
Total revenue ('000 JD) ‡	8.91	6.50	13.4	44.2	18.6	34.7	11.3	17.6	4.72	17.6
Constraints (1=excellent; 5=very poor)										
Soil fertility	2.10	0.56	2.06	0.66	2.56	0.96	2.63	0.89	2.12	0.63
Irrigation water amount	2.78	0.83	2.83	0.96	3.89	0.85	3.55	0.84	2.24	0.94
Irrigation water quality	2.12	0.64	2.26	0.78	3.72	0.84	3.55	1.01	2.44	0.97
Canal position	2.75	0.99	2.56	0.88	3.11	1.01	3.12	0.94	2.84	1.17
Drainage	2.49	0.66	2.60	0.67	2.80	0.76	2.94	0.84	2.63	0.69
Irrigation water situation										
Planned water ('000 m^3) - winter‡	16.9	10.0	20.0	20.3	12.5	24.9	9.34	21.6	14.3	19.8
Actual water ('000 m^3) - winter‡	20.2	11.5	25.6	38.4	18.8	37.4	10.2	8.48	17.2	23.2
Average water quality - winter (1=excellent, 5=very poor)	2.33	0.55	2.42	0.62	3.75	0.90	3.33	0.87	2.46	0.85
Planned water ('000 m^3) - summer‡	5.05	7.38	4.96	8.01	4.34	3.37	4.44	7.55	7.10	14.2
Actual water ('000 m^3) - summer‡	8.22	12.3	5.91	9.52	7.07	5.70	6.20	9.16	7.53	14.2
Average water quality - summer (1=excellent, 5=very poor)	2.32	0.61	2.11	0.66	3.73	0.97	3.29	0.83	2.26	0.85
Water sufficiency	0.43	0.50	0.36	0.48	0.06	0.23	0.16	0.37	0.78	0.41
Have spray irrigation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.42
Have drip irrigation	0.70	0.46	0.83	0.37	0.93	0.26	0.89	0.31	0.45	0.50
Have water storage tank	0.22	0.42	0.12	0.33	0.30	0.46	0.40	0.49	0.19	0.39
Use pumps	0.04	0.21	0.08	0.28	0.32	0.47	0.47	0.50	0.35	0.48
Spending on pumps	45.7	237	59.5	210	492	1071	413	727	586	1085
Spending on network	549	788	260	395	585	650	577	758	274	352
Changed crop mix because of water shortage	0.00	0.00	0.00	0.00	0.14	0.35	0.20	0.40	0.02	0.13
Have water quality problems	0.08	0.27	0.27	0.45	0.88	0.33	0.90	0.30	0.35	0.48
Subjective water quality rating	6.24	1.43	6.22	2.28	4.40	1.62	4.08	1.68	5.95	1.92
Amount paid for water each year	337	165	485	471	630	818	897	2545	52.3	285.9
Water user association exists	0.39	0.49	0.23	0.42	0.36	0.48	0.01	0.10	0.00	0.00
Member of WUA	0.11	0.31	0.06	0.23	0.11	0.32	0.00	0.00	0.00	0.00
Effectiveness of WUA‡	2.76	0.83	2.40	0.82	2.41	0.97	2.00	.	.	.

Notes: Variables for which some observations are missing are noted by the symbol ‡. A more complete list of variables is available upon request. Inputs and revenues are only reported for farms with activity in that season, and hence have smaller sample sizes.

We also note that willingness-to-pay for a more regular supply of blended water, which was the subject of a contingent valuation exercise conducted in the baseline survey, was uniformly low in the North Jordan Valley, and fairly high in the South Jordan Valley, which is consistent with the fact that the latter zone has had experience using such water for irrigation purposes, contrary to the former.

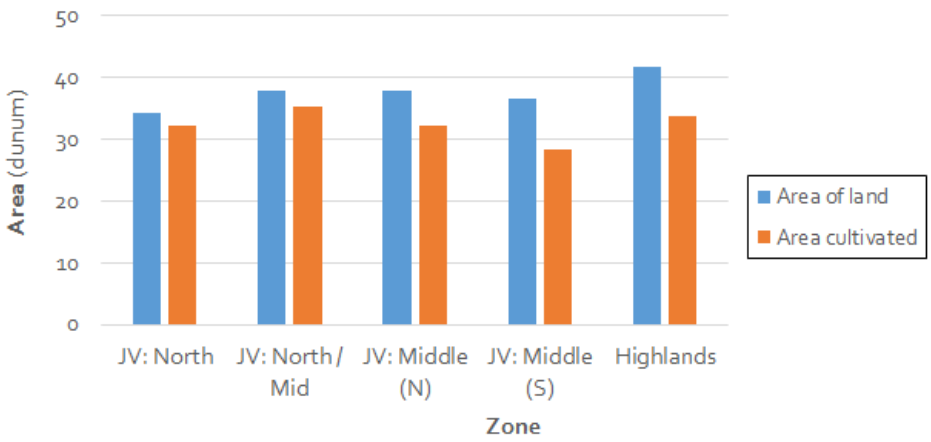

Figure 7.2. Farm area and cultivated area, by sample zone

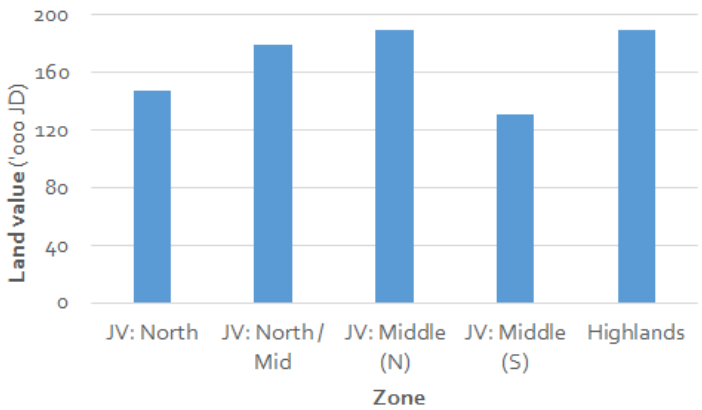

Figure 7.3. Reported land values for farms, by sample zone

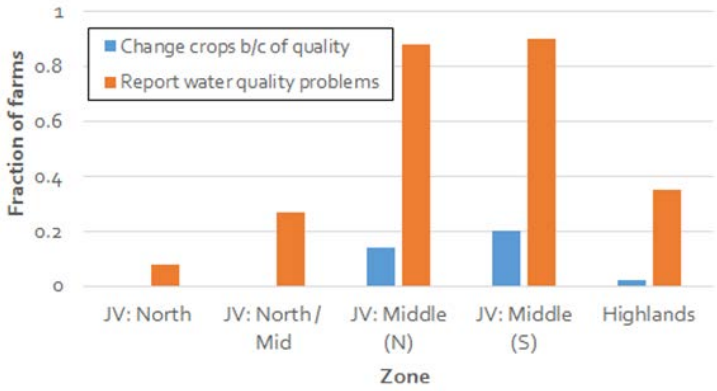

Figure 7.4. Reported water quality problems and related changes in cropping

7.2 Internal and external validity of the baseline sample

7.2.1 Internal validity

In many respects, the results of the baseline survey conform with *ex ante* expectations, and suggest the integrity and logic of the natural experiment strategy being used to track impacts of water sourcing on agricultural decisions and welfare. Specifically, we observe that farmers prefer trees and citrus crops in

the North Jordan Valley, and more salinity-tolerant crops in the South Jordan Valley, where water quality and scarcity problems appear more pronounced. Somewhat surprisingly, these water issues do not appear to threaten farm productivity in the Jordan Valley however; the data suggest that vegetable and field crops are highly profitable for farmers in the Middle and South Valley, even if land is used less intensively, and even though input costs are higher.

Nonetheless, there are other important differences that will need to be considered in the econometric analysis of the effects of water sourcing changes (due to the Compact investments) across the affected regions. Examples of such differences include farm size, wealth, ownership of water-related assets (that perhaps help to buffer losses), spatially varying presence and effectiveness of water user associations. For time-invariant differences, the difference-in-differences analytical strategy will help to mitigate threats to internal validity (subject to confirming parallel pre-intervention trends).[12] Time-varying and other differences will then need to be accounted for using statistical control.

The other issue affecting interpretation of changes in water sourcing concerns the threat of confounding, from non-Compact changes in the water balance to different zones. Perhaps most important among these are increases in water supply (due to Disi or other new supply enhancements, as well as natural hydrological variability) and increases in demand (in all areas contributing to the supply of blended water in the King Talal Dam). These issues cannot be controlled for econometrically, since they affect the entire Jordan Valley, but rather must be analyzed as part of the larger water balance exercise described in this report, in order to isolate the incremental changes attributable to the Jordan Compact.

7.2.2 External validity

The sample was purposely selected to exploit variation in the source of irrigation water, and as such is not representative of farms in Jordan. In addition, we do not have secondary data that can be used to assess the representativeness of the final sample within the sampling frame, except relative to the information in the sampling frame, which only applies to the "official cropping patterns" that are registered in the Jordan Valley (no prior frame existed for the highlands, where we undertook a listing exercise to create the final sample). A brief comparison using these data is presented below (Table 7.5), and suggests that our sample mostly cultivates land in accordance with the distribution of lands recorded in the registry, with slightly more cultivation of field crops (especially in summer in the northern zones), and vegetables (in winter in the central and southern zones).

We can also use agricultural Census data (collected only in the Jordan Valley) to compare our sample more fully to a representative sample of farms in the Jordan Valley. This comparison follows in Table 7.6. Most variables are consistent, with a few key differences, that may reflect changes in farms over time, or real differences for farmers in our sample. There is more cultivation of tree and vegetable crops, and less of field crops, compared to the full set of Jordan Valley farms; far fewer farms have livestock (which is more commonly owned in the South Jordan Valley beyond the limits of our sample); and our farms appear slightly more asset rich, particularly in terms of tractor, pump and plough ownership, as well as

[12] Our DiD analysis will consider the validity of this assumption using secondary data, specifically the data available on cropping patterns recorded in the sampling frame.

drip irrigation. The increased asset ownership may reflect the effects of wealth accumulation and promotion of drip irrigation in the recent past, given that the agricultural Census was conducted in 2006/7.

Table 7.5. Survey sample areas (in dunum), relative to farms located within the sampling frame

Variable	Zone 1: North		Zone 2: North/Central		Zone 3: Central		Zone 4: Central/South	
	Our farms	Land Registry	Our farms	Land Registry	Our farms	Land Registry	Our farms	Land Registry
Total area	34.1	30.8	37.9	35.0	37.8	37.0	36.5	36.9
Non-cultivated area	1.9	0.84	2.7	0.76	5.7	1.76	8.2	3.49
Area: Field crops	7.27	1.58	3.94	1.79	1.11	1.29	3.31	1.08
Area: Vegetables	2.14	0.82	3.62	1.54	19.7	13.4	23.5	13.1
Area: Trees	25.2	25.5	25.1	27.5	10.3	8.04	1.24	4.31
Area: Flowers	0.0	0.0	0.0	0.04	0.0	0.01	0.50	0.07

Notes: We report the maximum area of a crop type across seasons, among farmers cultivating in those seasons. Thus, the totals by crop may exceed the total area, due to crop switching by season.

Table 7.6. Survey sample characteristics, relative to the data in the agricultural Census

Variable	Our sample	DoS agricultural census
Farm area (dunum)	37.6	33.0
Area: Field crops (dunum)	4.56	9.03
Area: Vegetables (dunum)	12.2	3.52
Area: Trees (dunum)	14.5	10.3
Area: Uncultivated (dunum)	5.3	6.9
Literacy	93%	88%
Farmer/agricultural training	3%	9%
Use loans for financing	3%	3.7%
Have livestock	4%	30%
Have tractor	14%	3.7%
Have transport vehicle	32%	26%
Have cooling equipment	1.0%	3.2%
Have miller	0.1%	1.9%
Have pumps	25%	1.7%
Have plough	11%	4.2%
Have drip irrigation	76%	37%
Have spray irrigation	5.0%	6.0%

7.2.3 Other measurement issues

The data quality from this survey was generally good, but a few concerns are noteworthy, and can be summarized as follows:

- A concern over respondent status (documented during data collection), given that farm owners were not always available in person or by phone, which often resulted in reliance on reports by farm managers, who were not always able to accurately answer survey questions;
- Missing data or "don't know" responses on some important variables, specifically reported land values (15% missing or "don't know"), wealth (2.5% missing), or expectations of future wealth (7.6% missing), and some subjective measures of water quality (specifically by season). In general, though, date completeness was good;
- The challenge in reporting of some key variables by respondents, most notably farm outputs and water amounts used (this may be the reason for the outliers discussed directly below);
- A few variables have large outliers, particularly those related to reported land area, input costs, assets, and revenues. In the presentation above, outliers were generally maintained, but the future comparative analyses (over time and across space) may require additional work to reduce the effects of outliers (e.g., for multivariate regression); and
- The presence of problematic skip patterns in the Java program that was fielded, that resulted in missing data for some crop-specific questions related to areas, output, and revenues by crop (aggregated questions were not affected in this way).

We expect that many of these issues will be resolved in the follow-up data, given the transition to an SI-managed programming platform.

7.3 Analytical considerations

The data presented above, especially in Table 7.4, suggest that there are important differences across areas in the Jordan Valley, and that a spreading of irrigation with blended water from the King Talal Dam over time, should thus be discernible, if it in fact occurs. In addition, our sample looks reasonably representative of the farms located in these survey zones. Thus, we have confidence that careful investigation using this sample will yield valuable insights about the nature of the evolving irrigation situation in the Jordan Valley.

8 Administration

8.1 Institutional Review Board clearance

SI houses an internal IRB that is used to review and approve the study before any data collection activity commences. Upon addressing final comments received from MCC and local stakeholders, the evaluation team submitted the agriculture survey to SI's Internal IRB as a terminal step in the survey development process. Internal IRB approval was granted within two weeks of submission, whereby approval documentation was submitted to MCC prior to formal survey implementation.

Participation in a local Jordanian IRB was not required; however, the Implementing Entity Terms of Reference ensured that DoS would assume responsibility for receiving IRB approval from a local institution.

8.2 Data Access, Privacy and Documentation Plan

Given that DoS, a government entity, has have access to potentially sensitive respondent data, SI requires DoS to maintain an encrypted server to house data, accessible only by critical personnel approved by SI. As stated and agreed to by DoS, the Implementing Entity Terms of Reference states: All datasets and other data collected shall be the sole and exclusive property of MCA-J, and DoS is not authorized to use the data or derivatives of the data for its own purposes in any form without the express written consent of MCA-J. DoS will be required to securely store copies of all datasets on their own premises during the entire life of the project.

Data from both electronic surveys was entered directly into tablets and stored in a data cloud, with all confidential data encrypted and only accessed with a password. Farm survey data was stored using the web platform Java, a renowned data management system, which DoS has previously used extensively. The server housing the data was accessible only to senior members of the DoS field management team, with data sets downloaded and sent to SI directly from the DoS technician assigned to the enterprise survey activity. Tablets used by enumerators were password protected, and select data managers within DoS had access to data (for spot verification purposes) for both surveys prior to server upload.

While the MCC requires an identifiable dataset for their records, all personally identifiable data will be removed prior to data reporting. SI will anonymize data in accordance with MCC guidelines in preparation for final data set submission to MCC's public database.

8.3 Evaluation Team roles and responsibilities

The SI evaluation team has several key personnel that will work together to design and implement this Component of the IE, analyze the data, and produce final reports. Team composition is detailed in Table 8.1 as follows:

Table 8.1. Evaluation Team Roles and Responsibilities

Position	Responsibilities
Senior Analyst/ Water Specialist **Marc Jeuland**	Dr. Jeuland serves as the technical and methodological lead. He is heavily involved in the evolution of the proposed IE design throughout consultations with MCC DC staff and MCA-Jordan. Dr. Jeuland leads the IE design and ERR activities, manages any changes to the design required during the implementation process and provides guidance to data analysis, consulting with the Senior Network Engineer, Dr. Albert, as necessary. He contributes to written sections of evaluation reports, and other project deliverables, including serving as lead author of the final IE report.
Water Balance Modeling Consultant **Amani Al-Farra**	Ms. Alfarra was contracted by SI to complete a number of tasks related to water balance modeling. Specifically, Ms. Alfarra developed and analyzed hydrologic models simulations and forecasts and created an updated time-series of releases from the King Talal Reservoir and other inputs into the Jordan Valley irrigation system. She also assisted in the development of farm survey instruments and analysis of the survey results.
Statistician/ Sampling Expert **Danae Roumis**	Ms. Roumis advises on statistical and sampling issues. She oversees the technical aspects of the propensity score matching and survey sampling design, and consults directly with MCC and MCA-J staff regarding instrument pre-testing, enumerator training, and piloting. She also manages data collection, quality, cleaning and analysis.
Research Assistant **Jenny Orgill**	Ms. Orgill supports the technical aspects of the IE, including conducting data cleaning and analysis, as well as providing contributions to deliverables.
Program Assistant **Caroline Perkinson**	Ms. Perkinson provides administrative and logistical support to the IE team, including drafting consultant agreements, arranging travel, monitoring program budgets and reconciling expenditures, and providing technical support on an occasional basis.
Program Manager **Karen Azeez**	Ms. Azeez is the administrative lead for the project and the liaison between MCC, MCA-J and SI. She manages the work plan, budget, and timeline of the IE, and provides technical assistance as required. She is also responsible for procurement, consultant and subcontractor management, coordinating travel and research approvals, and participating in fieldwork such as enumerator training.

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