DECOUPLING NATIONAL WATER NEEDS FOR NATIONAL WATER SUPPLIES:
Insights and Potential for Countries in the Jordan Basin

West Asia-North Africa Institute, June 2017

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Abbreviations

CBS	Israeli Central Bureau of Statistics
GDP	Gross Domestic Product
JD	Jordanian Dinar
JV	Jordan Valley
JVA	Jordan Valley Authority
KAC	King Abdullah Canal
MCM	Million Cubic Meters
MENA	Middle East and North Africa
MWI	Jordanian Ministry of Water and Irrigation
NCARE	National Centre for Agricultural Research and Extension
NIS	New Israeli Shekel
NRW	Non Revenue Water
OECD	Organisation of Economic Cooperation and Development
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
WAJ	Water Authority of Jordan

Executive Summary

This report analyses and compares the water allocation and management experience of Jordan, Palestine and Israel using the lens of economic and resource decoupling to highlight past trends and future potential for jurisdictions in the region to circumvent limits on natural water resources. Like most Middle East economies, Jordan and Palestine face extreme water scarcity and potential food insecurity. These conditions are increasingly seen as threats to human security and to the natural environment. Israel, which shares a similar geography, has adopted a combination of policy and technological interventions that have allowed it to largely overcome such pressures, become a leader in irrigated agricultural production and enjoy a version of sustainable water and food security. In economic terms, Israel has been able to 'decouple' its economic and social[1] water demands from its internal water resource availability. In terms of water productivity, Jordan likewise, has identified agricultural methods by which it achieves regionally unmatched levels of productivity for certain specific crops. The extent to which these good practices — effective allocation and management of water resources, water ecosystem stewardship, and economic, social and environmental decoupling — can be transferred between these countries, as well as to other economies that share similar environmental endowments is the subject of this research.

We examine and compare decoupling trends in Jordan, Israel and (within data limitations) Palestine. From this, we gauge the potential scope for decoupling with a view to decreasing pressure on water resources, increasing agricultural water productivity and allowing new and existing water resources to be prioritised for more economically productive uses. The approach begins with a secondary-data analysis of economic and population growth trends, food production, and agricultural water needs. From this, the potential water productivity gains from increased effluent reuse and the adoption of agricultural best practices is calculated, focusing on 14 key crops. Scenario modelling is then used to understand the potential volumetric gains that could be realised through maximised decoupling. Observations from farm-level interviews are used to verify the national assessment at directly comparable local levels, and provide data on different knowledge pathways and concerns within the agricultural communities of Palestine, Jordan and Israel.

The analysis suggests that improved agricultural productivity could potentially reduce water consumption by up to 168 Million Cubic Metres (MCM) per year in Jordan (approximately 33 per cent of current agricultural water consumption). Strategic import substitution could add an additional 52.5 MCM/year to the volume of water consumed in agriculture, and a further 140 MCM/year could be mobilised through enhanced effluent reuse. In Palestine, major advances in agricultural water productivity could be realised, particularly in olive, eggplant, tomato and cucumber production, through the adoption of regional best practices, in addition to 115 MCM/year if treated wastewater could be substituted for freshwater.

In the light of these findings, we consider what changes in the regulatory framework, water infrastructure and agricultural practice would be required to realise these gains as well as the political, social and institutional barriers that would have to be overcome. We also assess how

[1] Social water use includes domestic water needs, and associated non-economic uses including medical and educational water use. Economic water use includes industrial water needs, and water use for the tertiary sector, including offices and other economic activities (including tourism).

enhanced decoupling would complement (or disrupt) current and planned initiatives geared towards enhancing Jordan's water supply. Finally, we evaluate opportunities to promote decoupling in Jordan, including options for enhanced agricultural and livelihoods investment, knowledge sharing and best practice uptake, and improving policy coordination to realise simultaneous advantages in water and agriculture. Analysis for Palestine, although limited due to data constraints, includes an assessment at the crop level of improved water productivity, and farmer knowledge networks.

We present our findings in four sections. Section 1 explains and extends the development of water resource decoupling theory. Section 2 sets out water policy and existing decoupling trends in Israel (updated from previous work by Gilmont)[2] and in Jordan, and reviews available data for Palestine. Section 3 quantifies potential gains through enhanced decoupling in Jordan and models the impact of decoupling on future water resource scenarios. Section 4 compares the national assessments set out in Section 3 with farm-level interview data on water productivity, confirming the trends in water productivity for a number of crops, and highlighting crops where further research is necessary. The section also examines the agricultural and political opportunities and challenges to enhanced water resource decoupling in Jordan. To the extent possible, areas of decoupling potential in Palestine are identified and possible savings for selected crops are quantified. Section 5 presents results of scenario modelling for enhanced decoupling in Jordan, and demonstrates how decoupling can contribute to future water security. Section 6 sets out the conclusions and outlines future research and pilot implementation.

[2] Michael Gilmont 2014. Decoupling dependence on natural water: Reflexivity in the regulation and allocation of water in Israel. *Water Policy* 16 (1): 79-101.

1. Water Resource Decoupling: Theory and Exemplification

1.1 The Concept of Decoupling

Resource decoupling — the idea that economic growth can be realised without a reciprocal increase in growth in natural resource consumption and environmental impact — has become a key concept in the global discourse on natural resources management.[3] [4] [5] [6] In 2011, UNEP developed a model centred around two mechanisms of decoupling. The first, 'Resource Decoupling' occurs when resource consumption increases at a slower rate than economic growth, resulting in a reduction in relative resource intensity per unit of economic output. The second, 'Impact Decoupling' takes place when the environmental impact of economic growth through resource consumption is reduced or eliminated through changed behaviour, such as the use of renewable rather than fossil energy sources. Decoupling of both types can be absolute, namely a reduction in resource use or impact in the context of continuing growth, or relative growth, whereby resource consumption continues to grow, but impact per unit of economic activity declines.[7]

While this model is useful for understanding the global use and consumption of, and impact on, finite resources, such as minerals and fossil energy resources, it has limited application for conceptualising how economies can manage limited natural freshwater resources.[8] At this point it is important to highlight the condition that unlike other finite resources, freshwater at a global scale *is* a renewable resource, as well as a sufficient resource.[9] [10] [11] Thus, while individual countries and regions may be water-scarce, sufficient resources exist at the global level. UNEP's conceptualisation of impact decoupling does not apply to situations where a country 'externalises' its resource consumption, and therefore mitigates domestic natural resource impacts, by importing essential commodities. However, importing food, especially water-intensive food from water-abundant areas, is an acceptable and strategic means of circumventing local national water resource

[3] Tim Jackson, 2009. *Prosperity without growth: Economics for a finite planet*. London: Earthscan
[4] OECD 2001. *Decoupling environment from economic growth.* Paper presented at OECD forum 14 May 2001: The transition to Sustainable Development: are we making progress in Decoupling Economic Growth from Environmental Degradation.
[5] UNEP 2011. *Decoupling natural resource use and environmental impacts from economic growth. A report of the working group on decoupling to the international resource panel.*
[6] UNEP. 2012. *Measuring water use in a green economy. A report of the working group on water efficiency to the international resource panel*
[7] UNEP 2011 ibid.
[8] In this document, the term 'natural freshwater' or 'natural water' is used to refer to any water resources derived from the natural environment that can be productively for social, economic or agricultural uses without desalination. This includes surface and renewable and non-renewable groundwater, and moderately saline resources that are successfully used in agriculture either on their own or through blending with fresh water.
[9] Ulris Baldos, Lantz C., and Thomas W. Hertel. 2016. Debunking the 'new normal': Why world food prices are expected to resume their long run downward trend. *Global Food Security* 8 : 27-8.
[10] Baldos, Uris Lantz C., and Thomas W. Hertel. 2015. The role of international trade in managing food security risks from climate change. *Food Security* 7 (2): 275-90.
[11] Gilmont, Michael. March 2016. *Analysing the economic development impact of semi-arid lands, and mitigation by food-trade water resource decoupling.* ODI PRISE Working Paper.

limits. Moreover, where imported crops are rain-fed rather than irrigated and substitute for domestic irrigated crops, these imports *reduce* the global use of freshwater resources.[12]

A further limitation of the UNEP model concerns desalination and recycled water resources. In absolute terms, these new sources of supply bring about an increase in water resource availability. Additionally, the fossil fuels consumed in treating desalinated or recycled water result in a new environmental impact on the global environment, and with it, possible changes in rainfall and long-term water resource distribution. For the generally sun- and land-rich Middle East, energy-related impacts are arguably a result of national and regional energy policies and financing, rather than an inherent result of alternative water production. From the perspective of the natural freshwater environment, recycling and desalination provide an effective means to circumvent water resource limits and allow past over-abstraction of natural freshwater to be redressed. Conceptualising these management strategies within the UNEP decoupling framework, would see desalination, recycling and food imports as both additional resources and additional impact, which masks the ability of these strategies to significantly reduce pressure on national natural freshwater supplies in water-scarce regions.

The above discussion makes clear that resource and impact decoupling is complex and, as with many water management challenges, involves factors outside the water sector.[13] It also reveals that the classic decoupling concept lacks the analytical power needed to address national water scarcity within the context of a water-sufficient world. The robustness of the decoupling theory, however, suggests that a water-specific decoupling model does have great potential. Such a model would present a framework through which to test the interconnections between, and knock-on effects of, different policy choices and technical approaches, with a view to identifying the most strategic approach that balances the sectoral consumption of natural water resources.

To address this policy challenge Gilmont[14] developed a water decoupling model, built around the notion that (i) food trade and (ii) water recycling/desalination were modalities with which a country could 'decouple' its population's water needs from national water resource consumption. This model was further refined by Gilmont[15] [16] to take into account the importance of (iii) economic diversification that led to water consumption being moved to sectors where the economic return on water was highest — commonly referred to as increasing 'dollar-per-drop'. A final decoupling mechanism is added in this research, namely (iv) agricultural-water use productivity, whereby the volume and value of crop production grow with constant or reduced agricultural levels of water consumption. These four decoupling mechanisms (food trade; water recycling and desalination; economic diversification; and agricultural-water use efficiency) are presented in Figure 1 below, and are applied to Jordan and Israel in the following section.

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[12] Marta Antonelli, Michael Gilmont, and Roberto Roson. 2012. Water's green economy: Alternative pathways for water resource development in agriculture. *L'Europe En Formation* 365 (Autumn 2012): 23-47.

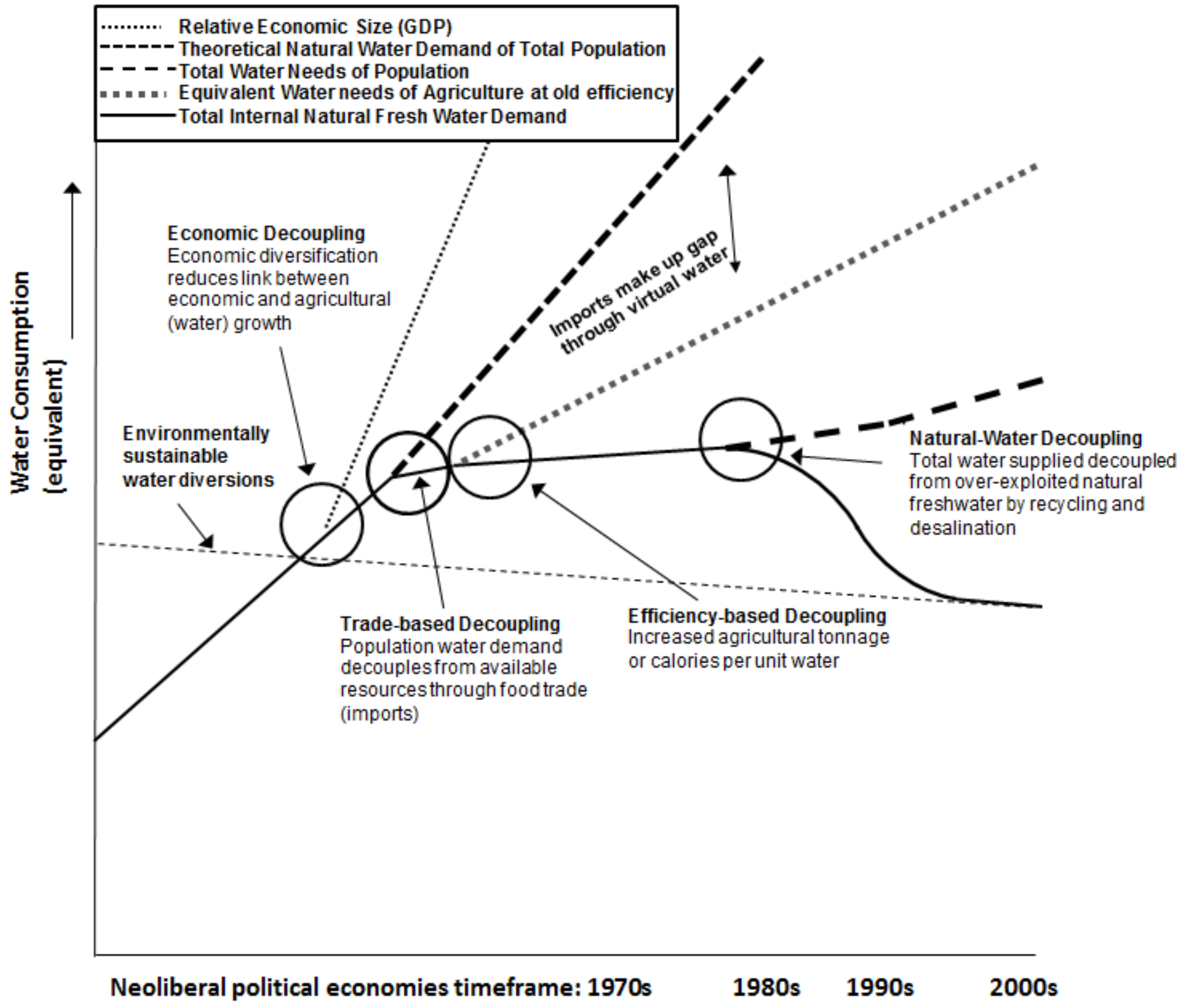
[13] John Anthony Allan, 2013. Food-water security: Beyond water resources and the water sector. In *Water Security: Principles perspectives practices.* eds. Bruce Lankford, Daren Bakker, Mark Zeitoun and Declan Conway, 321-335. Earthscan: London.

[14] Gilmont 2014. Decoupling dependence on natural water

[15] Gilmont 2015. Drivers of food trade: Water resource decoupling in the MENA as a mechanism for circumventing national water scarcity. *Food Security* 7 (6): 1113-31.

[16] Gilmont, 2016. *Analysing the economic development impact*.

Figure 1: Revised Water Resource Decoupling Model (Developed from Gilmont 2014, 2015), Incorporating Four Mechanisms of Decoupling.[17]



Decoupling Mechanisms:

Food-trade decoupling: States can meet the food needs of a growing population more efficiently by importing water-intense foods, rather than producing them domestically.

Water recycling/desalination decoupling: An economy can maintain, or even grow, total water supply while reducing freshwater offtake from the natural environment through recycling and desalination.

Economic decoupling: Pressure on water resources is reduced by redirecting economic activity away from agriculture into less water-intensive activities.

Agricultural-water use efficiency decoupling: The adoption of technological and management advancements can increase agricultural production while using the same amount of water.

[17] Note that environmentally sustainable water diversions are characterised as being in decline, reflecting observed rainfall in many semi-arid areas during the 20th century.

The imperative of maximising returns on scarce water resources has led to these decoupling mechanisms being adopted in many water-scarce countries. Indeed, economic decoupling is now practised almost universally where water is a limited factor of supply.[18] Moreover, the existence of a sophisticated and generally reliable international food market has ameliorated the disadvantages once associated with a country not being self-sufficient in food production.

1.2 The Water Decoupling Model

The key mechanisms of the Water Decoupling Model are explained in more detail below:

- *Economic decoupling*: Greater returns per unit of water can usually be obtained in the industrial and service sectors compared to the agricultural sector. Focusing on growth in these areas thus results in a less water-intensive national economic output (dollar/drop), and ensures that such growth is less constrained by the need to mobilise additional freshwater. Reducing the imperative for agriculturally-driven economic growth also creates greater scope to increase proportional allocations to the domestic sector, and with this improved quality of life, economic and social development.
- *Food-trade decoupling*: Where national food security is met through domestic supply, population growth will necessitate a commensurate increase in agricultural production, and with this, water resource use. A direct competition also exists between the water needed for the domestic and industrial sectors, and the water needed for food production. In situations of extreme water scarcity, this will be impossible. One way to overcome this tension is to import food, and hence 'virtual water', thus increasing the economy's total water supply. Virtual water[19] is the water required to grow a crop that is then imported (as the crop's water requirement does not need to be met in the country where the calorific benefit is realised). Since the 1970s, many Middle East countries have increased their dependency on food imports, developing significant and complex economic and logistical links with the global food market, without posing an overt or significant threat to national security above other forms of global market exposure (including energy and finance).
- *Agricultural-water use efficiency decoupling*: This modality of decoupling enables agricultural production to increase within the limits of existing water supply volumes, or in some cases allows production to increase with a reduction in water supply to agriculture. Investing in improved agriculture water productivity, and with it new technical, education and institutional capacity, nullifies the need to develop new volumetric resources that would otherwise be required to increase food output. Water productivity investments can also act to stimulate the rural economy and encourage the growth of industries and expertise that supports productivity improvement.
- *Water recycling/desalination (natural water) decoupling*: In a water-scarce environment, where existing natural resources are already being used beyond their sustainable yield, natural water decoupling can be an important instrument to move towards restoring sustainable offtake, while maintaining or enhancing overall volumes of national water supply. In the long run, such decoupling, if strategically deployed, can allow a degree of natural resource recovery. Seawater desalination is physically limited only by access to the sea, but has

[18] ibid
[19] John Anthony Allan. 2001. *The Middle East Water Question*. London: I B Tauris.

constraints in terms of energy consumption, brine discharge impacts and conveyance. When blended with brackish resources, desalinated water can be extended even further in application by improving lower-quality water. Recycled domestic wastewater is increasingly suitable for agriculture application, and residual nutrients can enhance crop production. Wastewater reuse also reduces the need to dispose of effluent, and associated environmental impacts. Where a high percentage of domestic water is recovered for reuse, the volumetric value of supply expansion in the domestic sector is compounded by gains in recycled water volumes. By substituting freshwater with wastewater in agriculture, freshwater can be reallocated to domestic and other applications where high quality water is essential. Favourable pricing of wastewater to agriculture is an effective tool for enhancing uptake, and can also allow a degree of cross subsidy between more expensive urban water and lower-cost/higher volume agricultural supplies.

1.3 Challenges of Decoupling

The adoption of decoupling strategies is not risk- or cost-free, and such challenges need to be evaluated as trade-offs against the potential benefits. First, a relative reduction in domestic food production will necessarily impact those dependent on agricultural livelihoods, requiring new job opportunities to counter unemployment. Second, the agriculture sector and the production of certain crops play important roles in a consolidated cultural and national identity. Date and olive production in Middle East economies are prime examples. Third, the logic of diverting water into higher value sectors, such as industrial production, assumes that untapped potential for growth of these sectors exists, as well as markets and other requisite factors of production. In Jordan, tourism is among the most profitable sectors, however, there are natural limits on its expansion, and levels of regional security and stability play a pivotal role in its profitability. Similarly, in order for Jordan's technology and service sectors to grow, prerequisites include a pool of suitably educated workers, and demand from regional and global markets. Fourth, the uptake of increased 'crop-per-drop' methods will likely require large-scale investment in irrigation technology, as well as crop and soil management knowledge and practice.[20] The economic justification of such resource outlays is made difficult in cases where water prices are low, and the financial savings made through water productivity investments are therefore limited. Likewise, desalination and wastewater recycling require expensive infrastructural investments and pose technological challenges. In the case of Jordan, limits to brine discharge in the Red Sea severely curtail the volume of water that can be safely desalinated. The reuse of wastewater may also be resisted on religious and cultural grounds.[21]

[20] Likewise, supplying crops with their exact water needs can easily result in soil degradation and salinity build up, and needs to be carefully managed.
[21] Although the increasing normalisation of reuse often is mitigating this obstacle.

2. Water Challenges of Israel, Jordan and Palestine

This section reviews publicly available water resource data for Israel, Jordan and Palestine, along with an understanding of decoupling trends to date where data permits. The review of data for Israel updates and develops previous analysis by Gilmont[22], and presents the most data rich of the three cases. The Jordan case is analysed second, with new long-term data assembled and analysed. Finally, the more data-challenged case of Palestine is evaluated.

2.1 Israel

Israel is a high income, semi-arid country that sits on the coast of the Mediterranean Sea. Its territory spans several climate zones, including desert in the south, cold and warm semi-arid areas in the centre, and a warm Mediterranean zone in the north. Rainfall varies between less than 100mm/year in the south, to 100-700mm/year in the centre and coastal plains, and over 700mm/year in the north. Nationally, the average annual rainfall is 435mm/year and total natural renewable water availability is 1800MCM/year. When desalinated water and recycled effluent are included, Israel's total water resources stood at 2085MCM as at 2014, providing an available water volume per capita of 251m^3. Considering the domestic and business sectors alone, water supply for 2014 was 91m^3/capita per year, or 248 litres/person/day. Israel is also obligated to supply water to the Palestinian authority (under the Israeli Palestinian Interim Agreement Annex III, 28 September 1995)[23] and to Jordan (under the Israel-Jordan Peace Treaty Annex 2, 25 August 1999).[24]

Since 1993, annual rainfall is estimated to have decreased by an average of 9 per cent, with an increase in extreme (low and high) rainfall years. Israeli experts estimate that overall renewable water resources will continue to decline by up to 25 per cent by the end of the century, when compared with 1961-1990 averages, as a result of climate change. Related environmental challenges, including decreasing flow to the River Jordan, are likely to be exacerbated by these trends[25].

Today, Israel's economy is dominated by services[26] and industry,[27] with agriculture contributing only 1.3 per cent of GDP and employing 1.1 per cent of the labour force as at 2016.[28] Despite the low contribution of the agricultural sector to overall economic activity, agriculture consumes over

[22] Gilmont 2014. Decoupling dependence on natural water.
[23] Under Israeli-Palestinian Interim Agreement Annex III, Jordan Valley allocation (MCM/year) to Palestinian 24MCM (Wells) 30 (Springs), North East Aquifer 4, Western Aquifer 22MCM (mfa.gov.il)
[24] Israel-Jordan Peace Treaty Annex 2, for the Yarmouk River, Jordan is allocated (all summer flow minus 12MCM to Israel, and all winter flow minus 13MCM to Israel). A further water swap of 20MCM can be made between the Yarmouk (to Israel in Winter) and Jordan (to Jordan in Summer), and Jordan can store flood water in the Jordan system below the Yarmouk confluence. Jordan is entitled to 10MCM of desalinated spring water or equivalent from saline springs diverted from the Jordan River. Israel to supply additional 50MCM to Jordan beyond the original peace Treaty based on cooperation with Jordan to identify sources, with a subsequent amendment committed Israel to supply a further 5MCM from the Sea of Galilee (mfa.gov.il). The Red-Dead project will also see Israel supply an additional 50MCM in the North in return for a similar quality of desalinated water from Jordan in the south.
[25] OECD 2013. *Water and climate change adaptation.* https://www.oecd.org/env/resources/Israel.pdf
[26] 82 per cent of the labour force and 80% of GDP (as of 2014)
[27] 16 per cent of the labour force and 18% of GDP (as of 2014)
[28] OECD. 2016. *Agriculture policy monitoring and evaluation 2016.* OECD Publishing.

half of Israel's total water resources (55 per cent of all water, 43 per cent of fresh water, as of 2014), albeit at a high level of productivity. Known as a "world leader in the area of irrigation water management in arid environments",[29] Israel's agriculture sector has indeed proven itself to be adaptive and highly resilient. Israel has a diversifying and modernising economy which has provided a combination of policy tools and incentives. It has been able to leverage its meagre water resources strategically, allowing it to balance food-water needs and the need for water conservation against a growing population,[30] and meet increased water demand from a modernising economy. Since the mid-1980s, farmers have adjusted to the use of treated wastewater, improving irrigation technologies, crop varieties and cropping patterns. There has also been a shift towards the production of higher-value crops. As a result, Israel's agricultural sector has seen an ongoing increase in yields, combined with reduction of freshwater consumption in agriculture over the past 30 years.

2.1.1 Israel's Water Sector Development

From 1948 until the early 1970s, agriculture featured prominently in the Israeli economy, contributing 11 per cent to GDP and employing 17 per cent of the population in 1960.[31] This agricultural production was water-intensive and required the mobilisation of significant water resources. Initially, such needs were met through an unsustainable exploitation of local aquifers. This placed a considerable burden on the coastal aquifer, where the population was concentrated. The result was significant seawater intrusion as freshwater was pumped out. Hydrological craters developed in aquifers where freshwater was displaced by saltwater in rocks susceptible to saline erosion. The 'National Water Carrier' was designed in the 1950s and completed in 1964. It transferred water from the Sea of Galilee/Lake Tiberias and the Upper Jordan River to agricultural and urban use in the centre and south of the country. Additionally, large-scale investments in water storage infrastructure were made, including a highly efficient distribution network that minimised water leakage. Significant expenditure was directed to the National Water Carrier, amounting to around 5 per cent of GDP over its eight-year construction.[32] While the Carrier relieved immediate dependence on groundwater resources, it created a new dependence on the Sea of Galilee/Lake Tiberias and its use as a freshwater reservoir. Lake levels fell, and the flow into the Lower Jordan River ceased almost completely, leading to a knock-on decline in flow to the Dead Sea.

Between 1985 and 1991, the government cut agricultural water allocations significantly (see Figure 3), encouraging the farming community to adopt more innovative farming methods in order to maintain profits. It also used policy incentives to encourage farmers to move towards high-value crops, and began to substitute freshwater allocations with recycled urban wastewater.

In 1986, Israel invested in programmes to treat urban effluent for agricultural use, initially through a treatment plant serving the greater Tel Aviv area with a pipeline to farms in the centre-south of

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[29] Water resources management in an arid environment: The case of Israel. Background Paper 3. World Bank analytical and advisory assistance program China: Addressing water scarcity. environmental and social development East Asia and Pacific region. Washington DC: World Bank, East Asia and Pacific Region, 2006. p.18

[30] As at 2016, Israel had a population of 8,600,000 (2016), growing at an average of 1.9 per cent, and a population density of 391 persons/km^2.

[31] Bank of Israel. 1961. *Annual report 1960.* Bank of Israel.

[32] Seth Siegel. 2014. *50 years later, national water carrier still an inspiration*. *YNetNews*2014.

the country, commencing supply in 1989.[33] Over time, other municipal treatment plants have been connected to effluent distribution networks, with storage reservoirs also built to balance supply and demand. While initially restricted to tree crops and crops tolerant to low quality water, improvements in treatment technology have allowed farmers to extend the use of effluent to a broad range of crops. Increasingly, local water treatment plants have been connected to regional effluent grids, giving agriculture across the centre and south of the country access to reduced price and larger quantities water. Effluents are priced up to 50 per cent lower than freshwater as treatment costs are met by urban wastewater producers, and larger quantities of wastewater are allocated in exchange for farmers surrendering access to freshwater. Farmers with effluent-suitable crops who were irrigating with freshwater thus found themselves at a commercial disadvantage, incentivising further efficiencies.

Today, a bloc rate tariff system that is structured to discourage excessive water consumption applies to agriculture. The pricing tiers are set at a percentage of quota, rather than absolute volume, although the quota itself is related to the size of the agricultural land plot. As of 2010 water tariffs were as follows:

- first 50 per cent of quota NIS 1.650/m^3
- next 30 per cent of quota NIS 1.902/m^3
- final 20 per cent of quota NIS 2.411/m^3

Above the quota, an additional charge for 'irregular quantities' is imposed. Farmers can therefore exceed their quota, but at significant cost.[34]

Regional adjustments are made to the water price based on freshwater salinity, and the availability of alternative water sources. Therefore, freshwater has historically been priced higher in areas where alternatives such as recycled wastewater are available. Wastewater is also charged according to quality; water from the Shafdan treatment plant south of Tel Aviv, produces the highest quality available and has the fewest restrictions on use. Shafdan water is charged at NIS 0.934/m^3, while other lower quality effluents are charged at NIS 0.803/m^3.

Urban water supplies have been priced to control demand. Israel's water prices to the domestic sector are based on a block rate tariff ranging from NIS 7.676/m^3 for the first block up to (3.5m^3/person/month), to NIS 12.355/m^3 for the second block (over 3.5m^3) as at 2016 (average NIS 10/m^3).[35]

By the mid-1990s desalination was increasingly being considered by the water management community as a means of supplying additional volumes of water. However, a 1996 sector-wide assessment found that delivering further efficiency savings in the urban and agricultural sectors were more cost-effective, and that desalination could be delayed for 10 years. Urban efficiency savings were estimated to cost around 35 per cent of the then production price of \$1/m^3 for

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[33] This was prompted by the obligations imposed by the Barcelona Convention (Convention for the Protection of the Mediterranean Sea Against Pollution) of 1976, which regulated effluent discharge into the Mediterranean.
[34] Kislev, Yoav. *The water economy of Israel.* Taub Center, 2011.
[35] Water Authority. 2016. *Water and sewage rates for domestic consumers in municipal water and sewage corporations.* Tel Aviv, Israel: Water Authority.

seawater desalination, while savings in agriculture would cost 5 per cent of the desalination cost.[36] There was therefore a strong economic rationale for prioritising water efficiency measures and productivity gains.

In the 1990s and 2000s, Israel launched effective public information campaigns, via television and the print media. It also mandated the installation of government-funded water-saving devices at the household level, such as flow aerators. Together, public sensitisation, price increases and water-saving devices combined to reduce domestic water consumption by up to 10 per cent.[37] Block rate tariffs were increased during the 2009-2013 period, peaking at an average of NIS 12/m^3 in July 2013.

Most recently, aided by falling costs of desalination and in an effort to develop a climatically independent water base supply (Gilmont 2014), Israel rolled out an extensive seawater desalination programme, with the first 100 MCM/year plant opening on the Mediterranean coast in 2005. (See Figure 2 for the dates when desalination and recycling started.) By 2016, the desalination production capacity was 700 MCM/year, although production has been scaled back in recent (wetter) years.

Finally, Israel closely regulates water allocation. Under the Water Law (1959), all water is state-owned, with no scope for private ownership over a water body or a perpetuity in water rights. This legal status of water and the operational practices that it enables makes Israel unique. The importance of these conditions cannot be overestimated. The Water Authority (and its predecessor until 2006 the Water Commissioner) yearly determines the total amount of water available, and how much water each sector and geographical locality receives. For agricultural supply, the Ministry of Agriculture then sets allocations among the different agricultural regions and regional 'Water Unions'. These are umbrella bodies representing a group of agricultural water users. In some cases, Water Unions have been allowed to purchase 'bulk water' from the state and retail it directly to farmers, although a 2016 legislative amendment required that all water allocations from the state were to be retailed through the national water company, Mekorot. Allocations are based on community and farm sizes, facilitating a level of predictability for agriculturalists. Formally, there is no mechanism for trading allocations between different water users, although small-scale trade within users in the same Water Union region does occur.

Allocations are affected by government priorities; the amount of water allocated to the agricultural sector, for example, is only determined after the needs of the domestic sector are satisfied.[38] Within sectors, the block rate pricing set by the water authority is used to control demand and incentivise water saving. A policy of cost recovery through increased pricing, since the 1990s has made the domestic sector cost neutral, i.e. revenues meet operational and investment costs. In 1985, agricultural water allocation began to decline (from its peak of 1465 MCM/year[39] to an average of 1110 MCM/year from 2010, Figure 2). Recent price adjustments in the agricultural sector aim to

[36] Saul Arlosoroff, 1997. The public commission on the water sector reform (the general ideas underlying its recommendations). *International Water and Irrigation Review* 5: 1-9.
[37] Gilmont 2014. Decoupling dependence on natural water
[38] There has been some small-scale formal environmental allocation, although to date this has not been reflected in official statistical data.
[39] as water was allocated to the industrial and domestic sectors

achieve similar cost recovery and eliminate the agricultural subsidy in water.[40] This system of tightly controlled measurement, with respect to both networked and individual supply in domestic and agricultural use, almost completely prevents water theft. Moreover, tight leakage controls mean that, based on official statistics, there is generally a discrepancy of less than 10 per cent between water supplied at the national level and water consumed across homes, industry and agriculture.

Future plans to address ongoing pressures on water and environmental resources include (i) a new desalination plant in the north, although this faces staunch social and professional opposition, (ii) initiatives to rehabilitate the northern Jordan River watershed and coastal streams, including by using the transit of high quality treated effluent to restore flow and (iii) investigating the feasibility of re-injecting freshwater into depleted aquifers to enhance the natural recovery process.

2.1.2 Israel's Decoupling Story

The above section has briefly summarised the key elements of Israel's water development and management, including how agricultural freshwater use has been reduced while increasing outputs. These policy changes and outcomes were achieved through iterative, often reactive and experimental approaches to developing both the domestic and agricultural water sectors, aided by access to global markets and technological advancement. When broken down into their component elements, it can be seen that each of the four decoupling instruments were pivotal in this process (see Figure 2).

- *Economic decoupling*: Israel increasingly diverted freshwater away from agriculture and into the industrial and service sectors where GDP/unit of water input is higher (Figure 3). The industrial and service sectors today comprise the largest and fastest growing sections of Israel's economy. Moreover, the equivalent water needs of the economy, based on 1961 drop-per-dollar values, exceeds 16,000 MCM/year above current water availability. Since the mid-1980s, volumes of naturally-derived water used by the Israeli economy have reduced, back to 1960 levels from 2009 (see Figure 2).
- *Water recycling/desalination (natural water) decoupling:* Since 2010, Israel has used recycled effluent in agriculture and desalination. A recycling average of 61.6 per cent of the total domestic water supple, has led to a reduction of natural freshwater water use to around 1270MCM/year (figure 4).[41] This is a decline from a peak of 2078MCM/year in 1985, and means that abstractions from 2009 onwards have been comparable to 1959-1964 levels.

[40] There are some exceptions. Agricultural water is allocated to particular hydrologically defined territories, with the Water Authority deciding what sources of water are used in each region to meet the allocated needs. Some areas are hydrologically independent, for example the spring valleys of Emek Harod or the hydrological unit of the Golan heights forming the eastern watershed of the Sea of Galilee. Until 2016, the Water Authority allowed Water Unions to retail allocations directly to agricultural users. This facility was removed in 2017, resulting in a backlash from farmers who faced higher prices. Today, the government does not permit users or private sector actors to trade water, although limited trade may occur within a single community of private farmers (A. Moshav). Within a collective Kibbutz, water is allocated at the community level and cannot be traded outside that community.

[41] Data from the Israeli Central Bureau of Statistics in September 2016 (CBS 2016). 2014 was the third-lowest recorded year with 1271MCM used (surpassed only by the years 2009 and 1961). Especially following the very dry 2014 winter, given that allocation appears to correlate to the volume of rainfall in the previous year (Gilmont 2014). This research demonstrates that such reductions are being sustained; further desalination and reduced natural freshwater offtake are expected in 2015 data. Data analysis based on numbers from CBS (Israel Central Bureau of Statistics). *Statistical abstract 2016*. table 21.4 water production and consumption.

While there is no official stated environmental allocation, the fact that less water is being abstracted can be regarded as a de facto replenishment of environmental sources (especially groundwater); i.e. water is being left in the environment rather than abstracted. Total natural water decoupling from recycled wastewater and desalination as of 2014 was 810MCM/year.

- *Food trade-based decoupling*: A rise in the volume of food imports, from 36 per cent of total national food tonnage in 1961 to 46 per cent in 2013, and a change in import composition towards water-intensive products, such as meat, have reduced the impact on natural water resources.[42] When accounting for water intensive production, including meat/animal domestic and imported production,[43] Israel's import dependency has risen, from 40 per cent in 1961 to 57 per cent in 2013 (Figure 5). Imports have continued to grow while domestic food production growth rates have slowed. Excluding meat production, and assuming equivalent water intensity between of imports and domestic production, present-day Israeli food imports are at least equivalent to 2000MCM/year, i.e. this is the minimum volume of additional agricultural water that would be required if Israel were to be self-sufficient in non-animal based food supplies.
- *Efficiency Decoupling:* Agricultural technology, especially irrigation and crop varieties, have facilitated both an increase in output faster than the increase in water consumption (from the early 1970s), but without reducing the amount of water going to agriculture,[44] and from 1985, increased output with absolute reductions in agricultural water[45] (Figure 6). Based on aggregate crop tonnage/m^3 values from the early 1970s, productivity savings by 2013 equate to around 813 MCM/year. This is equivalent to the volume of additional water needed if current production tonnages were produced at 1970 water productivity levels.

However, as intimated above, Israel's decoupling advancements have not been cost- or risk-free, and how these have played out should be considered when evaluating the scope for uptake in other contexts. Israel's trade-based decoupling enabled the 'import' of considerable volumes of virtual water.[46] This switch to externally sourced staple foods[47] could theoretically have had a knock-on impact on employment patterns and economic structures. In practice, this change evolved alongside a natural shift of labour towards higher value industries, and economic growth outside the agricultural sector.

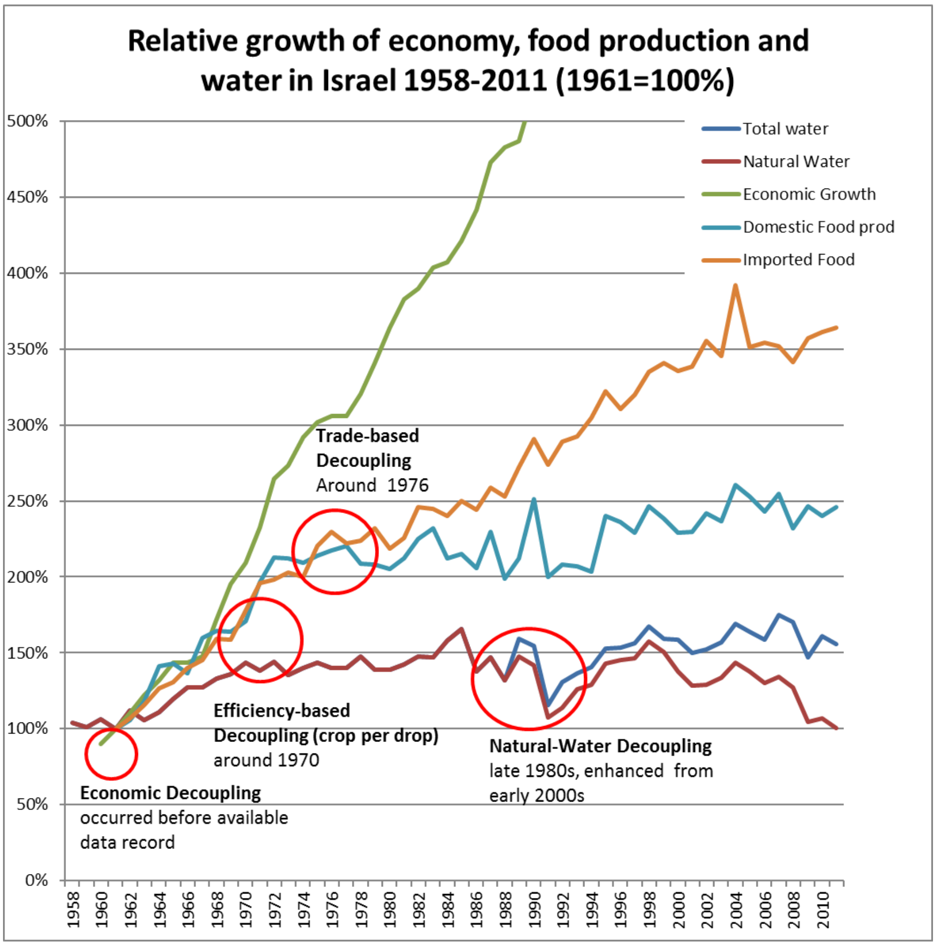
The government's efforts to reduce water use both through price increases and limiting supply involved politically and technically challenging adjustments, often resisted by the agricultural community. Allocation cuts by the Water Commission proved politically possible in the early 1990s under conditions of severe drought (Figure 4). However, these cuts could not be politically sustained when rains returned, as shown in the spike in rainfall in 1991 (Figure 4). The result was

[42] Allan, 2001. *The Middle East Water Question*.
[43] This means that there is significant 'double counting' of water when examining total food tonnages, especially in the case of domestic or imported feed production for domestic meat. Isolating domestic animal produce provides a way of reducing the analytical impact of this double counting (Gilmont 2015).
[44] David Katz, 2016. Undermining demand management with supply management: Moral hazard in Israeli water policies. *Water* 8 (4): 13pp.
[45] Water saved was re-captured by agriculture to further boost output.
[46] Allan, 2001. *The Middle East Water Question*.
[47] Absolute tonnages of imported, plant-based foodstuffs increased four-fold from 1961 to the mid-1990s.

that the imperative to limit supply weakened dramatically. The increase in allocation of agricultural water until the next drought crisis in 1998 can be linked to sympathetic stakeholders high up in the Water Commission hierarchy.[48]

Reversal of the previous cuts in allocation were also influenced by a policy of brinkmanship, including running storages low in anticipation of future rain. These trends served both to maximise supply and minimise water held in surface and groundwater storage. It was only in the late 1990s, when the brinkmanship policy once again failed under severe drought, accompanied by greater volumes of recycled and the prospect of future desalination capacity, that significant changes in natural water and sectoral allocations could be achieved. The enhancement of wastewater recycling and the introduction of desalination was, however combined with a policy of *reducing* natural freshwater use. The result of this trend was that while total national water volumes are now at record levels, the use of natural water resources has reduced, and from 2009, has stabilised at levels comparable with the early 1960s (Figure 4).

Figure 2: Four Mechanisms of Water Resource Decoupling as Exhibited by Israel between 1958 and 2011



48 Feitelson, Eran., Itay. Fischhendler, and Paul Kay, 2007. The role of a central administrator in managing water resources. *Water Resources Research* 43 (11).

Figure 3: Economic Output of Water[49]

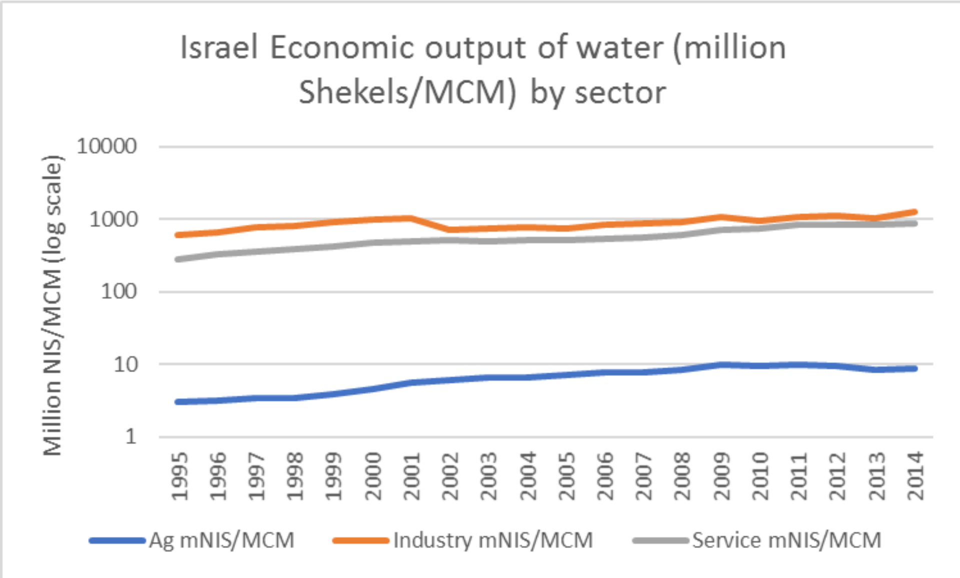
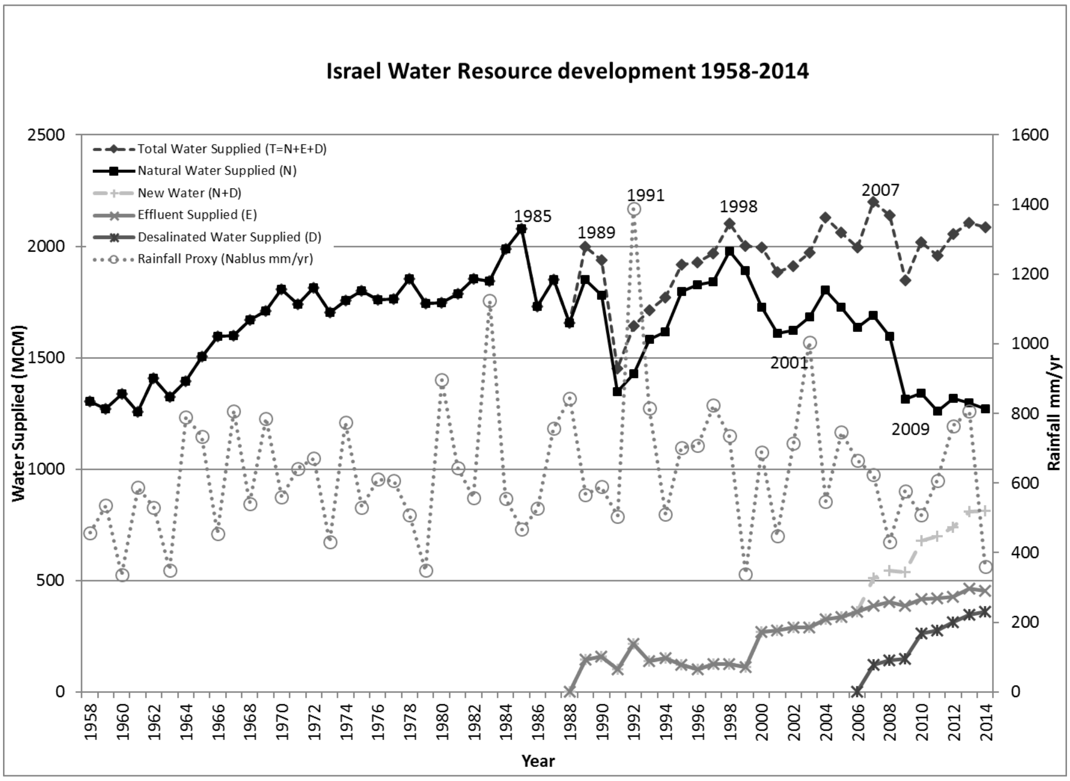


Figure 4: Israel's Water Resource Development 1958-2014. Based on Gilmont 2014 Figure 4, with the Additional Data from Israel CBS 2016.



[49] Note that due to lack of disaggregation between water sent to businesses and homes, the 'service' category includes all water not supplied to Agriculture and Industry.

Figure 5: Domestic and Imported Food Production (with Domestic Animal Produce Isolated) 1961-2013. Source: FAO Food Balance Dataset.[50]

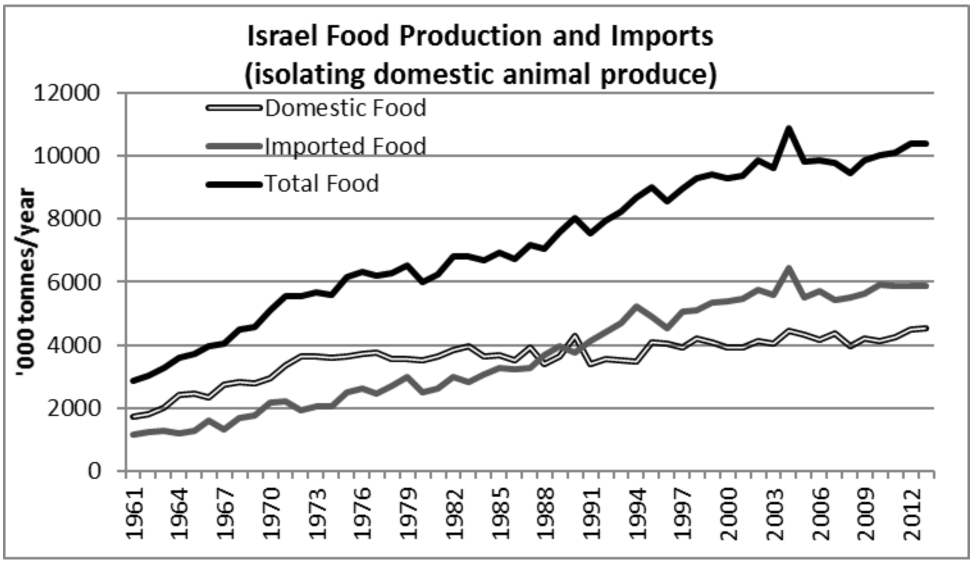
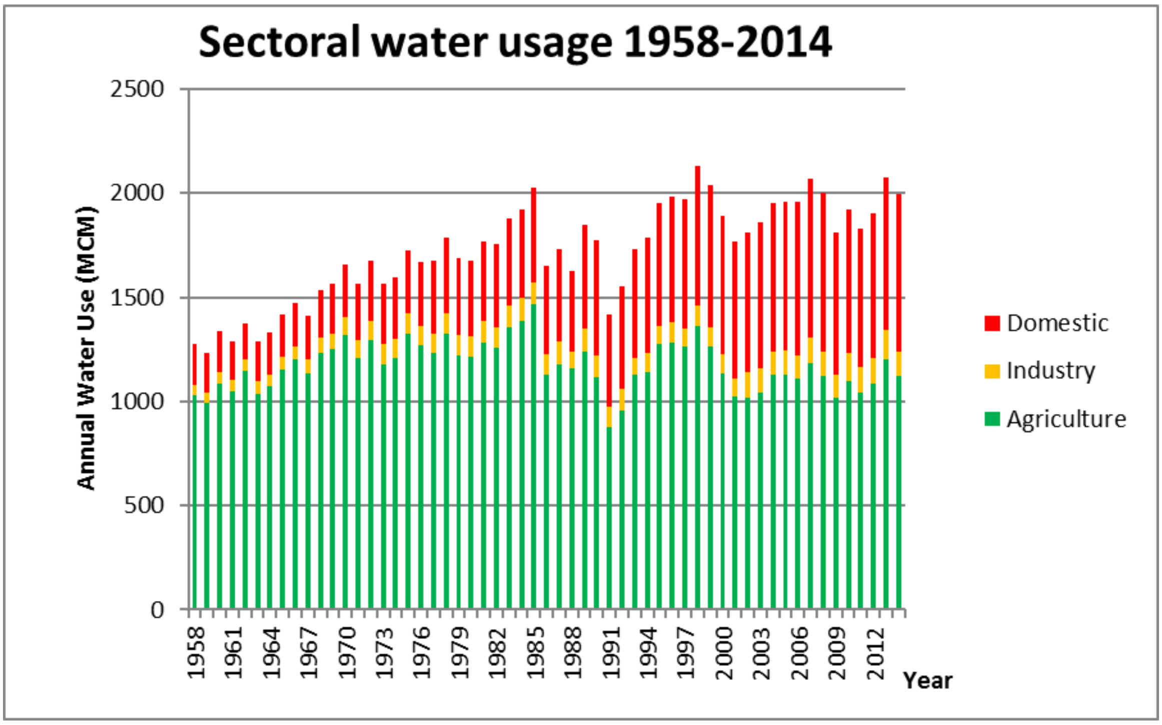


Figure 6: Israel Sectoral Water Usage. *This figure shows the decline in agricultural allocation since the mid-1980s and the proportional rise in domestic water use (data: Gilmont 2014 (derivation) and CBS 2016).*[51]



50 FAO. *Food balance tables* 1961-2011. in United Nations Food and Agricultural Organisation. Available from fao.org.
51 CBS (Israel Central Bureau of Statistics). *Statistical abstract 2016*. table 21.4 water production and consumption.

2.2 Jordan

2.2.1 Jordan's Water Context

Jordan is a resource-poor, middle-income country facing a set of complex environmental challenges.[52] Geographically, the Kingdom is almost entirely semi-arid or arid. 90 per cent of the governorates receive an annual rainfall of less than 200 mm.[53] [54] This rainfall is spatially concentrated in the north-eastern part of Jordan, and temporally, rainfall is unevenly concentrated between October and May. Jordan has annual renewable water resources of less than 100 m^3/capita/year, significantly below the global average of 500 m^3/capita/year.[55] Its total national water supply, as at 2015, equated to 106 m^3/capita/year, with domestic supply capacity at 48 m^3/capita/year (131 litres/cap/day).

These water challenges have been exacerbated by both steady population growth and a series of unanticipated population surges, as shown in figure 1.[56] The country currently hosts 656,400 Syrian refugees registered with UNHCR, a situation that has placed unprecedented pressure on water resources, water infrastructure and solid waste management capacities. Moreover, refugee camps in Jordan are located upon the two largest aquifers, the long-term consequences of which have not been fully established. As a result, Jordan is drawing upon its non-renewable aquifer sources, leading to a deterioration in water quality and an overall decline in supply. If supply levels remain constant, per capita domestic consumption is projected to fall to 90 litres/person/day by 2025.

Climate change is expected to exacerbate these challenges in years to come. Historical meteorological data collected from points throughout the country indicate that annual precipitation is now decreasing at a rate of 1.2mm per year, while temperatures are increasing by at least 0.03 degrees per year.[57] Dynamical downscaling models (a statistical technique that makes it possible to use large-scale models to make local-scale predictions) suggest that it is extremely likely that Jordan will see warmer summers and a generally drier climate. Predictions regarding

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[52] Ministry of Water and Irrigation (MWI). 2016. *National water strategy – Jordan 2016 2025.*

[53] M Van Aken, Courcier, R., Venot, J. P., and Molle, F. *Historical trajectory of a river basin in the middle east: The lower Jordan river basin (in Jordan).* Amman, Jordan: International Water Management Institute/French Regional Mission for Water and Agriculture, 2007

[54] Historical Trajectory beyond this, Jordan can broadly be divided into three climatic zones. In the Jordan Rift Valley to the west, where the average elevation is 250m below sea level, the climate is semi-arid to arid., with hot summers and warm winters. In the mountains bordering the eastern side of Jordan Rift Valley, which run from the north of the country to its south with a width of 30 to 60km and an altitude of 1,000m above sea level, the climate is Mediterranean with warm, dry summers and cold, wet winters. The eastern and southern deserts of Jordan, better known locally as *Badia*, have a semitropical climate with very little rainfall.

[55] MWI 2016 *National water strategy*

[56] Population surges include: (i) Between 1988-1992 administrative ties between Jordan and the West Bank were dissolved. (ii) The Gulf War in 1990-1991 triggered the immigration of Jordanian and Palestinians from these areas back to Jordan. (iii) From 2003 to 2005 Iraqi refugees came to Jordan after the Second Iraq War. (iv) In 2008 the global economic crisis many Jordanian expatriates returned to Jordan due to global cut backs. (v) Finally, in 2011 there was an increase in the population due to the Syrian Crisis. The last sudden population increase due to the Syrian crisis, putting additional pressure on Jordan's already scarce water resources.

[57] Hashemite Kingdom of Jordan. *Jordan's third national communication on climate change. submitted to the united nations framework convention on climate change (UNFCCC)*. 2014 Available from http://unfccc.int/resource/docs/natc/jornc3.pdf

Jordan's weather patterns have likewise concluded that drought events will become more likely, with longer periods of consecutive dry days.

In exploring how Jordan can address its water deficits more effectively, it is important to understand the economic backdrop against which water is consumed. Jordan represents one of the smallest economies in the Middle East, and one of the few not endowed with oil and gas reserves.[58] One result is that Jordan relies heavily on external rents including foreign aid, remittances, and foreign direct investment for financial support and to generate economic activity.[59] In terms of domestic inputs, Jordan's economy remains mostly service-oriented, with trade and services accounting for 68.3 per cent of economic activity, followed by industry at 29.2 per cent, and agriculture at 3.8 per cent.[60] Reform efforts have been hindered by recurrent cycles of economic slowdown, which have hampered efforts to reduce poverty rates and impeded improvements in efficiency of the public sector.[61] One factor contributing to Jordan's strained financial resources is its heavy reliance on food imports. Vulnerability to international market prices has impeded proper fiscal planning and exposed the economy to external shocks. Price shocks are either passed on to consumers (Jordanians spend, on average, 41 per cent of their income on food),[62] or absorbed by the government through subsidies, which has driven a high and persistent budget deficit. Also relevant is Jordan's high rate of unemployment. At the end of 2015, unemployment stood at around 13.6 per cent (11 per cent for men and 22 per cent for women).[63] [64] Despite this, Jordan's productive capacity is supported by a large pool of migrant workers (324,410 as at 2014) who are willing to undertake low and semi-skilled jobs, with 33 per cent of work permits for foreign labourers going to the agricultural sector.[65]

The agricultural sector plays a somewhat incongruous role within Jordan's economic framework. Only 5 per cent of lands receive adequate supporting rainfall,[66] and agriculture is Jordan's heaviest water consumer, accounting for up to 60 per cent of national water allocations. Moreover, while

[58] Jordan is a lower-middle income country with a population of 9.5 million as at 2015 and a per-capita GDP of USD 5,422.6 as at 2014. National Census Results 2015," *Department of Statistics* (2016).
"The World Bank GDP per capita data," accessed March 12, 2016, http://data.worldbank.org/indicator/NY.GDP.PCAP.CD

[59] Erica Harper, Sean Thomas and Mays Abdel Aziz. *Forging new strategies in protracted refugee crises: Syrian refugees and the host state economy,* Amman, Jordan: WANA Institute, 2015.

[60] CIA. *Jordan economy, the CIA world factbook*. 2015 [cited March 29 2016]. Available from https://www.cia.gov/library/publications/the-world-factbook/geos/jo.html

[61] ibid

[62] Harper et al 2015 *Forging new strategies in protracted refugee crises*

[63] Ministry of Labour. 2014. *Annual report (arabic).* Amman: Ministry of Labour.

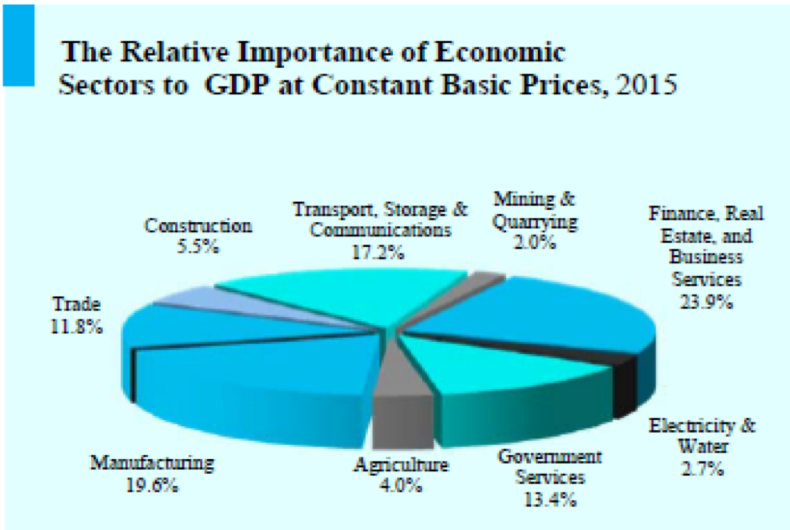
[64] Jordan's unemployment rate is high reaching on average 14 per cent since the early 1990s and has not changed since. Jordan's unemployment rate increased by 1.1 per cent to reach 13.0 per cent during 2015. The Central Bank of Jordan 2015 annual report attributes this increase to the Syrian refugee influx and subsequent competition over a large portion of job opportunities and to the low paid foreign labour. ("Jordan's Unemployment Rates," accessed March 12, 2016, http://www.tradingeconomics.com/jordan/unemployment-rate). Youth, which represent a little over two-thirds of the Jordanian population, is the largest group of unemployed. Over the past five years, youth unemployment had stood at an average of 28.8 per cent, against a total average unemployment of 10.42 per cent. "Unemployment, youth total", *The World Bank* (2015), accessed April 28, 2016.

[65] According to multiple personnel interviewed in the Ministry of Labour, a large percentage of Egyptian workers work in other sectors despite holding a work permit to work exclusively in agriculture. Nonetheless, the sector has the highest ration of foreign workers. Source: Ministry of Labour (2014) *Annual Report (Arabic)* page 43. This official data was anecdotally supported during fieldwork for this project, which confirmed that Syrian refugees fill jobs which do not attract Jordanians, such as labour work in farms. Many farmers reported facing difficulties retaining Jordanian farm labour after the first few months of their employment in farms whereas Syrians welcome this employment opportunity.

[66] MWI 2016. *National water strategy.*

irrigation accounted for 497.5 MCM in 2014 alone, farmers irrigate less than 10 per cent of total agricultural land.[67] The result is that agriculture accounts for more than half of the nation's water use while generating around 4 per cent of GDP as at 2015 (Figure 7).[68] [69]

Figure 7: Composition of the Jordanian GDP in 2015. Source: Central Bank of Jordan, 2016



It is widely recognised that for the Kingdom to meet its economic potential, it must move its economy towards activities that generate value-added economic activity. At the same time, it needs to create new opportunities to accommodate the youth 'bulge', boost complementarity between the competencies of the workforce and sectorial needs, and nationalise the workforce by making certain occupations more attractive. A critical step is to direct water away from sectors that offer low employment opportunities and low GDP contribution, and towards sectors with high employment growth potential and economic value-added, such as tourism and industry.

As illustrated in figures 8 and 9, agriculture accounts for most of the water used in the economy, although its use is declining in favour of domestic allocations.[70] However, the economic return on water is highest in the industrial and service sectors. This is because the relative economic productivity of agricultural water has remained steady over recent years while industrial output/water unit has risen, and the service economy has grown. There is no disaggregation between domestic and economic/commercial uses of water in official statistics. This prevents a calculation of the economic productivity of water solely used by the service sector. Given that much of the 'domestic' water allocation is likely to be at the household level, the real economic

[67] ibid
[68] Central Bank of Jordan. 2016. *Annual report (2015).* Amman: Central Bank of Jordan.
[69] It should be noted that this attribution is often contested by the farming community and the Ministry of Agriculture since it is calculated as the direct sales of agricultural commodities. It does not take into account all of the associated services and professions that agriculture generates. Van Aken et al. (2007) report that agriculture taking into account all relevant industries actually constitutes 25 per cent of the GDP of Jordan. Source: M. Van Aken, R. Courcier, J. P. Venot, F. Molle, *Historical trajectory of a river basin in the middle east: The lower Jordan river basin (in Jordan).* Amman, Jordan: International Water Management Institute/French Regional Mission for Water and Agriculture, 2007.
[70] This is one of the longest available time series covering recent years to be derived. Our research found that the Ministry of Water and Irrigation only has available data back to 1993. This has therefore been spliced with earlier data made available via Nortcliff et al (2008) to create a time series for 30 years from 1985 to 2014.

productivity per unit water in the service sector is likely to be much higher than all other sectors. This comparison in economic returns means that the largest economic opportunity for new water resource application lies in the non-agricultural sector. As at 2014, economic returns on water in industry are 66 times what they are in agriculture, and in the domestic/service sector they are 20 times higher.

Figure 8: Jordan Water Use 2002-2014. Data from 1993 to 2014: Jordanian Ministry of Water and Irrigation (pers. coms.).[71] Data from 1985 to 2001: Nortcliff et al. (2008).[72]

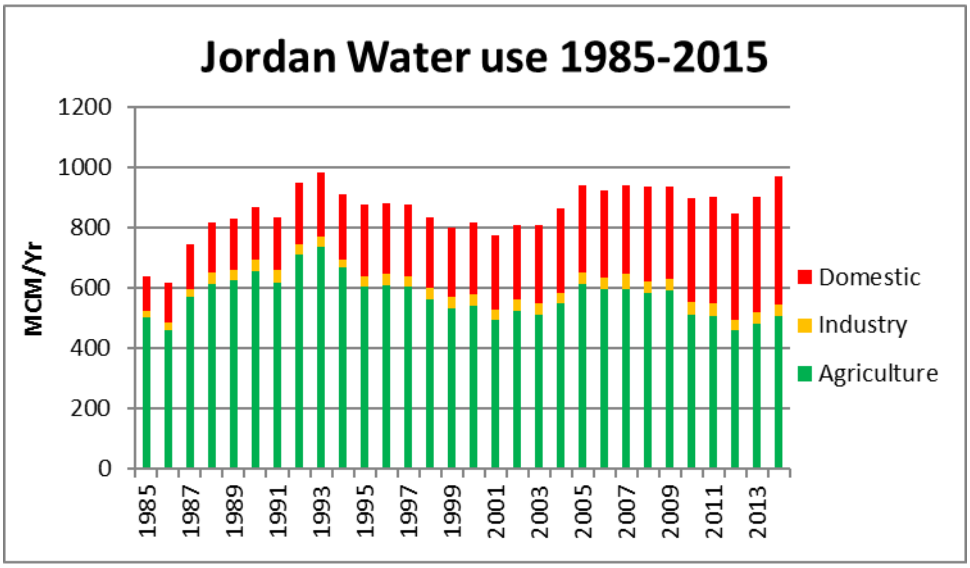
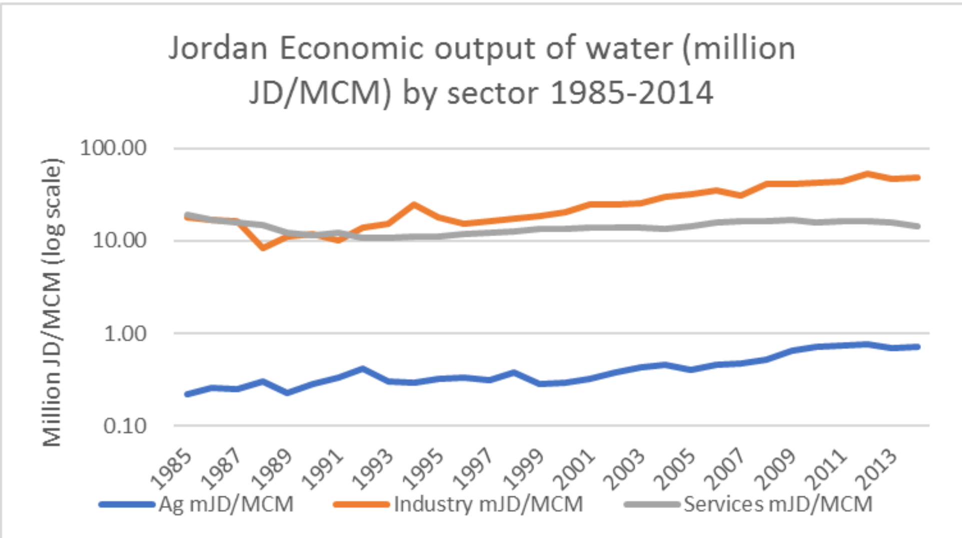


Figure 9: Economic Output per Unit Water[73]



[71] Note that the agriculture category includes sub-category of 'livestock', which comprises on average 1.5 per cent of agricultural water.

[72] Stephen Nortcliff, Gemma Carr, Robert B. Potter and Khadija and Karmame. *Jordan's water resources: Challenges for the future.* Geographical Paper No. 185.

[73] Note that due to a lack of disaggregation between water sent to businesses and homes, the 'service' category includes all water not supplied to agriculture and industry.

This is not to say that Jordan should not produce food. A strategically composed nationally produced food basket is essential for any country. Middle East states are particularly susceptible to food insecurity as all are net food importers and are thus vulnerable to international price fluctuations. Small changes in commodity prices can have a disproportionate impact on the cost of staple foodstuffs, and this price volatility most severely impacts the poor. The 2008 food price hike created an additional 4 million undernourished people in Arab countries[74] and drove an estimated 44 million more people into poverty.[75] Brown (2011) describes what he calls the new geopolitics of food: "…for the planet's poorest 2 billion people, who spend 50 to 70 per cent of their income on food, these soaring prices may mean going from two meals a day to one. Those who are barely hanging on to the lower rungs of the global economic ladder risk losing their grip entirely. This can contribute — and it has — to revolutions and upheaval".[76] While MENA economies do not comprise the poorest of the world's population, the political and social impacts of food prices are pertinent.

Moreover, agriculture plays an important socio-cultural role and provides a lifeline to some of the most marginalised economic groups. But the scope and structure of such food production must make strategic use of Jordan's natural resource assets, and make available the necessary water resources to accommodate a growing population and economy. None of these goals can be met without investment in water infrastructure, new water technologies, improved knowledge on water use and application, as well as by a more strategic allocation of water resources and institutional coordination.

2.2.2 Jordan's Institutional Framework

The public entities with primary responsibility over the water sector are the Jordan Valley Authority (JVA), the Water Authority of Jordan (WAJ) and the Ministry of Water and Irrigation (MWI). Despite significant evolution in this organisational structure, it is still affected by overlapping responsibilities and administrative deficits, as detailed below.[77]

The JVA was created in 1977 and is the governmental organisation responsible for the social and economic development of the Jordan River Valley, the provision of infrastructure and water resource distribution, and the protection and conservation of resources and conditions for maintaining the welfare of the valley.

The WAJ was created on 18 March 1988 under the 1988 Water Authority Law. It is mandated to cover all operational functions of the water sector which includes the management of water and wastewater services, regulation of infrastructure construction, and quality of service provision projects, operation and maintenance. It also manages all contracts with water companies. Together, WAJ and JVA recommend water service cost changes and capital projects, with the Cabinet having the ultimate regulatory authority for tariff setting.[78]

[74] World Bank, FAO, and IFAD. 2009. *Improving food security in Arab countries.* Washington DC: World Bank. p.xii
[75] World Bank, and FAO. 2012. *The grain chain; food security and managing wheat imports in Arab countries.* Washington DC: World Bank.
[76] Lester R. Brown, The new geopolitics of food. in Foreign Policy. 2011 Available from http://foreignpolicy.com/2011/04/25/the-new-geopolitics-of-food/.
[77] MWI 2016. *National water strategy.*
[78] ibid

The MWI, created in 1992, is responsible for overall strategic direction and planning in coordination with WAJ and the JVA. It is also responsible for the formulation of national policies and strategies, planning water resources development, procuring financial resources, and monitoring water and wastewater projects. It was established in response to the need for a more integrated approach to effective national water management. To this end, the Ministry has taken over the responsibility of the JVA and WAJ, both headed by the Minister of Water and Irrigation. The MWI has taken significant steps to enhance coordination, including through a nation-wide evaluation of resource needs and planning. Its first water strategy was produced in 1998, followed by another strategy covering the years 2008-2022, which was then replaced by a 2016-2025 strategy to account for the changed conditions brought on by the Syrian refugee crisis and adoption of the Sustainable Development Goals in 2016.

These strategies have focused on ground water overexploitation, water allocation and increasing water supply. Supply increases are planned through seawater desalination, an increase in treated wastewater, dam construction and new fossil groundwater exploitation. The planned Red-Dead conveyance, whereby water will be desalinated at the Red Sea and brine discharged at the Dead Sea, will add 85 MCM (25 for irrigation) in phase one and another 150 MCM in phase 2. Other large-scale projects include a conveyance system that will transport 100 MCM/year of high quality fossil (non-renewable) water from the Disi aquifer[79] in southern Jordan to Amman and the southern governorates for an expected 50-100 years. It is expected that, at least between 2014-2022, Disi flows will facilitate a reduction in renewable groundwater over-extraction during the winter, provide the flexibility needed to meet peak demand requirements during the summer, and dilute the salinity of treated wastewater serving the Jordan Valley.

Significant challenges to these efforts to increase national water stability are water theft and leakage due to aging infrastructure. As at 2014, it was estimated that of the 126 litres/capita/day used in the domestic sector, 65 litres, or 52 per cent, is unaccounted for. In 2013, the ministry launched a crackdown on illegal wells, identifying 22,305 violations of water mains and resources, and sealed 747 illegal wells.[80] [81]

The resources spent on water projects and augmenting supply, including from remote sources, has seen the cost of water per cubic metre increase significantly. Water from the Disi aquifer, for example, is extracted from depth and pumped uphill over 400km to reach population centres in the north. To keep consumer water prices low, the government applies a subsidy system. Water sector expenditure in 2010 totalled approximately JD 500 million,[82] JD 38 million of which was provided in subsidies for irrigation in the Jordan valley, and around JD 213 million in subsidies for the domestic sector. Relative to total expenditure, Jordan Valley irrigation accounts for 7.6 per cent of subsidy spending, and domestic supplies account for 42.6 per cent.

While the domestic sector has the largest charges and highest subsidy, the agricultural supply still has the lowest user charges. Taking inflation into account, prices as at 2011 are as follows:

[79] The Disi Aquifer is shared with Saudi Arabia.
[80] Namrouqa, Hana. 2016, 4 June. Authorities continue crackdown on water theft. *Jordan Times* 2016, 4 June.
[81] MWI 2016. *National water strategy*
[82] ibid

- In the Jordan Valley, a block tariff water structure runs from JD 0.14/m^3 to JD 0.65/m^3.[83]
- For domestic supply, across both utility (company) and non-company supplies, a tiered structure with eight blocks is used. There is a flat rate for the first 18m^3 per quarter of JD 2.13/m^3 (1.5 for non-company supplies), thereafter prices per cubic metre ranges from JD 0.145/m^3 (0.08 for non-company supplies) to JD 19.2 (1.16)/m^3. In addition, wastewater charges are levelled ranging from JD 0.045 to JD 1.105/m^3, dependent upon block.

In 2016, the MWI introduced a Water Allocation Policy that saw a move away from augmenting supply, and towards controlling water allocation among sectors. This policy is somewhat constrained by legal impediments in specific locales. In the Jordan Valley, for example, water allocations to land owners are set out in the Jordan Valley Development Law, and vary according to land area and crops grown. In the highlands, where land benefits from surface water (from springs and wadis), entitlements are usually set out in the land title.

The government is also exploring how to harness 'non-conventional' water resources, such as treated wastewater (TWW) and desalinated sea and brackish water. Currently 33 wastewater treatment plants are used to treat 98 per cent of collected wastewater in Jordan.[84] As of 2014, however, only 63 per cent of the population was served by wastewater and sanitation services,[85] suggesting significant expansion potential. 2015 data show that 29 per cent of total domestic supply was re-supplied as wastewater to agriculture.

Based on the WAJ Board Decision Number 3 (20 June 1999), approved by the Prime Minister, the tariffs of treated wastewater are determined as follows:

- Treated wastewater tariff is 10 fils/m^3 for irrigation purposes.
- Treated wastewater tariff is 50 fils/m^3 for industrial reuses including power generating and cooling.
- Treated wastewater is free of charge for research and study purposes, provided that water quantity does not exceed 200m^3/day and a copy of the research results are to be submitted to the Water Authority of Jordan.
- 10 fils/m^3 are added to tariff to cover energy costs.

2.2.3 Jordan's Decoupling Story

Jordan has practised the modalities of decoupling for some time, both as a concerted effort and in reaction to other socio-economic pressures.

- *Trade-based decoupling:* While Jordan's agricultural food production has correlated with population growth since 1975, the data analysis demonstrates considerable, on-going decoupling from before the start of available data in 1961, with imports of plant-based foods increasing from an initial 1961 value of 25 per cent, reaching a new equilibrium

[83] World Bank. 2016. *The cost of irrigation water in the Jordan Valley.* Washington DC: World Bank,
[84] MWI 2016. *National water strategy*
[85] ibid

average of 63 per cent between 1975-2013 (Figure 10).[86] Two mechanisms appear to be behind this trend. The first is the reduction in domestic production coinciding and, possibly related to, economic and social adjustment to the higher population and loss of land following the 1967 war. The second is the increase in food import tonnages from the 1970s.

- *Natural water decoupling:* As shown in figure 11, the use of recycled wastewater has increased from 6 per cent (of the total water supply) in 1991, to 13 per cent as at 2014 — the result of a deliberate effort to deal with sewage problems and shortages in water supply.[87] By 2014, treated wastewater contributed 51.5 MCM/year to agricultural supply. This is expected to increase given current policies promoting wastewater reuse, along with desalination (both direct and through water swaps) facilitated by the Red-Dead conveyance.[88]
- *Economic decoupling:* The data analysis suggests that Jordan began to decouple economic growth from water use at some point prior to the peak in water resource use in 1993. This outcome resulted from economic diversification into sectors that offered high economic growth but low water use, such as technology and tourism. While a robust analysis to compare water resource use and growth rates is not possible without time-series water data, Jordan's economy has — except in the1988-1992 period — grown exponentially at a rate likely to be much faster than the historical mobilisation of water resources.
- *Efficiency decoupling:* Starting in 1992, crop output was maintained despite an overall reduction in water quantity used, and from 2002, crop output grew while agricultural water allocations were static or declining. This appears to indicate that farmers have been adopting more water efficient techniques in response to the MWI reducing water allocations to agriculture (Figure 12).[89]

The 2016 MWI Water Plan includes additional volumes of recycled wastewater and new desalination capacity that will enhance decoupling trends to 2025. However, it also prioritises increasing per capita allocations and total sector allocation to both domestic and agricultural uses to 700 and 703 MCM/year respectively. Assuming a linear increase from the current sector supply of 466 and 514 MCM/year, there will be a deficit of 115 MCM/year between forecast demand and available supply by 2025. The gap between demand and sustainable supply is projected to be 233 MCM/year by 2025 (Figure 13). In order to bridge this gap, there is a long-term need for either additional increments in supply, or demand management, including through enhanced decoupling trends. The following sections examine the scope for this based on past achievements and practices

[86] The Jordanian Department of Statistics publishes detailed commodity production and trade data, down to specific crop types, with comprehensive numbers available from 1985. These closely match FAO crop total tonnages, creating a verifiable link between national and FAO reported data, with the FAO Food Balance data providing a longer time series than the direct government data set. While stable from 1975, analysis of the FAO data demonstrates considerable, ongoing, decoupling from before the start of available data in 1961, with imports of plant-based foods increasing from an initial value of 25 per cent, adopting a new equilibrium average of 63 per cent from 1975 to 2013. Importantly, much of the increased import dependency up until 1970 appears to have been caused by a decline in domestic production, partly associated with the loss of population and territory during the 1967 Arab-Israeli War. Data source: FAO. *Food balance tables* 1961-2011. in United Nations Food and Agricultural Organisation. Available from fao.org

[87] Due to limitations of long-term data available from the Water Authority, a disaggregated record of water supply is only available from 1994.

[88] ibid

[89] As shown in Figure 12, growth in water correlates to increased agricultural output until 1993, which marked the start of reduced water allocations.

in Jordan and elsewhere, as well as the benefits that might accrue in terms of resolving supply and demand discrepancies.

Figure 10: Food Production and Import (Non-animal-based) by Tonnage *(Derived from FAO Data and Verified Using Official Jordanian Statistics from 1985 onwards).*

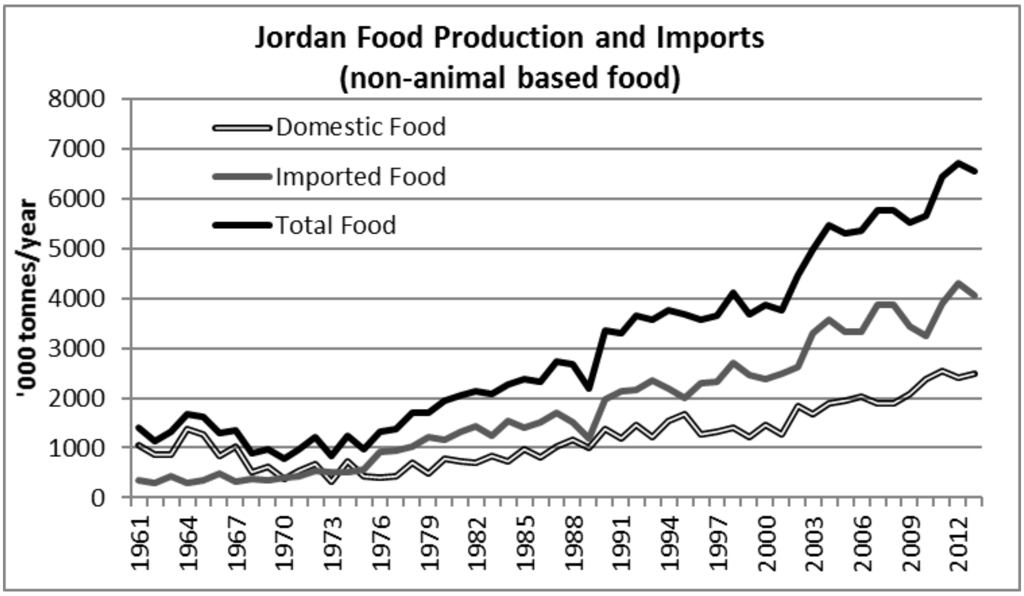


Figure 11: Jordanian Water Supply by Source 1994-2015. Data: Ministry of Water and Irrigation.

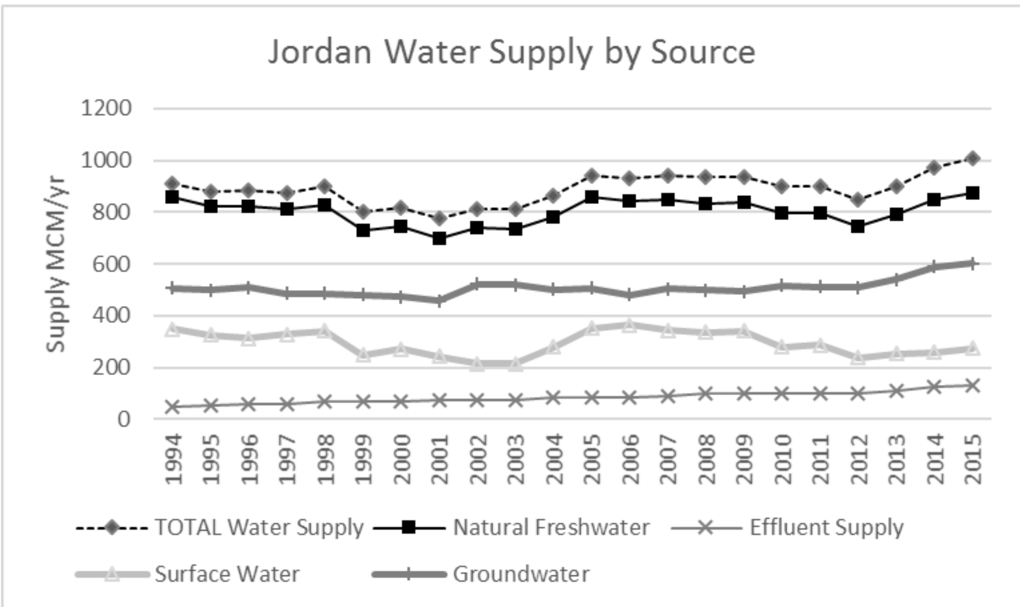


Figure 12: Relative Agricultural Production Tonnage and Agricultural Water Allocation, Showing Likely Decoupling from the Early 1990s.

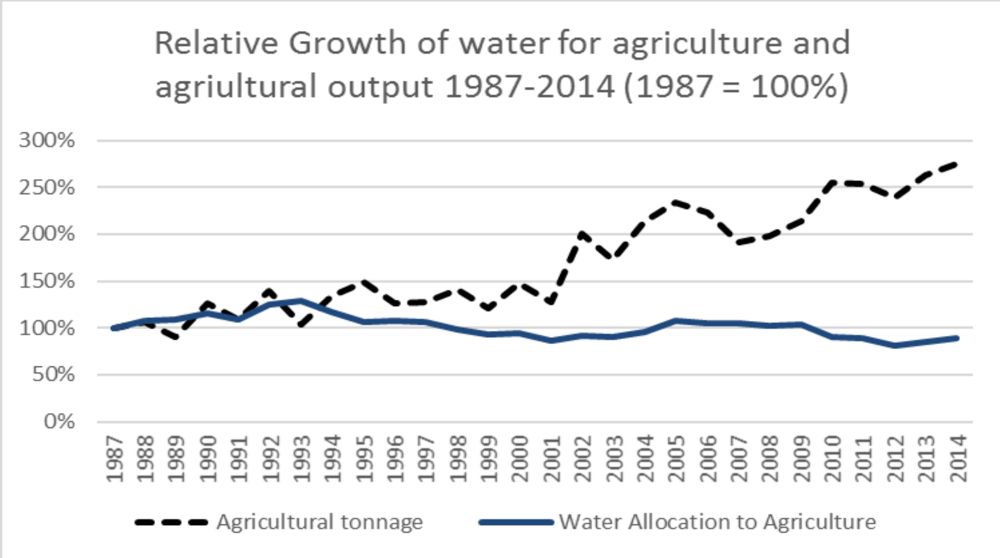
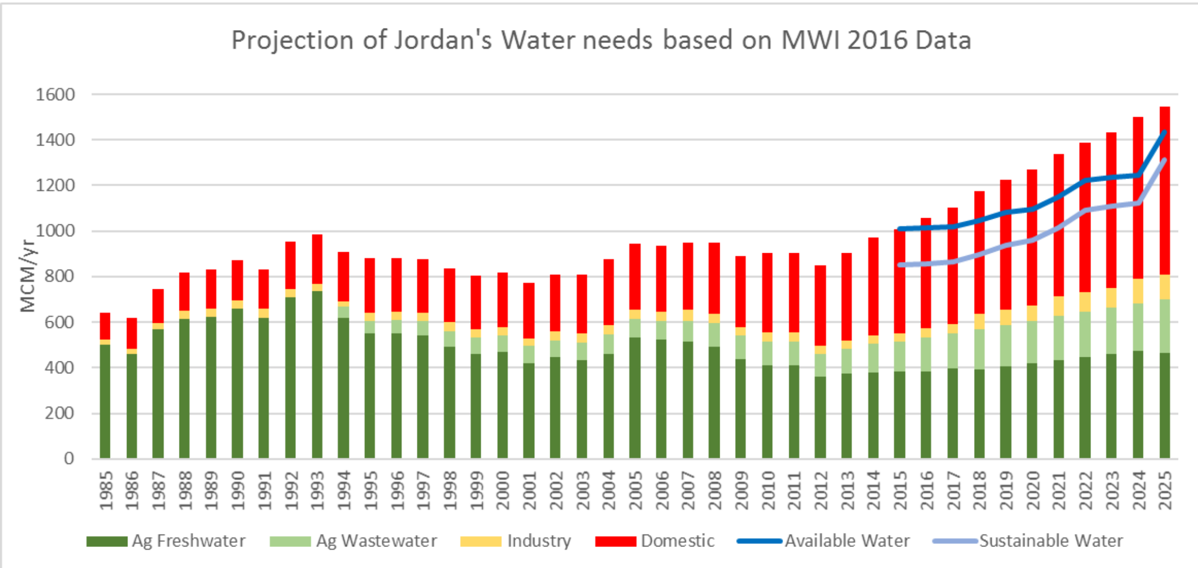


Figure 13: Projection of Jordanian Water Allocation per Sector beyond Current 2015 Data, Based on Current MWI Supply and Demand Trends. *This figure shows a continued deficit between national demand and national supply by 2025 of 115 MCM/year.*



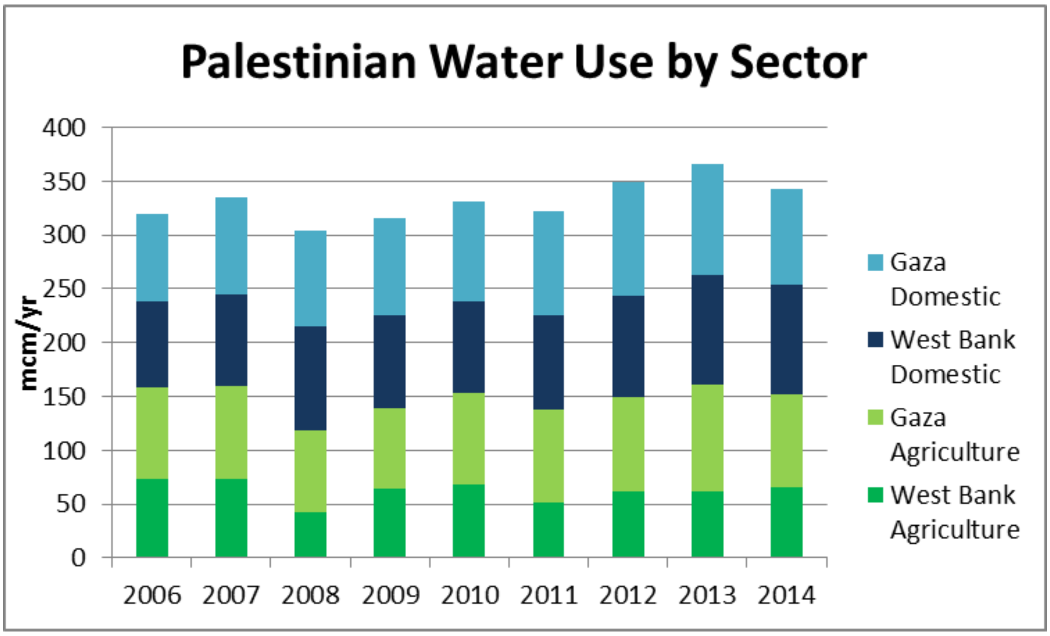
While limited long-term data prevent a full analysis of decoupling timing and relative trends, the data do show both historic and ongoing water resource decoupling occurring. Food imports rose dramatically up to 1975, allowing Jordan to externalise much of its food-water needs. Economic diversification, especially in tourism and technology, appears to have decoupled economic growth from water resource mobilisation from 1993. Also in the early 1990s, agricultural productivity (output) increased despite relatively constant agricultural water allocations. The development of recycled water has enabled limited natural water decoupling, which will be increased under plans for additional wastewater reuse and desalination from the Red-Dead project.

2.3 Palestine (West Bank and Gaza)

A complete examination of the water resource context, history, and complexities of resource development and management in Palestine is beyond the scope of this study, moreover it is well covered in existing literature.[90] [91] [92] The following section summarises the results of new analysis of assembled available long-term data on water use and crop production. Much of this data was derived from the Palestinian Bureau of Statistics annual reports on Agricultural Statistics from 1994/5-present and Water Statistics from 2000-present.

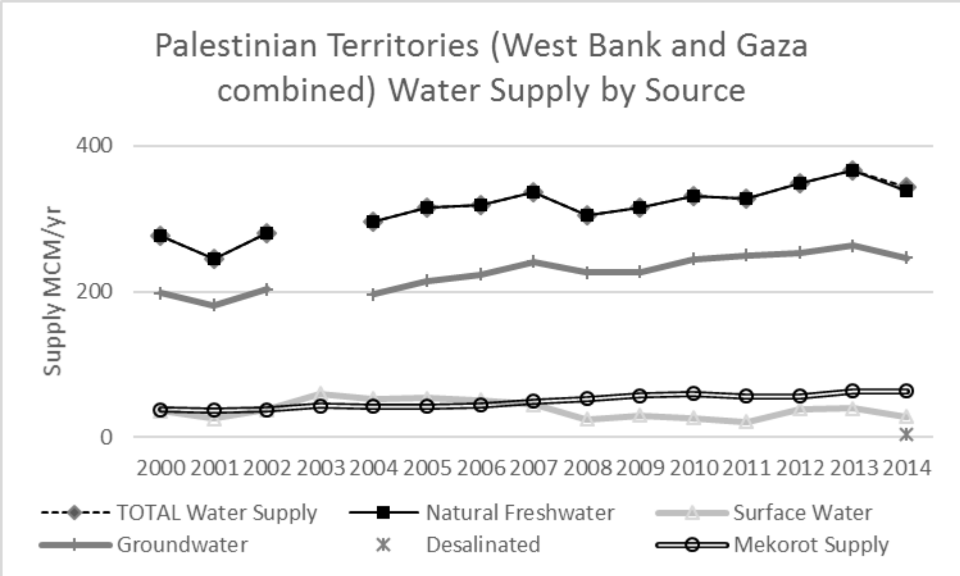
A complete time series of water resource use in Gaza and the West Bank was assembled from 2006-2014 (Figure 14), and a time series of water supply (by source) was assembled from 2000 to 2014 (Figure 15). Agricultural allocations have remained mostly constant during the observed period, with volumetric growth focused on the domestic sector

Figure 14: Water by Use in West Bank and Gaza 2006-2014.[93] *Source: Official Water Yearbooks, Palestinian Central Bureau of Statistics (2000-2015).*[94]



[90] Hillel Shuval and Hassan Dweik (eds). 2007. *Water resources in the middle east: Israel-Palestinian water issues – from conflict to cooperation*. Heidelberg: Springer.
[91] Dima Wadi Nazer, *From water scarcity to Sustainable Water Use in the West Bank, Palestine.* Boca Raton: CRC Press., 2009.
[92] Haddad, Marwan. 2009. Palestinian water rights: Past, present and future. In *Water values and rights (2nd proceedings of the international conference on water values and rights) 13-15 April 2009.*, eds. C. Messerschmid, et al. Palestine Academy Press.
[93] Note that only for 2011 the data are published for all four categories of use. For all other years, agricultural use is derived by subtracting published domestic supply from data on total supply by source by territory.
[94] Palestinian Central Bureau of Statistics 2015. *Water year books from book 586 (2000) to 2015 (various).* Palestinian National Authority,

Figure 15: Palestine (Total) Water by Source of Supply. *Source: Official Water Yearbooks, Palestinian Central Bureau of Statistics (2000-2015).*[95]



No complete time series of agricultural production tonnage could be obtained. However, a single year of detailed data was published in 2009, covering the year 2007-2008, giving total crop production by crop type (rain-fed and irrigated, areas and yield) for the combined areas of the West Bank and Gaza. Analysis of these data is set out in Table 1, revealing that 77 per cent of tonnage is irrigated. The Palestinian Authority provides the only set of agricultural data, albeit for a single year, where there is a clear, official breakdown of production according to irrigated and rain-fed methods; similar data are not publicly available for Jordan or Israel.

Table 1: Crop Production for Palestine 2007 - 2008.
Total Data Derived from Tables 6, 24, and 42, Palestinian Bureau of Statistics (2009).

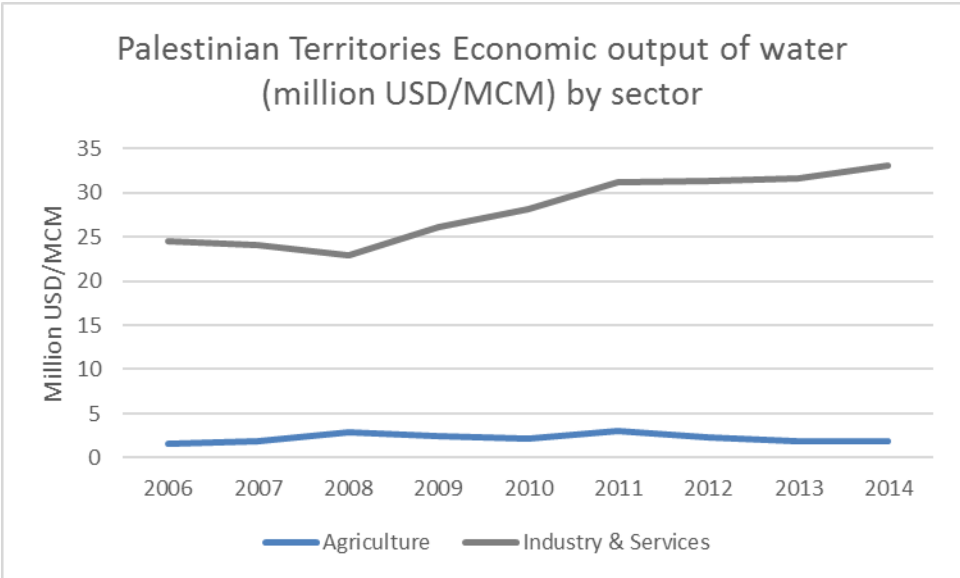
	Production Irrigated (ton)	Production Rain-fed (ton)	Total Production (ton)	% Tonnage Irrigated
Tree crops	94093	160406	254499	37%
Vegetables	676658	19605	696263	97%
Field Crops	101270	84104	185375	55%
Total	872021	264116	1136137	77%

Economic data are available from 1994-2015 from the Palestinian Central Bureau of Statistics. Combined with the available water data by sector for 2006-2014, it is evident that there is a significant difference between economic output per unit of water in the agricultural and non-

[95] ibid

agricultural sectors (Figure 16). Further, economic growth since 2008 has been achieved with a static level of water supply, indicating at least superficially, that there has been additional economic decoupling. However, significant aid flows into Palestine mean that the relationship between domestic resource inputs and economic outputs cannot be properly assessed. The limits in the duration and range of available data for Palestine are a significant obstacle to further assessing decoupling potential. The lack of secondary data precludes a Palestinian assessment of water productivity in the next section, although Palestinian data are analysed at the farm level in Section 3.

Figure 16: Economic Output per Unit Water for Palestine (West Bank and Gaza Strip) 2006-2014. *Economic Data Source: Palestinian CBS (multiple years).*[96]



Data limitations preclude an effective analysis of decoupling trends for the West Bank and Gaza. The higher value of water in the non-agricultural sector does indicate that economic diversification and economic decoupling is occurring. An absence of long-term agricultural production and import data precludes an assessment of productivity and trade based decoupling. Limited small-scale desalination from 2014 does point to early natural water decoupling.

[96] Palestinian Central Bureau of Statistics. 2015. *Value added in Palestine by economic activity for the years 1994-2015 at constant (2004) prices.*

3. Potential for Enhanced Decoupling

This section examines the potential for Jordan and Palestine to meet their water and food security goals by extending decoupling, using Israeli productivity norms as a benchmark. More simply, if Jordan and Palestine could achieve similar water productivity levels as Israel, how much water could be saved? Three areas of potential advancement are examined: i) expanding total water supply through wastewater recycling (natural-water decoupling), ii) re-aligning the composition of food imports in favour of water-dense products (trade-based decoupling), and iii) integrating new technologies to increase agricultural production while using the same amount of water (efficiency-based decoupling).

It is important to note that desalination is *not* considered an additional decoupling pathway for Jordan beyond the capacity already planned. Although Israel's recent water achievements have — volumetrically — been derived from desalination, this is a technical solution that is contingent on sea access, which in the case of Jordan is limited. Moreover, the viable extent of desalination is already planned for in Jordanian policy through the Red-Dead initiative, as articulated in the 2016 Master Plan.[97] [98]

3.1 Wastewater Recycling (Natural Water Decoupling)

Between 2010-2014, Israel reused just over 60 per cent of the 750 MCM consumed by the domestic sector. This 60 per cent represents a reuse of close to 90 per cent of sewage captured.[99]

Jordan commenced wastewater recycling in the 1980s, and since then Jordan Valley water from the King Abdullah Canal (KAC) has been sent to Amman in exchange for treated effluent. In 2014, Jordan's domestic water supply was 428.2 MCM, with 29 per cent of that volume (125.3 MCM) supplied as wastewater to agriculture in 2014. By 2025, MWI estimates see wastewater production grow, maintaining around 30 per cent of domestic supply volumes. If the Israeli level of reuse could be achieved (i.e. 60 per cent recovery), Jordan could recover 257 MCM/year based on present domestic supply volumes (an addition of 140 MCM above current volumes of wastewater reuse).[100] However, these figures may not capture the entire story. Of the domestic water supply, an estimated 50 per cent is lost in leakage and illegal abstraction (Non-Revenue Water, NRW).[101] Taking this condition into consideration, Jordan is actually already achieving a reuse rate of around 60 per cent of water that legally is used in the domestic sector. To increase

[97] MWI 2016. *National water strategy*

[98] Moreover, this technology has played a minor role when compared to food trade and economic diversification. Jordan's capacity for seawater desalination is limited by the environmental impact of brine discharge into the Red Sea. The Red-Dead conveyance circumvents this problem by allowing brine to flow to the Dead Sea. Phase 1 of this project is currently under tendering. Direct water supply, and water swaps with Israel (to provide Jordan with water closer to Amman) will result in total of 233 MCM/year by 2025. Data Source: Ministry of Water and Irrigation (MWI). 2016. *National water strategy, Jordan 2016 2025.*

[99] Water and Wastewater International. *Israel reuses nearly 90% of its wastewater*. 2016 Available from http://www.waterworld.com/articles/wwi/2016/12/israel-reuses-nearly-90-of-its-water.html

[100] Importantly, this 60% target is volumetrically close to the 240 MCM/year that Jordan plans to recycle by 2025 (MWI, 2016), but without addressing losses and NRW. Current Jordanian policy is closely aligned to regional best practice.

[101] According to MWI (2016), total water supply for 2014 of 429 MCM was sufficient for 126 litres/capita/day. Actual household receipt is estimated to be 61 litres/capita/day, meaning around 65 litres/capita/day are lost. This 'non-revenue water' is attributed to "physical and administrative gaps" (MWI 2016).

wastewater recycling further, in addition to increased connections to the sewage system, leakage and NRW would need to be reduced. However increased capacity for wastewater recycling means that every cubic meter saved through reduced leakage or improved regulation can be considered as worth 1.6 cubic meters to the Jordanian water economy.

The situation for wastewater potential changes as domestic supply increases to meet population growth to 2025, and estimates of potential water recycling volume should be revised upwards. The MWI intends to increasingly meet growing irrigation need through expanded wastewater volumes to 2025. The MWI also envisages sending treated wastewater to large industrial establishments, however this will depend on changes in the physical and regulatory acceptance of treated effluent in industry. Jordan's most recent Water Plan estimates 738 MCM of domestic allocation by 2025, with a 30 per cent recovery rate for wastewater to agriculture. However, assuming that leakage and non-revenue abstraction will be minimised and the optimum 60 per cent reuse benchmark is maintained, a potential 443 MCM/year effluent yield might be secured. Importantly, any expansion of wastewater would be conditional upon improved connectivity of household wastewater to central collection systems, the treatment of water, and distribution of treated wastewater to agriculture.

Tree crops in Jordan (those most suited to recycled wastewater) currently use 279 MCM/year, most of which is fresh water. Assuming all of the 2014 supply of 125 MCM is used in tree crops (ignoring fodder crops), there remains a further 145 MCM/year natural freshwater that could be released to other uses through the additional wastewater supply. A long-term 60 per cent recovery of 443 MCM would be sufficient for current tree and field crops, while allowing expansion of these crops to meet growing domestic needs, and potentially export earnings, within available wastewater volumes. Such a strategy would involve an adjustment of the national crop mix, and should be the subject of further research.

In Palestine, domestic water use was 191 MCM in 2014. Applying the same 60 per cent target recovery rate, a recycling potential of 115 MCM/year could be achieved (62 MCM in the West Bank and 53 MCM in Gaza). These volumes would again be dependent on significant infrastructure development, a task that is currently constrained by political challenges related to control over infrastructure planning and construction, and the sharing of systems between Palestinian and Israeli users.[102]

[102] The issue of water and wastewater infrastructure development and management is highly politicised, and beyond the scope of this research. Challenges and politicisation of coordination, development and resource sharing are discussed and exemplified by World Bank (2009), Fischhendler et al. (2016) and Selby (2013). See: World Bank 2009. *West Bank and Gaza: Assessment of restrictions on Palestinian water sector development. sector note, April 2009.* Washington DC: World Bank.

Itay Fischhendler, David Katz and Eran Feitelson. 2016. Identifying synergies and trade-offs in the sustainability-security nexus: The case of the Israeli-Palestinian wastewater treatment regime. *Hydrological Sciences Journal* Special Section: Hydrology and Peace in the Middle East: 1358-69

Selby, Jan. Cooperation, domination and colonisation: The Israeli-Palestinian joint water committee. *Water Alternatives* 6 (1): 1-24.

3.2 Strategic Food Trade

In 2014, Jordan imported 62 per cent of its overall food needs,[103] and 64 per cent of its plant-based food needs. This high dependence on food imports allows water to be focused on crops for which there is local demand and that cannot be easily imported.

To illustrate the nature of different crops' water intensity, Table 2 sets out the average water consumption of six highly import-dependent crops.[104] The analysis suggests that further refining this food import basket could yield additional water savings. Potatoes and bananas, for example, require moderately high amounts of water and lend themselves to transport and storage, making a strong case for increased import substitution. Wheat, which is currently 98 per cent imported, is another case in point given its low economic value and relative water intensity. To identify a food-import basket that optimises water productivity, while still allowing a requisite level domestically-derived food security, more detailed research would be required. However, for illustrative purposes, the analysis below sets out the water savings that could accrue if production of these 6 import-dependent crops was halved and substituted with imports. Again, this total saving of 52.5 MCM would need to be considered against loss of domestic livelihoods and the risks associated with increasing Jordan's exposure to volatile international food markets.

Table 2: Water Use of 6 Import-dependent Crops & Potential Further Water Savings.[105]

Crop	Average Water Use 2009-2014 (MCM/year)	Current (2014) Import Dependency	Saving (MCM/year) if Domestic Production Halved
Banana	25.8	56%	12.9
Apples	18.8	53%	9.4
Dates	23.4	64%	11.7
Wheat	3.5	98%	3.5 (1)
Onion	7.1	57%	3.5
Potato	23	36%	11.5
TOTAL	101.7		52.5

3.3 Agricultural Water Productivity

3.3.1 Assessment of Relative Agricultural Water Productivity Using Available Data

To gauge relative agricultural water productivity (crop yield per unit water) in Israel and Jordan, secondary data from government and past studies were used to calculate average national water use per crop ton for key crops. In Israel, water productivity was calculated for 47 crops, and in Jordan for 56 crops, thus capturing all major plant-based production tonnage for the two countries

[103] Based on 2013 FAO values. While national data on Jordanian production closely matches FAO data during the available record, import data only matches from 2006; the national record recording a large number of null categories prior to that. Indeed, on a regional scale, Jordan has one of the most import-dependent food economies in the MENA region (Gilmont 2015, Drivers of Food trade.).

[104] This calculation is based on derivation of official numbers of production and imports from the bureau of statistics.

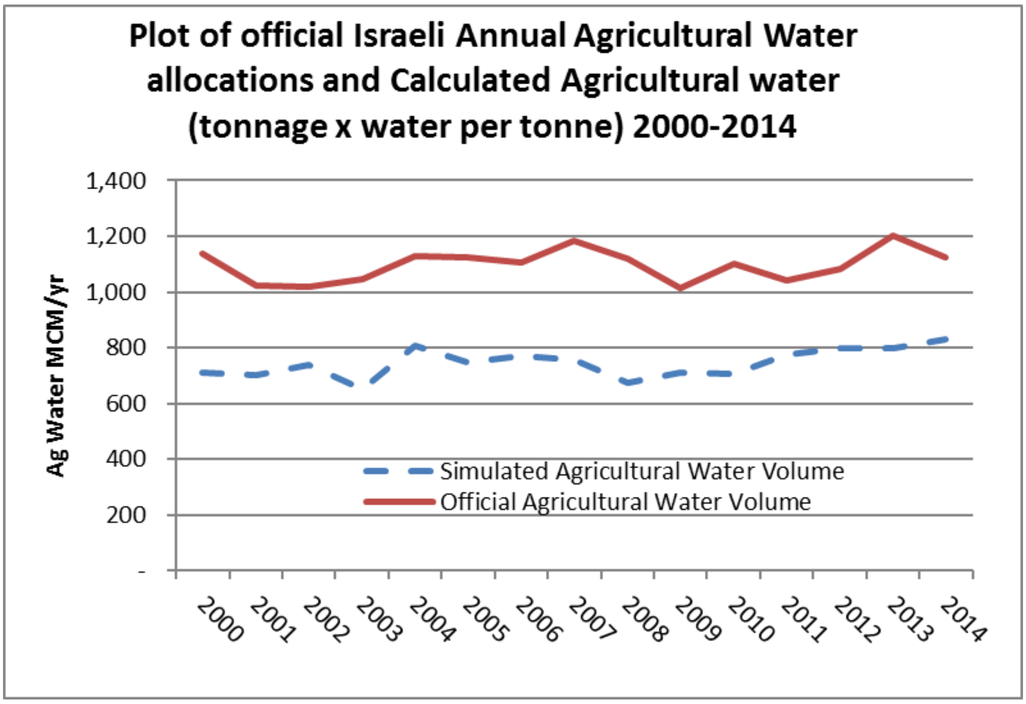
[105] Note: Wheat Proposed Total Import Substitution (Reflecting 100% Saving)

for which tonnage and water data were available. The complete derivation of water productivity numbers used is set out in Box 1.

In the case of Israel, when these numbers were compared to official data on agricultural water allocation for the same years,[106] the simulation of average water productivity appeared to significantly *underestimate* agricultural water use (Figure 17). Possible explanations for this discrepancy, including the impact of averaging crop water requirements across the country, are discussed in Box 1. To correct for this, crop water requirements in Israel were inflated by 42 per cent. The aim of substituting this more conservative estimate was to guard against proposing unrealistic targets for water productivity for Jordan.

By contrast, the Jordanian data appeared to *over-estimate* agricultural water use, by approximately 115 MCM in 2010 — the year on which the Jordan numbers are based (Box 1 and Figure 18). Interestingly, this quantity almost exactly equals the 110 MCM of illegally abstracted water recently re-captured through government enforcement between 2013-2016. This close reconciliation between simulated water use and known data on official and illegal abstraction meant that no correction in the Jordanian numbers was made.

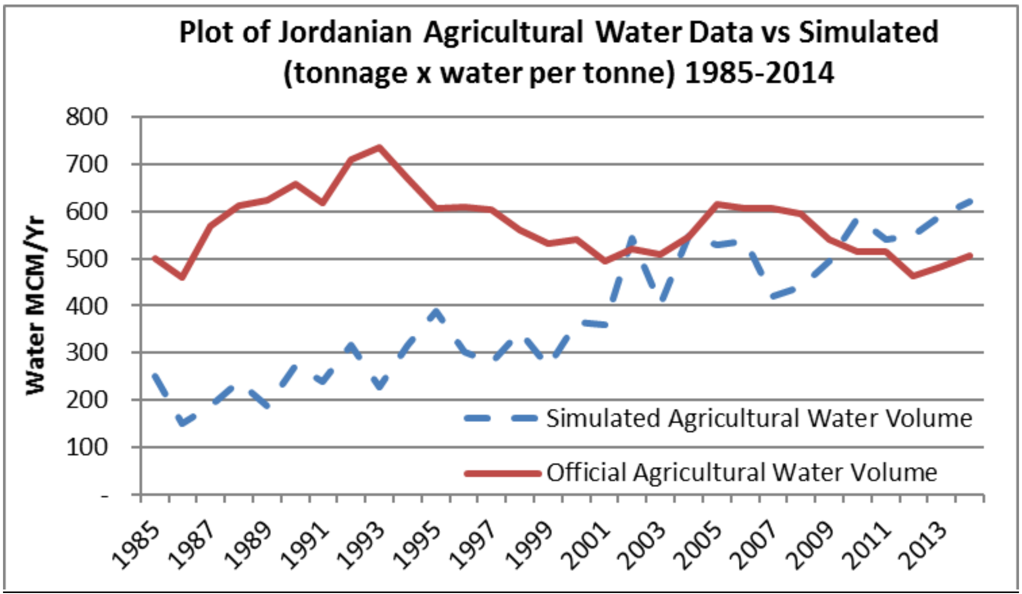
Figure 17: Comparison for Israel of Official Value for Agricultural Water Use, with Simulated Value



The simulated value is calculated through official data on crop tonnage multiplied by average water/tonne. The diagram shows the underestimation of agricultural water use when combining water productivity and tonnage values, and required inflation of Israeli water values to provide a conservative comparison of potential regional water productivity gains.

106 CBS (Israel Central Bureau of Statistics). *Statistical abstract 2016*. table 21.4 water production and consumption.

Figure 18: Simulated and Official Data for Jordan on Agricultural Water Use 1985-2014



Having calculated water per unit crop for Israel and Jordan, a basket of 14 crops was selected for comparison purposes. These crops were selected based on (i) major differences in water productivity, (ii) a potential for major savings based on large volumes being grown, and (iii) crop importance to the agricultural sector. For Jordan, these 14 crops accounted for 508 MCM as at 2010 (the benchmark year of the USAID numbers used in crop water computation – see Box 1), against a simulated total agricultural water use of 587 MCM, or 86 per cent of Jordanian crop water needs.

Table 3 sets out the potential savings that could be accrued if Israeli levels of agricultural water productivity were applied to Jordanian crops. These savings are based on average production tonnages over the 2009-2014 period.

The analysis suggests that 168 MCM of the average 508 MCM water consumed by the 14 crops during 2009-2014, could be recovered if Jordan was able to adopt Israeli water productivity levels. Such savings relate particularly to olives, tomatoes, apples and clover. Potato and cucumber production in Jordan, by contrast, appeared to be *more* water productive when compared to Israel. In the case of cucumber, the data are considered reliable — even using uninflated Israeli water consumption, Jordan remains more efficient. In the case of potatoes, however, the inflated figures place Jordan only slightly more water productive than Israel; it is only when Israel's water productivity is reduced by 42 per cent that Jordan becomes more efficient. In the interests of setting conservative targets in water productivity for Jordan, these data do not feature in the calculation of total potential water savings for Jordan in Table 3.

Another important observation to draw attention to concerns clover cultivation, which Israel does not irrigate due to its low commercial value and the retail and opportunity cost associated with agricultural water. If Jordan similarly moved to rain-fed clover production, savings of 71 MCM could be achieved (Table 3).[107] Such a move would necessarily involve a relocation of some production, and require farmers who traditionally grew their own feed to purchase rain-fed crops from other producers. Such challenges would need to be considered against the possible water savings.

Table 3: Basket of 14 Key Crops, Jordanian Water Intensity and Average Annual Water Needs, Israeli Water Intensity and Equivalent Water Needs of Jordanian Production at Israeli Water Productivity Levels[108]

	Jordan Water Use MCM (2010)	Jordan Average Tonnage '000s (2009-14)	Jordan Water/ Crop Ton	Jordan Average Water Use 2009-14 MCM/ Year	Israel Water/ Crop Ton @142% Inflation	% of Present Scenario	Water Used under New Scenario (MCM)	Water Saved/ Year
Clover	84.0	190.1	376	71.41	Rain-fed	0%	0	71.4
Olives	167.1	110.5	1,627	179.75	1278	79%	141.2	38.6
Tomatoes	74.1	753.6	100	75.73	75	75%	56.3	19.4
Banana	26.6	42.4	609	25.81	449	74%	19.0	6.8
Apples	15.0	36.1	522	18.82	187	36%	6.7	12.1
Dates	24.6	10.7	2,187	23.44	1879	86%	20.1	3.3
Watermelon	14.8	117.6	96	11.33	81	84%	9.5	1.8
Grapes	14.6	34.7	491	17.02	426	87%	14.8	2.3
Wheat	3.5	21.6	160	3.46	57	35%	1.2	2.2
Onion, dry	4.2	27.0	265	7.14	185	70%	5.0	2.2
Citrus	35.1	108.7	293	31.89	227	77%	24.7	7.2
Eggplant	11.7	106.6	111	11.87	99	89%	10.6	1.3
Potato	25.2	159.8	144	23.00	189	132%	30.3	-
Cucumber	7.1	191.4	41	7.75	68	168%	13.0	-
Total	507.5	1910.7		508.4		352.5		168.4

[107] To make more detailed recommendations, further research is needed into Israeli varieties and rainfall conditions. Certainly, however, initial desk analysis suggests that Israel is growing clover without irrigation within similar climate limits as exist in Jordan. Trifolium Clypeatum is grown is the arid/semi-arid zone near the southern Israeli Dead Sea (Boller et al 2005), where rainfall is less than 300mm/year. The FAO records that 5.9 per cent of Jordan's area receives 200-300mm, the 'marginal' zone just above the classification of aridity (Al-Jaloudy, 2001). This compares to a total cultivated area in Jordan (rain-fed and irrigated) of 3 per cent of the country, indicating in theory, a significant land area potential to further develop rain-fed crops in the marginal zone. Sources: Al-Jaloudy, Mahmoud, A., *Country Pasture/Forage resources profiles: Jordan* (edited by Suttie, J. M., and Reynolds, S. G., in May 2006 for FAO), 2006. Available from http://www.fao.org/ag/agp/agpc/doc/counprof/PDF%20files/Jordan.pdf
Boller, B., E. Willner, L. Maggioni, and E. Lipman. 2005. *Report of a working group on forages. Eights meeting, 10-12 April 2003. Linz, Austria*. Rome, Italy.: International Plant Genetic Resources Institute.

[108] Note that olive tonnages are taken as the irrigated proportion of total production, as calculated by proportions derived from the USAID study used for crop water numbers.

Box 1: Agricultural Water Productivity Calculation Methodology

National average data on crop productivity per unit water was calculated for Israel and Jordan. For Israel, regional data from the agricultural extension service was used to calculate a national average of crop yield and water needs per dunam for the 49 main crops where national production data was available[109] (see Appendix 1). For Jordan, a USAID funded study by IRG and Karablieh[110] for crop water use in the Jordan Valley and the Highlands[111] was combined with official statistics on national crop production to calculate national average water intensities. The split between rain-fed and irrigated olives was based on calculations in the USAID study.[112] Using official production tonnage data for both Israel and Jordan, simulations were then made of historic agricultural water use, based on calculations of crop water intensities. The results are set out in Figures 17 and 18.

In the case of Israel, the simulation dramatically under-estimated the actual agricultural water allocation. Part of this this discrepancy stems from the national averaging of crop water intensity; in reality certain regions contribute more of a crop than others, and a national average may underestimate the water needs of the majority of the production tonnage, but there is no regionally disaggregated data on annual crop production tonnages. Additionally, no data could be obtained on the other agricultural uses of water, including fish farms and non-food crops, nor on the additional water required to flush soils of salts. To close this gap, and ensure a conservative estimation of Israeli agricultural water productivity, crop water requirements were inflated by 42 per cent.

In Jordan, there was a lower discrepancy between simulated and recorded agricultural water use. Further, there was a strong gradient in the case of simulated water use, indicating a growth in agricultural water productivity from 1985. By 2014, however, simulated demand exceeded 660 MCM/year. This exceeds the official 2014 water use of 505 MCM by more than 30 per cent. This discrepancy of 155 MCM closely aligns with the estimated 110 MCM recovered as a result of the government's actions to curtail illegal surface water diversions and groundwater pumping.[113] This close alignment meant that the Jordanian water productivity numbers were not adjusted.

[109] Source: personal communication with the Ministry of Statistics
[110] International Resources Group (IRG), and E. Karablieh. 2012. *Institutional support and strengthening program (ISSP) ISSP water valuation study: Disaggregated economic value of water in industry and irrigated agriculture in Jordan.* USAID.
[111] IRG and Karablieh, 2012, Water Use by crop for 2010 derived from Table 23 (Field Crops), Table 25 (Winter Vegetables), Table 27 (Summer Vegetables), Table 29 (Fruit Trees).
[112] Based on Table 36 from IRG and Karablieh (2012), who state an irrigated olive tonnage of 102700t for 2010 (irrigation water use of 167.1 MCM) compared to total Jordanian olive production that year off 171,672t, giving a 60% irrigated tonnage.
[113] Oma Obeidat. Ministry ends large-scale water theft in Jordan Valley. *Jordan Times*, 03 September 2016.

3.3.2 Examining the Potential for Improved Water Productivity Against Farming Practices

i) Water Productivity Differences

To verify the secondary data used in the above analysis, and obtain water productivity figures for Palestine given the lack of available data, interviews were conducted with farmers of the 14 crops examined above, at locations summarised in Table 4. The results on relative productivity are set out in Table 5, and the full interview schedule is provided in Appendix 2. A further aim was to gain access to granular crop data on both sides of the Jordan Valley so as to enable a direct comparison of water productivity.

> Volumetrically, the interview data seems to suggest that farmers in the locations surveyed in both Jordan and Israel were more water-efficient than the national average. However, in terms of comparative efficiency, Israeli farmers were more efficient than their Jordanian counterparts.

While it was anticipated that differences would be observed as the unit of analysis moved from the national to the individual farm level, for both Jordan and Israel, the data provided through interviews were largely consistent with the disparities in water productivity observed in the secondary data discussed above. Interview data also suggested that farmers' water use was generally *lower* than the nationally-averaged secondary data. In Israel, this might be explained by the inflation of Israeli water productivity explained above. In Jordan, it is likely that crop water productivity has improved since the 2010 IRG and Karablieh USAID study.[114] The interviews with Palestinian farmers produced very limited data on crop yield and water use; data for 10 of the 14 crops was obtained. In part, this was due to farmers not necessarily keeping track of how much water they use, which in itself poses a challenge for improved water productivity.

While overall disparities in water productivity were confirmed, there are some anomalies in the two data sets concerning individual crops that warrant further explanation. First, Israeli farmers appear to be less water productive in the case of apples (although the interview data closely matches the water use recommended by the Agricultural Extension Service for the northern region), citrus, wheat, watermelon and cucumber.[115] In Jordan, wheat,[116] onion and cucumber production were found to be less water productive than the national average numbers. On the other hand, Jordanian farmers appeared to be more water productive in the case of olives and dates. Follow-up interviews revealed that in Jordan these crops were rain-fed with supplemental irrigation,[117] despite being selected as 'irrigated' producers, while in Israel farmers believed that without complete irrigation, crops could not be sold at a market price to make them profitable. This is a powerful finding relevant to Israeli agriculture reform, and potential multi-directional knowledge exchange, and is further explored later in this paper.[118]

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[114] See efficiency gradient in the simulated water time series in Figure 18.
[115] Eggplant production in Israel is concentrated in the hands of a few farmers, and none were willing to be interviewed, so no primary eggplant data is available.
[116] Only one wheat farmer was interviewed, from the highlands rather than the Jordan Valley for other crops.
[117] Interviews across a larger sample would be necessary to determine how widespread this practice is.
[118] Watermelons also appeared to have a higher water productivity in Jordan, but this was mainly due to the very high water usage of the single Israeli farmer interviewed, which greatly exceeded the extension service recommendation for the area.

When the discrepancies between the secondary and primary data are considered more broadly, it suggests that the findings for 6 crops (tomatoes, bananas, apples, wheat, onions, citrus) are very reliable — that is the discrepancies in water productivity are confirmed in both the primary and secondary data. These are all crops where significant gains in agricultural water productivity could be achieved in Jordan if Israeli norms could be reproduced. In the case of other crops (potato, cucumber, dates, olives, watermelon, eggplant, clover and grapes), the primary and secondary data are not consistent. With the exception of cucumber, olives and dates, it may be the case that these are also crops where adopting Israeli productivity levels would result in water savings; more thorough investigation is needed for certainty around this conclusion however. For the purposes of maintaining conservative estimates regarding the scope of total water savings possible for Jordan and the targets for water productivity that should be adopted, a revised summary of certain versus uncertain potential savings is presented in Table 6. This table shows that 49.9 MCM of the 168 MCM from the secondary data is reliable according to the interview data. Taken together, the farm interviews confirm the secondary data analysis findings above that tomatoes, bananas, apples, wheat, onions and citrus are all crops where there is a high degree of confidence that significant gains in agricultural water productivity could be achieved in Jordan if Israeli norms could be reproduced.

In Palestine, marginal gains in water productivity might be possible for tomatoes and dates, while significant savings appear possible for olives, citrus and cucumbers.[119] But there are also crops where Palestinian and Jordanian farmers appear to be enjoying much higher water productivity than Israel, including Palestinian bananas, onions and potatoes, and the aforementioned olives and dates in Jordan. These cases require further research to understand the reason for these trends, and the potential opportunities for two- or three-way regional learning on agricultural water productivity.

[119] The data on citrus was obtained from only once source in Gaza, with significantly lower quality, more saline groundwater than comparable fresh or effluent-irrigated citrus in Israel, which potentially increases the water volumes that need to be applied.

Table 4: List of Farm Interviews by Location and Crop Type

Location	Crop
Israel	
Centre and South	Potatoes and Sweet Potatoes
Jordan Valley North	Citrus
Bet Shean Valley	Wheat, cover, field crops
Bet Shean Valley	Dates, Olives
Jordan Valley North	Dates, Olives
North Galilee	Apples
Jordan Valley North	Citrus, Banana, Dates, Olives, Grapes, Watermelon, Onion, Tomato, Wheat
Carmel Coast	Banana, Citrus, Watermelon, Onion
Centre	Tomato, Cucumber
South West Negev	Citrus
Jordan Valley North	Banana, Olives
Nazareth	Olives

Location	Crop
Jordan	
Azraq	Olives, Grapes, Dates
Jordan Valley	Citrus
Al Jiza	Tomatoes, Cucumber, Eggplants, Potatoes
Al JIza	Vegetables (various)
Al Azraq	Clover
Al Azraq	Grapes, Apples (rainfed)
North Shouneh	Tomatoes, Cucumbers, Eggplants, Potatoes
Irbid	Olives, Wheat (rainfed)
Irbid	Grapes, Apples (rainfed)
Jordan Valley	Dates
Jordan Valley	Cucumber, Tomatoes, Eggplants, Potatoes
South Shouna	Dates
Jordan Valley	Citrus
Al Jiza	Olives, Wheat
Jordan Valley	Onions, Cucumbers
Jordan Valley	Dates
Al Jiza	Tomatoes and Watermelon
Jordan Valley	Banana
Jordan Valley	Potatoes, Watermelon

Location	Crop
Palestinian Territories	
Gaza	Citrus
Gaza	Olives trees
Gaza	Dates and Olives
Gaza	Citrus and Dates
Gaza	Onions, potatoes, eggplants
Bethlehem	Olives
Battir	Olives
Hebron	Grapes
Hebron	Grapes
Jericho	Dates
Jericho	Tomatoes, cucumbers, Bananas
Jericho	Eggplants, cucumbers, tomatoes
Tubas	Potato
Tubas	Onion
Tubas	Tomatoes (Ikram)
Jenin	Egyptian Grove
Jenin	Citrus and other tree, fodder and grain
Jenin	Cucumber
Jenin	Olive
Jenin	Wheat
Jenin	Olive, wheat, tomato
Qalqilya	Citrus
Qalqilya	Eggplant
Jenin	Vegetables (various)
Ramallah	Olives, wheat
Salfit	Olives
Nablus	Olives

Table 5: Water Productivity Comparison between Secondary and Farmer Interview Data, and between Israeli, Jordanian and Palestinian Cases.

These results show the Relative Water Productivity of Jordanian and Palestinian Farmers Relative to Israeli Farmers in Similar Locations.

	Israel Secondary Data (m3/t)	Extension Regional Data (m3/t)	Farmer Interview (m3/t)	Location	Farmer as% Secondary Data	Jordan Secondary Data (m3/t)	Jordan Farmer (m3/t)	Location	Jordan Farmer as% Secondary Data	Jordan Farmer as % Israel Farmer	Palestinian Farmer (m3/t)	Location	Palestinian Farmer as % Israel Farmer
Clover	Rain-fed	-	-		-	375.58	ND		-	-	ND		-
Olives	900	355	675	Average	75%	1,627.00	50.2	JV	3%	7%	3500	Jenin	519%
Tomatoes	52.6	38	38	JV	72%	100.5	61.2	JV & North	61%	161%	43	Tubas	113%
Banana	316.1	204.7	217	JV	69%	609.03	544	JV	89%	251%	8.75	Jericho	4%
Apples	131.5	153	156	North	119%	521.59	354	Highlands	68%	227%	ND		-
Dates	1323.5	1200	767	JV	58%	2,186.89	486	JV	22%	63%	889	Jericho	116%
Watermelons	57.1	45	150	JV	263%	96.33	96	Average	100%	64%	6	Jericho	4%
Grapes	300	453	75	JV	25%	491.06	130	Average	26%	173%	ND		-
Wheat	40	88	200	JV	500%	160.04	350	Highlands	219%	175%	ND		-
Onion, dry	130	88	92	JV	71%	264.77	422	JV	159%	459%	14	Tubas	15%
Citrus	160	161	203	Average	127%	293.45	342.9	JV	121%	169%	292	Gaza	144%
Eggplant	70		ND			111.31	143	JV	128%		700	Jericho	-
Potato	133.3	139	83	Centre	62%	143.9	125	Average	87%	151%	42	Tubas	51%
Cucumber	48		77	JV	160%	40.51	113	JV	279%	147%	382	Jenin	496%

Table 6: Summary of Savings Based on Reliability of Comparison between Secondary and Interview Data Calculations.[120]

	Israel Water/ Crop Ton @140% Inflation	Jordan Secon-dary Data (m³/t)	% Difference	Saving Based on 2009-2014 Tonnage	Israel Farmer Interview (m³/t)	Jordan Farmer (m³/t)	% Difference Farmer Interviews (m³/t)	Saving if Israel farmer results Scaled to Jordan National Tonnage
Clover	Rain-fed	375.58	100%	71.4	-	ND	ND	ND
Olives	1278	1,627.00	79%	38.6	675	50.2	1345%	-69.04
Tomatoes	**75**	**100.5**	**75%**	**19.4**	**38**	**61.2**	**62%**	**17.5**
Banana	**449**	**609.03**	**74%**	**6.8**	**217**	**544**	**40%**	**13.9**
Apples	**187**	**521.59**	**36%**	**12.1**	**156**	**354**	**44%**	**7.1**
Dates	1879	2,186.89	86%	3.3	767	486	158%	-3.0
Water-melons	81	96.33	84%	1.8	150	96	156%	-6.4
Grapes	426	491.06	87%	2.3	75	130	58%	1.9
Wheat	**57**	**160.04**	**36%**	**2.2**	**200**	**350**	**57%**	**3.2**
Onion, dry	**185**	**264.77**	**70%**	**2.2**	**92**	**422**	**22%**	**8.1**
Citrus	**227**	**293.45**	**77%**	**7.2**	**203**	**342.9**	**59%**	**15.2**
Eggplant	99	111.31	89%	1.3	ND	143		ND
Potato	189	143.9	131%	-7.3	83	125	66%	6.7
Cucumber	68	40.51	168%	-5.25	77	113	68%	6.9
Saving (secondary-primary general agreement)				**49.9**				**65.9**
Saving (uncertain)				118.7				

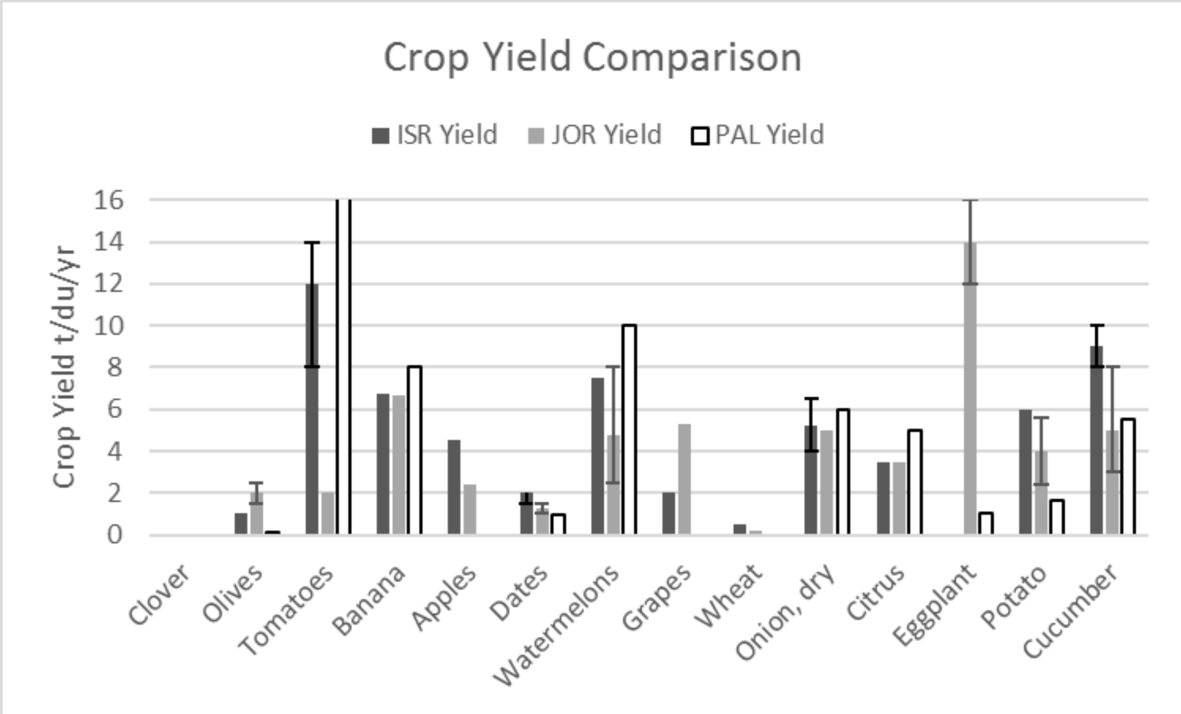
[120] Reliable values (general agreement between primary and secondary data) in bold confirming reliable trends seen in secondary data for tomatoes, banana, apples, wheat, onion and citrus, equating to around 50 to 66MCM per year of agricultural water reduction.

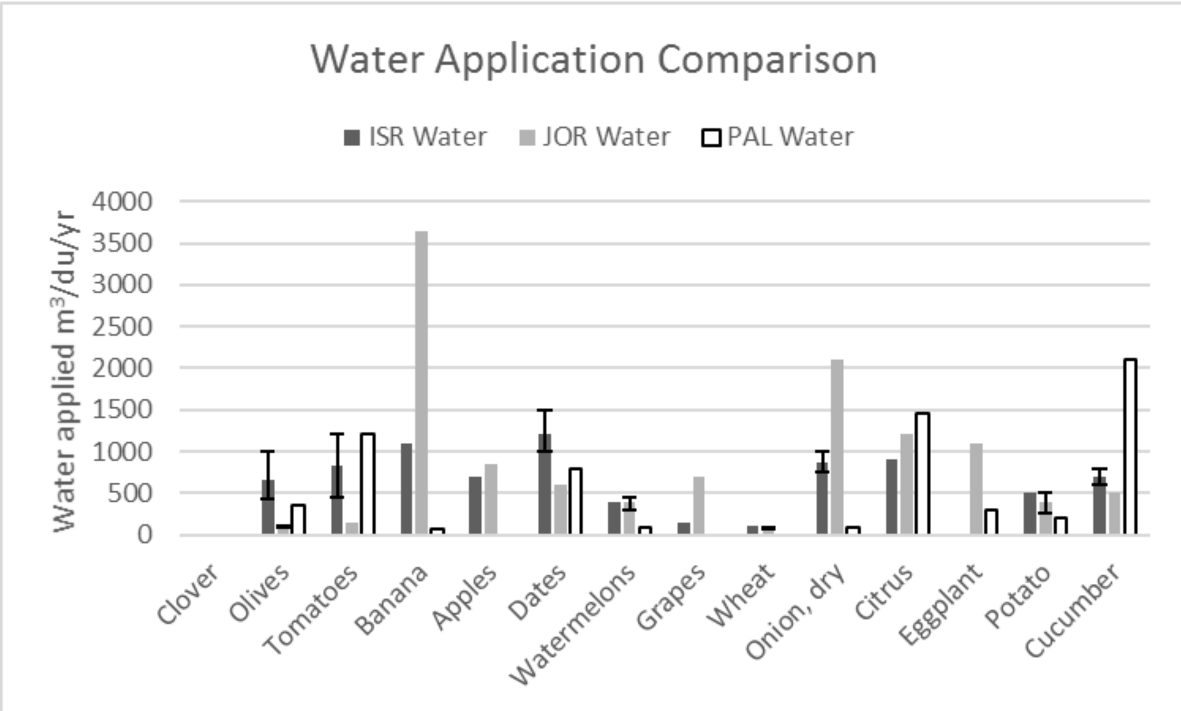
(ii) Water Application and Yield

The above discussion on efficiency decoupling assumes that enhanced water productivity reduces the amount of water required for each unit of crop output. This benefit can be achieved either by reducing water input and maintaining yield, or by increasing yield for the same input, or a combination of the two. In the above analysis, it is unclear whether the water productivity disparities observed between Israel, Jordan and Palestine are due to disparities in water used/dunam, or the result of disparities in crop yield/dunam given a certain amount of water. In response, Figure 19 sets out the water and yield data per dunam derived from farm interviews, revealing large differences in yield vis-a-vis water intensity in some crops. Understanding which driver is causative is important as this provides insight into possible avenues of corrective action i.e. where adopting the 'best practice' could increase water productivity. For example, in the case of bananas, onions and citrus, Israel, Jordan and Palestine produce similar yields, but Jordan and Palestine use far greater amounts of water, suggesting that water in these countries could be reduced without interrupting yield if relevant norms were adopted. For tomatoes, Israel produces a far greater yield using less water compared to Jordan. This suggests that it may be possible to both reduce water application and increase yield.[121]

[121] For Palestinian bananas, it appears that they have a slightly greater yield, but with far more water use. This anomaly is inconsistent with the secondary data and thus requires further investigation. The farmer interviewed received around 230 mm/year rainfall, well below that which is required for Bananas, yet the farmer reports very low levels of irrigation for the crop.

Figure 19 and 20: Comparison of Yield and Water Figures for Individual Crops, as Informed by Farmer Interviews[122]





[122] Note that the Palestinian tomato yields (off scale) were given as 28 ton/dunam by the one farmer who supplied data. The data encompasses the entire survey, rather than a regional skew (especially to the Jordan Valley) of water/crop data above.

3.3.3 Dollar-Per-Drop – Water Valuation

A final important lens through which to view water productivity is relative crop price. Farm interviews confirmed that crop prices are generally comparable across Jordan, Israel and Palestine (Table 7), despite variations in water use.[123] That for the same market value, crops consume hugely different amounts of water, and that water is a limitation on production (whether due to price, availability or reliability), suggests that there is a financial rationale for improving water productivity. Improving the water productivity of onion production, for example, could result in a near fivefold financial return per unit water. It also strengthens the case for enhanced import-substitution. Jordanian onions, wheat, apples, bananas and perhaps clover,[124] which have the lowest return per unit water of the crops surveyed, should hence be increasingly imported, allowing water to be reallocated to other sectors or the production of more efficient crops.

Dates and olives require special mention. Jordanian dates command almost twice the price of Israeli equivalents.[125] Despite this, Jordanian farmers appear to rely predominantly on rainfall and use small volumes of supplementary irrigation. As discussed previously, Israeli farmers irrigate, based on the rationale that this is the only way to obtain a market price that makes them profitable to produce. The Jordanian evidence challenges the notion that rain-fed olives and dates are less economically viable than irrigated olives, which is an important observation for Israeli farmers.

[123] Further exceptions include highly priced Israeli tomatoes (likely due to the interviewee's industrial supply contract) and low Israeli grape prices (likely due to the interviewee mainly supplying wine producers).
[124] If clover is similarly computed using the secondary data of 376m^3/t, the financial return on the water is only USD 0.8/m^3
[125] The data on tonnage and prices for olive oil were converted to the fruit equivalent at an approximate conversion rate of 30 per cent (so 1 kg olives prices 300 ml of oil). Prices for olives sold as fruit and oil were generally similar, so a higher ratio of oil production does not explain the higher price in Jordan.

Table 7: Summary of Average Quoted Prices From Farmer Interviews, Comparable Average Crop Yields, and Equivalent Revenue per Unit Water for Each Crop [126]

Crop	Jor USD/ kg	Isr USD/ kg	Pal USD/ kg	Jor m^3/t	Isr m^3/t	Pal m^3/t	Jor USD/ m^3 Crop Water	Isr USD/ m^3 Crop Water	Pal USD/ m^3 Crop Water
Clover	0.31	0.24	ND	ND	-	ND	ND	Rain-fed	ND
Olives	1.62	1.37	2.11	50.2	675	3500	32.24	2.02	0.60
Tomato	0.32	1.99	0.55	61.2	38	43	5.24	52.30	12.72
Banana	0.78	0.83	0.56	544	217	8.75	1.43	3.81	64.45
Apples	0.39	1.33	ND	354	156	ND	1.10	8.49	ND
Dates	3.10	1.63	2.12	486	767	889	6.38	2.13	2.38
Water-melon	0.28	0.48	ND	96	150	ND	2.95	3.18	ND
Grapes	1.35	0.66	1.07	130	75	ND	10.39	8.83	ND
Wheat	0.52	0.32	0.40	350	200	ND	1.48	1.59	ND
Onion	0.50	0.53	0.27	422	92	14	1.18	5.76	18.93
Citrus	0.63	0.68	3.31	342.9	203	292	1.85	3.35	11.34
Eggplant	0.28	ND	0.76	143	ND	700	1.97	ND	1.09
Potato	0.55	0.32	0.60	125	83	42	4.37	3.83	14.20
Cucumber	0.51	0.80	0.55	113	77	382	4.47	10.32	1.43

JD/NIS to USD, 1 Sept 2016 market conversion rate

[126] Showing Generally Similar Pricing, with Differences in Water Productivity the Main Reason for Major Differences in 'Dollar-per-Drop' Values

4. Understanding Current Agricultural Practices, Opportunities and Challenges for Enhanced Decoupling

The feasibility of improving water productivity may be related to the social, economic, and political environment in which agriculture takes place. Gaining insights into the differences in these contexts facilitates a first attempt to deepen understanding of the challenges and opportunities of improved agricultural water productivity.

4.1 Farm-Level Conditions

Farm-level interviews also discussed crop pricing and the social dimensions of farming, including alternative income streams, education, owner-farmer relationships, and perceptions on the future of farming.[127] The key results (summarised below), provide important insights into the feasibility of policy development. Of the farmers interviewed, size varied several orders of magnitude both within and between country samples. The sample for Israel produced an average farm size of 5900 dunams, ranging from 100-44000 dunams; for Jordan, the average of our sample was 145 dunams (ranging from 12-650); for Palestine the average was 140 dunams, ranging from 3-1357 dunams.

4.1.1 Farmer Education

In Jordan, 10 of the 14 farmers reported having a graduate degree or professional qualification or training; in 6 cases their education related directly to engineering or economics, and the in others to public service or teaching. The remaining farmers received high school or basic education. In Israel, 8 of the 10 farmers were tertiary educated; 7 studied plant sciences, business or economics. The remaining two farmers had high school education only. In Palestine, 13 of the 26 farmers had high school education, 11 had professional diplomas or degrees in agriculture, economics or land-related disciplines, and two had no education. Education levels are therefore similar in Jordan and Israel, and lower for Palestinian farmers, reflecting differences in wealth and education opportunities nationally.

4.1.2 Farming as a Main Income Source

For Israeli farmers, 8 out of 10 relied on farming as their primary source of income, whereas in Jordan, 8 out the 15 respondents relied on pensions, government work or real estate as their principal income source. In the case of two respondents, farming was complemented by other agriculturally allied businesses including export and seed supplies. Only in 5 cases was agriculture the primary source of income. This is an important nuance. On the one hand, alternate income may mean that there is less of an imperative to make changes to maximise returns on resource

[127] The full interview schedule is covered in Appendix 2, with interviews occurring from July-September 2016 (Israel), August and December 2016 (Jordan) and August-October 2016 (West Bank) and September 2016 (Gaza). Farmers were interviewed, usually one-on-one by a member of the project team, or a nominated agent. Where necessary, follow up data was obtained by phone or email. In some instances, alternative farmers or experts were used to obtain water and crop yield data where this was not forthcoming from the farmers; this was primarily done during the second round of interviews focusing on crop water and yields in Jordan in December 2016. Additionally, two roundtables were held with the Jordanian policy community in July and November 2016 aiming to both elicit feedback on initial results, and deliver deeper insights on policy opportunities and constraints.

inputs (including water); on the other, such income may enable farmers to make the necessary investments to improve productivity, especially given the dearth of agriculture-specific loans. For Palestinian farmers 18 out of 26 respondents reported farming as their main income stream, with some reporting livestock and crop processing along with crop production. Of the farmers who had other income streams, these included other business activities, employment in Israel, and professional activities. Two farmers reported that subdivisions of their land, either through inheritance or through Israeli actions had eliminated the commercially viability of agriculture for them.

4.1.3 Irrigation Methods

In all three study areas, irrigation methods were dependent on crop type, with sprinkler and drip irrigation being common. Israeli farmers used mainly drip irrigation, especially for vegetable and tree crops, and sprinklers for field crops such as wheat. Jordanian farmers used a mix of drip and open tube delivery of water into a basin around tree bases (although there may have been some conflation between high-pressure drip systems and low-pressure open tube systems). Palestinian farmers use a mix of drip and sprinkler systems, with one farmer using a roman-era canal system as part of a community smallholding system. Importantly, *method* of irrigation is only one way that irrigation influences water productivity. With reliable water supplies, Israeli farmers irrigate at frequencies suitable to the crop. Palestinian farmers cannot do this; even if water volume is sufficient, lack of reliability in supply means they have to use water when it is available rather than when it is needed. Technologies to modify the quality of water sent to irrigation, including in extremis on-farm desalination, are also employed in Israel, albeit at significant investment cost and requiring advanced knowledge capacity. The size of Israeli farms, discussed at the start of this section, likely enable single farmers to operate water systems at an economy of scale that may not be possible for an individual farmer elsewhere.

4.1.4 Information and Knowledge

Knowledge and information appears to be a crucial determinant of water productivity. Israeli farmers are heavily dependent on the Extension Service to advise on irrigation volumes and frequency, supplemented by electronic monitoring of soil moisture. By contrast, in Jordan farmers are more dependent on their own experience and private companies (including seed vendors). Notably, many Jordanian farmers reported a poor or unreliable experience with the National Centre for Agricultural Research and Extension (NCARE); some noted a lack of proactivity on the part of the extension service in advising them, or the advice not being reliable, especially when provided by newly qualified agricultural engineers. Five farmers highlighted that they avoided government data due to its lack of reliability and associated negative experiences. Five farmers highlighted the important role of neighbours and family in providing them with the latest information of agricultural knowledge. For Palestinian farmers, 19 out of the 27 relied on the Ministry of Agriculture either solely or jointly for information, along with their own experience and independent research. Like Israel, and in contrast to Jordan, there appears to be a strong government structure in place with farmers receptive to information.

4.1.5 Crop Type Updating

Updating crop strain and/or moving towards less water intensive species, particularly for annual crops, represents an important means by which Israel has improved its water productivity. Indeed, of the Israeli farmers interviewed, 75 per cent reported changing crop varieties to maximise yield and/or reduce water needs, even for tree crops such as olives.[128] In Jordan, 8 farmers reported updating crop varieties at intervals of between 2-5 years, for both water and yield productivity and in response to market demand. Those farmers who did not update crops were focused on using local varieties, valued either for their traditional importance or local market preference. It is not known if there has been any research into improved strains of local varieties. One farmer noted that they lacked the investment capital needed to improve their crop stock. Of Palestinian farmers, 18 of 27 reported updating crop types in response to latest varieties or market demands, thereby improving crop and financial yield. One farmer stated that he followed the latest Israeli vegetable strains. As in Jordan, the importance attached to local varieties and market demand, was often cited as the reason for not adjusting crop types.

4.1.6 The Future of Farming

Across all three study sites, owner-operated farmers and broader family involvement in a farm's day-to-day operation was common, even in the case of commercial farms. While the majority of Israeli farmers predicted that the next generation would continue to engage in agriculture, there was a perception that other economic activities, particularly the high-tech sector, would become more attractive. Others believed that farmers would shift to business or other urban-based activities. Most Palestinian respondents viewed business, academic or government employment as being more appealing than agriculture in the future, with only three predicting that their children would engage in agriculture.[129] In Jordan, 10 of the 13 respondents did not envisage the next generation being involved in agriculture, particularly in light of low prices and limited opportunities in the sector. One respondent highlighted the absence of government incentives to the promote continuity of farming. The three respondents who did foresee a future generation of farmers highlighted the importance of involving the next generation at a young age.

4.2 Policy Challenges and Opportunities[130]

- *Price and supply reform*: The most straightforward way of incentivising efficiency in water use is through price control. Due to subsidies, the price of agricultural water in Jordan is very low, with the result that there is little incentive for farmers to improve water productivity. Israel, by contrast, has imposed price reforms to pass a more accurate costing of water onto domestic, agricultural and industrial users. An alternate approach is to cap agriculture water supply allocation. The key challenge of either policy is resulting popular discontent;

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[128] There was no further probing on how farmers decide, or the trade-offs for example in tree crops between continuing with established trees or investing in new and young plants.

[129] Two of these respondents produced high value crops (dates, olives and specialist herbs).

[130] This section is based on the discussion of a roundtable held in Amman on 21 November 2016. Participants were given a presentation on the emerging research results, and also presented their own work on agricultural water productivity change. In a roundtable format, participants then discussed the challenges and opportunities for improving agricultural water productivity and enhancing reallocation of water and thereby resource decoupling in Jordan. Participants included representatives of senior and middle management from Ministries of Agriculture, Water, and Environment, along with representatives of the farming community.

certainly in Jordan, the perception is that agriculture is already receiving less water than it needs to operate. Indeed, farmers appear to be using less water than is currently targeted in policy; they use between 500-600 MCM/year of the agricultural allocation rather than the targeted 700 MCM/year benchmark the 2016 water plan.

- *Financial incentives:* Tax breaks, low cost loans or tailored insurance schemes are seen by the policy community as possible mechanisms to incentivise on-farm water saving techniques, such as rainwater harvesting, hydroponics, purchasing irrigation equipment and irrigation technologies. Such incentivisation could also apply to the substitution of freshwater with wastewater on suitable crops, or a strategic zoning of agricultural land based on crop suitability. Conversely, farmers might be punitively taxed or charged on water being used to grow unsuitable crops, or growing crops in unsuitable areas.
- *Augmenting supply:* There is recognition by the policy community, backed up by recent action, of the need to curtail illegal use of groundwater. Likewise, minimising leakage by investing in the upgrading and repair of water infrastructure, should be prioritised. In addition to already planned measures, the potential for investment in rainwater harvesting as an alternative water source was also raised.
- *Improved policy coordination:* A clear deficit in Jordan is that the regulatory environment is plagued by contradictions, overlapping legal regulations and departmental responsibilities, particularly as relates to land use. This needs to be replaced by an overarching policy for water and food security, under which water is understood as a key input into the agricultural, domestic and industrial sectors, as well as a crosscutting issue in the sub-sectors of land use, food production, industry, trade and the environment. The basis of such policy should be a comprehensive evaluation of national food security, and an assessment of how production or import of particular crop types impacts on water needs. To this end, a study of crop water footprints would be a useful tool to assess the relative value of domestic production and imports of particular crops. The principal challenge is to synthesise the interests and priorities of different government authorities, particularly the Ministries of Water and Agriculture. Ministry of Agriculture objectives, for example, hamper water reallocation by opposing the reallocation of water from agriculture to other uses. Lessons from Israel might prove instructive; here, reforms commencing in the 1980s paved the way for a robust symbiosis being forged between the Water Authority and farmers.[131] It must be highlighted, however, that the institutional capacity, monitoring and control of water in the Israeli case is almost unique in global terms.
- *More efficient practices:* The agricultural sector faces the challenge of more attractive income opportunities being available in other sectors. On the one hand, this situation underscores the need for strategic policy reform to encourage the development of a leaner and more cost-effective sector. On the other, it is likely that some reduction in the size of the agricultural sector would be beneficial. The challenge will be to manage this natural shrinkage with a view to realising an optimally sized agriculture sector that operates in an efficient and competitive manner. Such a transition will likely require investment in new technologies and equipment, technical and knowledge support, and an enabling support

[131] However, Israel has seen recent tensions between the government and the agricultural sector, especially over changes to agricultural water prices in January 2017, and growing concerns over commodity prices, which indicates a changing political landscape for agriculture.

for the production of higher-value crops. What specific steps are required, beyond drip irrigation, which is already used fairly consistently in all three states, should be the subject of further research, including scientific research into improvements in local crop varieties and yields. The creation of a seed bank or catalogue to support the production of drought resistant and water productive crops, together with a knowledge base on their cultivation, was suggested by policy stakeholders as an action to be considered.

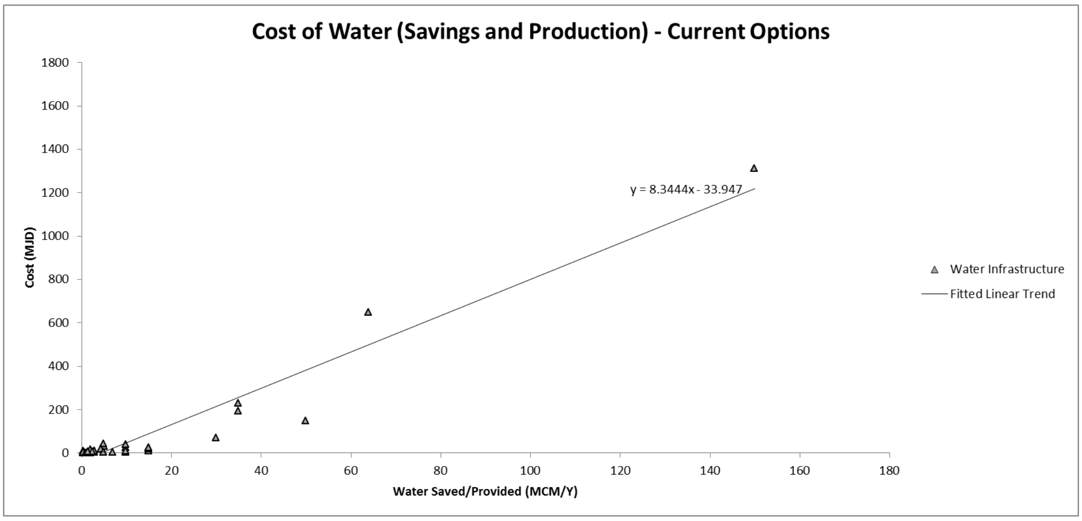
- *Risks:* A chief concern among agricultural scientists is the risk that reduced agricultural water volumes may leave farmers vulnerable with respect to the quality and quantity of agricultural products. There was also concern over biological and environmental systems, particularly any increased environmental stress resulting from reduced water input. The threat of climate change, and the increased temperature and reduced rainfall/increased drought predicted by some climate models for the region also pose limits to reducing water in agriculture. It is possible that climate change impacts in Jordan will eat away at margins that may currently exist through improved water productivity, and in doing so will counteract the long term gains of water productivity that may be available at present. New avenues for knowledge sharing between the agricultural sectors of the region, and in policy and technical innovation, will be critical in combatting this. While this report does not address improved urban efficiency in depth, gains achieved here (reducing up to 50 per cent non-revenue water) may augment future reallocation of both fresh and wastewater supplies to mitigate climate impacts and the reduced availability of resources.

5. Scenario Modelling of Enhanced Decoupling based on Agricultural Productivity and Food Trade in Jordan

This section details how the potential additional decoupling discussed in section 3 complements and/or may impact existing water polices and planning in Jordan. It reviews the economic baselines that enhanced decoupling needs to compete with, and presents a range of different combinations of agricultural productivity and food trade to be considered. Using uncertainty modelling, based on different population growth rates, and therefore water demands, the potential value of different combinations of decoupling are summarised. Finally, two decoupling scenarios are used to demonstrate how the strategy could help Jordan mitigate its anticipated gap between supply and demand by 2025, and achieve sustainability in its water resource use.

A risk-based modelling approach was used to understand the robustness of different future planning options. As highlighted earlier, under current scenarios and with anticipated population growth, a shortfall between national water demand and available supply is expected by 2025. A regression model was then developed to calculate the incremental cost of increasing supply, based on new infrastructure currently planned for. The result is a non-linear trend, whereby new water supply development costs between (i) JD 2.36/m^3 for new surface storage capacity, (ii) JD 5.81/m^3 for additional wastewater treatment and (iii) JD 9.17/m^3 for water through the Red-Dead conveyance (Figure 21). The analysis therefore lays out a baseline for the economic costs associated with decoupling, dictating the level at which decoupling strategies will become economically rational (based on a purely volumetric analysis).

Figure 21: Cost of Water Savings (Efficiency) or Increased Supply Infrastructure in Jordan[132], according to prices published by the MWI[133]



132 This figure shows the approximately linear increase in cost of new volumetric capacity.

133 Ministry of Water and Irrigation 2016. *Water sector capital investment plan 2016 - 2025.* Amman: Ministry of Water and Irrigation,

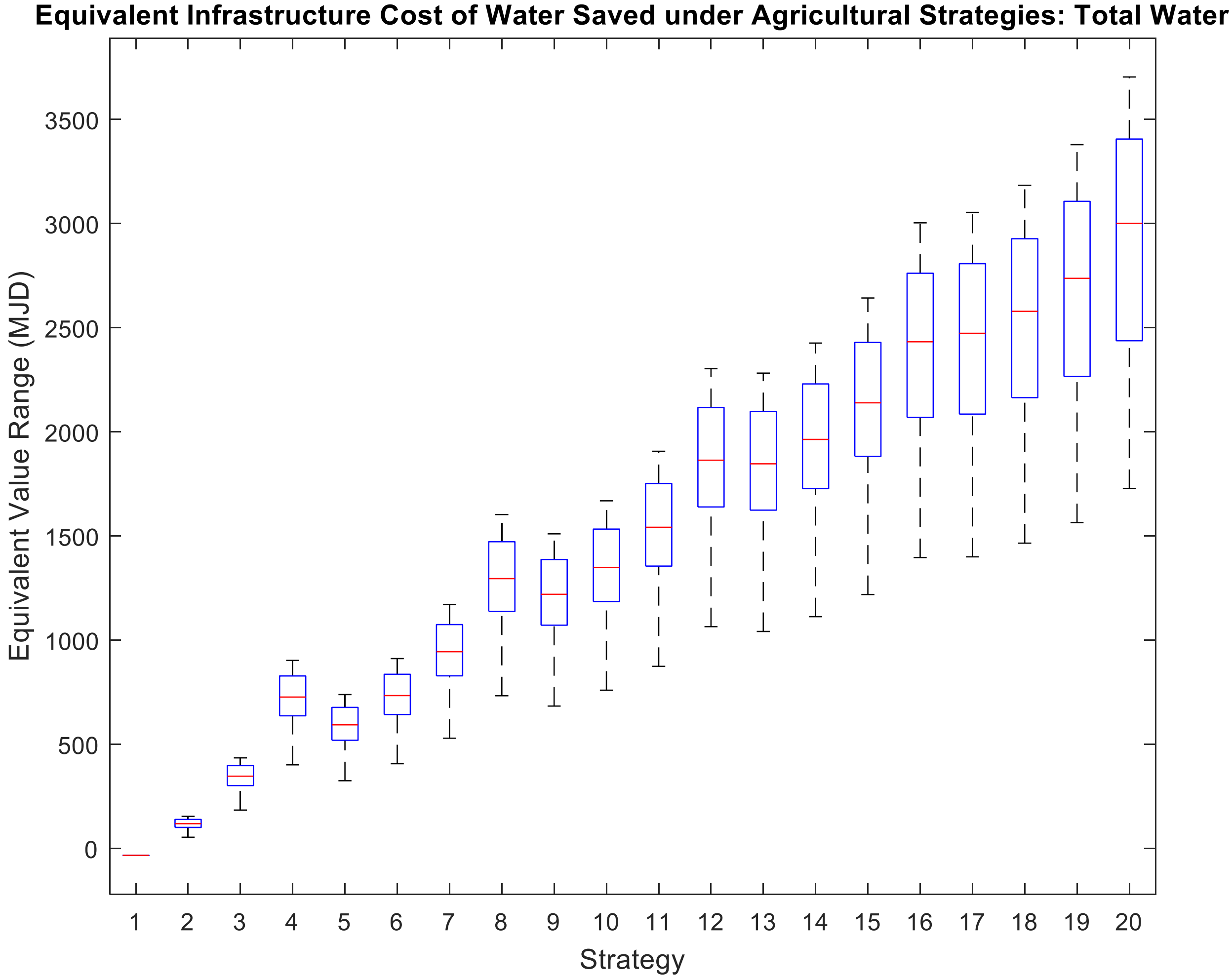
The ultimate decoupling potential outlined earlier in this document represents an ideal: 168 MCM/year reduction based on current production, and a further 52.5 MCM through enhanced import substitution. It is accepted that, in the short-medium term, achieving these goals may be ambitious, as well as having a high degree of uncertainty over exact values, as discussed in Section 3. Twenty future scenarios were thus tested based on different combinations of food import substitution and improved water productivity.

Table 8: Agricultural Scenarios Based on Productivity Changes from 0 to 100 per cent (where 100 per cent is a Saving of 168 MCM/year Based on Current Production Trends), and Import Substitutions (where 50 per cent is the Maximum Reduction of the 6 Crops Identified above).

		Efficiency Improvement					Food Trade			
		0%	25%	50%	75%	100%	0%	10%	25%	50%
Strategy	1	■					■			
	2	■						■		
	3	■							■	
	4	■								■
	5		■				■			
	6		■					■		
	7		■						■	
	8		■							■
	9			■			■			
	10			■				■		
	11			■					■	
	12			■						■
	13				■		■			
	14				■			■		
	15				■				■	
	16				■					■
	17					■	■			
	18					■		■		
	19					■			■	
	20					■				■

Figure 22 combines the different volumetric scenarios with equivalent cost if new alternative supplies were to be developed. These values are set out in figure 22. The statistical range of values for each scenario is based on uncertainty over population growth rates, reductions in non-revenue water, industrial growth and per capita water consumption level. It shows that, depending on these variable trends, the maximum acceptable cost, when compared to other options is between 1.7-3.7 billion JD, with a central value of 3 billion JD.

Figure 22: Value of Water Saved by Implementing Different Decoupling Scenarios[134]



This analysis suggests that economically rational expenditure to deliver enhanced decoupling has an upper limit. At scenario 20, a maximum import substitution (52.5 MCM) and maximum water productivity saving (168 MCM) is reached.

Further analysis on the relative role of decoupling illustrates how the strategy compares with other supply options being pursued. As set out in Figure 23, the full efficiency gains proposed are close in volume to the Red-Dead supply volumes, indicating significant volumetric potential.

[134] Note that the error bars indicate uncertainty over future population growth (i.e. domestic and agricultural water demand), per capita demand, urban leakage reduction and industrial growth.

Figure 23: Expected Water Savings from Each Agricultural Strategy Compared with the Existing Portfolio of Planned Water Infrastructure – 2017 Values

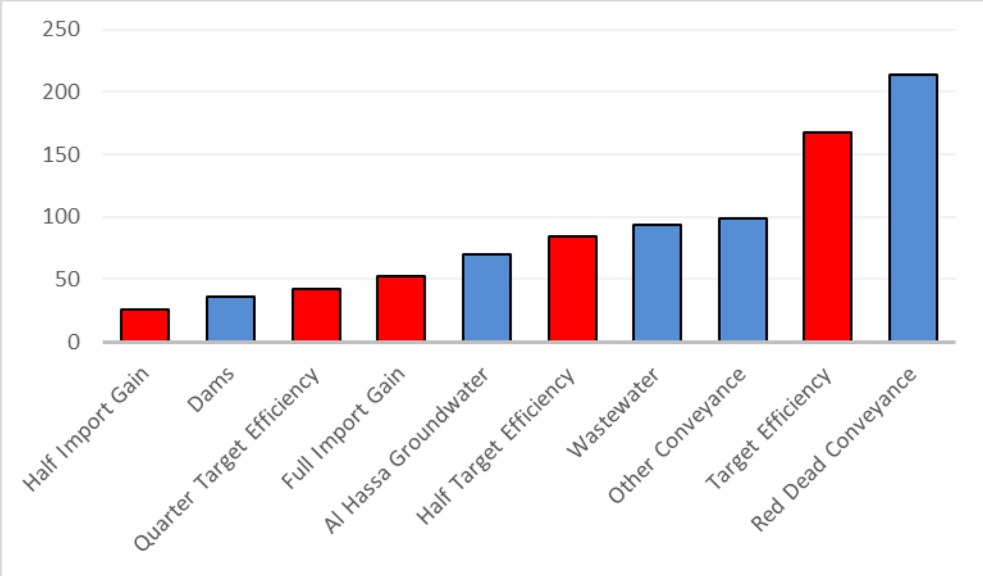


Figure 13 (in Section 2) set out a continued water deficit by 2025, even with additional planned supply augmentation. Applying the proposed enhanced decoupling strategies against the existing suite of supply augmentation options being delivered as per the 2016-2025 Water Plan, shows how they will help eliminate the current forecast deficits in Jordan's water resource needs. Two of the 20 modelled strategies are presented below, showcasing maximum productivity improvements alone, and productivity *plus* import substitution.

Figure 24, which includes full agricultural productivity improvements of 168 MCM over the period 2018-2025 (Strategy 17 in Table 4) shows this deficit being halved. Figure 25, which also includes 168 MCM in productivity gains and 52.5 MCM from import substitution (Strategy 20) eliminates the deficit, and shows a surplus created between sectoral needs and national supply capacity. This surplus could eliminate groundwater overdraft and move Jordan towards a healthy water balance. The results support the power of decoupling to eliminate the projected deficits in Jordan's water supply and to redress remaining environmental over-dependency.

While enhanced agricultural water productivity and food trade decoupling could sustain current output using less water resources, it must be recognised that population growth of around 15 per cent by 2025 (based on 1.9 per cent annual growth rates estimated by MWI, 2016)[135] will necessitate an increased food supply of fresh and non-importable products. It is further noted that there is no political appetite for reduced water allocations to agriculture; rather, current supply volumes (which are already below desired) might be held static. The scenarios presented below account for this through phased decoupling enhancement, while allowing for increased production growth at the same time up until 2025. The net result of these trends in both cases (i.e. with or without enhanced food trade decoupling) is an absolute reduction in natural freshwater to agriculture due to wastewater substitution. The over trend is that enhanced decoupling is used to maintain current levels of agricultural water use to 2025, with savings from increased water productivity redirected

135 MWI 2016. *National water strategy*

to allow expanded agricultural production. The Import Substitution scenario assumes that this saving will result in an absolute reduction in agricultural water use in order to cut back on unsustainable use of groundwater resources.

Figure 24: Incorporation of Agricultural Productivity Gains into Future Water Demand Scenario Showing Reduced Deficit between Demand and Supply Capacity

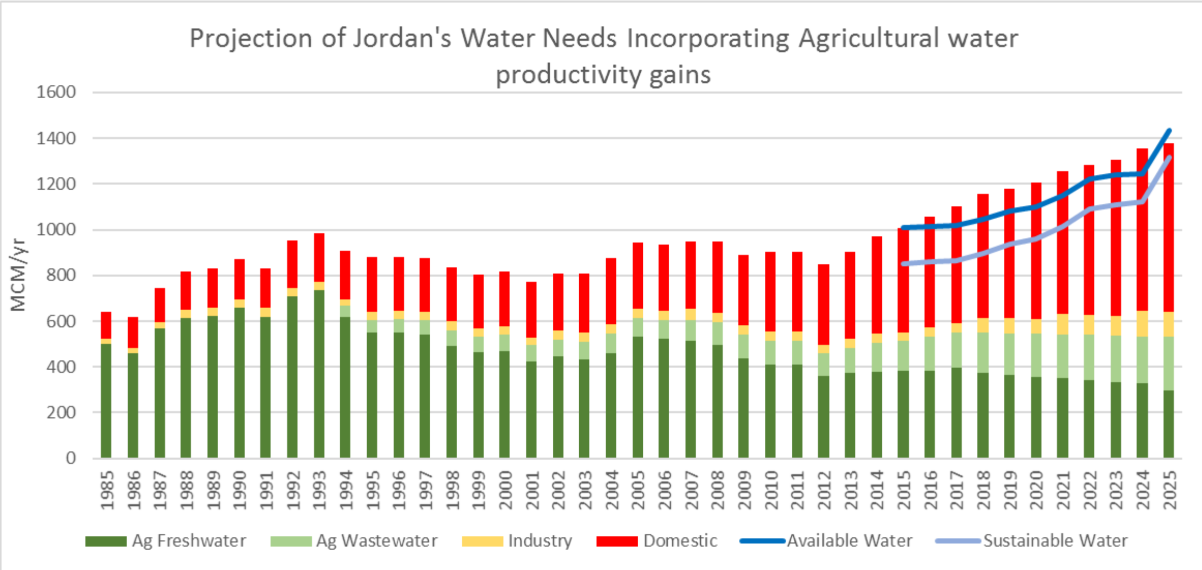
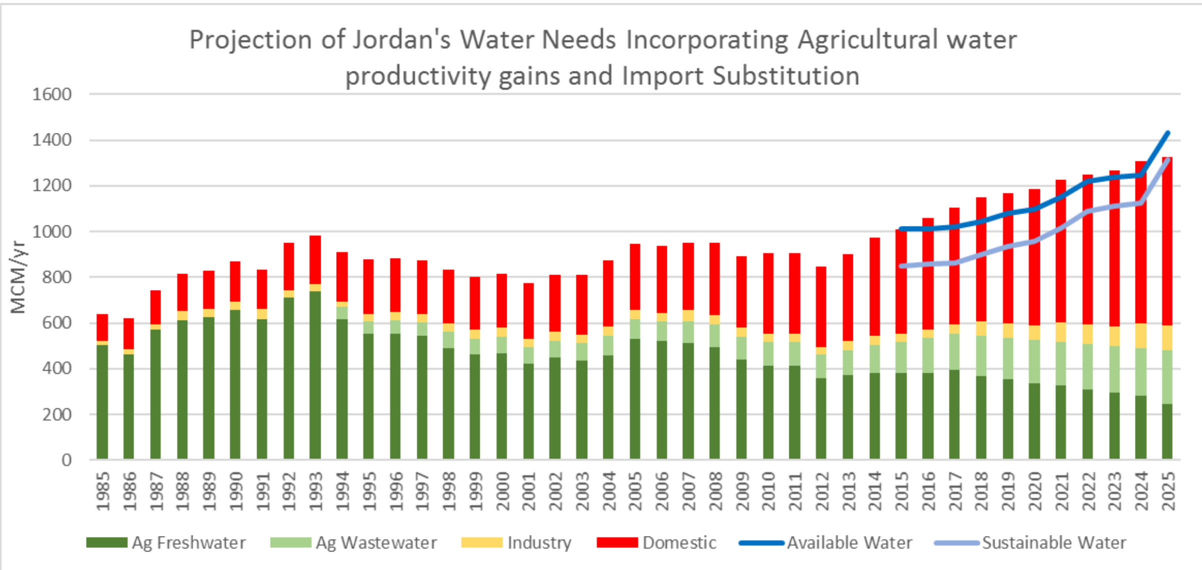


Figure 25: Incorporation of Agricultural Productivity Gains and Increased Import Substitution into Future Water Demand Scenario, Showing Elimination of Deficit between Water Demand and Supply Capacity through Slightly Reduced Agricultural Allocation



6. Conclusions

6.1 Findings

The broader challenge that this research seeks to address is the water scarcity and resultant food insecurity faced in three specific contexts: Jordan, Palestine and Israel. Based on current water projections, Jordan will face a continuing deficit between projected demand and available supply, and a consequential overdraft of groundwater resources. In addition to reversing this trend, Jordan needs to increase agricultural production to support a growing population, and free up water resources for use in other sectors where the return value on water is higher. The impact of climate change is likely to exacerbate these challenges in years to come.

All three economies have employed techniques to address their water scarcity, including economic diversification, wastewater recycling, strategic food import and increasing agricultural water productivity. Collectively, these techniques are mechanisms for 'decoupling' national water resource needs from economic and population growth. A further form of decoupling — natural water decoupling — is playing a growing and important role in Israel and Jordan. In Israel, five major seawater desalination plants already have the capacity to produce 700 MCM/year, while Jordan is investing in a new desalination project in Aqaba with a 260 MCM/year capacity and a pipeline to convey brine to the Dead Sea.

Of the three economies, the highest levels of water use productivity have been achieved in Israel. Through a combination of policy, regulatory and technological advances, it has managed to contain its water security challenges. The question of this research has therefore been whether Jordan and Palestine can achieve similar levels of water productivity, and if so, how much water might be freed up for alternate purposes? The principal finding is that if Israeli benchmarks on wastewater recycling and agricultural water productivity could be met in Jordan, combined with strategic food import substitution, Jordan could make available volumes of water in the range of 168 MCM/year, and Palestine in the range of 80 per cent reductions in applied water for some crops.

Table 9: Summary of Potential New Resource Capacity or Equivalence through Enhanced Decoupling in Jordan and Palestine

	Jordan	**Palestine**
Wastewater Recycling Potential (60 per cent reuse benchmark)	257 MCM/year (current domestic use) 443 MCM (2025 domestic use) (Currently: 125 MCM/year of recycled water available)	115 MCM/year could be achieved (62MCM in the West Bank and 53 MCM in Gaza). (Currently: 4 MCM/year recycled)
Import Substitution	52.5 MCM/year	n/a
Water Efficiency	168 MCM/year	n/a (up to 80 per cent for some crops)

The analysis for Palestine has been limited by limited available data, however; it also shows significant scope for improved water productivity based on Israeli levels for some crops olives, tomatoes, dates, citrus, cucumbers.

The more specific findings listed below relate only to Jordan.

- *Wastewater recycling:* If the Israeli benchmark of 60 per cent wastewater reuse was achieved, Jordan could, based on present urban supply recycle 257 MCM/year rather than the current 125 MCM. If domestic supply increases in line with government projections, up to 443 MCM might be produced by 2025. This 60 per cent level of recovery would be conditional upon reduced non-revenue water which currently limits recycling potential. New recycled water supplies could be fed into tree crops, to recover the 145 MCM freshwater currently used for irrigation. As crop demand increases with population growth in the future, the production of tree crops that suit recycled wastewater could be increased. Reliability of wastewater supplies will buffer these crops from drought impact, and allow remaining agricultural freshwater to be focused on crops requiring higher quality water.
- *Food import substitution:* Importing crops whose production requires a high water content is a strategic means of meeting domestic food needs in a water efficient way. Jordan already imports a high proportion of its food needs, and it must be recognised that over-exposing a country to volatile international food markets has associated risks. Likewise, impacts on livelihoods and employment must be considered against water reallocation opportunities.[136] This said, the analysis suggests that there may be scope for a strategic rebalancing of Jordan's imported food basket. The exact composition of such a basket requires economic analysis beyond the scope of this research, however a simple exercise of substituting the domestic production of already import-dependent, water-intensive food products for imports by 50 per cent would result in a 52.5 MCM/year water saving based on current production levels.
- *Water productivity:* The research found reliable evidence that Israel enjoys greater agricultural water productivity over Jordan in six crops, and semi-reliable evidence pertaining to a further eight crops. More simply, if Jordan was to enjoy Israeli water productivity levels in the 14 crops analysed, it could maintain agricultural output but reduce agricultural water allocation between 50-168 MCM/year, depending on exact productivity differences, and changes achieved. As noted, Israel has employed a complex set of regulatory, policy and technological innovations to reach such productivity benchmarks.

It must be highlighted that Jordan and Palestine must not only reduce agricultural water consumption, they must also increase yields to support a growing population for crops that are not easily importable. Again, the research found that replicating Israeli benchmarks is a potential means of achieving sustainable levels of water consumption in the case of certain crops, including tree crops with increased production facilitated by greater volumes of recycled water. Recycled water has a special value; it is available in the height of summer as well as in the humid winter, and given the relative inelasticity of domestic water use, is generally reliable through wet or dry years.

One unexpected research finding was that in the case of two individual crops — olives and dates — Jordan enjoys greater water productivity compared to Israel. This is important insofar as it

[136] Primary data collected highlighted cost-barriers to increased food trade, both import and export. Poor infrastructure and accountability at ports and airports regarding handling perishable cargos were also highlighted as hindrances to trade.

suggests scope for the exchange of knowledge and technique between countries, rather than a one-way transfer, in the effort to improve regional water security.

Current policy aims to significantly increase water allocations to agriculture in order to redress the perceived deficit in agricultural water, as well as meet future population food needs. This research questions the validity of the perception that increased supplies of agricultural water would be necessary to increase future agricultural capacity; the data suggests that it should be possible to maintain current production with less water, or in the period to 2025, increase production within current volumetric limits, given the right technical and policy environment. Carefully crafted policies to counter such perceptions, and at the same time facilitate transition to water savvy practices, are needed. Positively, all three economies show considerable adaptability on the part of farmers. A significant percentage of farmers had relevant graduate qualifications, which may suggest an easy uptake of new technologies and crop management approaches.

6.1.1 Towards an Enabling Environment for Future Decoupling

Given the potential for the economies studied to mitigate water scarcity through a combination of increased wastewater production, strategic food imports and enhanced agricultural water efficiency, the next question is how to realise such gains. Israel is a wealthy country with a robust governance architecture; this undoubtedly facilitated the resource-intense investments made in irrigation, wastewater treatment, storage capacity and knowledge innovation. It also introduced comprehensive policy reforms, some of which caused political backlash and necessitated an amount of stepping back and iterative reworking on route to progress. At the same time, the Israeli agricultural sector created its own momentum in water productivity, which generated economic opportunities and other spinoff benefits.[137] By contrast, Jordan and Palestine face significant internal and external challenges, water-food security being just one of them. Moves towards Israeli benchmarks will be financially costly and involve some painful reforms, including changes in livelihoods. These benefits need to be evaluated against the costs. The remainder of the conclusions set out some of the changes needed to facilitate such a transition, and how the associated challenges might be overcome.

Achieving optimum levels of wastewater recycling would involve adjustments in the national crop mix, and be contingent on reduced infrastructural leakage and illegal water abstraction. Improved connectivity of household wastewater to central collection systems, water treatment, and agricultural distribution networks, would also be required. This would require infrastructural investment and institutional support to ensure technical and economic functionality. Furthermore, in Palestine, such progress is currently constrained by political challenges related to control over infrastructure planning and construction, and the sharing of resource systems between Palestinian and Israeli populations.

Food import substitution should be approached cautiously, due to the potential impacts on employment and livelihoods. A further challenge is that, irrespective of the economic rationale,

[137] Jon Fedler, *Israeli agriculture coping with growth*. in Israeli Ministry of Foreign Affairs. 2002 Available from http://mfa.gov.il/MFA/AboutIsrael/IsraelAt50/Pages/Israeli%20Agriculture-%20Coping%20with%20Growth.aspx.

certain crops are difficult to phase out for cultural reasons.[138] [139] As noted, an optimal food import basket that balances the need for food security and water productivity would need to be calculated based on future food needs, import-export behaviours, and trade-offs in terms of unemployment. Insofar as import substitution is a modality to reduce the size of the agricultural sector to free up water resources for domestic purposes or direct them into sectors where GDP/unit of water input is higher, this would need to be evaluated against the social and environmental roles agriculture plays in the country, as well as its contribution to the national food supply.

The precise extent and mechanisms by which Jordan and Palestine could replicate Israeli water productivity benchmarks is beyond the scope of this present research. It is clear, however, that irrigation techniques, crop selection, soil conditioning, plant husbandry and other agricultural technology are all relevant, along with pathways for appropriate transfer of science to farmers, and positive engagement between farmers and government agencies. Again, it will be important to evaluate potential gains against costs. For example, if Jordan transitions from irrigated to rain-fed clover, a relocation of some production would be required and farmers who traditionally grew their own feed would need to purchase rain-fed crops from other producers. In all cases, carefully planned adjustments that minimise social disruption and replace social and economic opportunity are imperative.

6.1.2 Potential Policy Interventions to Promote a More Water-productive Agricultural Sector

(i) Increased sectoral productivity

Across all countries, the agricultural sector faces the challenge of more attractive opportunities in other sectors. On the one hand, this underscores the need for strategic policy reform to encourage the development of a leaner and more cost-effective sector. On the other, it is likely that some reduction in the size of the agricultural sector would be beneficial. The challenge will be to manage this natural shrinkage with a view to realising an optimally sized sector that operates in an efficient and competitive manner. Such a transition will likely require investment in new technologies and equipment, technical and knowledge support, and an enabling environment for the production of higher-value crops. What specific steps are required, beyond drip irrigation, which is already used fairly consistently among all three economies, should be the subject of further research. Positively, all three case studies show considerable adaptive capacity on the part of farmers, as well as a significant percentage with relevant graduate qualifications.

(ii) Information

Alongside technical measures, there is strong potential for information pathways to spread knowledge of improved water productivity. The information and advice supplied by the Extension Service/Ministry of Agriculture to Palestinian and Israeli farmers is both effectively provided and well-received. The scepticism of Jordanian farmers towards governmental advice highlights the

[138] Hanna Namrouqa. 2016, April 11. Raising irrigation water for date palms, vineyards good for agriculture, economy-sector insiders. *Jordan Times*2016, April 11.

[139] Current policy is actually geared to an increase in domestic date production (Namrouqa 2016, ibid), with a significant portion of total Jordanian date crops (domestic and imports) being exported. Importantly official Jordanian trade statistics show a significant proportion of date imports are from the Gulf, which are then re-exported after value adding activities. Any action of further import substitution in dates therefore needs a holistic understanding of the value chain.

scope for investment in government-led agricultural knowledge sharing. Additionally, benchmarking and recommended targets for water use and crop yield in particular areas would be beneficial. At the same time, there appears to be a tradition of social and neighbourly learning, which could prove an effective modality for sharing good practices at the community level.

(iii) Diplomacy and knowledge transfer

This study has been built on a comparison of decoupling evidence and potential across Israel, Jordan and Palestine. It has found that Israel exhibits greater water productivity for many crops compared to its neighbours, but that Jordan also has promisingly high productivity practices in some areas. There is considerable scope for direct learning in terms of on-farm practices and technologies, and wider understanding of different regional water allocation and management experience. There is also evident potential for farmers to learn best practices within their communities, given the considerable variation in water use and crop yield between individual farmers. Identifying such practices and promoting avenues for learning and dissemination will be a valuable mechanism to enhance decoupling. Further, developing an internal national network, and promoting avenues for indigenous improvements in water productivity, will help build capacity and innovation within agricultural sectors. Consideration should be paid to the feasibility of direct and indirect mechanisms of international knowledge exchange, especially in ways that do not create dependency on external parties. Action on improved water decoupling would also enhance efforts to meet the UN Sustainable Development Goals, particularly those relating to hunger, economic growth, industry and innovation, climate action and institutional strengthening.

6.2 Further Research

6.2.1 Additional Understanding of Detailed Agricultural Behaviours Across the Region

- A greater understanding of the disparity between date and olive production on a national level compared to the small samples in the Jordan Valley showing reduced water needs.
- A wider and detailed survey of farms across Jordan to enable a more reliable understanding of both agricultural and water productivity and the potential advantages of increasing water productivity within Jordan.
- Scenario planning on crop mixes to use a higher proportion of recycled wastewater.

6.2.2 Wider-scale Verification of Trends, Including Development of a Methodology That Could Be Applied Across the Wider MENA Region to Understand Crop Water Productivity

- Investigation of the potential to use remote sensing technologies to analyse relative national and regional disparities in crop water productivity, with appropriate ground-truthing of remote-sensed data.

6.2.3 Pathways to Realise Agricultural Productivity Gains in Jordan

- In-depth pilot analysis on crops (tomato, banana, apple and citrus) that exhibit high potential for water savings, including an expert assessment of production systems in both

Israel and Jordan, and the identification of on-farm and institutional improvements. Such analysis might focus on: irrigation technologies, irrigation timing and amount, water quality, the role of rainfall in affecting irrigation timings and amounts, crop varieties, soil conditioning, plant husbandry, and mechanisms to reallocate 'saved' water to new opportunities (farm output growth or other industries).

- Assessment, through calculation and on-farm pilots, of the relative cost of agricultural productivity, in direct comparison to other means of delivering additional water capacity.

6.2.4 Potential Policy Pathway for Enhanced Decoupling in Jordan

- Understanding political appetite for decoupling to improve Jordan's water security.
- Examining the scope for existing policies to incorporate strategic decoupling.
- Understanding the science, knowledge and evidence needs of Jordanian policy systems.
- Evaluation of support mechanisms for farmers to improve water productivity.

Appendix 1 – Official Water and Yield Data for Israeli Crops

National average yield/dunam and water/dunam derived from species, area, and season-specific recommendations by the Israeli Agricultural Extension Service. The most recent benchmark year was used. In some cases, recommended water and target yield values have not been updated for some years (e.g. Chillies and Peppers have 2005 for their most recent year).

Benchmark Year (Most Recent Available)		Water (m^3)/Dunam	Yield (kg)/Dunam	Water/Ton
2012	Anise, badian, fennel, coriander	4.0	400.0	100.0
2015	Apples average	5.1	666.7	131.5
2000	Artichokes	1.7	500.0	294.1
2012	Artichokes	2.0	500.0	250.0
2012	Asparagus	0.7	1000.0	1428.6
2015	Avocado average	1.9	1000.0	534.7
2014	Banana	5.7	1802.0	316.1
2012	Beans	3.5	500.0	142.9
2012	Cabbages and brassicas	8.0	450.0	56.3
2012	Carrots and turnips	7.5	550.0	73.3
2012	Cauliflowers and broccoli	3.0	320.0	106.7
2015	Cherries	1.0	650.0	650.0
2005	Chillies and peppers	9.3	1246.0	133.4
2014	Corncob	2.6	400.0	153.8
2015	Cottonseed	0.3	470.0	1615.1
2012	Cucumbers and gherkins	25.0	1200.0	48.0
2014	Dates average	1.3	1500.0	1323.5
2012	Eggplants	10.0	700.0	70.0
2014	Figs average	2.5	1275.0	526.2
2012	Garlic	2.0	500.0	250.0

2015	Grapefruit average	7.5	850.0	114.3
2015	Guavas	4.0	750.0	187.5
2015	Lemons	5.0	750.0	150.0
2012	Lettuce and Chicory	8.0	180.0	22.5
2015	Limes	3.0	750.0	250.0
2014	Maize grains	1.8	550.0	305.6
2015	Mangoes average	3.8	850.0	233.3
2000	Maize	1.7	383.0	224.0
2012	Melonseed	60.0	500.0	8.3
2015	Nectarine average	3.3	583.3	178.7
2011	Olive oil	0.2	540.0	2571.4
2012	Onions	5.0	650.0	130.0
2012	Other melons, including cantaloupes	7.0	700.0	100.0
2015	peaches average	3.5	600.0	172.7
2015	Pears average	3.1	650.0	217.8
2012	Pepper	8.0	1400.0	175.0
2015	Persimmons	5.0	900.0	180.0
2008	Pineapple	5.0	400.0	80.0
2015	Plums average	2.5	550.0	220.8
2012	Potatoes	3.0	400.0	133.3
2012	Pumpkins, squash and gourds	4.5	500.0	111.1
2015	Sorghum	2.1	225.0	107.1
2012	Spinach	5.0	400.0	80.0
2012	Strawberries	8.0	1100.0	137.5
2012	Sugar beet	6.0	250.0	41.7
2012	Sweet potatoes	4.5	700.0	155.6
2012	Tomatoes	19.0	1000.0	52.6
2012	Watermelons	7.0	400.0	57.1
2014	Wheat for silage	1.0	40.0	40.0

Appendix 2 – Schedule of Farmer Interviews

Topic	*Question*
Questions about farm	
	How long have you/your family been farming in this area?
	What size is the farm (area)? How many people work here (including seasonal workers)? Do members of your family work on the farm?
	What crops do you grow on your farm? How much do you produce per year? If more than 1, what area and yield?
	What is the core purpose of your farm – commercial, medium scale agriculture, family/subsistence agriculture? What are the qualifications of the management of the farm?
	Do the farm owners actively work and manage the farm? Is farming the main source of income for the farm owners? If not, what is their main income?
Water use in crops	
	What irrigation methods do you use on each crop you grow (e.g. drip, sprinkler, flood – for which crops)?
	How much water do you use on each crop in a year? (water/dunam)
	What seasons do you irrigate?
	What yield per dunam do you generally get for each crop?
	Where does your water come from at different times of year (e.g. surface/canal, reservoir, tanks, wells, drinking supply)?
	What rain-fed crops to do you grow? Are some crops both rain-fed and irrigated at different times of year?
	What information do you use on timing and amount of irrigation? Where does this information come from?
	How does rainfall during irrigation season affect your irrigation timing/amount?
	Has your water use changed during the time you/your family have been a farmer? (e.g. technical changes, water type changes, crop varieties)
	What are the opportunities and challenges over using water more efficiently (using less water per unit yield)?
	What techniques (old and new) do you use to reduce water use?
	Do you have any residual soil water for a second crop? If so, how much water do you 'save'?
	What happens to any irrigation run off? how much is there? Is it recaptured on the farm? If not, do you know where your return flows go?
	Do you harvest rainwater in winter time, by collecting water in cisterns, or by using capturing surface/stream water, etc.?
Price and market opportunities for crops	
	What price do you get for your different crops? What unit do you sell in (kg, box, bale – how much in each?)
	Where do you get price and market information from? How do you determine when to sow crops?
	Do you grow crops for local or export markets? Where do you sell? Does your market demand certain quality of crop?

	How stable is the market?
	How do you prepare the land before planting – machines, animals, hand …
	What input costs could you reduce while maintaining crop quality?
	Have you considered changing crops to improve economic output per input costs? If so, what crops might you change to? Why do you not change?
Double cropping, reuse of water, and return flows	
	Do you grow a single crop, or is there opportunity for planting additional crop? If so, why do you switch between crops or plant more than one crop at a time?
	Do you have a guaranteed market? What are the challenges of the market, including from imported crops?
	Do changes in price affect when you harvest or plant?
Water rights – farmers perception – who allocates water	
	Who determines how much water you receive on your farm?
	How much do you pay for your water? Do you pay different prices for different quality water?
	Does water cost increase the more water you use?
	Are you concerned about reduced availability of water in the future?
	If there was less water available, due to environmental or policy changes (including urban demand), would this influence which crops your grow? How would it change your crops?
Motivations for growing this crop and ability to change – economic role (value for crop), how long growing (generations), opportunities and barriers to change.	
	Why do you grow the crops you grow – (price of inputs, market price, water availability, suitable soil etc.)
	How long have these crops been grown on this farm?
	What other crops could you consider growing? Why? Will these crops give you a higher income?
	What barriers are there to moving to crops that use less water and/or generate higher profits?
Potential to use lower quality water in crops	
	Does water quality and quantity affect the quality and quantity of the crop(s) that you produce, which probably affect also the prices of the crops?
	Would you consider using recycled urban wastewater on your crops (if suitable)? What are the barriers and opportunities for recycled wastewater?
Questions about the future of farm	
	Have you considered leaving your land as a farmer and to moving to another job? Why? What other jobs would you consider and why?
	Do you see the next generation engaged in agriculture in this area? What alternative economic activities could they engage in?
Other Issues	Finally, what other important factors negatively or positively impact your agricultural productivity and water use?
	Are there any other issues you would like to raise regarding agriculture and water use, including access to land, ownership, tenure etc., government or military intervention?

References

Al-Jaloudy, Mahmoud, A., *Country Pasture/Forage resources profiles: Jordan (*edited by Suttie, J. M., and Reynolds, S. G., in May 2006 for FAO).2006. Available from http://www.fao.org/ag/agp/agpc/doc/counprof/PDF%20files/Jordan.pdf.

Allan, John A. 2001. *The Middle East Water Question*. London: I B Tauris.

Allan, John A. 2013. Food-water security: Beyond water resources and the water sector. In *Water Security: Principles perspectives practices.* eds. Bruce Lankford, Daren Bakker, M. Zeitoun and Declan Conway, 321-335. Earthscan: London.

Antonelli, Marta, Michael Gilmont, and Roberto Roson. 2012. Water's green economy: Alternative pathways for water resource development in agriculture. *L'Europe En Formation* 365 (Autumn 2012): 23-47.

Arlosoroff, Saul. 1997. The public commission on the water sector reform (the general ideas underlying its recommendations). *International Water and Irrigation Review* 5 : 1-9.

Baldos, Ulris Lantz C., and Thomas W. Hertel. 2016. Debunking the 'new normal': Why world food prices are expected to resume their long run downward trend. *Global Food Security* 8 : 27-8.

Baldos, Uris Lantz C., and Thomas W. Hertel. 2015. The role of international trade in managing food security risks from climate change. *Food Security* 7 (2): 275-90.

Bank of Israel. 1961. *Annual report 1960*. Bank of Israel.

Boller, B., E. Willner, L. Maggioni, and E. Lipman. 2005. *Report of a working group on forages. eights meeting, 10-12 April 2003. Linz, Austria.* Rome, Italy.: International Plant Genetic Resources Institute.

Brown, Lester R.,. The new geopolitics of food. in Foreign Policy. 2011 Available from http://foreignpolicy.com/2011/04/25/the-new-geopolitics-of-food/.

CBS (Israel Central Bureau of Statistics). *Statistical abstract 2016*. table 21.4 water production and consumption.

Central Bank of Jordan. 2016. *Annual report (2015).* Amman: Central Bank of Jordan.

CIA. *Jordan economy, the CIA world factbook*. 2015 [cited March 29 2016]. Available from https://www.cia.gov/library/publications/the-world-factbook/geos/jo.html.

FAO. *Food balance tables* 1961-2011. in United Nations Food and Agricultural Organisation. Available from fao.org.

Fedler, Jon. *Israeli agriculture coping with growth*. in Israeli Ministry of Foreign Affairs. 2002 Available from http://mfa.gov.il/MFA/AboutIsrael/IsraelAt50/Pages/Israeli%20Agriculture-%20Coping%20with%20Growth.aspx.

Feitelson, Eran., Itay. Fischhendler , and Paul Kay . 2007. The role of a central administrator in managing water resources. *Water Resources Research* 43 (11).

Fischhendler, Itay, David Katz, and Eran Feitelson. 2016. Identifying synergies and trade-offs in the sustainability-security nexus: The case of the Israeli-Palestinian wastewater treatment regime. *Hydrological Sciences Journal* Special Section: Hydrology and Peace in the Middle East : 1358-69.

Gilmont, Michael. March 2016. *Analysing the economic development impact of semi-arid lands, and mitigation by food-trade water resource decoupling.* ODI PRISE Working Paper.

———. 2015. Drivers of food trade: Water resource decoupling in the MENA as a mechanism for circumventing national water scarcity. *Food Security* 7 (6): 1113-31.

———. 2014. Decoupling dependence on natural water: Reflexivity in the regulation and allocation of water in Israel. *Water Policy* 16 (1): 79-101.

Haddad, Marwan. 2009. Palestinian water rights: Past, present and future. In *Water values and rights (2nd proceedings of the international conference on water values and rights) 13-15 April 2009.*, eds. C. Messerschmid, et al. Palestine Academy Press.

Harper, Erica, Sean Thomas and Mays Abdel Aziz. *Forging new strategies in protracted refugee crises: Syrian refugees and the host state economy,* Amman, Jordan: WANA Institute, 2015.

Hashemite Kingdom of Jordan. *Jordan's third national communication on climate change. submitted to the united nations framework convention on climate change (UNFCCC).* 2014 Available from http://unfccc.int/resource/docs/natc/jornc3.pdf.

IMF. *Costly Mideast subsidies need better targeting.* 2012. Available from https://www.imf.org/external/pubs/ft/survey/so/2012/car051412b.htm.

International Resources Group (IRG), and E. Karablieh. 2012. *Institutional support and strengthening program (ISSP) ISSP water valuation study: Disaggregated economic value of water in industry and irrigated agriculture in Jordan.* USAID.

Jackson, Tim. 2009. *Prosperity without growth: Economics for a finite planet.* London: Earthscan.

Katz, David. 2016. Undermining demand management with supply management: Moral hazard in Israeli water policies. *Water* 8 (4): 13pp.

Kislev, Yoav. *The water economy of Israel.* Taub Center, 2011.

Ministry of Labour. 2014. *Annual report (arabic).* Amman: Ministry of Labour, .

Ministry of Water and Irrigation (MWI). 2016. *National water strategy – Jordan 2016 2025.*

———. 2016. *Water sector capital investment plan 2016 - 2025*. Amman: Ministry of Water and Irrigation.

Namrouqa, Hana. 2016, 4 June. Authorities continue crackdown on water theft. *Jordan Times* 2016, 4 June.

Namrouqa, Hana. 2016, April 11. Raising irrigation water for date palms, vineyards good for agriculture, economy-sector insiders. *Jordan Times*2016, April 11.

Nazer , Dima Wadi. *From water scarcity to Sustainable Water Use in the West Bank, Palestine*. Boca Raton: CRC Press., 2009.

Nortcliff, Stephen., Gemma Carr, Robert B. Potter and Khadija and Karmame. *Jordan's water resources: Challenges for the future*. Geographical Paper No. 185.

Obeidat, Omar. Ministry ends large-scale water theft in Jordan Valley. *Jordan Times*, 03 September 2016.

OECD. 2016. *Agriculture policy monitoring and evaluation 2016*. OECD Publishing.

———. 2013. *Water and climate change adaptation*. Available from: https://www.oecd.org/env/resources/Israel.pdf

———. 2001. *Decoupling environment from economic growth*. Paper presented at OECD forum 14 May 2001: The transition to Sustainable Development: are we making progress in Decoupling Economic Growth from Environmental Degradation.

Palestinian Central Bureau of Statistics. 2015. *Value added in Palestine by economic activity for the years 1994-2015 at constant (2004) prices*.

———. 2015. *Water year books from book 586 (2000) to 2015 (various)*. Palestinian National Authority.

———. 2009. *Agricultural statistics, 2007/2008*. Ramallah: Palestinian CBS, .

Selby, Jan. Cooperation, domination and colonisation: The Israeli-Palestinian joint water committee. *Water Alternatives* 6 (1): 1-24.

Shuval, Hillel., and Hassan Dweik (eds). 2007. *Water resources in the middle east: Israel-Palestinian water issues – from conflict to cooperation*. Heidelberg: Springer.

Siegel, Seth. 2014. *50 years later, national water carrier still an inspiration*. *YNetNews*2014.

UNEP. 2012. *Measuring water use in a green economy. A report of the working group on water efficiency to the international resource panel.*

———. 2011. *Decoupling natural resource use and environmental impacts from economic growth. A report of the working group on decoupling to the international resource panel.*

Van Aken, M., Courcier, R., Venot, J. P., and Molle, F. *Historical trajectory of a river basin in the middle east: The lower Jordan river basin (in Jordan).* Amman, Jordan: International Water Management Institute/French Regional Mission for Water and Agriculture, 2007.

Water and Wastewater International. *Israel reuses nearly 90% of its wastewater*. 2016 Available from http://www.waterworld.com/articles/wwi/2016/12/israel-reuses-nearly-90-of-its-water.html.

Water Authority. 2016. *Water and sewage rates for domestic consumers in municipal water and sewage corporations.* Tel Aviv, Israel: Water Authority.

World Bank. 2016. *The cost of irrigation water in the Jordan Valley.* Washington DC: World Bank.

———. 2009. *West Bank and Gaza: Assessment of restrictions on Palestinian water sector development. sector note, April 2009.* Washington DC: World Bank.

———. *Water resources management in an arid environment: The case of Israel. Background Paper 3. World Bank analytical and advisory assistance program China: Addressing water scarcity. environmental and social development East Asia and Pacific region.* Washington DC: World Bank, East Asia and Pacific Region, 2006.

World Bank, and FAO. 2012. *The grain chain; food security and managing wheat imports in Arab countries.* Washington DC: World Bank.

World Bank, FAO, and IFAD. 2009. *Improving food security in Arab countries.* Washington DC: World Bank.

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