A SOCIO-ECOLOGICAL APPROACH TO COMBAT DESERTIFICATION FOR SUSTAINABLE FUTURE

EcoFuture

Work Package 3

Deliverable 3.2 Water Distribution Modelling of the Jordan Valley

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June 2024

This project is part of the PRIMA programme supported by the European Union. GA n° [2243] [EcoFuture] [Call 2022 Section 1 NEXUS WEFE IA].

Project no. 2243

Project acronym: EcoFuture

Project title: A socio-ecological approach to combat desertification for a sustainable future

Call: PRIMA Call 2022 Section 1 NEXUS WEFE IA

Start date of project: 01.04.2023

Duration: 36 months

Deliverable title: Water Distribution Modelling of the Jordan Valley

Due date of deliverable: 30 June, 2024

Project Coordinator: Nikolaos Nikolaidis

Organisation name of lead contractor for this deliverable: Technical University of Crete (TUC)

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Dissemination level		
PU	**Public/ Confidential**	**PU**

History			
Version	**Date**	**Reason**	**Revised by**
01	2/8/2024	First Draft	Ami Reznik, Iddo Kan, Israel Finkelshtain,
02	6/8/2024	Contribution – 2nd draft	Stelios Rozakis
03	14/8/2024	Review - contribution	Suleiman Halasah, Abeer Albalawneh, Luma Hamdi, Mohammad Mudabber, Safaa Aljaafreh, Maram al Naimat
04	15/8/2024	Review - Final	Nikolaos Nikolaidis and Maria Lilli

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Executive Summary

The Jordan Valley is a critical region where the interplay of water, energy, food, and ecosystem dynamics presents both challenges and opportunities for sustainable development and climate change mitigation and adaptation. The valley's unique geographical and climatic conditions have historically made it a focal point for agriculture, requiring intensive water management strategies to overcome its arid climate. Water scarcity in this region is acute, with sources such as the Jordan River and underground aquifers under increasing pressure from over-extraction and pollution, directly impacting agricultural productivity and food security.

The growing population in the region along with climate change poses a serious threat to the sustainability of the already extremely fragile natural water resources in the JV area. The ability of these resources to further support the growing demand for domestic consumption and irrigation of agricultural production is already reaching its limits. All entities in the region acknowledge these challenges and are making individual plans to confront these issues. In Palestine and Jordan replacing aging infrastructure and increasing the efficiency of monitoring and enforcement of water agencies, and consequently eliminating related water losses have an important role in achieving sustainability goals. Additionally, in Jordan, the increase of treated wastewater reuse for agricultural purposes is a significant component of future development plans, and large conveyance infrastructure is already under construction to enable the replacement of freshwater with treated wastewater in irrigated agriculture in the JV. In Israel, spatial reallocation of treated wastewater supply is planned to increase the efficiency of water resources use in the country. Additionally, the expansion of seawater desalination capacity and the flexibility of the national conveyance system are designed from both country- and regional-level considerations to mitigate uncertainties in natural water resources availability.

In view of these existing conditions and future challenges in the region, and in the JV area specifically, the following report provides a comparison to an economically driven optimization plan of water resources management for the area. This can help identify additional gaps and challenges of the existing system and policies, as well as to suggest potential solutions or alternatives to be examined as future scenarios.

The analytical tool used for the water allocation analysis in the JV is the Multi-Year Water Allocation System (MYWAS) model (Fisher and Huber-Lee, 2011; Reznik et al., 2016, 2017). MYWAS is the extended multi-year version of the one-year steady-state WAS (Water Allocation System) model (Fisher et al., 2005). It is a dynamic non-linear mathematical programming model that searches for optimal water allocation and infrastructural investments over time and space, while taking into account a range of economic data, physical factors and constraints.

The development of the MYWAS model for Israel, recalibration processes and routine data updates over the years are recorded in several publications (Reznik et al., 2014, 2016, 2017; Slater et al., 2020, 2022). Recently, the model was updated and recalibrated to reflect data from 2019 (Slater et al., 2022). The model represents the Israeli water sector in detail, encompassing 21 urban regions that consume freshwater for domestic and industrial uses, and 18 agricultural regions that can consume freshwater, treated wastewater and brackish water. The water sources are represented in the model by 19 naturally enriched freshwater stocks, 5 seawater-desalination plants, 4 non-enriched brackish-water aquifers, 19

wastewater-treatment plants, 163 freshwater pipelines and 74 pipelines for sewage, treated wastewater and brackish water.

The data for the West Bank and Gaza were largely provided by the Palestinian Water Authority (PWA). Demand for both urban and agriculture are aggregated to the governorate level, summing up to 10 in the West Bank and 5 in Gaza. Because of large data gaps, in many instances costs of supply and capacity data was adopted for the Palestinian system from similar counterparts in the Israeli system. Unfortunately, we do not have sufficient data to distinguish between brackish water and freshwater supply in the West Bank and Gaza, hence the implicit assumption that all natural sources of water to Palestine are freshwater.

A difficulty arises when trying to calibrate demand curves for Palestine because observed data regarding consumed quantities is distorted. In such a case, the calibration of demand curves using observed data on consumption levels will result in underestimate of the calculated economic benefits from water consumption. To overcome this potential misrepresentation of demands, we use per capita consumption rates from specific governorates (namely, Tulkarm and Jericho) that presumably are not quantity constrained and extrapolate the consumed quantity levels used for calibration for all other governorates in Palestine.

Two noticeable differences in water management realities between Israel and Palestine that are relevant from a conceptual modelling perspective, are the existence of significant leakage rates and untreated wastewater in Palestine. Untreated wastewater creates health hazards and environmental pollution and is therefore considered in economic terms – an externality, in which an economic activity conducted by one party creates a negative impact on the economic welfare of another. We do not attempt to explicitly represent transboundary untreated wastewater flows in the MYWAS model. Instead, we assign a social cost proxy to any quantity of untreated wastewater generated in the regional economy. That proxy is calculated according to existing costs of wastewater collection and treatment observed in Israel as a lower bound on the real health and environmental damages associated with untreated wastewater flows. Lacking the ability to distinguish between physical leakage of broken infrastructure and inefficiency of monitoring and revenue collection mechanisms in Palestine, we define these quantities in general terms as leakage. We then allow the model to endogenously determine, in a similar manner to infrastructure development, the level of investment in leakage reduction ratios, such that to completely remove leakage, the leakage reduction ratios and initial conditions of leakage ratios will sum up to 1. We use an estimate of 0.2 NIS/CM for annuity payments on these investments.

In Jordan, the model comprises of 3 agricultural demand regions, 7 urban demand regions, 14 fresh water sources, 4 brackish water sources, and 6 wastewater treatment plants. Data for the model was attained from Halaseh (2015), as well as from official sources.

We apply the combined model of Israel and Palestine to compare the existing water allocation with the suggested optimal plan according to the model from an economic perspective. We also study the optimal development of infrastructure suggested according to the model results. The model is set to run for a 30-year planning horizon into the future, in which natural recharge is assumed to remain at the same level as the long-term annual average in the region at about 1,300 MCM/year. A discount rate of 3.5% (Nordhaus, 2007) is applied to bring all future costs and benefit accruing in the model's water economy to present value terms. Population growth predictions are adopted from the Israeli Central Bureau of

Statistics (CBS), and a 1.8% annual growth rate is assumed. As an end condition, we mandate retaining a minimum of 5% of the extractable stock from each naturally enriched freshwater source.

While the model developed for the JV area in Jordan is very preliminary, results from initial trails demonstrate large differences in economic values of water between domestic and agricultural uses and across the landscape of this area. The analysis of Israel and Palesine combined points to several interesting insights as well. It is demonstrated that substitution of freshwater with treted wastewater in irrigated agriculture is an efficient strategy from a regional perspective. It is implied that treated wastewater reuse, which is already being practiced in Israel in large scale should also be adopted in Palestine. This strategy should help relieving some of the pressure on the region natural water resources, but also potentialy to support additional irrigation demand in the region, and specificaly in the JV area. With respect to the latter, the results of the analysis also provide evidence that within the existing conveyance system limitations, the importance of treated wastewater reuse for irrigation of agricultural crops is higher in the JV area compared to other areas in the region, on average. Finally, the comparison of trends in economic values across competing uses, geographical definitions (JV area, the rest of the region) and between entities, suggest that there are regional economic gains assoicated with higher system integration in the future.

1. Introduction

The Jordan Valley is a critical region where the interplay of water, energy, food, and ecosystem dynamics presents both challenges and opportunities for sustainable development and climate change mitigation and adaptation. The valley's unique geographical and climatic conditions have historically made it a focal point for agriculture, requiring intensive water management strategies to overcome its arid climate. Water scarcity in this region is acute, with sources such as the Jordan River and underground aquifers under increasing pressure from over-extraction and pollution, directly impacting agricultural productivity and food security. The water distribution analysis presented herein aims at identifying the main challenges associated with water management in the region and to suggest potential solutions from an economic point of view.

1.1 Current conditions

The municipal water supply in the Jordanian section of the JV area is primarily from groundwater sources and is estimated at 23.62 Mm3. An additional 4 Mm3/yr are estimated to supply industrial purposes. The Ministry of Water and Irrigation (MWI) in Jordan estimates that 40% of the water is lost due to leakage in the drinking water network, attributed to inadequate maintenance. Consequently, the actual per capita water usage annually is believed to be around 60 cubic meters. The total supply of irrigation water for the Jordanian section of the JV is 225.92 Mm3/year. This quantity comprises about 133 Mm3/yr of treated wastewater (94% of TWW) and 93 Mm3 of surface water diluted together in King Talal dam. This surface water supply originates in the north King Abdallah Canal (73.77Mm3), and in the middle Ghors (19.15Mm3). The primary sources of water in the JV are the Jordan River from Sea of Galilee, Jordanian main rivers such as Yarmouk and Zarqa, treated wastewater from King Talal Dam (blended with rainwater) and underground aquifers. The Yarmouk River is the main water source of the King Abdullah Canal (KAC), which also receives water from the Sea of Galilee as well as treated wastewater. In the northern part of the JV area in Jordan, about 30% of the fresh water comes from the King Abdullah Canal. Further down south in the JV area 60% of the canal's water are supplemented with treated wastewater, primarily from King Talal Dam (KTD), which is the recipient of treated wastewater from Kherbit AlSamra, the most significant wastewater treatment facility in Jordan.

The Israeli municipal water supply is estimated at 7.09 Mm3. The total supply of irrigation water for the Israeli section of the JV is 134.84 Mm3/year. Aquaculture uses 67 Mm3/yr mostly saline water which is close to 50% of the total irrigation water. Freshwater and treated wastewater which are used for crop irrigation account for about 45%, and 5%, of total agricultural water use in the region, respectively. The JV region of interest is distinct in the Israeli water system, which is almost completely integrated, being relatively isolated and relies primarily on three sources, the Sea of Galilee and the Eastern and Northeastern Mountain groundwater aquifers. The water supplied from the Sea of Galilee is about a quarter of the total water used in the region of interest. The Eastern and Northeastern Mountain aquifers, which are the main sources of freshwater water supply to the region are shared resources between Palestine and Israel. This aquifer system is naturally characterized by low connectivity between hydrogeological cells, salinization processes, and large gradient flows to the southeast. As a result, even though annual average recharge to this system is about 350 MCM, the production from local wells as well as groundwater levels and flow of springs in this system is very unpredictable and exhibits large variation in quantity and quality over time. In addition, this JV region in Israel is mostly rural and therefore characterized exclusively with local systems for wastewater treatment and reuse.

The freshwater supply in the Palestinian section of the JV originates mostly from local groundwater wells and springs, harvesting of rainwater and treated wastewater reuse. The Palestinian annual municipal water supply is estimated at 6.4 Mm3. Losses in the drinking water supply network are in excess of 40-50% of the supply which brings the annual consumption to similar levels as in the Jordanian section of the JV. The total supply of irrigation water for the Palestinian section of the JV is around 52 Mm3/year. Only 2.3% of the cultivated land is irrigated. Groundwater wells and springs contribute 48.1 Mm3/yr, harvested rainwater 2.7 Mm3/yr and wastewater reuse approximately 0.7 Mm3/yr. The JV area in Palestine comprises the governorates of Tubas and Jericho, water supply is predominantly from the Eastern and Northeastern Mountain aquifer system and is mostly local with almost no conveyance network between municipalities. Most Palestinian localities in the JV area are connected to the Israeli Mekorot system and rely on its supply for domestic use purposes. Whereas agriculture is mostly irrigated from local groundwater wells. The city of Jericho is unique in that context, relying mostly on surface water for domestic and agricultural purposes, originating in the Ein Sultan Spring, which drains from the Eastern mountain aquifer system.

1.2 Future challenges

The growing population in the region along with climate change poses a serious threat to the sustainability of the already extremely fragile natural water resources in the JV area. The ability of these resources to further support the growing demand for domestic consumption and irrigation of agricultural production is already reaching its limits. All entities in the region acknowledge these challenges and are making individual plans to confront these issues. In Palestine and Jordan replacing aging infrastructure and increasing the efficiency of monitoring and enforcement of water agencies, and consequently eliminating related water losses have an important role in achieving sustainability goals. Additionally, in Jordan, the increase of treated wastewater reuse for agricultural purposes is a significant component of future development plans, and large conveyance infrastructure is already under construction to enable the replacement of freshwater with treated wastewater in irrigated agriculture in the JV. In Israel, spatial reallocation of treated wastewater supply is planned to increase the efficiency of water resources use in the country. Additionally, the expansion of seawater desalination capacity and the flexibility of the national conveyance system are designed from both country- and regional-level considerations to mitigate uncertainties in natural water resources availability.

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2 Methodology

The analytical tool used for the water allocation analysis in the JV is the Multi-Year Water Allocation System (MYWAS) model (Fisher and Huber-Lee, 2011; Reznik et al., 2016, 2017). MYWAS is the extended multi-year version of the one-year steady-state WAS (Water Allocation System) model (Fisher et al., 2005). It is a dynamic non-linear mathematical programming model that searches for optimal water allocation and infrastructural investments over time and space, while taking into account a range of economic data, physical factors and constraints.

2.1 The Model

Consider a small open economy with natural sources for freshwater and brackish water, urban regions with demands for domestic and industrial uses of freshwater, agricultural regions that demand irrigation water of various qualities, and an infrastructural system incorporating wastewater-treatment plants, desalination plants for seawater and treated wastewater, pumping stations and pipelines. Long-run efficient management of such a water economy is the objective of MYWAS.

MYWAS is a discrete-time dynamic optimization model. Let us denote by the subscript indices a ($a = 1,\dots,A$) an agricultural region, u ($u = 1,\dots,U$) an urban region, f ($f = 1,\dots,F$) a source for freshwater, b ($b = 1,\dots,B$) a source for brackish water, and h ($h = 1,\dots,H$) a wastewater-treatment plant. We use the superscripts ϕ, β, l and w to indicate freshwater, brackish water, sewage, and treated wastewater, respectively. Time is denoted by t, $t = 1,\dots,T$, where T is the optimization planning horizon. Water quantities consumed in demand regions are represented by Q; for instance, Q_{ut}^{ϕ} is the amount of freshwater consumed in region u during time t. E stands for extractions from sources; for example, E_{ft}^{ϕ} and E_{bt}^{β} are, respectively, the amounts of freshwater and brackish water extracted at time t from sources f and b, and E_{ht}^{w} and E_{ht}^{φ} are the quantities of treated, and treated-and-desalinated wastewater produced by plant h during t, respectively. Water transfers between spatial points are denoted by G; thus, G_{bat}^{β} is the amount of brackish water delivered during time t from brackish-water source b to agricultural region a. Accordingly, the vectors $\mathbf{Q}$, $\mathbf{E}$ and $\mathbf{G}$ incorporate all of the water quantities consumed in the various regions, extracted from sources, and transferred between points, respectively; these are all optimization decision variables.

Water extractions ($\mathbf{E}$) and transfers ($\mathbf{G}$) are constrained by infrastructural capacities; the latter can be extended periodically, where the levels of the extension constitute additional decision variables. We symbolize capacity expansions by the letter N; for instance, EN_{bt}^{β} is the increase in the capacity of extraction of brackish water from source b during time t, and GN_{uht}^{l} represents the increase in transfer capacity of sewage water produced in urban region u to wastewater treatment plant h at time t. The vectors $\mathbf{EN}$ and $\mathbf{GN}$ incorporate all of the increases in extraction and transfer capacity, respectively.

We further define state variables that represent the cumulative increases in infrastructural capacities; these variables are denoted by $\mathbf{EM}$ and $\mathbf{GM}$ for extraction and transfer capacities, respectively. For example, $EM_{bt}^{\beta} = \sum_{\tau=1}^{t-1} EN_{b\tau}^{\beta}$ is the cumulative increase in the extraction capacity of brackish-water source b until time t. In addition, we define the starting level of capacities; for instance, GM_{uh0}^{l} is the capacity of sewage-water transfer from urban region u to wastewater-treatment plant h at the beginning of the planning problem. Accordingly, $GM_{uh0}^{l} + GM_{uht}^{l}$ is the overall transfer capacity at this link; hence, $G_{uht}^{l} \leq GM_{uh0}^{l} + GM_{uht}^{l}$.

Additional state variables represent the extractable amounts of water stocks stored in the various natural freshwater and brackish-water sources. For some freshwater source f, the amount of water available for extraction at time t is denoted V_{ft}, and it is physically restricted by $\bar{V}_f$ from above and by $\underline{V_f}$ from below. We also introduce k_{fT} as the unit value of each cubic meter left in aquifer storage after time T, representing the marginal welfare contribution from water to future generations. Alternatively, an end-point minimum constraint $\underline{V_{fT}}$, $\bar{V}_f \geq \underline{V_{fT}} \geq \underline{V_f}$, can be additionally introduced to reflect the same welfare considerations beyond the planning horizon T. The extractable stock at some time t is given by: $V_{ft} = V_{f0} + \sum_{\tau=1}^{t} R_{f\tau} - \sum_{\tau=1}^{t-1} \left(E_{f\tau}^{\phi} + L_{f\tau} \right)$ where V_{f0} is the initial extractable content of the source, R_{ft} is the natural recharge during time t, and L_{ft} is the spillover from the source during time t, where by definition $L_{ft} = max\left(0, V_{ft} - \bar{V}_f\right)$. A minimum overflow level $\underline{L_{ft}}$ may be assigned to each freshwater source (e.g., to reflect "water for nature" regulations); the vectors $\mathbf{L}$ and $\underline{\mathbf{L}}$ are defined accordingly.

Under the above specifications, desalination plants can be considered as freshwater sources with annual stock of zero i.e. $V_{ft} = 0$. However, for notational simplicity we set $V_{ft} \equiv EM_{f0}^{\phi} + EM_{ft}^{\phi}$, such that only the plants' capacity constraints can be effective. Also note that in brackish-water sources $R_{bt} = 0$, and therefore $L_{bt} = 0$.

We use C to denote variable costs per volumetric unit, where these costs incorporate energy, as well as variable operational and maintenance costs. For instance, C_{hat}^{w} is the per-unit transfer cost of treated wastewater from wastewater-treatment plant h to agricultural region a at time t, and $C_{ft}^{\phi}\left(V_{ft}\right)$ stands for the cost of extracting one unit of freshwater from source f at time t; in the latter, the cost depends on the source's stock V_{ft}, where lower stocks entail larger extraction costs (note that for wastewater-treatment plants, stock is irrelevant).

Costs of capacity increase, which mostly comprise capital investments, are represented by S; for example, S_{ht}^{w} is the per-time-unit cost of increasing the capacity of wastewater-treatment plant h by one unit at time t. Likewise, S_{fat}^{ϕ} is the per-time-unit cost associated with increasing by one unit the capacity of freshwater transfer from source f to agricultural region a at time t. These costs are expressed in terms of per-time-unit payments for a loan taken to finance the capacity increase, computed based on a constant interest rate and constant payments during the entire lifetime of the respective infrastructure. We further assume that increased infrastructural capacities are rebuilt at the end of the infrastructure's lifetime and therefore, the per-time-unit payments prevail forever; this assumption eliminates impacts of the planning horizon T on the optimal course of capacity increases.

The benefits associated with water consumption are based on constant-elasticity demand functions. The function $(\mu + 1)^{-1} \upsilon_{ut} \left(Q_{ut}^{\phi}\right)^{\mu+1}$ is the total willingness to pay for the amount of freshwater consumed in region u at time t, Q_{ut}^{ϕ} [i.e., the area below the inverse-demand function $\upsilon_{ut} \cdot \left(Q_{ut}^{\phi}\right)^{\mu}$], where υ_{ut} and μ are parameters, and $\frac{1}{\mu}$ is the urban-demand elasticity.

To represent benefits in the agricultural sector, we apply the function $(\eta+1)^{-1}\alpha_{at}\cdot\left(Q_{at}^{\phi}+\delta Q_{at}^{w}+\gamma Q_{at}^{\beta}\right)^{\eta+1}$, which represents the value of production (VP) associated with the consumption of freshwater, treated wastewater and brackish water (see Feinerman et al., 2001). In this case, if either $Q_{a1}^{w}>0$ or $Q_{a1}^{\beta}>0$, the demand elasticity does not equal $\frac{1}{\eta}$, and therefore it is not constant, and depends on the overall water consumption from the various water types. The parameters γ and δ translate treated wastewater and brackish water to freshwater in terms of their value of marginal product (VMP). That is, the freshwater VMP equals $\alpha\cdot\left(Q^{\phi}+\delta Q^{w}+\gamma Q^{\beta}\right)^{\eta}$, and the treated-wastewater VMP is $\delta\alpha\cdot\left(Q^{\phi}+\delta Q^{w}+\gamma Q^{\beta}\right)^{\eta}$; hence, $\delta=\frac{vmp^{w}}{vmp^{\phi}}$. In other words, δ is the increase in the regional consumption of freshwater required to maintain the regional VP unchanged in response to a reduction of one unit in the regional consumption of treated wastewater.

Additional benefits, or costs, are associated with spillovers from freshwater storage, $\mathbf{L}$. We let ψ_{ft} represent the net benefits per unit of overflow, where benefits may be related to environmental contributions of surface streams, and costs to damages, such as floods.

Given the interest rate r, the initial levels of the state variables, and the levels assigned to the exogenous factors throughout the planning horizon (e.g., aquifer recharge levels, expansion of demands that are introduced through changes in parameters υ_{ut} and α_{at}, etc.), the problem solved by MYWAS is

$$\max_{\mathbf{Q,E,G,EN,GN}} \sum_{t=1}^{T}\frac{1}{(1+r)^{t}}\left[\begin{array}{l}\sum_{u=1}^{U}\frac{\upsilon_{ut}\cdot\left(Q_{ut}^{\phi}\right)^{\mu+1}}{\mu+1}+\sum_{a=1}^{A}\frac{\alpha_{at}\cdot\left(Q_{at}^{\phi}+\delta Q_{at}^{w}+\gamma Q_{at}^{\beta}\right)^{\eta+1}}{\eta+1}+\psi_{ft}L_{ft}\\ -\sum_{f=1}^{F}\sum_{u=1}^{U}G_{fut}^{\phi}\cdot C_{fut}^{\phi}-\sum_{f=1}^{F}\sum_{a=1}^{A}G_{fat}^{\phi}\cdot C_{fat}^{\phi}-\sum_{f=1}^{F}E_{ft}^{\phi}\cdot C_{ft}^{\phi}\left(V_{ft}\right)-\sum_{b=1}^{B}\sum_{a=1}^{A}G_{bat}^{\beta}\cdot C_{bat}^{\beta}\\ -\sum_{b=1}^{B}E_{bt}^{\beta}\cdot C_{bt}^{\beta}\left(V_{bt}\right)-\sum_{u=1}^{U}\sum_{h=1}^{H}G_{uht}^{l}\cdot C_{uht}^{l}-\sum_{h=1}^{H}\sum_{a=1}^{A}\left(G_{hat}^{w}\cdot C_{hat}^{w}+G_{hat}^{\phi}\cdot C_{hat}^{\phi}\right)\\ -\sum_{h=1}^{H}\left(E_{ht}^{w}\cdot C_{ht}^{w}+E_{ht}^{\phi}\cdot C_{ht}^{\phi}\right)+\sum_{f}^{F}k_{fT}\cdot V_{fT}\end{array}\right]$$

$$-\sum_{t=1}^{T-1}\frac{1}{(1+r)^{t}}\left[\begin{array}{l}\sum_{f=1}^{F}\sum_{u=1}^{U}GM_{fut}^{\phi}\cdot S_{fu}^{\phi}+\sum_{f=1}^{F}\sum_{a=1}^{A}GM_{fat}^{\phi}\cdot S_{fa}^{\phi}+\sum_{f=1}^{F}EM_{ft}^{\phi}\cdot S_{f}^{\phi}+\sum_{b=1}^{B}\sum_{a=1}^{A}GM_{bat}^{\beta}\cdot S_{ba}^{\beta}\\ +\sum_{b=1}^{B}EM_{bt}^{\beta}\cdot S_{b}^{\beta}+\sum_{u=1}^{U}\sum_{h=1}^{H}GM_{uht}^{l}\cdot S_{uh}^{l}+\sum_{h=1}^{H}\sum_{a=1}^{A}\left(GM_{hat}^{w}\cdot S_{ha}^{w}+GM_{hat}^{\phi}\cdot S_{ha}^{\phi}\right)\\ \sum_{h=1}^{H}\left(EM_{ht}^{w}\cdot S_{h}^{w}+EM_{ht}^{\phi}\cdot S_{h}^{\phi}\right)\end{array}\right]$$

Subject to:

$$(1)\ Q_{at}^{\phi}\le\sum_{f=1}^{F}G_{fat}^{\phi}+\sum_{h=1}^{H}G_{hat}^{\phi}\ \forall a,t;\quad (2)\ Q_{ut}^{\varphi}\le\sum_{f=1}^{F}G_{fut}^{\phi}\ \forall u,t;\quad (3)\ Q_{at}^{\beta}\le\sum_{b=1}^{B}G_{bat}^{\beta}\ \forall a,t;$$

(4) $Q_{at}^{w} \leq \sum_{h=1}^{H} G_{hat}^{w}\ \forall a,t$; (5) $\sum_{u=1}^{U} G_{fut}^{\phi} + \sum_{a=1}^{A} G_{fat}^{\phi} \leq E_{ft}^{\phi}\ \forall f,t$; (6) $\sum_{b=1}^{B} G_{bat}^{\beta} \leq E_{bt}^{\beta}\ \forall b,t$;

(7) $\sum_{h=1}^{H} G_{uht}^{l} \leq \theta Q_{ut}^{\phi}\ \forall u,t$; (8) $E_{ht}^{w} \leq \rho \sum_{u=1}^{U} G_{uht}^{l}\ \forall h,t$; (9) $\sum_{a=1}^{A} G_{hat}^{w} \leq E_{ht}^{w} - E_{ht}^{\phi}\ \forall h,t$;

(10) $\sum_{a=1}^{A} G_{hat}^{\phi} \leq E_{ht}^{\phi}\ \forall h,t$; (11) $E_{ht}^{\phi} \leq E_{ht}^{w}\ \forall h,t$; (12) $GM_{fat}^{\phi} = \sum_{\tau=1}^{t-1} GN_{fat}^{\phi}\ \forall f,a,t$;

(13) $GM_{fut}^{\phi} = \sum_{\tau=1}^{t-1} GN_{fut}^{\phi}\ \forall f,u,t$; (14) $GM_{bat}^{\beta} = \sum_{\tau=1}^{t-1} GN_{bat}^{\beta}\ \forall b,a,t$;

(15) $GM_{uht}^{l} = \sum_{\tau=1}^{t-1} GN_{uht}^{l}\ \forall u,h,t$; (16) $GM_{hat}^{w} = \sum_{\tau=1}^{t-1} GN_{hat}^{w}\ \forall h,a,t$;

(17) $GM_{hat}^{\phi} = \sum_{\tau=1}^{t-1} GN_{hat}^{\phi}\ \forall h,a,t$; (18) $EM_{ft}^{\phi} = \sum_{\tau=1}^{t-1} EN_{ft}^{\phi}\ \forall f,t$; (19) $EM_{bt}^{\beta} = \sum_{\tau=1}^{t-1} EN_{bt}^{\beta}\ \forall b,t$;

(20) $EM_{ht}^{w} = \sum_{\tau=1}^{t-1} EN_{ht}^{w}\ \forall h,t$; (21) $EM_{ht}^{\phi} = \sum_{\tau=1}^{t-1} EN_{ht}^{\phi}\ \forall h,t$;

(22) $G_{fut}^{\phi} \leq GM_{fu0}^{\phi} + GM_{fut}^{\phi}\ \forall f,u,t$; (23) $G_{fat}^{\phi} \leq GM_{fa0}^{\phi} + GM_{fat}^{\phi}\ \forall f,a,t$;

(24) $G_{bat}^{\beta} \leq GM_{ba0}^{\beta} + GM_{bat}^{\beta}\ \forall b,a,t$; (25) $G_{uht}^{l} \leq GM_{uh0}^{l} + GM_{uht}^{l}\ \forall u,h,t$;

(26) $G_{hat}^{w} \leq GM_{ha0}^{w} + GM_{hat}^{w}\ \forall h,a,t$; (27) $G_{hat}^{\phi} \leq GM_{ha0}^{\phi} + GM_{hat}^{\phi}\ \forall h,a,t$;

(28) $E_{ft}^{\phi} \leq EM_{f0}^{\phi} + EM_{ft}^{\phi}\ \forall f,t$; (29) $E_{bt}^{\beta} \leq EM_{b0}^{\beta} + EM_{bt}^{\beta}\ \forall b,t$;

(30) $E_{ht}^{\phi} \leq EM_{h0}^{\phi} + EM_{ht}^{\phi}\ \forall h,t$; (31) $E_{ht}^{w} \leq EM_{h0}^{w} + EM_{ht}^{w}\ \forall h,t$;

(32) $EM_{h0}^{\phi} + EM_{ht}^{\phi} \leq EM_{h0}^{w} + EM_{ht}^{w}\ \forall h,t$; (33) $V_{ft} = V_{f0} + \sum_{\tau=1}^{t} R_{ft} - \sum_{\tau=1}^{t-1} \left(E_{ft}^{\phi} - L_{ft}\right)\ \forall f,t$;

(34) $V_{bt} = V_{b0} - \sum_{\tau=1}^{t} E_{bt}^{\beta}\ \forall b,t$; (35) $E_{ft}^{\phi} \leq V_{ft}\ \forall f,t$; (36) $E_{bt}^{\beta} \leq V_{bt}\ \forall b,t$;

(37) $V_{fT} \geq \underline{V}_{fT}\ \forall f$; (38) $V_{bT} \geq \underline{V}_{bT}\ \forall b$; (39) $L_{ft} = max\left(0, V_{ft} - \bar{V}_{f}\right)\ \forall f,t$;

(40) Q,E,G,EN,GN $\geq 0, L \geq \underline{L}$

The objective function includes two aggregative elements: one is associated with the sets of water variables Q, E, G, covering the period $t = 1,\ldots,T$; the other refers to the sets of capacity expansions EN and GN, ranging from $t = 1$ to $t = T - 1$.

The set of constraints (1) through (4) ensures that, for the water type (ϕ, β or w), the amount consumed in each region will not exceed the amounts delivered to that region from all sources. Constraints (5) and (6) guarantee that the amounts delivered to demand regions from freshwater and brackish-water sources will not exceed the amounts extracted from those sources. The set of limits (7) constrains the aggregated sewage amounts delivered to wastewater-treatment plants from each urban region such that it will not exceed the amount of sewage produced in that region, where the parameter θ is the sewage/freshwater production rate. According to (8), production of treated wastewater at each wastewater-treatment plant will not exceed the amount of sewage transferred to the plant from all urban regions, where ρ stands for the wastewater/sewage-conversion rate. The constraints in (9) ensure, for each wastewater-treatment plant, that the total amount of wastewater delivered to agricultural regions from the plant will not exceed the plant's wastewater production that has not been desalinated. Equation (10) limits the deliveries of desalinated wastewater to agricultural districts to the amount produced at each wastewater-desalination plant, and equation (11) ensures that desalination of treated wastewater will not exceed wastewater production in each plant. Equations (12) through (21) define the cumulative capacity state variables, and the limits (22) through (31) restrain the extractions and transfers by their corresponding capacities. Equation (32) confines the capacity of wastewater desalination to not exceed its corresponding wastewater-treatment plant. Equations (33) and (34) define the extractable stocks in freshwater and brackish-water sources, respectively, where (35) and (36) use these stocks as upper limits to the corresponding extractions, and (37) and (38) impose endpoint minimum stocks. Equation (39) defines the spillover from freshwater sources, and (40) are non-negativity and minimal spillover constraints.

Considering the limitations of using the constant-elasticity functional form for water demand curves (i.e., asymptotic approaching zero from above and having extreme variation of calibrated values for fixed parameters), as part of updating and recalibration of the model we represent demand curves for all water consuming sectors in exponential form $A \cdot e^{-\rho Q}$. All else described above remains the same, this change implies replacing the inverse-demand curve $v_{ut} \cdot \left(Q_{ut}^{\phi}\right)^{\mu}$ for urban regions with $A_u \cdot e^{-\rho_{ut} \cdot Q_{ut}}$, and replacing the inverse-demand curve $\alpha \cdot \left(Q_{at}^{\phi} + \delta Q_{at}^{w} + \gamma Q_{at}^{\beta}\right)^{\eta}$ for agricultural demand regions with $A_a \cdot e^{-\rho_{at}\left(Q_{at}^{\phi}+\delta Q_{at}^{w}+\gamma Q_{at}^{\beta}\right)}$. This in turn implies that the benefits associated with water consumption in urban regions become $\frac{A_u}{\rho_{ut}}(1 - e^{-\rho_{ut} \cdot Q_{ut}})$, and in agricultural regions $\frac{A_a}{\rho_{at}}\left(1 - e^{-\rho_{at}\left(Q_{at}^{\phi}+\delta Q_{at}^{w}+\gamma Q_{at}^{\beta}\right)}\right)$, replacing the corresponding first two components in the objective function above. Finally, we note that the calibration of the additional parameters A, and ρ, follows the definitions in equations (41) and (42) below, respectively.

$$(41) \;\; A_u = p_{u0} \cdot e^{-\mu} \;\; \forall u, t\,; \quad A_a = p_{a0} \cdot e^{-\eta} \;\; \forall a, t\,;$$

$$(42) \;\; \rho_{ut} = \frac{1}{\mu Q_{u0}^{\phi}} \;\; \forall u, t\,; \quad \rho_{at} = \frac{1}{\eta\left(Q_{a0}^{\phi} + \delta Q_{a0}^{w} + \gamma Q_{a0}^{\beta}\right)} \;\; \forall a, t\,;$$

Where, quantities and prices used in equations (41) and (42) are observed in the base year calibration of the model, and expansion of demands can be introduced through the recalibration of the parameters ρ_{ut} and ρ_{at}, according to the predictions regarding population and economic growth patterns.

2.2 Data collection and model calibration for Israel

The development of the MYWAS model for Israel, recalibration processes and routine data updates over the years are recorded in several publications (Reznik et al., 2014, 2016, 2017; Slater et al., 2020, 2022). Recently, the model was updated and recalibrated to reflect data from 2019 (Slater et al., 2022). The model represents the Israeli water sector in detail, encompassing 21 urban regions that consume freshwater for domestic and industrial uses, and 18 agricultural regions that can consume freshwater, treated wastewater and brackish water. The water sources are represented in the model by 19 naturally enriched freshwater stocks, 5 seawater-desalination plants, 4 non-enriched brackish-water aquifers, 19 wastewater-treatment plants, 163 freshwater pipelines and 74 pipelines for sewage, treated wastewater and brackish water. Figures 2.1 through 2.3 describe the water system as represented in the model, and tables 2.1 through 2.12 list the data on costs and capacities of the different supply sources and conveyance lines represented.

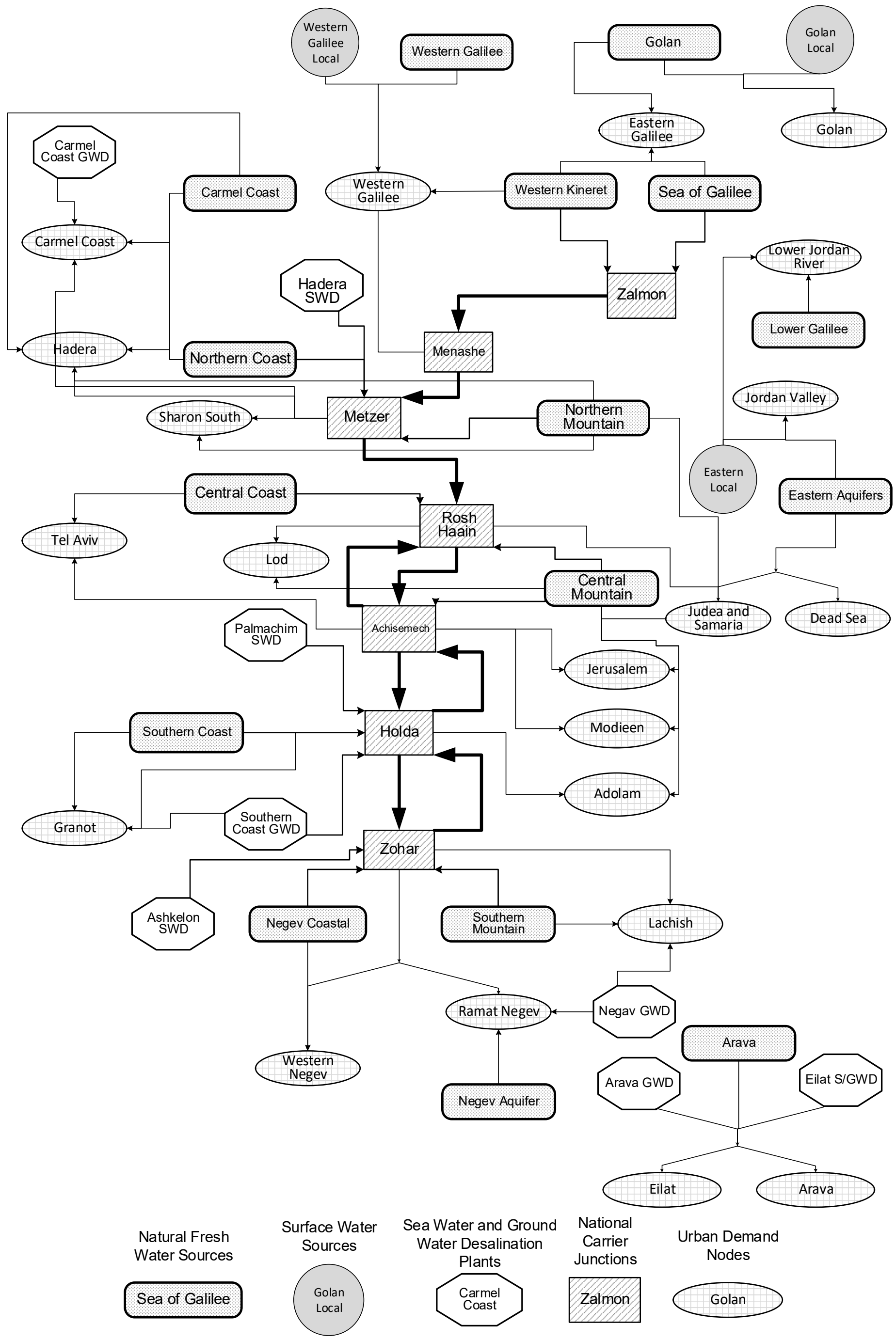


Figure 2.1-Topology Scheme for Urban and Industrial Region Fresh Water System

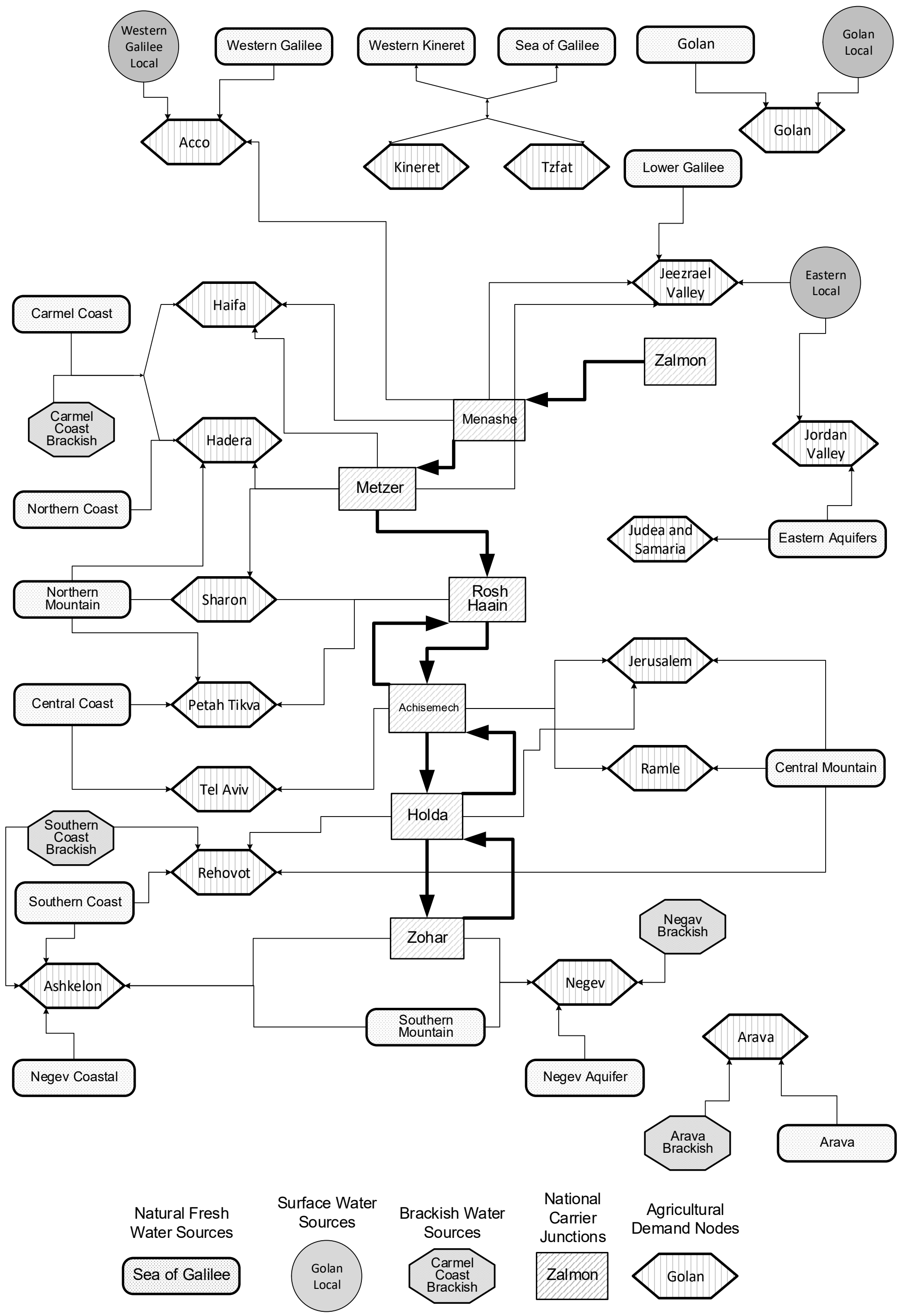


Figure 2.2 Topology Scheme for Agriculture Fresh and Brackish Water System

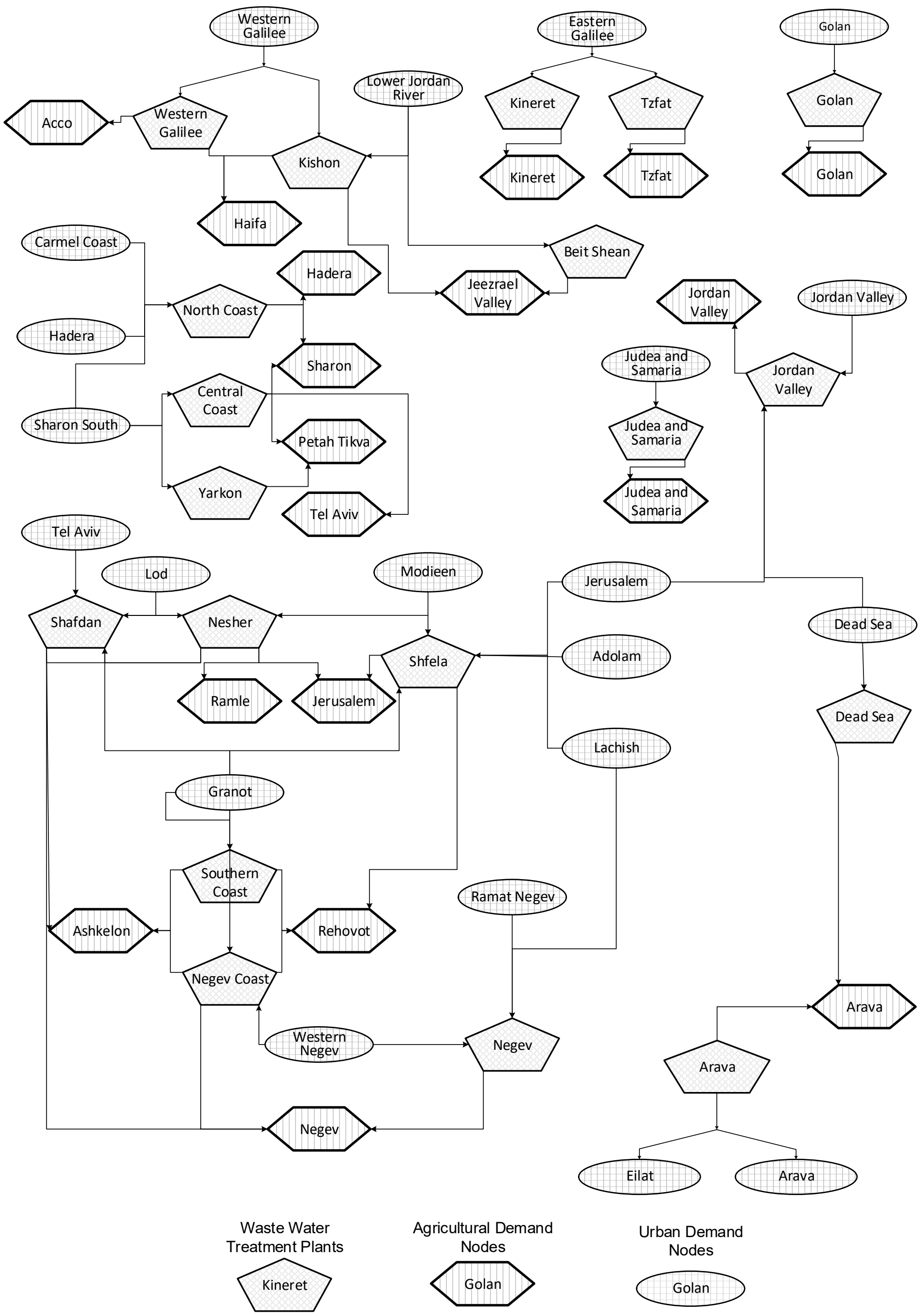


Figure 2.3 Topology Scheme for Waste Water Reclamation System

Table 2.1 Natural water sources

Name	Extraction Capacity (MCM)	Cost (NIS/CM)
Sea of Galilee	500	0.42
Golan	58.5	0.80
Western Kineret	82	0.34
Western Galilee	116	0.21
Lower Galilee	24	0.26
Eastern Mountain	90	0.29
Northern Mountain	135	0.15
Carmel Coast	31.98	0.11
Northern Coast	127	0.11
Central Coast	45	0.12
Central Mountain	214	0.54
Southern Coast	252	0.12
Negev Coastal	60	0.14
Southern Mountain	43	0.66
Negev Aquifer	11.7	0.17
Arava	23	0.17

Table 2.2 Desalination plants

Name	Capacity (MCM)	Cost (NIS/CM)
Sea Water		
Acco	0	1.23
Hadera	158.7	1.76
Palmahim	98.5	1.76
Sorek	174	1.10
Ashdod	98.3	1.41
Ashkelon	124.6	1.76
Eilat	3	1.76
Brackish Groundwater		
Western Galilee	6	0.99
Carmel Coast	25	0.99
Southern Coast	14	0.99
Negev	2.5	0.99
Arava	21	0.99

Table 2.3 Wastewater treatment plants

Name	Capacity (MCM)	Cost (NIS/CM)
Golan	4	1.14
Tzfat	10	1.17
Kineret	9	1.19
Beit Shean	4	1.37
Kishon	70	1.28
Western Galilee	33	1.29
Jordan Valley	12	1.07
Judea and Samaria	6	1.17
North Coast	25	1.31
Central Coast	58	1.29
Southern Coast	8	1.26
Negev Coast	29	1.37
Yarkon	16	1.41
Shafdan	145	1.40
Nesher	23	1.38
Shfela	56	1.39
Negev	45	1.31
Dead Sea	1	1.31
Arava	8	1.37

Table 2.4 Conveyance costs in the national system (sources to the National Water Carrier)

From	To	Cost (NIS/CM)
Potable Water Sources		
Sea of Galilee	Zalmon	0.22
Western Kineret		0.13
Northern Mountain	Metzer	0.18
Northern Coast		0.18
Central Coast	Rosh Haain	0.04
Central Mountain		0.04
Central Mountain	Achisemech	0.09
Southern Coast	Hulda	0.09
Negev Coastal	Zohar	0.13
Southern Mountain		0.04
Desalination Plants		
Acco	Menashe	0.26
Carmel Coast	Metzer	0.18
Hadera		0.18
Sorek	Rosh Haain	0.44
Ashdod	Hulda	0.48
Palmahim		0.13
Southern Coast		0.09
Ashkelon	Zohar	0.26

Table 2.5 Conveyance costs in the national system (within the National Water Carrier)

From	To	Cost (NIS/CM)
Southbound Conveyance		
Zalmon	Menashe	-
Menashe	Metzer	-
Metzer	Rosh Haain	-
Rosh Haain	Achisemech	0.13
Achisemech	Hulda	0.18
Hulda	Zohar	0.13
Northbound Conveyance		
Achisemech	Rosh Haain	0.19
Hulda	Achisemech	0.14
Zohar	Hulda	0.24

Table 2.6 Conveyance costs in the national system (National Water Carrier to urban regions)

From	To	Cost (NIS/CM)
Menashe	Western Galilee	1.69
Metzer	Hadera	1.41
	Carmel Coast	1.56
Rosh Haain	Lod	1.19
	Judea and Samaria	2.17
Achisemech	Tel Aviv	1.30
	Lod	1.27
	Jerusalem	2.11
	Modieen	1.58
	Judea and Samaria	2.74
Hulda	Adolam	2.62
	Granot	1.19
	Jerusalem	3.03
	Modieen	1.58
	Judea and Samaria	2.78
Zohar	Lachish	1.91
	Western Negev	1.47
	Ramat Negev	1.32

Table 2.7 Conveyance costs in the national system (National Water Carrier to agricultural regions)

From	To	Cost (NIS/CM)
Menashe	Acco	0.51
	Haifa	0.51
	Jeezrael Valley	0.51
Metzer	Jeezrael Valley	0.43
	Haifa	0.56
	Hadera	0.43
	Sharon	0.34
Rosh Haain	Petah Tikva	0.29
	Sharon	0.29
Achisemech	Jerusalem	0.87
	Ramle	0.38
	Tel Aviv	0.32
Hulda	Rehovot	0.34
	Jerusalem	1.79
Zohar	Ashkelon	0.56
	Negev	0.51

Table 2.8 Conveyance costs in local systems (desalination plants to urban regions)

From	To	Cost (NIS/CM)
Western Galilee	Western Galilee	1.51
Carmel Coast	Carmel Coast	1.39
Southern Coast	Granot	1.23
Negev	Lachish	1.38
	Ramat Negev	1.32
Arava	Arava	1.52
	Eilat	1.52
Eilat	Arava	1.48
	Eilat	1.48

Table 2.9 Conveyance costs in local systems (natural sources to urban regions)

From	To	Cost (NIS/CM)
Golan	Golan	1.35
	Eastern Galilee	1.90
Sea of Galilee	Eastern Galilee	1.85
Western Kineret	Eastern Galilee	1.63
	Western Galilee	1.56
Western Galilee	Western Galilee	1.51
Lower Galilee	Lower Jordan River	1.36
Eastern Mountain	Lower Jordan River	1.36
	Judea and Samaria	1.33
	Jordan Valley	1.34
	Dead Sea	1.34
Northern Mountain	Hadera	1.32
	Judea and Samaria	1.33
Central Mountain	Lod	1.23
	Jerusalem	2.55
	Modieen	1.54
	Adolam	2.00
	Judea and Samaria	1.33
Southern Mountain	Lachish	1.29
Carmel Coast	Hadera	1.32
	Carmel Coast	1.34
Northern Coast	Carmel Coast	1.34
	Hadera	1.32
Central Coast	Tel Aviv	1.36
Southern Coast	Granot	1.23
Negev Coastal	Western Negev	1.38
Negev Aquifer	Ramat Negev	1.45
Arava	Arava	1.34
	Eilat	1.48

Table 2.10 Conveyance costs in local systems (potable water sources to agricultural regions)

From	To	Cost (NIS/CM)
Golan	Golan	0.34
Sea of Galilee	Kineret	0.34
	Tzfat	0.34
Western Kineret	Tzfat	0.34
	Kineret	0.34
Western Galilee	Acco	0.34
Lower Galilee	Jeezrael Valley	0.34
Eastern Mountain	Jordan Valley	0.34
	Judea and Samaria	0.34
Northern Mountain	Hadera	0.34
	Sharon	0.38
	Petah Tikva	0.38
Central Mountain	Jerusalem	0.34
	Ramle	0.34
	Rehovot	0.34
Southern Mountain	Ashkelon	0.34
	Negev	0.34
Carmel Coast	Hadera	0.34
Northern Coast	Hadera	0.38
Central Coast	Petah Tikva	0.38
	Tel Aviv	0.38
Southern Coast	Rehovot	0.47
	Ashkelon	0.34
Negev Coastal	Ashkelon	0.34
Negev Aquifer	Negev	0.34
Arava	Arava	0.34

Table 2.11 Conveyance costs in local systems (non-potable water sources to agricultural regions)

From	To	Cost (NIS/CM)
Brackish Water Sources		
Western Galilee	Acco	0.34
Eastern Mountain	Jeezrael Valley	0.34
	Jordan Valley	0.34
Carmel Coast	Haifa	0.34
	Hadera	0.34
Southern Coast	Ashkelon	0.34
	Rehovot	0.47
Negev	Negev	0.34
Arava	Arava	0.34
Wastewater Treatment Plants		
Golan	Golan	0.34
Tzfat	Tzfat	0.34
Kineret	Kineret	0.34
Beit Shean	Jeezrael Valley	0.34
Jordan Valley	Jordan Valley	0.34
Western Galilee	Acco	0.69
	Haifa	0.69
Kishon	Haifa	0.87
	Jeezrael Valley	0.87
North Coast	Hadera	0.43
	Sharon	0.43
Central Coast	Sharon	0.38
	Petah Tikva	0.38
	Tel Aviv	0.38
Yarkon	Petah Tikva	0.38
Shafdan	Ashkelon	0.69
	Negev	1.00
Shfela	Ashkelon	0.56
	Jerusalem	0.56
	Rehovot	0.56
Nesher	Ramle	0.56
	Jerusalem	0.56
Judea and Samaria	Judea and Samaria	0.34
Southern Coast	Ashkelon	0.47
	Rehovot	0.47
Negev Coast	Ashkelon	0.38
	Rehovot	0.38
	Negev	0.43
Negev	Negev	0.43
Dead Sea	Arava	0.38
Arava	Arava	0.38

Table 2.12 Costs of wastewater collection in urban region and conveyance to wastewater treatment plants

From	To	Cost (NIS/CM)
Golan	Golan	2.82
Eastern Galilee	Tzfat	2.99
Eastern Galilee	Kineret	2.99
Lower Jordan River	Beit Shean	2.90
Dead Sea	Jordan Valley	2.90
Jordan Valley		2.90
Jerusalem		3.51
Western Galilee	Western Galilee	2.84
Lower Jordan River	Kishon	2.90
Western Galilee		2.84
Eastern Galilee		2.99
Carmel Coast	North Coast	2.90
Hadera		2.68
Sharon South		2.82
Sharon South	Central Coast	2.82
Sharon South	Yarkon	2.82
Lod	Shafdan	2.79
Tel Aviv		3.50
Granot		2.64
Sharon South		2.82
Jerusalem	Shfela	3.51
Modieen		2.24
Adolam		2.90
Granot		2.64
Lachish		2.56
Lod	Nesher	2.79
Modieen		2.24
Judea and Samaria	Judea and Samaria	2.94
Granot	Southern Coast	2.64
Granot	Negev Coast	2.64
Western Negev		2.57
Lachish	Negev	2.56
Ramat Negev		3.21
Western Negev		2.57
Dead Sea	Dead Sea	2.90
Arava	Arava	2.90
Eilat		2.90

2.3 Data collection and model calibration for Palestine

The data for the West Bank and Gaza were largely provided by the Palestinian Water Authority (PWA), unless otherwise noted. As is noted below, there are several data gaps, largely around demands and costs (both operation and maintenance and capital). We note in the appropriate places, and describe in detail, where assumptions were made to fill in any data gaps that exist. The additional network components introduced to the MYWAS model system to represent the inclusion of West Bank and Gaza is presented in figures 2.4 and 2.5.

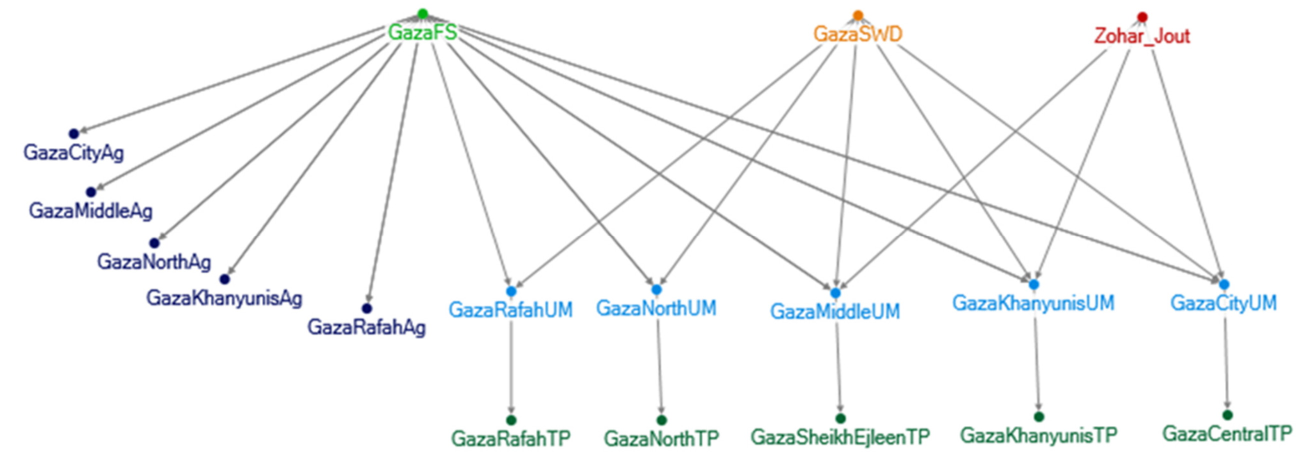


Figure 2.4 Model network for Gaza in the first year (Ag: Agriculture; FS: Freshwater source; Jout: Junction (Mekorot); SWD: Seawater desalination; TP: Wastewater treatment plant; UM: Urban and industrial)

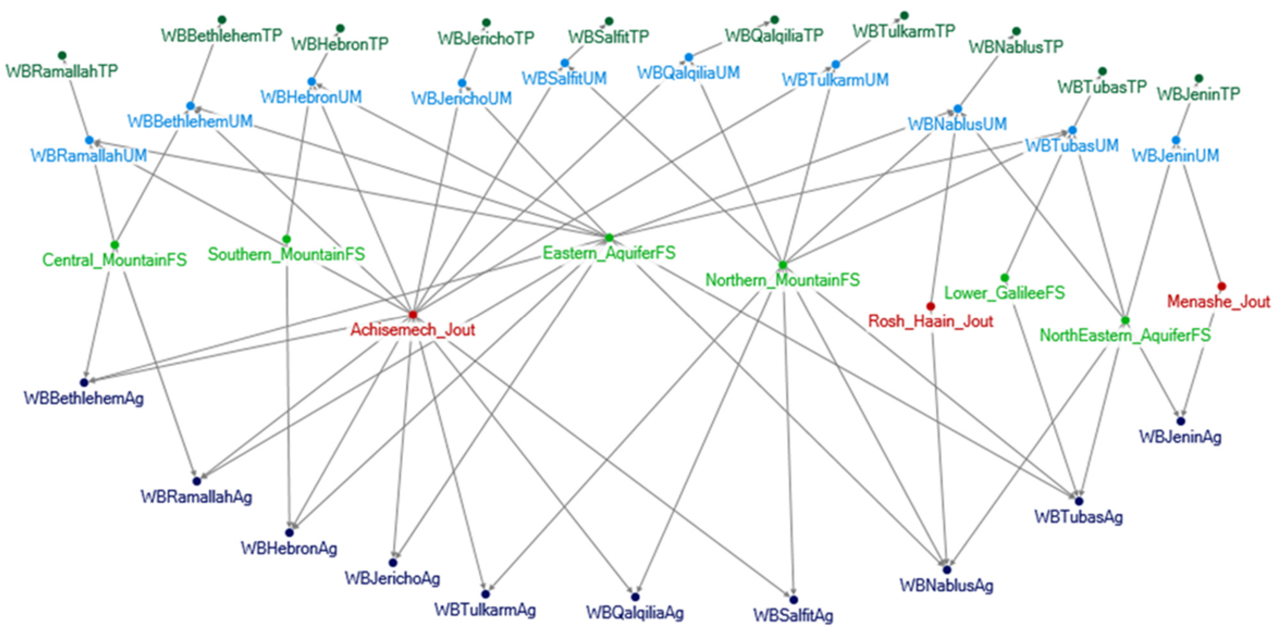


Figure 2.5 Model network for West Bank in the first year (Ag: Agriculture; FS: Freshwater source; Jout: Junction (Mekorot); SWD: Seawater desalination; TP: Wastewater treatment plant; UM: Urban and industrial)

Water supply data for 2020, as well as capacity of supply infrastructures, at the governorate level for West Bank, and Gaza, are presented in tables 2.13 and 2.14, respectively. Unfortunately, we do not have sufficient data to distinguish between brackish water and freshwater supply in the West Bank and Gaza, hence the implicit assumption that all natural sources of water to Palestine are freshwater.

Table 2.13 Water supply sources and infrastructure capacity in the West Bank: observed for 2020 per governorate (MCM)

	Groundwater sources (wells and springs)				Capacity
Name	Eastern Mountain	Northeastern Mountain	Western Mountain	Mekorot transfers	Wastewater treatment
Jenin		9.0		2.5	2.6
Tubas	0.5	0.5		6.1	1.3
Tulkarm			25.0	0.5	
Nablus	1.5	25.5		5.0	10.9
Qalqilia			17.7	0.9	0.1
Salfit			0.6	3.3	0.7
Ramallah	3.1		1.9	24.5	3.4
Jericho	48.6			2.8	1.3
Bethlehem	10.0		0.5	15.5	
Hebron	1.6		0.5	16	4.6
Total	65.3	35.0	46.7	77.1	24.9

Groundwater sources in the West Bank are shared with Israel. Therefore, data regarding costs of extraction and conveyance presented in tables 2.1 through 2.12 applies, where it is relevant, to the West Bank as well. Wastewater treatment cost in the West Bank is also assumed like that in similar regions in Israel, specifically Judea and Samaria.

Table 2.14 Water supply sources and infrastructure capacity in Gaza: observed for 2020 per governorate (MCM)

	Groundwater extractions			Capacity	
Name	Municipal	Agriculture	Mekorot transfers	Desalination	Wastewater treatment
North Gaza	29.2	22.2		0.6	13.0
Gaza City	28.9	9.5	8.0	2.2	21.9
Middle	13.5	16.6	2.0	1.3	18.3
Khanyunis	13.3	32.5	3.2	0.7	5.5
Rafah	10.8	13.4		0.9	7.3
Total	95.7	94.2	13.2	5.7	66

Storage capacity of the groundwater aquifer system in Gaza is estimated at 500 MCM, and annual average long-term natural recharge at 55 MCM/year (UN-ESCWA and BGR, 2013). Costs of groundwater extraction, conveyance, sewage collection and wastewater treatment in Gaza are also adopted from adjacent regions in Israel, specifically the South Coast. Official data from the PWA indicates a cost of 4.1 NIS/CM for existing seawater desalination plants in Gaza. This high cost is primarily reflected in the size of the existing plants. For future development of new mega-desalination capacity in Gaza we assume similar technology, and therefore similar costs, to those assumed for potential development in Israel.

Table 2.15 lists data on water consumption for the West Bank and Gaza for the year 2020.

Table 2.15 Domestic water consumption in Palestien: observed for 2020 per governorate

Name	Supply (MCM)	Consumption levels (MCM)	Population	Loss rate (%)	Extrapolated quantities (MCM)
West Bank					
Jenin	13.9	8.5	335,485	38.8	15.9
Tubas	2.3	1.7	65,211	26	3.1
Tulkarm	15.3	9.3	197,098	39.2	9.4
Nablus	18.1	12.7	411,680	29.8	19.5
Qalqiliya	8.2	6.2	120,357	24.4	5.7
Salfit	3.2	3.1	81,162	3.2	3.9
Ramallah	29.4	21.1	517,097	28.2	24.5
Jericho	4.2	2.5	52,836	40.5	2.5
Bethlehem	8.9	5.9	232,734	33	11.0
Hebron	20.7	12.8	771,993	38.2	36.6
Gaza					
North Gaza	27.7	15.4	406,866	45	19.3
Gaza City	40.2	22.2	714,457	45	33.9
Middle	17.0	8.9	299,519	48	14.2
Khanyunis	17.4	12.0	405,005	31	19.2
Rafah	11.9	7.2	256,831	39	12.2

It can be noticed that quantities supplied and consumed are unidentical and these gaps are significant. The calibration of demand curves according to equations (41) and (42) requires observed data on consumption levels and prices for a given year, as well as on estimates of demand price elasticity. For Israel, estimates of elasticity from Bar-Shira et al. (2005) for urban demand, and from Bar-Shira et al. (2006) for agricultural demand, are used along with official Israeli Water Authority (IWA) data on consumption levels and prices to calibrate these demand curves. The difficulty that arises when trying to calibrate demand curves for Palestine is that observed data regarding consumed quantities is distorted; much water use is unaccounted for (due to physical leakage or inefficient monitoring and enforcement mechanisms), and in many places, people cannot consume as much as they would wish. The observed quantities consumed therefore cannot be taken to reflect the quantities that would be used at the reported prices in the absence of different factors that limit consumption. In such a case the calibration of demand curves using observed data on consumption levels will result in underestimate of the calculated economic benefits from water consumption. To overcome this potential misrepresentation of demands we use per capita consumption rates from specific governorates (namely, Tulkarm and Jericho) that presumably are not quantity constrained and extrapolate the consumed quantity levels used for calibration for all other governorates in Palestine.

Two noticeable differences in water management realities between Israel and Palestine that are relevant from a conceptual modelling perspective, are the existence of significant leakage rates and untreated wastewater in Palestine. At present, Palestine has low levels of wastewater treatment. In Israel almost 100% of wastewater generated is collected and treated in centralized treatment plants, and roughly 90%

is then reused for irrigation of agricultural crops. Untreated wastewater creates health hazards and environmental pollution and is therefore considered in economic terms – an externality, in which an economic activity conducted by one party creates a negative impact on the economic welfare of another. Using economic tools such as taxes to incentivize the polluter to internalize the social cost of the economic activity is considered the optimal solution according to economic theory. Thus, following the polluter pays principle, and analogous to emission or carbon taxes for fossil fuel use in transportation or electricity production, urban dwellers usually bear the cost of wastewater treatment. In a transboundary setting, the challenge is demonstrating the mutual benefits when the costs of building plants and treating the wastewater are private. We do not attempt to explicitly represent transboundary untreated wastewater flows in the MYWAS model. Instead, we assign a social cost proxy to any quantity of untreated wastewater generated in the regional economy. That proxy is calculated according to existing costs of wastewater collection and treatment observed in Israel as a lower bound on the real health and environmental damages associated with untreated wastewater flows. The model then compares these social costs with the costs of investing in wastewater treatment capacity development in Palestine, as well as the potential benefits from reuse to decide whether treatment capacity investment in Palestine is of mutual benefit to both entities. The model does not separate net benefits in Israel from those in Palestine, nor the social costs of pollution, and does not currently include conveyance of treated wastewater between governates.

According to PWA official data 30% to 50% of the water supplied for domestic use in Palestine is defined as unaccounted for (see table 2.15). Lacking the ability to distinguish between physical leakage of broken infrastructure and inefficiency of monitoring and revenue collection mechanisms in Palestine, we define these quantities in general terms as leakage. To represent these leakages in the MYWAS model we introduce as initial conditions to the model at the planning horizon onset, a parameter of existing leakage levels (as given in table 2.15). We then allow the model to endogenously determine, in a similar manner to infrastructure development, the level of investment in leakage reduction ratios, such that to completely remove leakage, the leakage reduction ratios and initial conditions of leakage ratios will sum up to 1. We use an estimate of 0.2 NIS/CM for annuity payments on these investments.

2.4 Data collection and model calibration for Jordan

The Jordan Valley forms part of the larger Jordan Rift Valley. The internationally recognized World Heritage values of the Jordan Valley are strongly related to its unique historic, religious, cultural, economic, and environmental values, not at least due to its typical rift valley topography. The lower part of the Jordan River (LJR) originates at the Sea of Galilee and meanders along 200 km down to the Dead Sea through the Jordan Valley. The study area has a total surface area of 2508 km2, most of which (61.5 %) consists of uncultivated land. A total of 803 km2 (32 %) is used for agriculture and 89.6 km2 (3.6 %) as built-up area. The average annual rainfall in the study area and the wider region varies from over 500 mm per year in the north to less than 100 mm in the south close to the Dead Sea. With high temperatures and average dry conditions, the average annual evaporation is high, varying from 2,150 to 2,350 mm per year. The dominant soil types in the area are regosols, rendzinas, and serozems, which are mainly tertiary deposits, and to a lesser extent lithosols, all of them generally fertile. As a result, the majority of land in the area that can be provided with water is used for agriculture and horticulture. (Wiki media) Historically, the lower part of the Jordan River received about 600 MCM/year from Sea of Galilee in the north and about 470 MCM/year from the Yarmouk River in the northeast. With some additional inflow from the Zarqa River and nine other streams from the East Bank, the lower part of the Jordan River had an outflow into the Dead Sea of about and 1200–1300 MCM/year. Since the 1950s, the water from the river had been increasingly diverted by Israel, Syria, and Jordan for domestic water supply and development of their agricultural sectors. The water is diverted mainly by the Israeli National Water Carrier taking water from Sea of Galilee, and through the development of various dams and canals in Syria and Jordan, including the Unity Dam on the Yarmouk river on the border between Jordan and Syria, the King Talal Dam in the Zarqa Basin, and the King Abdullah Canal running east and parallel to the river. Today, the outflow into the Dead Sea is about 70–100 MCM/year or less.

Jordan faces interconnected challenges in its water, food, and energy sectors, all crucial for sustainable development. The country's water scarcity is severe, with sustainable water resources amounting to approximately 800 million cubic meters per year, translating to a per capita availability of only 61 cubic meters annually, well below the global water poverty line. This scarcity directly impacts the agriculture sector, which relies heavily on water, limiting food production and threatening food security (Jordan National Water Strategy, 2023-2040). In the domestic sector, the major water challenge is facing Jordan is the demand far exceeds the supply, where water availability averages between 69 – 100 liter per capita per day (l/c/d) (source) roughly the WHO minimum water use requirement for health and hygiene (World Health Organization 2003). In addition, another major challenge is the high cost of producing and transporting water (80% energy cost). The Energy intensity of water production and transmission is nearly 5.3 kWh/m3 (MWI 2013) which is 150% of the seawater desalination production rate. The South Shoonah system serves 39,185 inhabitants in a number of localities in South Shoonah district. The population served by the system is expected to increase to 52,890 in 2040. The system is fed from Jrai'ah, Kafrain, Sokhneh wellfields and some private wells, in addition to Zara Maeen.

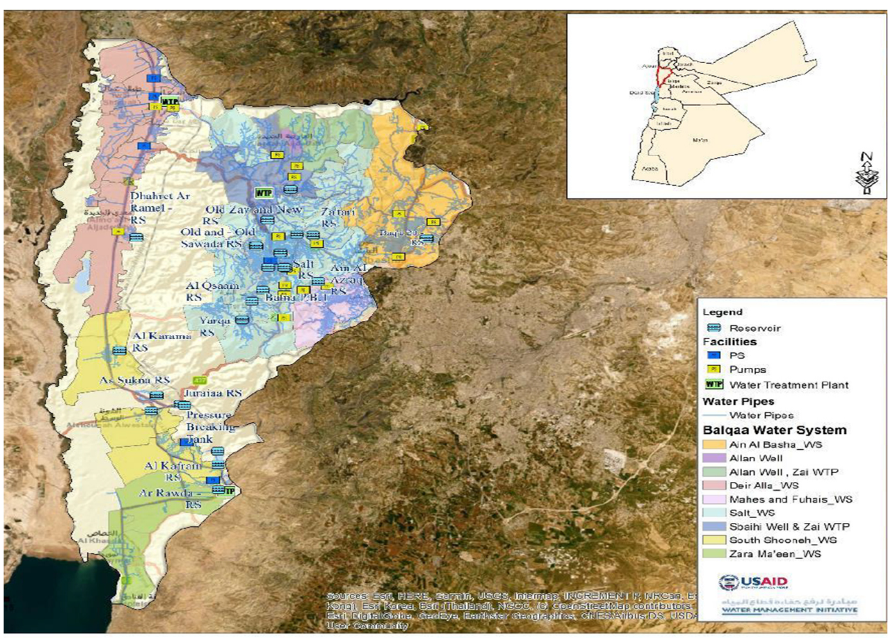


Figure 4-32. Balqa Existing Water Supply System

Figure 2.6 Balqa governorate existing supply system

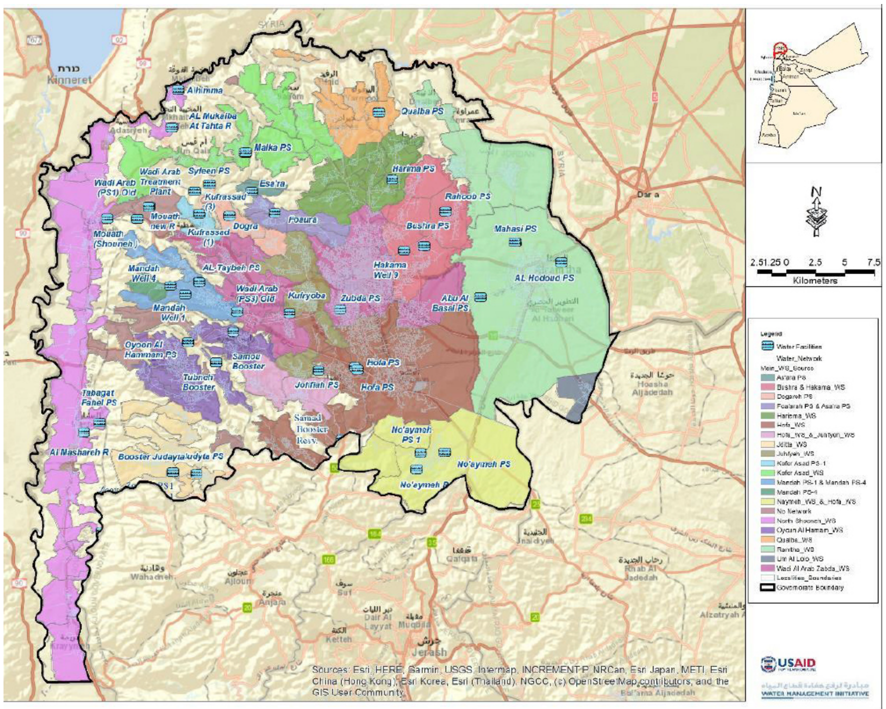


Figure 2.7 Irbid governorate existing supply system

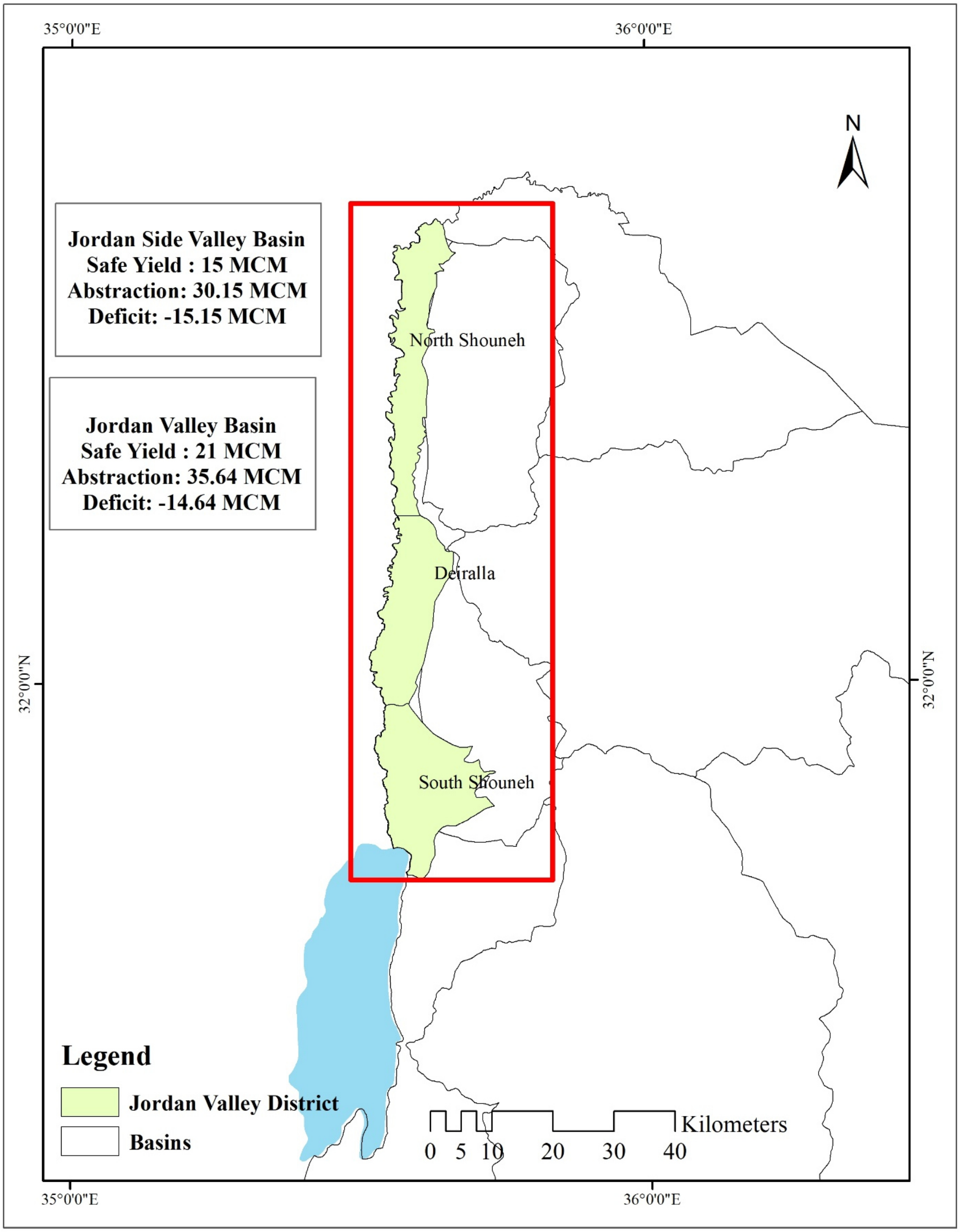
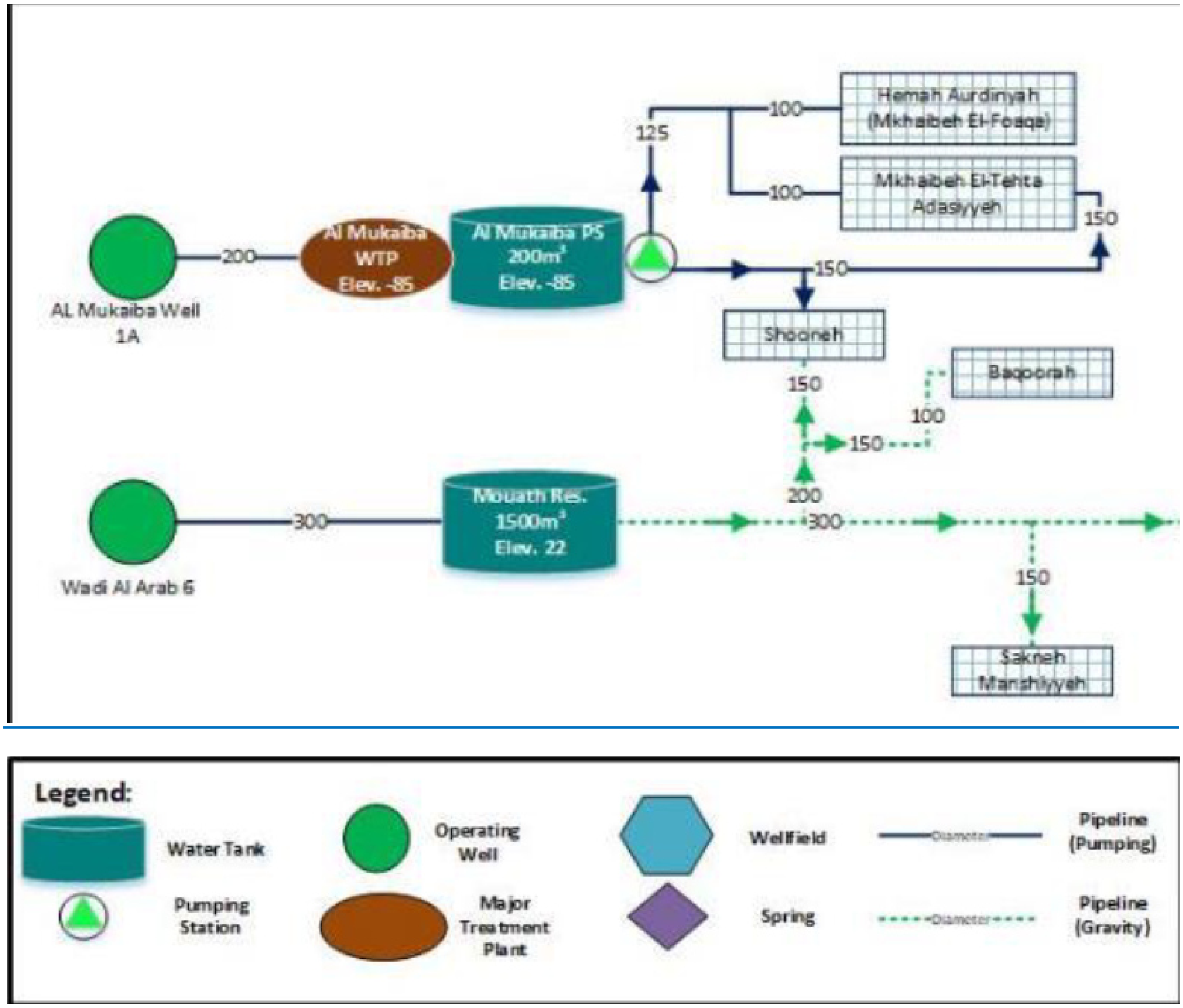


Figure 2.8 Groundwater Aquifers in Jordan, Safe Yield, Abstraction and Deficit for 2022

Water Supply System flowchart presentation

Schematic representations including details on Water tanks, pumping stations, operating Wells, Major treatment plants, Wellfields, Springs, and pipelines (both pumping and gravity driven) (WMI, 2021)
Deir Alla water system (page 71)
South Shouneh water system (page 72)
North Shouneh water system (page 129)



Source: WMI, 2021, NATIONAL WATER INFRASTRUCTURE MASTER PLAN, USAID

Figure 2.9 North Shouna schematic existing water supply system

Water Evaluation And Planning System Model (WEAP)

This process was based on the WEAP capabilities to simulate and draw the Water System Features through the legend tools and its functionality, thus the following assumptions were considered (Hussein et al. 2009):

1. King Abdulla Canal (KAC), All Wadis, and the official Rivers drawn as Rivers in the Scheme at WEAP Model.
2. Lake Taiberia (LT) and all Dams in the Basin will be Surface Water Reservoirs.
3. Mukhaibeh Ground Water (GW) is simulated as River to transfer water to KAC.
4. One GW source (Azraq GW Reservoir)
5. Some connection points between the resources are simulated by Diversion tool

   (Wadis to Jordan River (JR), Pump water from Yarmouk to LT then Pump

   Water from LT to KAC, Pump Water from KAC to Karameh Dam then Pump

   Water from Karameh Dam to KAC)

   Thirteenth International Water Technology Conference, IWTC 13 2009, Hurghada, Egypt

6. Other connections are built directly like Wadis to KAC (River connects to other)
7. One Wastewater Treatment Plant (WWTP).
8. Transmission and Return Links for Amman city, Zarqa city, and Assamra WWTP
9. Transmission links to cover the irrigation projects.

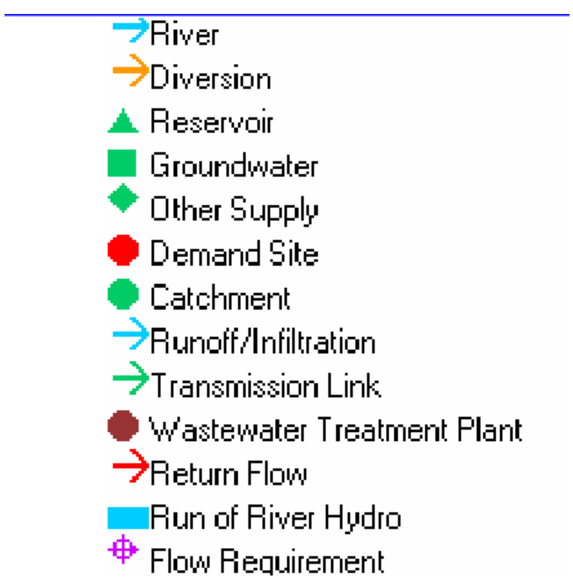


Figure 2.10 Jordan Valley WEAP application : network flowchart

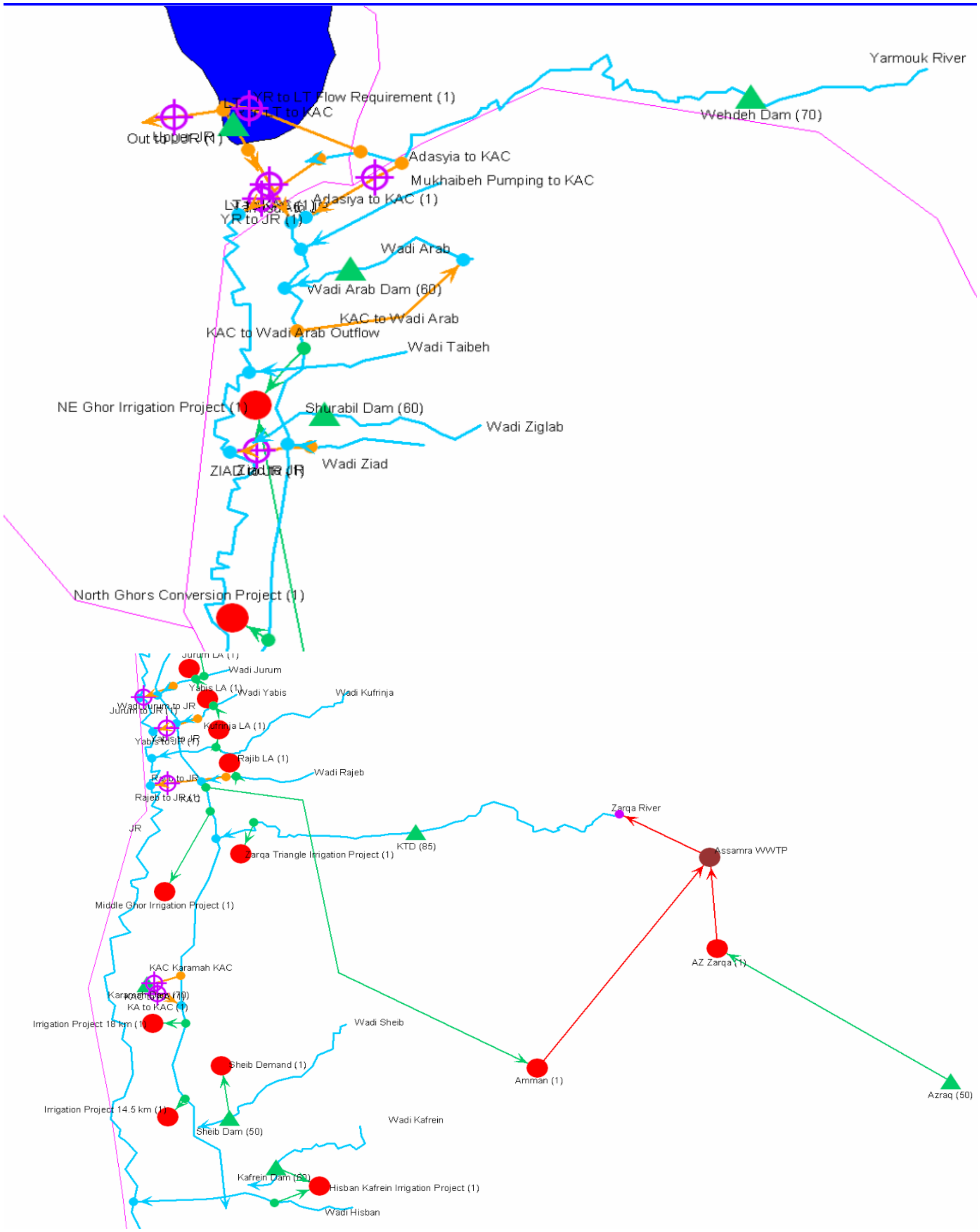


Figure 2.11 North Shouna, Deir Alla and South Shouna water supply system network image

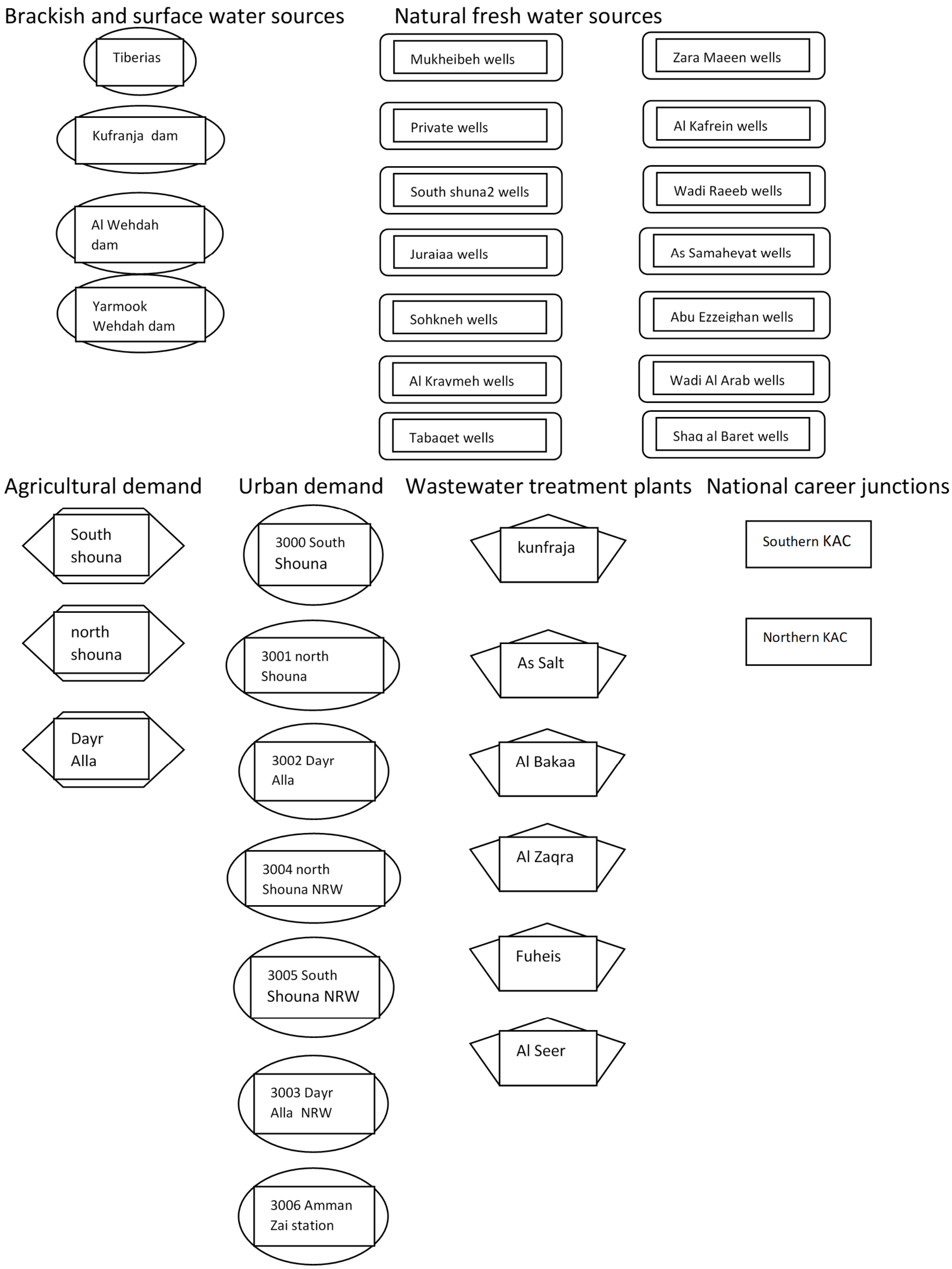


Figure 2.12 Model topology components in Jordan

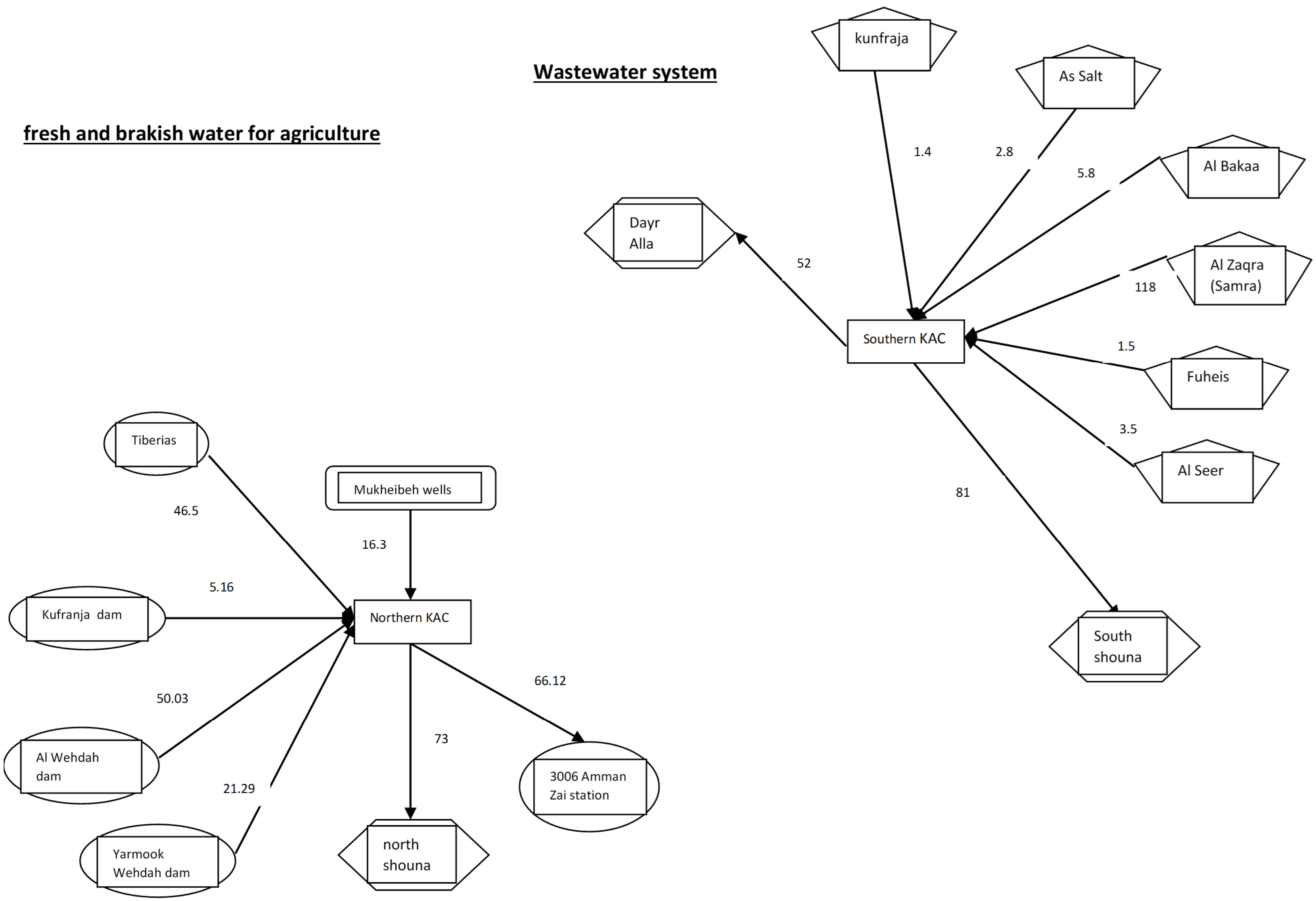


Figure 2.13 Jordan valley area of focus (Jordan side): Water supply and demand and transmission system

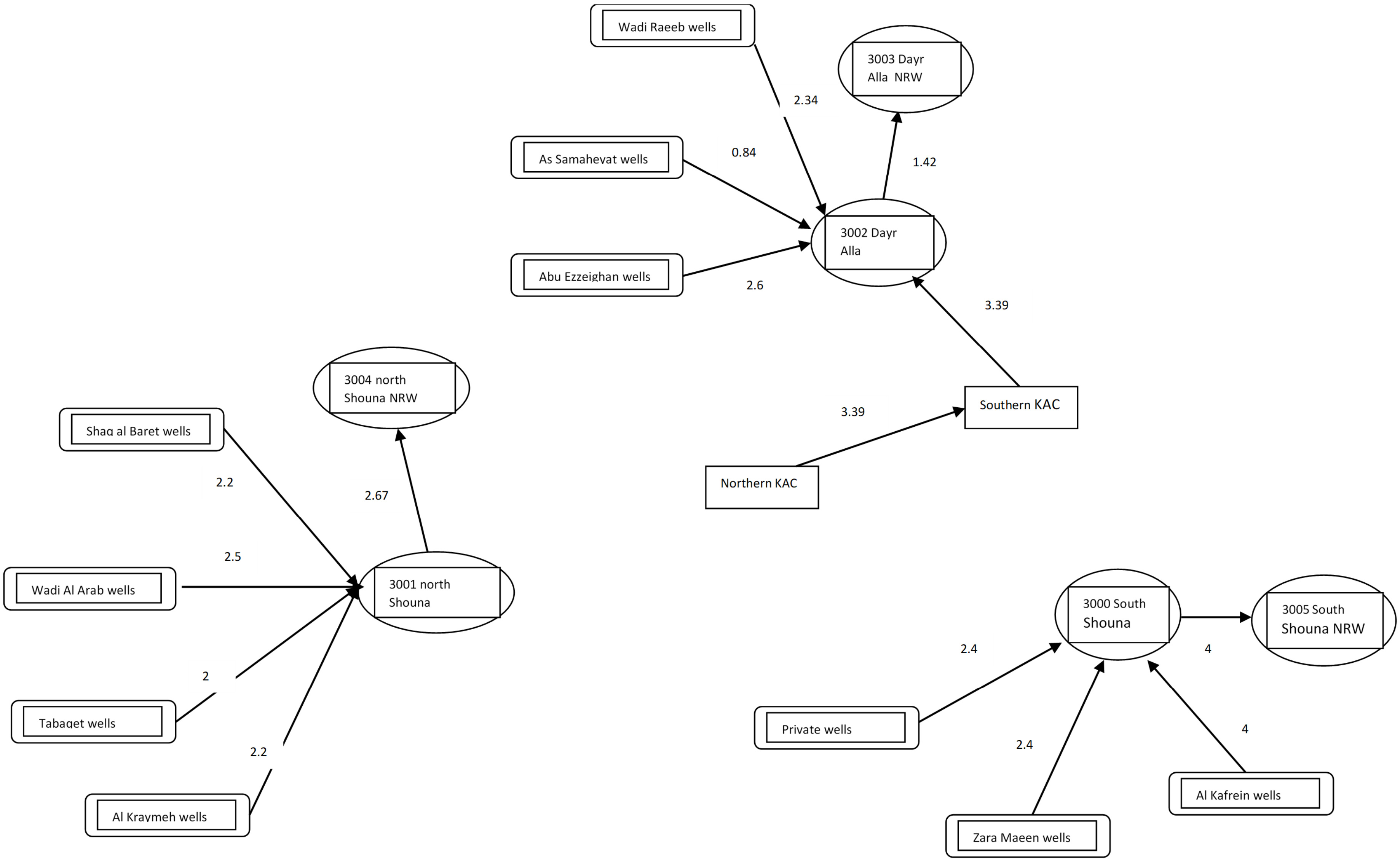


Figure 2.14 drinking water network

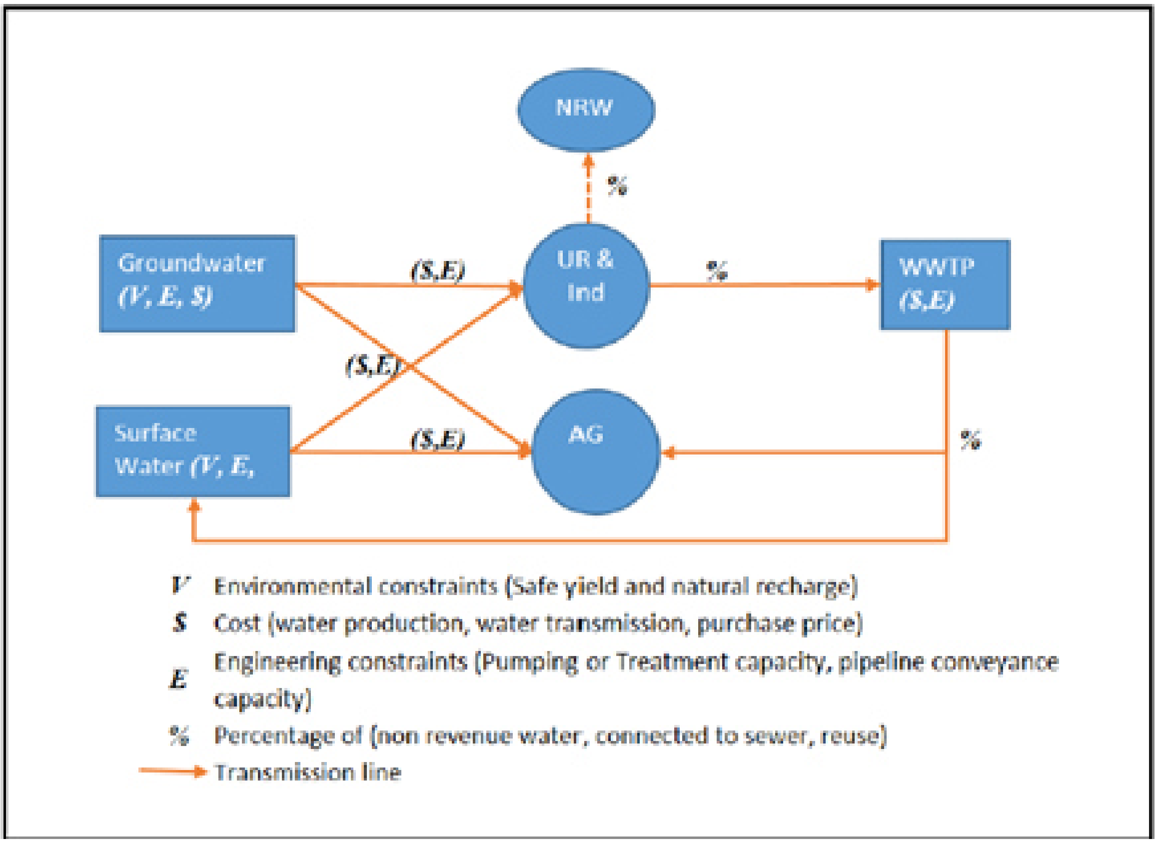


Figure 2.15 Generalized flow schematic of the north governotes water system

The set of tables 2.16 through 2.25 presents the parameterization used for the Jordan stylized MYWAS model and values assumed for the different components, and are partially calibrated based on data and information from previous work (Halaseh, 2015).

This project is part of the PRIMA programme supported by the European Union. GA n° [2243] [EcoFuture] [Call 2022 Section 1 NEXUS WEFE IA].

Table 2.16 Model set elements

brakish water sources	wwt plants	junctions	fresh water sources	urban demands	agr demand
Shaq Al Bared GW	Kufranja TP	Northern KAC_J	Al Wehdah dam FS	North ShounaUM	North ShounaAg
Wadi Al Arab GW	As Samra TP	Southern KAC_J	Tiberias FS	Amman (Zai station) UMTable 8	Deir AllaAg
Tabaqet Fahel GW	Al Baqaa TP		Kufranja dam FS	Deir AllaUM	South ShounaAg
Mkaimnat-Kraimeh GW	As Salt TP		Yamouk/Wehdah FS	South ShounaUM	
Abu Ezzeighan GW	Fuheis Mahes TP				
As Samaheyat GW	Wadi Al Seer TP				
Wadi Rajieb GW	North Shouna TP				
Private Wells GW	Wadi Arab TP				
Zara Maeen GW	Irbid TP				
Al Kafrain GW	Ramptha TP				
Juraia'a GW	Wadi Shallalah TP				
South Shouna 2 GW	Wadi Hassan TP				
Sokhneh GW	Tal Mantah TP				
Al Mukhaibeh GW	As Sharea'a TP				
As Slaikhat GW					
North_SouthKAC					

Table 2.17 Cost of water conveyance for major water systems (in JD annually)

From	To	Cost ($/CM)
Shaq Al Bared GW	North ShounaUM	0.46
Wadi Al Arab GW	North ShounaUM	0.13
Tabaqet Fahel GW	North ShounaUM	0.46
Mkaimnat-Kraimeh GW	North ShounaUM	0.46
Abu Ezzeighan GW	Deir AllaUM	0.46
As Samaheyat GW	Deir AllaUM	0.46
Wadi Rajieb GW	Deir AllaUM	0.46
North_SouthKAC	Deir AllaUM	0.46
Private Wells GW	South ShounaUM	0.46
Zara Maeen GW	South ShounaUM	0.46
Al Kafrain GW	South ShounaUM	0.13
Kufranja TP	Southern KAC_J	0.46
As Samra TP	Southern KAC_J	0.46
Al Baqaa TP	Southern KAC_J	0.45
As Salt TP	Southern KAC_J	0.44
Fuheis Mahes TP	Southern KAC_J	0.46
Wadi Al Seer TP	Southern KAC_J	0.46
Southern KAC_J	Deir AllaAg	0.46
Southern KAC_J	South ShounaAg	0.46
Al Wehdah dam FS	Northern KAC_J	0.13
Tiberias FS	Northern KAC_J	0.46
Kufranja dam FS	Northern KAC_J	0.13
Yamouk/Wehdah FS	Northern KAC_J	0.13
Northern KAC_J	Amman (Zai station) UM	0.46
Al Mukhaibeh GW	Northern KAC_J	0.13
Northern KAC_J	North ShounaAg	0.46

*source Table 3 Annex I (east wellfields 0.13, west wellfields 0.46 $/m3)

Table 2.18 Production Cost per water unit ($ m^{-3}) Based on calculation in Table 2.19

Name	Cost ($/CM)
Al Wehdah dam FS	0.171733
Tiberias FS	0.15634
Kufranja dam FS	0.159507
Yamouk/Wehdah FS	0.147105
Shaq Al Bared GW	0.139671
Wadi Al Arab GW	0.172979
Tabaqet Fahel GW	0.14213
Mkaimnat-Kraimeh GW	0.135177
Abu Ezzeighan GW	0.155857
As Samaheyat GW	0.165375
Wadi Rajieb GW	0.154587
Private Wells GW	0.146454
Zara Maeen GW	0.134731
Al Kafrain GW	0.173695
Juraia'a GW	0.148041
South Shouna 2 GW	0.154167
Sokhneh GW	0.038
Al Mukhaibeh GW	0.025
As Slaikhat GW	0.025
North_SouthKAC	0.025

Table 2.19 Pumping costs calculation (source: Alqadi et al., 2019)

		wadi al arab		units
tariffs		2017	0.1	
		2018	0.14	JD/kwh
cost		2017	7.1	mJoD
		2018	8.7	mJoD
consumption		2017	75	GWh
		2018	70	
water mcm		2017	75	mcm
		2018	70	
		2017	0.095	JOD/m3
		2018	0.124	JOD/m3
JOD=1.41$		2017	0.13348	$/m3
		2018	0.17524286	$/m3

Environmental Constraints

Table 2.20 Annual recharge for ground water aquifer (MWI, 2019)

Aquifer Name*	Annual recharge (mcm/year)
Amman/Wadi Sir (B2/A7)	45
Kurnub (K)	8
Basalt (V)	28
Hummar (A4)	5
…	…

Table 2.21 Aquifer properties of the main wells drilled in the catchment area (Rakad et al., 2013)

Well / Location	Altitude	Well depth (m)	Aquifer	Yield(m3)	Salinity (ppm)
Al Kraymeh	-200	167	Not Defined	100	--
Al Mukhaibeh well	-80	350	Amman (B2)	6,000	544
Shaq Al Bared (As Slaikhat)	---	---	---	---	--
Tabaqet Fahel	140	550	Amman (B2)	30	---
Wadi Al Arab	-20	257	Amman/Wadi Sir (B2/A7)	1,486	553
Abu Ezzeighan Wellfield	-200	272	Kurnub	221	----
As Samaheyat Wellfield	0	288	Basalt	80	---
Wadi Rajeb Wellfield	-136	168	Hummar (A4)	40	---
Al Kafrain Wellfield	-50	500	Kurnub	110	450
Zara Maeen (GW/WWTP?)					
Sokhneh Wellfield	-100	190	Wadi Sir (A7)	75	602
Juraiaa Wellfield	-110	194	Hummar (A4)	84	614
South Shoonah 2 Well	-144	200	Amman/Wadi Sir (B2/A7)	6	480

Table 2.22 WWTP cost and capacity data

Name	Capacity (MCM)	Cost (NIS/CM)
Kufranja TP	3.0	0.160
As Samra TP	133.0	0.250
Al Baqaa TP	5.0	0.150
As Salt TP	3.0	0.150
Fuheis Mahes TP	1.0	0.150
Wadi Al Seer TP	1.0	0.150

Table 2.23 Domestic demand

Demand node	Elasticity	Population	Per capita (m3/year)*
North Shouna	-0.3	86600	130
Deir Alla	-0.3	101400	116
South Shouna	-0.3	72000	156

Halaseh reports between 12.775 to 46.72 m3/year

The per capita sustainable water resource availability is 272 m3/capita/yr as compared to a need of 1,700 m3/capita/yr (Haddadin 2006).

Table 2.24 Urban demand (mcm /annum) physical losses and non revenue water (NRW)

Demand node	Urban consumption metered	Physical loss (%)	Total NRW (%)
North Shouna	8.9	7.092	23.64%
Deir Alla	9.17	3.684	12.28%
South Shouna	8.8	10.68	35.6%

Drinking water for urban demand: (0.4-0.6 JD/m3)

Table 2.25 Urban Demand Function Parameters (calibrated for Jordan model)

District	dpu	btu	epsu
	t1		
North ShounaU	6.858092729	-0.95	0.76982911
Amman (Zai station) U	6.858092729	-0.9	0.46982911
Deir AllaU	6.558092729	-0.96	0.56982911
South ShounaU	6.859093	-0.98	0.79982911

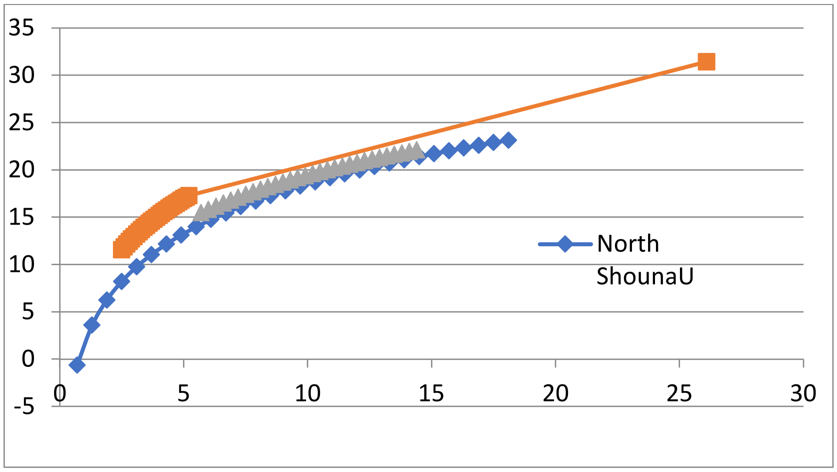


Figure 2.16 Surplus from water consumption in urban districts

Table 2.26 Agriculture water tariff

Agriculture Water Tariff

Water Quality	Usage Block (m³ per billing cycle)	Current Tariff (Fils/m³)	Proposed Tarrif (Fils/m³)	Change
1 (freshwater)	0 - 2,500	8	15	88%
	2,501 - 3,500	12	30	150%
	3,501 - 4,500	20	45	125%
	More than 4,500	35	55	57%
2 (mixed fresh/effluent)	0 - 2,500	8	8	0%
3 (only effluent)	2,501 – 3,500	12	12	0%
4 (highly saline)	3,501 – 4,500	20	20	0%
	More than 4,500	35	35	0%

Source: Halaseh, 2015

Each demand curve for water is constructed following Halaseh (2015). The procedure used to estimate the demand curves for the water use sectors (agricultural, domestic and industrial) is to measure the consumer willing to pay point on every demand curve, along with an assumed price elasticity taken from the literature. Table 2.27 summarizes the demand curve parameters.

Table 2.27 Agriculture – water for irrigation function parameters ($Q=AP^{a}$)

Demand node	Elasticity (a)	Area (ha)	Irrig requirement (m3/ha)	Constant A	Q* (mcm)
North Shouna	-0.3	13000	16153	146.267	209.89
Deir Alla	-0.3	10100	13861	97.56	140
South Shouna	-0.3	9900	15151.5	104.527	150

Notes: Based on the observed crop mix (Annex I); Agricultural Demand (m3) (Agricultural Area X Irrigation Requirement); Q quantity water for p*=0.3 JD, source: (Halaseh, 2015).*

Table 2.28 Area cultivated and sales/area from agricultural products (based on crop data Annex II)

district	summer crops	winter crops	permanent
Average cultivated area 2017-2021 in dunam			
north shouneh	3,928	71,558	75,175
south shouneh	2,836	75,793	6,503
Deir alla	5,370	102,894	6,886
area in dunam 2021			
north shouneh	1,784	3,953	62,789
south shouneh	1,500	24,016	20,000
Deir alla	7,000	51,510	18,000
sales per dunam	**average sales JD per dunam**		
north shouneh	87.607	106.360	113.118
south shouneh	77.036	96.694	55.282
Deir alla	71.727	101.820	63.638

Table 2.29 Sales for districts based on average production 2017-2021 (in JD)

district	crop sales	fruit sales	Total sales
Winter			
north shouneh	7,610,964	8,503,715	16,458,813
south shouneh	7,328,716	359,507	7,906,696
Deir alla	10,476,659	438,201	11,300,036
Summer			
north shouneh	344,134		
south shouneh	218,473		
Deir alla	385,176		

Weighted Average Agricultural Requirement					
Total Ag Area (DU)	6548	116492	11570	17662	108743
Total Ag Area (ha)	654.8	11649.2	1157	1766.2	10874.3
Total Ag Demand (m^3/yr)	3,037,115	58,585,303	5,340,796	7,863,311	63,357,715
Average Ag Requirement (m^3/ha)	4,638.23	5,029.13	4,616.07	4,452.11	5,826.37

Aggregate calculations: example from Halaseh

3 Water allocation in Israel and Palestine

We apply the combined model of both entities to compare the existing water allocation with the suggested optimal plan according to the model from an economic perspective. We also study the optimal development of infrastructure suggested according to the model results. The model is set to run for a 30-year planning horizon into the future, in which natural recharge is assumed to remain at the same level as the long-term annual average in the region at about 1,300 MCM/year. A discount rate of 3.5% (Nordhaus, 2007) is applied to bring all future costs and benefit accruing in the model's water economy to present value terms. Population growth predictions are adopted from the Israeli Central Bureau of Statistics (CBS), and a 1.8% annual growth rate is assumed. As an end condition, we mandate retaining a minimum of 5% of the extractable stock from each naturally enriched freshwater source.

3.1 Results

We start be describing the optimal plan suggested by the model results in terms of water allocation between the different sectors, water types, and geographical spread (figure 3.1).

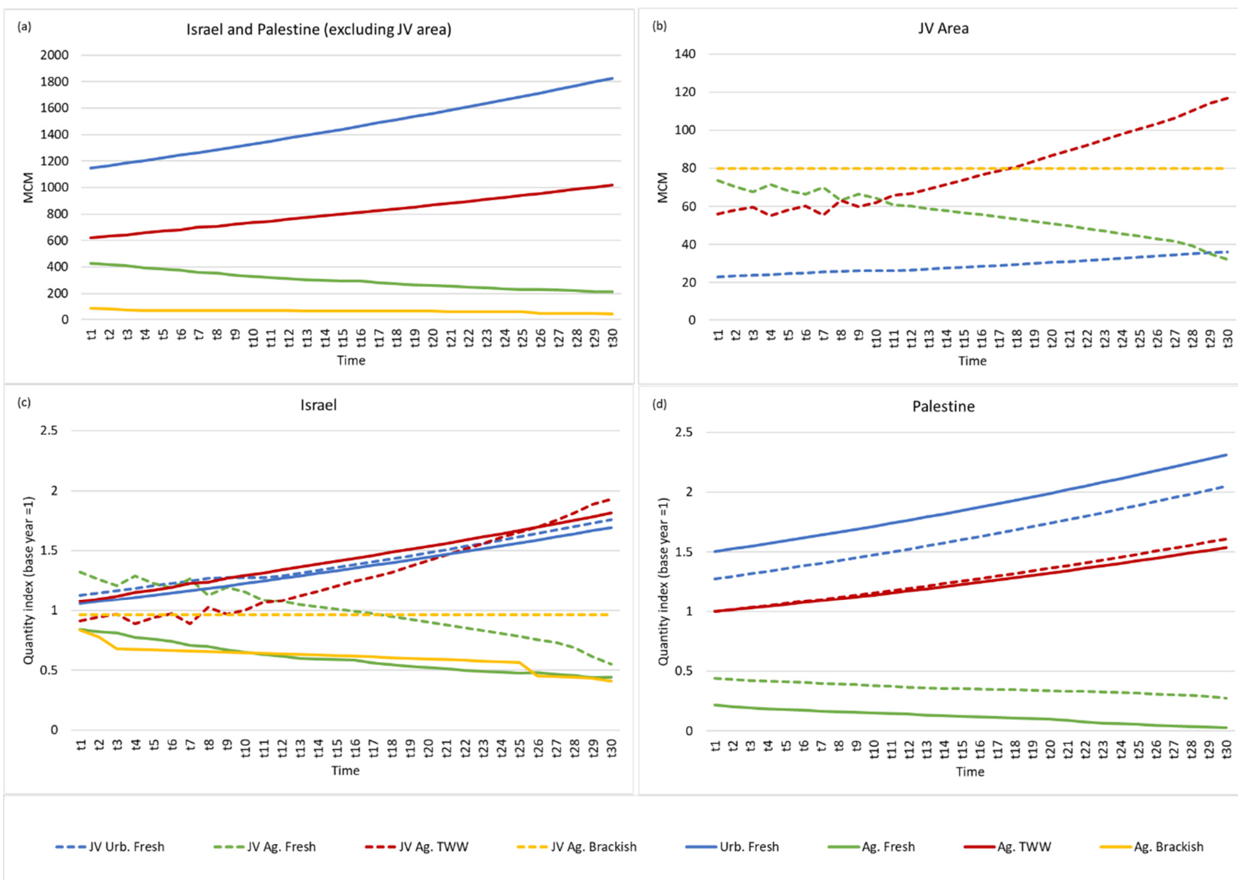


Figure 3.1 Optimal allocation of water types (Fresh, TWW-treated wastewater, Brackish) between users (Urb.-Urban, Ag.-Agriculture), and across regional diffrentiation (JV area and the rest of the region) and entities (Israel and Palestine): Total quantities allocated for Urban and Agricultural use outside the JV area (panel a) and in the JV area (panel b); Changes in

allocation compared to observed level of consumption in Israel (panel c) and Palestine (panel d). Note: In panel (d) for TWW in Palestine the first time-period in the model run is set to 1 becuse in the observed base year no TWW is consumed.

We note that the results are similar to previous applications of the model for Israel only (Reznik et al. 2017; Bar-Nahum et al. 2020). Propeled by populaion growth, quantities allocated to the urban sector are increasing with time, consequently generating larger availability of treated wastewater, which the model finds optimal to substitute for freshwater over time in irrigated agriculture (panels a and b). In general, quantities allocated to the urban sector are higher than observed, whereas for fresh water use in agriculture it is the opposite (panels c and d). The exception is for fresh water use in the JV area in Israel (panel c), where at the onset of the planing horizon the model warrnats 30% larger use of water with respect to the observed levels. Focusing on panels (c) and (d), it can be noticed that the rate of expansion in water consumption for the urban sector is similar across the region and in between entities. However, in Palestine allocated quntities in the JV area are of smaller proportions compaed to allocation to other Palestinian governorates. Interestingly, substitution rates between treated wastewater and fresh water in irrigated agriculture in the JV area for Israel are larger than those found optimal for the rest of the country (panel c). A similar, but much more moderate trend can be obseved in Palestne as well (panel d). This outcome implies that in the JV area the relative importance of treated wastewater for the sustainability of agricultural production grows with time more than for the rest of the region.

Figure 3.2 presents the optimal level of efficient economic prices as suggested by the model. These prices correspond to the optimal allocation presented in figure 3.1. It is implied that in a fully competitive water economy, setting water prices equal to the levels suggested by the model outcomes will results in the optimal allocation.

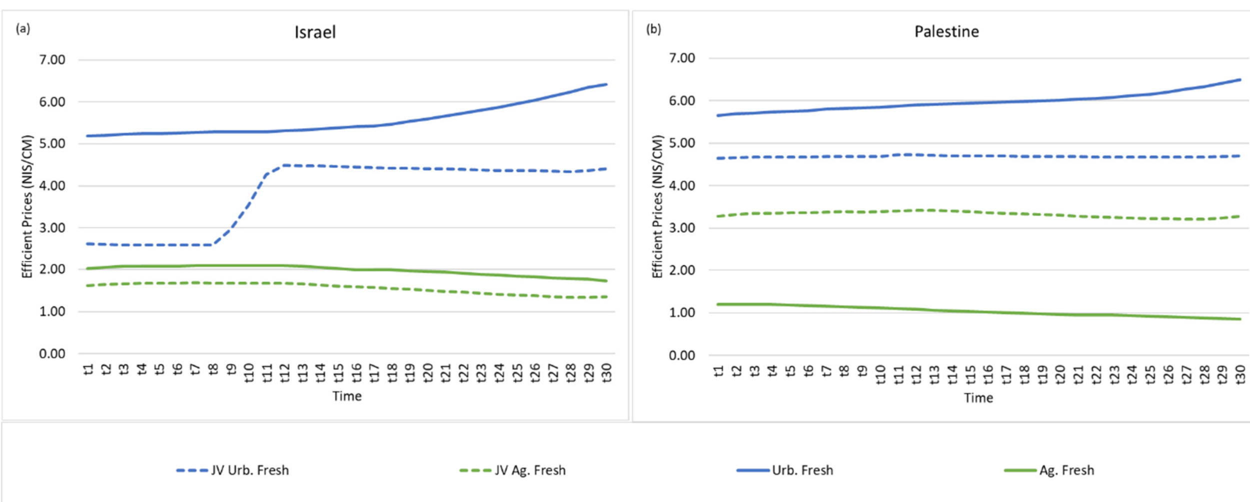


Figure 3.2 Weighted average of optimal prices for water in differet uses in the JV area and the rest of the region for both entities: (a) Israel; (b) Palestine. Note: For agriculture, a single price is presented, which is the VMP of fresh water use, but also of the total water consumed (of different types) in an agricultural region translated to fresh water equialents.

Focusing first on urban prices, we can observe a converging trend between entities and across the region. This is most prominent comparing urban use in Israel and Palestine outside the JV area, where at the onset of the planing horizon efficienct prices in Israel are lower than thse in Palestine, but at the end they are nearly identical. That convergence suggets that with time, all consumers in the region utilize similar supply, and therefore prices converge to the regional alternative cost of water. However, comparing the JV area effcient prices with the rest of the region a gap remains. This gap is primarily asserted to the assumed avaialbility of relatively cheaper surface water sources in that region. Focusing on Israel, an interesting block-rate trend is observed over time for the JV area (panel a). This is explained by the optimal composition of water sources used for supply in the region, which abraptly change approximately after one decade into the planning horizon (figure 3.2). In the agricultural sector there are observable differences between the two entities. In Israel, similarily to the urban sector, efficient prices in the JV are lower than for the rest of the country, whereas for Palestine it is the opposite. Also, it is prominent that prices outside the JV area are lower in Palestine than in Israel, however it is the opposite within the JV area. Time trend is slightly decreasing in both entities and across the region due to the substitution of (expensive) fresh water sources with (cheaper) treated wastewater. We assert the large differences in results for the agricultural sector to the miss-specification of brackish water avaialbility in Palestine, which we earlier acknowledged.

Figure 3.3 presents the changes in the composition of freshwater supply for the JV area over time to support and elaborate the differences in allocation and prices presented above in figures 6 and 7.

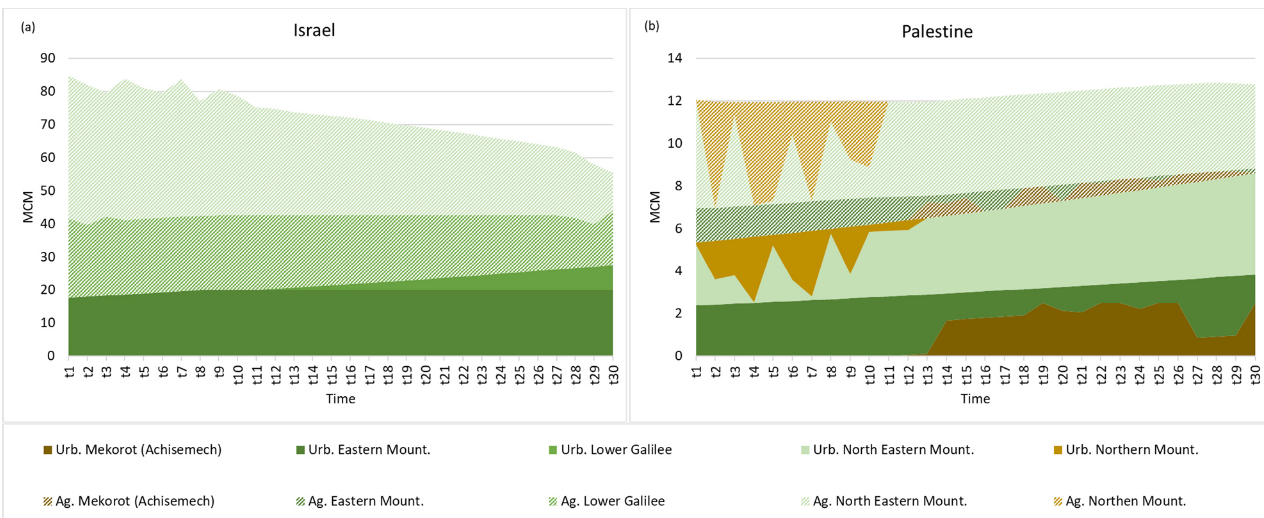


Figure 3.3 Optimal fresh water supply sources composition for urban and agricultural uses in the JV area for both entities: (a) Israel; (b) Palestine.

Observing the trends in supply for the JV area in Israel (panel a) supplies support for the step-wise trend in efficient prices (figure 6) for the urban sector discussed above. It can be noticed that approximately one dcade into the planning horizon the supply to the urban sector from the Eastern and North Eastern aquifers systems is supplemented by the Lower Galilee aquifer, which causes the costs to increase. In the agriculture sector, the earlier discussed decreasing trend in freshwater use is portrayed and it cn be observed that the North Eastern aquifer quantites are falling more sharply. In Palestine the picture is quite different (panel b). While in Israel total freshwater use decreases with time, it is increasing in the Palestinian JV area, however the quantities are substantially smaller in Palestine. Also, it can be noticed that the number of supply sources used is larger for Palestine. The reason for the latter, is that the Palestinian water systems are more localized, and it is assumed to remain the case within the current analysis, such that there are no inter-governorate transfers of water of any type. It can also be noticed that with time the composition of sources changes substantially for the Palestinian JV area. At the beginning of the planning horizon the Northern Mountain and the North Eastern Mountain aquifer systems replace each other intermitantly. This happens up to the point where it is no longer economically warranted to supply water from the Northern Mountain aquifer to the JV due to its higher alternative costs in urban uses in Israel and Palestine. A second trend is the increasing supply of water from the Israeli system through the Achisemech junction of Mekorot, which becomes larger in importance of the total water use in the JV area of Palestine.

3.2 Conclusions

The explicit inclusion of the Palestinian water system, its costs and limitations as well as the Palestinian consumers' preferncces does not change the qualitative model outcomes significantly, compared to previous results for the Israeli water economy alone. However, it is insightful because it explicitly portrays the allocation of different water types between competing uses in both entities, and also presents important information regarding spatial differences between the JV area and the rest of the region. The results presented are priliminary and suggest a first starting point with respect to future analyzed scenarios for the JV area and the region as a whole.

4 Water allocation in Jordan

4.1 Previous models: Scenarios, output and discussion

A. Managing the Deficit and considering Future Scenarios and corresponding results of WEAP model (Hussein et al., 2009). Jordan Valley suffers from the scarcity of water that could be allocated for irrigation and domestic purposes and this situation is expected to continue; therefore a number of conventional and non conventional water supply scenarios considered as suggestions for bridging the deficiency, these are:

1. The treated wastewater of three treatment plants in the North regions (Irbid, Duqarra, and Wadi Hassan) to be used in the future for irrigation practices
2. Raise the efficiency in the irrigation practices in the Jordan Valley by 10%.
3. Using 50 MCM from the Unity Dam to cover Amman city domestic demand.

With respect to relevance for future water use and/or availability in the Jordan River region; WEAP examined and implemented three Scenarios, to carry and calculate options which assist Decision Makers in finding alternative or enhancing water plans. Results were promising and prove that WEAP can be used efficiently and effectively for the case of JV and other similar cases in the region.

*From the **purely technical viewpoint*** (quantity and quality), adaptation of supplying the system with 50 MCM of fresh water from the Unity Dam proved to be the best scenario. Raising the efficiency at the irrigation facilities will increase the available water and scale down the unmet fraction by 10% was the second option. Utilization of the treated wastewater in the north will add 15-20 MCM/year to the system but certain but ranked technically as the third.

With the application of the unit costs (**economic viewpoint**), the reuse of treated wastewater was selected as the first, raising the efficiency is the second and the Unity Dam is the third. With considering the necessary precautions to avoid any blending of the treated water with the fresh water before reaching the point of pumping the KAC fresh water to Amman for domestic uses, the reuse option is the first option. A separate water irrigation system can be introduced to separate the fresh from treated wastewater.

Base case scenario: existing system in terms of water efficient allocation

B. Shadow values are significant outputs of the Hydrologic-economic model which can be evaluated for any constraint imposed on the system (MYWAS, Halaseh, 2015). The shadow values reflect the change in system wide net benefits if the particular constraint of concern were relaxed by one unit.

The system wide current operations are leading to depletion of existing groundwater aquifers. We estimate current groundwater pumping is and its sustainable limits. The shadow value on domestic water supply is extremely high (between 1 – 5 JD/m3) which indicates alarming water scarcity for domestic users. Yet, on the other hand, the model indicates very low shadow values for agricultural demand points, which highlights the inefficient water use in the agricultural sector.

4.2 MYWAS stylized model by Ecofuture – preliminary results

The basic version of MYWAS fed by data presented in the previous sections results in quantities of water demand for urban districts, surpluses from urban and agricultural uses and costs of pumping, treatment and transmission of water from supply to demand nodes, as well as shadow prices related to the demand and the pipeline connections as shown below. The model enables investigation of demand increases, reduction of system losses, limitation of non-revenue consumption, improved efficiency in irrigation by crop and district as well as increase in water availability resulted from technological advances.

Table 4.1 Urban water consumption and value at the optimal solution

	North ShounaU	Amman (Zai station) U	Deir AllaU	South ShounaU
qu water used in urban	11.971	65.120	11.557	11.873
lUrb tot benefit urban demand	20.084	40.538	20.200	18.927
average price water urban	1.678	0.623	1.748	1.594
shadow price at urban areas	0.625	1.095	0.632	0.614
	Northern KAC_J	Southern KAC_J		
shadow price at NWC junction	0.635	0.71		

Table 4.2 Agricultural consumption and related values at the optimal solution

	North ShounaAg	Deir AllaAg	South ShounaAg
qa water used in agriculture	55.237	33.652	32.379
lAgb tot benefit from agr products	-8.633	-3.667	-6.241
shadow price of water in agriculture	1.095	1.170	1.170
water for irrigation value	6.628	4.038	3.885
value of production (sales)			
winter crops	0.420	5.245	2.322
summer crops	0.156	0.502	0.116
Orchards	6.787	1.145	1.106

Table 4.3 water transfers through networks nodes

Q water tranferred between two junctions	Northern KAC_J	Southern KAC_J	North ShounaUM	Amman (Zai station) UM	Dayr AllaUM	South ShounaUM	North ShounaAg	Dayr AllaAg	South ShounaAg
Al Wehdah dam FS	23.29								
Tiberias FS	48.32								
Kufranja dam FS	7.16								
Yamouk/Wehdah FS	23.29								
Northern KAC_J				65.12			55.24		
Southern KAC_J								33.65	32.38
Kufranja TP		3.4							
As Samra TP		41.03							
Al Baqaa TP		7.8							
As Salt TP		4.8							
Fuheis Mahes TP		3.5							
Wadi Al Seer TP		5.5							
Wadi Al Arab GW			4.2						
Tabaqet Fahel GW			4.5						
Mkaimnat-Kraimeh GW			3.191						
As Samaheyat GW					2.84				
Wadi Rajieb GW					2.805				
Private Wells GW						1.473			
Zara Maeen GW						4.4			
Al Kafrain GW						6			
Al Mukhaibeh GW	18.3								
North_SouthKAC					5.39				

Table 4.4 water network operation and conveyance cost

	aggregate JV
total conveyance cost	160.072
total pumping cost	22.441
total treatment cost	14.042

Table 4.5 Value of water transfers through the network (shadow values at the optimum)

shadow price for pipeline capacity

	Northern KAC_J	Southern KAC_J	North ShounaUM	Amman (Zai station) UM	Dayr AllaUM	South ShounaUM	North ShounaAg	Dayr AllaAg	South ShounaAg
Al Wehdah dam FS	0.336								
Kufranja dam FS	0.338								
Yamouk/Wehdah FS	0.353								
Northern KAC_J				Eps			Eps		
Southern KAC_J								Eps	Eps
Kufranja TP		0.09							
As Samra TP		Eps							
Al Baqaa TP		0.11							
As Salt TP		0.12							
Fuheis Mahes TP		0.1							
Wadi Al Seer TP		0.1							
Shaq Al Bared GW			0.014						
Wadi Al Arab GW			0.327						
Mkaimnat-Kraimeh GW			Eps						
As Samaheyat GW					0.021				
Wadi Rajieb GW					Eps				
Zara Maeen GW						0.01			
Al Kafrain GW						0.312			
Al Mukhaibeh GW	0.48								
North_SouthKAC					0.147				

5 Summary and synthesis

The existing conditions of WEFE resources, and water in particular within the region, and in the JV area specifically, as well as the challenges associated with their sustainable use over time call for the examination of existing practicies and policies and future development plans. In this context, economic analysis tools have proven to be efficient in infroming policy design processes, as they carry unique insight on the costs and benefits to the population of alternative strategies and potential implemented practices. The MYWAS model is a hydro-economic non-linear dynamic optimization framework, which was originally developed within the context of Jordan, Israel and Palestine to support efficient mangement of water resources across the entire region by emphasizing the economic benefits associated with regional water system integration. In the passing decade this model was used to investigate various issues related to water managment policies through representation of the Israeli water economy alone. Within the scope of the EcoFuture project this model was further extended to include Palestine (both West Bank and Gaza), and as was earlier mentioned, initial efforts to develop the model for Jordan started by focusing first on the JV area of interest within Jordan.

While the model developed for the JV area in Jordan is very preliminary, results from initial trials demonstrate large differences in economic values of water between domestic and agricultural uses and across the landscape of this area. The analysis of Israel and Palesine combined points to several interesting insights as well. It is demonstrated that substitution of freshwater with treted wastewater in irrigated agriculture is an efficient strategy from a regional perspective. It is implied that treated wastewater reuse, which is already being practiced in Israel in large scale should also be adopted in Palestine. This strategy should help relieving some of the pressure on the region natural water resources, but also potentialy to support additional irrigation demand in the region, and specificaly in the JV area. With respect to the latter, the results of the analysis also provide evidence that within the existing conveyance system limitations, the importance of treated wastewater reuse for irrigation of agricultural crops is higher in the JV area compared to other areas in the region, on average. Finally, the comparison of trends in economic values across competing uses, geographical definitions (JV area, the rest of the region) and between entities, suggest that there are regional economic gains assoicated with higher system integration in the future.

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ANNEX I

Table 1. Water quality types

Water Type	Concentration (PPM)	Dissolved Solids (TDS)
Drinking Water	<1000	< 50
Low Salinity Brackish Water	1000-3000	500–3,000
Brackish Water	3000-10000	1,500–15,000
High Salinity Water	10000-35000	
Seawater	35000+	15,000–50,000

Table 2. Energy requirements for desalinization

	SEC [kWh/m³]		
Salinity	**Recovery = 30%**	**Recovery = 60%**	**Recovery = 70%**
5000ppm (Theoretical)	0.13	0.16	0.18
5000ppm (Measured)	0.29	0.30	0.31
3500ppm (Theoretical)	0.09	0.11	0.13
3500ppm (Measured)	0.26	0.28	0.29
2000ppm (Theoretical)	0.052	0.064	0.074
2000ppm (Measured)	0.22	0.24	0.27

Source: Staniforth & Davies (2018)

Cost of water (production and transmission) and calculations (source: Halaseh, 2015)

Table 3. Unit Cost of Water for the Major Water Systems in the Northern Governorates.

	Cost JD/m³*		
System	**Production**	**Transmission**	**Total**
East well fields (Aqeb, Zatary)	0.22	0.13	0.35
West well fields (Wadi Arab, Tabget Fahel)	0.09	0.46	0.55
**Cost is based on unsubsidized electricity cost (0.167 JD/kWh)*			

Table 9. Water transmission Energy and Cost for the Major Facilities in Northern Governorates

From	To	Length	DN	Delta H	Q	Velocity	Headloss	Total Head	Power	Unit pumping cost	Annual pumping cost
		m	mm	m	m^3/h	m/s	m	m	kW	JOD/m^3	JOD
Wadi Arab PS0	Wadi Arab SP1	8000	600	200	765	0.75	9.68	209.68	672.46	**0.146**	977,866
Wadi Arab SP1	Wadi Arab SP2	4500	800	200	2245	1.24	9.85	209.85	1,975.01	**0.146**	2,871,980
Wadi Arab SP2	Wadi Arab SP3	11000	800	200	2245	1.24	24.07	224.07	2,108.86	**0.156**	3,066,614
Wadi Arab SP3	Zubdah	10000	800	200	2245	1.24	21.88	221.88	2,088.26	**0.154**	3,036,670

Transmission from Waste Water Treatment Plants to Agriculture

Table 13. Return Flows from Wastewater Treatment Plants

WWTP	Destination Name	Capacity (MCM/year)	Transfer Cost (JD/CM)
Jerash East WWTP	IR Jordan Valley	2	0
Jerash West WWTP	IR Jordan Valley	4	0
Kufranja WWTP	Ajloun Agriculture	31.7075	0
	WWeff Kufranja	0.6935	0
Irbid Central WWTP	Jordan River	1	0

ANNEX II : Agriculture in the area of study
Data input tables by crop and region
Agricultural land (DU)

- Winter Crops: Add Winter and Summer crop

Year	District	Beans production/ton	Beans area /du	Pepper production/ton	Pepper area /du	Cucumber production/ton	Cucumber area/ du	Squash production/ton	Squash area /du	Eggplant production/ton	Eggplant area/ du	Tomato production/ton	Tomato area /du
2017	North Shouneh	425	425	900	900	0	0	8100	2700	3900	1300	0	0
2018		425	425	900	900	0	0	8100	2700	3900	1300	4200	1600
2019		0	0	402	402	538	538	0	0	712	712	1272	636
2020		**100**	**100**	**0**	**0**	**748**	**741**	**0**	**0**	**519**	**519**	**696**	**438**
2021		0	0	520	480	0	0	550	550	1500	500	2400	600
2017	South Shouneh	315	450	477	265	98	65	8252	4126	48500	9700	22725	5050
2018		255	101	4927	1911	0	0	18727	7593	18572	7002	21968	3494
2019		50	25	750	300	767	589	0	0	12987	4329	21520	4304
2020		**180**	**300**	**0**	**0**	**1767**	**589**	**0**	**0**	**15000**	**5000**	**26150**	**5230**
2021		1000	1000	0	1000	0	0	10000	4000	16000	4000	4250	850
2017	Dearalla	500	600	1500	2100	0	0	18000	6000	6000	1500	3400	850
2018		470	470	6695.5	1913	0	0	24586	8153	16907	1537	10200	1200
2019		900	450	3000	1500	3600	1800	0	0	8800	4400	2800	1400
2020				**0**	**0**	**6600**	**3300**	**0**	**0**	**8800**	**4400**	**2800**	**1400**
2021		90	90	2400	1200	0	0	3500	1500	2800	1400	2100	700

Year	District	Onion		Potato		Peas		Green Beans		Cabbage		Cauliflower	
		ton	Du	ton	Du	ton	du	ton	du	ton	du	ton	du
2017	North Shouneh	2900	1450	33750	5640	0	0	500	500	5200	1300	7500	1500
2018		2900	1450	33750	5640	0	0	500	500	5200	1300	7500	1500

2019		0	0	152570	4302	90	90	267	267	0	0	1614	538
2020		**1110**	**370**	**560**	**140**	**0**	**0**	**169**	**169**	**0**	**0**	**1032**	**344**
2021		0	0	17300	4300	50	50	250	250	0	0	1350	450
2017	**South Shouneh**	750	300	1400	350	0	0	503.5	671	1890	420	2000	500
2018		1588	488	693	291	0	0	688	425	6067	975	6786	2000
2019		660	2220	3252	813	0	0	826	413	4820	1205	5109	1703
2020		**2000**	**500**	**4065**	**813**	**0**	**0**	**2000**	**1000**	**4820**	**1205**	**6812**	**1703**
2021		2500	500	5000	1000	0	0	750	1000	9000	3000	7500	3000
2017	**Dear alla**	4500	3000	4500	15000	450	300	3000	2500	3000	2000	3000	1500
2018		6575	2630	54160	13540	0	0	3345	2230	3270	1090	2910	970
2019		5700	1900	54160	13540	0	0	1800	900	3270	1090	2100	700
2020		**5700**	**1900**	**54160**	**13540**	**0**	**0**	**1800**	**900**	**3270**	**1090**	**21000**	**700**
2021		4500	1500	37500	12500	500	500	1200	1200	2200	1100	2600	1200

Year		Spinach		Radish		Turnip		Lettuce		Carrot		Garlic	
	District	**ton**	**Du**	**ton**	**du**	**ton**	**du**	**ton**	**Du**	**ton**	**du**	**ton**	**du**
2017	**North Shouneh**	1950	650	3200	800	2800	700	244	244	928	232	0	0
2018		928	232	1950	650	3200	800	2800	700	244	244	928	232
2019		76	38	216	108	4525	181	5869	391	0	0	30	30
2020		**0**	**0**	**0**	**0**	**0**	**0**	**150**	**75**	**0**	**0**	**68**	**34**
2021		**200**	**100**	**750**	**250**	**300**	**100**	**500**	**250**			**60**	**30**
2017	**South Shouneh**	0	0	0	0	120	60	2700	1350	130	65	0	0
2018		1004	197	221	47	1512	327	395	85	1561	388	1004	197
2019		0	0	615	205	0	0	186	930	405	135	0	0
2020		**0**	**0**	**615**	**205**	**0**	**0**	**4000**	**2000**	**750**	**250**	**0**	**0**
2021		**200**	**200**	**2000**	**500**	**0**	**0**	**1500**	**1000**	**1500**	**500**	**0**	**0**
2017	**Dear alla**	0	0	3500	2500	0	0	2500	5000	4000	2000	250	150
2018		77	18	1436	321	842	187	27143	6379	6927	1433	200	100
2019		20	20	240	80	150	50	9000	4500	4200	1400	200	100
2020		**20**	**20**	**240**	**80**	**150**	**50**	**9000**	**4500**	**4200**	**1400**	**200**	**100**
2021		**100**	**100**	**800**	**400**	**800**	**400**	**3500**	**3500**	**3000**	**1500**	**800**	**400**

-Summer Crops:

Year	District	Pepper		Cucumber		Squash		Eggplant		Tomato		Melon		Okra	
		ton	Du	ton	du	ton	du	ton	du	ton	Du	ton	du	ton	du
2017	North Shouneh	850	470	1500	770	3400	2060	7500	2250	15000	5910	75	25	600	485
2018		705	470	2400	800	4300	2150	9000	2250	29550	5910	150	25	390	390
2019		1928	1928	0	0	1771	1181	3567	1189	4920	1640	4740	948	894	894
2020		1928	1928	0	0	1771	1181	3567	1189	4920	1640	4740	948	894	894
2021		1928	1928	0	0	1771	1181	3567	1189	4920	1640	4740	948	894	894
2017	Deiralla	0	0	0	0	0	0	0	0	0	0	0	0	875	700
2018		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019		0	0	0	0	0	0	0	0	0	0	0	0	4000	2000
2020		0	0	0	0	0	0	0	0	0	0	0	0	4000	2000
2021		0	0	0	0	0	0	0	0	0	0	0	0	2160	1080
2017	South Shouneh	0	0	0	0	1200	480	31200	7800	4000	1400	4960	1350	120	240
2018		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2020		75	300	0	0	0	0	12000	3000	5000	1000	3200	800	350	500
2021		450	300	0	0	0	0	4000	1000	4000	1000	5000	1000	500	1000

Year	district	Cauliflower		beans		molokhia		Lettece		Onion		Potato		spinach	
		Ton	Du	ton	du	ton	du	ton	du	ton	du	ton	du	ton	du
2017	North Shouneh	0	0	2000	2380	85	45	0	0	120	40	750	300	0	0
2018		0	0	4360	2180	390	130	0	0	180	60	2400	400	0	0
2019		1266	422	882	882	0	0	0	0	846	423	0	0	85	57
2020		1266	422	882	882			0	0	846	423	0	0	85	57
2021		1266	422	882	882	0	0	0	0	846	423	0	0	85	57
2017	Deiralla	0	0	0	0	2000	1000	4180	2090	0	0	0	0	0	0
2018		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019		0	0	0	0	3000	1500	0	0	0	0	0	0	0	0

2020		**0**	**0**	**0**	**0**	**3000**	**1500**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2021		**0**	**0**	**0**	**0**	**2000**	**1000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2017	**South Shouneh**	0	0	0	0	3300	1650	0	0	0	0	0	0	50	50
2018		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2019		0	0	0	0	0	0	0	0	0	0	0	0	0	0
2020		**0**	**0**	**0**	**0**	**17500**	**7000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
2021		**0**	**0**	**0**	**0**	**6000**	**3000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Citrus

Year	District	Citrus ton	area /du
2017	North Shouneh	223997	154068
2018		114196	35234
2019		151658	60289
2020		151658	60289
2021		151658	60289
2017	South Shouneh	13700	6100
2018		759	907
2019		907	907
2020		812	826
2021		1250	1000
2017	Deiralla	0	3260
2018		2827	2472
2019		4195	2470
2020		4720	2520
2021		5830	3000

Date palm

Year	District	Date palm ton	area/du
2017	North Shouneh	736	2000
2018		no data	500
2019		no data	354
2020		33750	354
2021		3750	2500
2017	South Shouneh	0	0
2018		no data	0
2019		no data	776

2020		18432	3000
2021		19000	19000
2017	Deiralla	1300	3707
2018		no data	0
2019		no data	2000
2020		13189	0
2021		22500	15000

Project Coordinator

Project Partners