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Abstract

Jordan is considered one of the 10 most water stressed countries in the world (Ministry of Water and Irrigation, Jordan, 2009a). Per capita available water is projected to decline from the current low of 145 cubic meters per year to only 90 cubic meters per year by 2025 (Ministry of Water and Irrigation, Jordan, 2009a; World Bank, 1997). In 2007, the deficit between total water supply and demand was 565 million cubic meters (MCM), with increasing water demand projected to exceed water supply by 33 % in 2025 (Haddadin, 2006; Ministry of Water and Irrigation, Jordan, 2009a). The combination of water scarcity and increasing water demand have mounted pressures on non-renewable aquifers in Jordan and intensified its dependence on shared water sources with its neighbors. Securing a reliable supply of water—adequate in quantity and quality—is one of the most challenging issues facing Jordan today. There is a strong belief that no single action can remedy the water shortage but many actions are needed to increase overall water availability so that future water needs can be met. The efficient use and conservation, re-allocation among uses and sectors, and establishment of good water governance are among the measures that could be implemented to reduce the imbalance between demand and supply in Jordan. It is imperative to understand and estimate the relationship between the demand for water in agriculture and the price charged per cubic meter. It is also crucial to estimate the marginal product of this water in different agricultural uses. This paper examines existing water problems in Jordan and makes appropriate recommendations for alleviating some of the ever-increasing gap between water demand and water supply. The paper first examines the availability of water and water uses in Jordan, followed by an analysis of key water issues facing Jordan at present and presents some future options for Jordan, focusing on policy change, particularly through economic approaches. In Jordan, the struggle for water access is an urgent concern, particularly as this struggle has led to violence, and therefore requires immediate action to develop solutions.

ملخص

تصنف الأردن بين العشر (10) دول الأكثر تضرراً من مشاكل نقص موارد المياه على مستوى العالم (وزارة المياه والري الأردنية، الأردن عام 2009). ومن المتوقع ان ينخفض نصيب الفرد من المياه من 145 متر مكعب سنويا إلى 90 متر مكعب فقط في العام بحلول عام 2025 (وزارة المياه والري الأردنية، الأردن عام 2009؛ البنك الدولي عام 1997). وقد بلغ العجز في موارد المياه في عام 2007 نحو 565 مليون متر مكعب، مع مراعاة أن الطلب على المياه يتوقع أن يتجاوز الكميات المتاحة بنسبة 33 % في 2025 (حدادين 2006؛ وزارة المياه والري، الأردن عام 2009). وقد أدى تصافر عوامل ندرة المياه وتزايد الطلب عليها إلى زيادة الضغوط الاستهلاكية على طبقات المياه الجوفية غير المتجددة في الأردن، مما دفع الأردن إلى تكثيف اعتمادها على مصادر المياه المشتركة مع جيرانها. ويعتبر تأمين مصدر مياه يعتمد عليه ومناسب من حيث الكم والنوع من أهم القضايا التي تواجه الأردن في الوقت الراهن. وهناك اعتقاد قوي بأن معالجة قضية نقص المياه تحتاج إلى اتخاذ العديد من الإجراءات وليس إجراء واحدا لزيادة الكمية الكلية المتاحة من المياه والذي سوف يؤدي بالطبع إلى توفير الاحتياجات المستقبلية من المياه. وتتضمن هذه الإجراءات الاستخدام الفعال لموارد المياه والحفاظ عليها من خلال إعادة تخصيص كميات المياه بين أوجه الاستخدام المختلفة وكذلك القطاعات التي تستخدمها، بالإضافة إلى إنشاء آلية حكومية جيدة لإدارة موارد المياه، ولاشك أن تفعيل مثل هذه التدابير سوف يحد من اختلال التوازن بين العرض والطلب على المياه في الأردن. ولا بد من فهم وتقدير العلاقة بين الطلب على المياه والسعر الذي يدفع للمتر المكعب الواحد في مجال الزراعة. وهذا أيضا ضروري لتقدير عامل الناتج الحدي لهذه المياه في الاستخدامات الزراعية المختلفة. تعرض هذه الورقة البحثية لمشاكل المياه الحالية في الأردن وتقدم توصيات ملائمة لتقليل الفجوة المتزايدة بين الطلب على المياه والكميات الموجودة منها. وتتناول الورقة في البداية قضية توافر المياه واستخداماتها في الأردن، وبلي ذلك تحليلا لقضايا المياه الرئيسية التي تواجه الأردن في الوقت الحاضر وتقدم الورقة بعض الخيارات المستقبلية التي يمكن أن تستعين بها الأردن للقضاء على مشاكل المياه، وفي ذلك فهي تركز على تغيير السياسات، ولا سيما من خلال المقاربات الاقتصادية. لاشك ان الصراع على الحصول على المياه وتوفيرها يعتبر من القضايا التي توليها الأردن اهتماما كبيرا، ولا سيما وقد أدى هذا الصراع إلى العنف، ويتطلب ذلك اتخاذ إجراءات فورية لوضع مجموعة جديدة من الحلول.

1. Introduction

Jordan is considered one of the 10 most water stressed countries in the world (Ministry of Water and Irrigation, Jordan, 2009a). Per capita available water is projected to decline from the current low of 145 cubic meters per year to only 90 cubic meters per year by 2025 (Ministry of Water and Irrigation, Jordan, 2009a; World Bank, 1997). In 2007, the deficit between total water supply and demand was 565 MCM, with increasing water demand projected to exceed water supply by 33 % in 2025 (Haddadin, 2006; Ministry of Water and Irrigation, Jordan, 2009a). Contributing to the imbalance between water demand and supply is the rapid growth in population augmented by a sudden influx of Iraqi and other refugees from the politically unstable region. The excessive rates of water loss from the municipal sector (estimates of up to 70%), inefficient use of water in all sectors, high water allocations to agriculture, incorrect pricing of water, mismatch between water intensity rates with production and value rankings, limited or absent conservation regimes, and problems related to water governance have combined to exacerbate water scarcity and inefficiency of water use. Advent of climate change and political instability in the region has also exacerbated the water scarcity issues, raising new alarms over water scarcity.

The combination of water scarcity and increasing water demand have mounted pressures on non-renewable aquifers in Jordan and have intensified its dependence on shared water sources with its neighbors. Currently, aquifers are being extracted at rates far exceeding the natural recharge rate, which has led to a noticeable lowering of Jordan's water tables and a major accompanying decline in water quality (Ministry of Water and Irrigation, Jordan, 2009a). These problems have resulted in an increase in tensions and disputes over water access within and outside of Jordan.

This paper examines existing water problems in Jordan and makes appropriate recommendations for alleviating some of the ever-increasing gap between water demand and supply. The paper first examines the availability of water and water uses in Jordan, followed by an analysis of key water issues facing Jordan at present. The final section presents some future options for Jordan, focusing on policy changes, particularly through economic approaches. The paper also briefly highlights the complex historical hydro-geopolitics in the region stemming from the asymmetry in regional power dynamics (in terms of economic and military might), and illustrates how this has led to inequitable sharing of water resources between neighbors. In Jordan, the struggle for water access is an urgent concern, particularly as this struggle has led to violence, and therefore requires immediate action to develop solutions.

2. Overview of Water Use in Jordan

To meet its water demand, Jordan uses both surface and ground water sources, though present abstraction rates are greater than recharge rates. At present, total renewable groundwater abstractions (392 MCM/yr) exceeds the average annual safe yield of groundwater (275 MCM/yr). Further, 77 MCM/yr of groundwater are being extracted from non-renewable sources. In contrast, surface waters are being used at lower rates (365 MCM/yr) than the average annual exploitable flow (535 MCM/yr). To supplement these traditional sources, non-conventional water resources are increasingly used, particularly treated waste water (80 MCM/yr) and desalinated water (10 MCM/yr) (Ministry of Water and Irrigation, 2007).

2.1 Distribution of Water between Jordan's Different Sectors

To manage water resources, adequate knowledge of water availability and usage in different sectors is necessary. Water use within Jordan is divided between the industrial, municipal and agricultural sectors. The industrial and municipal sectors—including the tourist sector—together consume 28% of Jordan's water supply while the agriculture/irrigation consumes 72% (Water for

Life, Jordan's Water Strategy 2008 - 2022). Jordan's total municipal and tourist water use has increased significantly during the past decades, from approximately 116 MCM in 1985 to 249 MCM in 2002 (Ministry of Water and Irrigation, Jordan, 2009a). Increased income and changes in lifestyle have contributed to this increased water consumption, especially in the urban areas of Greater Amman, Irbid and Aqaba (figure 1). Water consumption in Jordan's industrial sector is limited to nine big industries, located in five governorates and consuming about 86% of the total water used by all industries. Both industrial and municipal water uses are expected to rise to meet the demands of a growing and increasingly urbanized population, and the increasing importance of industry in the economy (figure 2).

The agricultural sector consumes the largest proportion of water in the Kingdom accounting for 64% of total water withdrawals in 2005 (Food and Agricultural Organization of the UN 2008), with most irrigation occurring in two distinct areas: the Jordan Rift Valley (JRV) and the Uplands. Yet, agricultural production accounted for only 3% of the GDP in Jordan in 2007, decreasing over time compared to 6% in 1992 (Food and Agricultural Organization, 2008). Water consumption in agriculture has declined recently, specifically in the JRV (figures 3 and 4), due to many factors: loss of irrigated farm area with persistent drought, economic competition in the agricultural sector from neighboring countries (particularly Turkey, Lebanon and Syria), the impact of the Gulf War on the Gulf export market, increased regulation of wells, and the implementation of new water saving technologies (Venot et al., 2007). Nonetheless, water use for irrigation is expected to increase again in the near future (figure 2) due to an increasing demand for food production and the expected rise in the availability of non-conventional water sources such as treated wastewater, rainwater harvesting and desalinated seawater.

Although sediment deposits from the river make the JRV the most fertile area of the country, the JRV also depends almost entirely on irrigation (Department of Statistics, Jordan, 2008). The Jordan Valley Authority (JVA) supplies irrigation water to the JRV, using surface water primarily from the Yarmouk River and side *wadis*, as well as some treated wastewater. Groundwater is used to a lesser extent in the JRV, and mostly in the southern part of the valley. Between 1953 and 1986 the government emphasized cropping patterns that would match soil and water availability. In spite of this, farmers tended to grow crops allegedly based on the highest commercial value, leading to problems in reduced water resources and soil quality depletion (Al-Zabet, 2002). Therefore, a trend exists for the overproduction of high water-consuming tree crops irrigated by flooding with open canals. Most of the land is used to produce either vegetables (54% of land area, 99.8% irrigated) or permanent fruit tree crops (33% of land area, 99.2% irrigated). Field crops are produced on 13% of the land area, 89% of which is irrigated. All numbers are averages between 1994 and 2008 (Department of Statistics, Jordan, 2008).

In the Uplands, irrigation water is pumped from licensed or unlicensed private wells, tapping both renewable and non-renewable groundwater and, to a lesser extent, from surface water (as most agricultural land is in the uplands (88%)). Most agricultural production in this area (57% of land area) is in field crops, with 34% of highland areas producing permanent fruit tree crops and 9% producing vegetables. Vegetables are the most heavily irrigated crop group in the highlands (91% of area), while field crops receive little irrigation water (4% of land area) and tree crops are moderately irrigated (33% of land area). All numbers are averages between 1994 and 2008 (Department of Statistics, Jordan, 2008).

2.2 Jordan's Water Footprint

Jordan's national "water footprint" in the different sectors is presented in table 1. The water footprint concept, which was developed by Hoekstra and Hung (2005), is measured by adding the total volume of freshwater used to produce goods consumed by individuals, businesses or a nation to the volume of freshwater needed to assimilate the waste produced by the same individual, business or nation (Hoekstra and Chapagain, 2007). A water footprint consists of two parts. The first part is the internal water footprint, which is calculated by subtracting the total annual water volume used from domestic water resources in the national economy from the annual virtual water flow to other countries in terms of export goods. The second part of the water footprint is the external water footprint of a country. This is defined as the annual volume of water resources used in other countries to produce goods and services consumed by the inhabitants of the country concerned (Hoekstra and Chapagain, 2007).

Jordan's per capita water footprint (1,303 M³/cap/yr) is slightly higher than the global average of 1,243 M³/cap/yr. However, Jordan's domestic, internal agricultural and industrial footprints are all lower than global average. The balance is offset by higher external agricultural and industrial footprints, reflecting the fact that Jordan imports a lot of agricultural and industrial goods for local consumption.

3. Anatomy of Water Scarcity

This section examines various factors contributing to the present water scarcity problems in all sectors of Jordan's economy.

3.1 Regional Context of Jordan's Water Problems

The Middle East is one of the world's most water poor regions, but also has the world's richest oil deposits. With only 1% of the world's renewable fresh water resources and over 66% of the total proven oil reserves, most of the regional politics are governed by control of scarce water and abundant oil. Thus water and oil frame the regional economic structure, underlying the geopolitical and power asymmetries, and create environmental problems (Kubursi, 2010). Exacerbating the issue of physical scarcity is the severe lack of incentive for efficient water use, and the uneven control of water resources through military might and strategic control of head water sources.

Most of the water in the region is trans-boundary, with important rivers passing through several countries along with shared groundwater and aquifers. Regional water sharing agreements are not well defined or lack enforcement, and are also far from equitable, reflecting asymmetrical power and military capabilities. Jordan currently has bilateral water agreements with both Israel and Syria to manage shared water resources in the Jordan basin, but lacks strategic position against these more powerful neighbors and has had little success in implementing some of the provisions of the agreements (table 3 in appendix 1 gives water sharing arrangements under different treaties). For instance, despite provisions of the Peace Treaty of 1994 between Jordan and Israel, desalination projects on the Lower Jordan River have yet to be built. Further, diversion of 60 MCM from winter floodwaters of the Yarmouk River to Lake Tiberias for use by Jordan has not materialized (Haddadin, 2006).

Also, counter to the Jordan-Syria Water Agreement of 1987 on the Yarmouk River, Jordan has been able to access less than half of its share of flow from that river (Haddadin, 2006). The Agreement of 1987 focuses on establishing the Al-Wehdah (Unity) Dam, with an annual gross capacity of 110 MCM and the capacity to generate 18,800 kWh of power (Ministry of Water and

Irrigation, Jordan, 2007 and 2009a). However, because of depletion of the Yarmouk's surface and groundwater by Syria, the water retained in the Dam has been well below its 110 MCM capacity, sitting at little more than 18 MCM since its construction in 2006 (Namrouqa, 2009). Even after the 1987 Agreement, the Syrians increased damming of the four recharge springs of the Yarmouk and have increased groundwater drilling in the river basin (Al-Kloub and Shemmeri, 1996; Haddadin, 2006; Ministry of Water and Irrigation, Jordan, 2009b), leading to significant reductions in base flow along the Jordanian/Syrian border (Haddadin, 2006; Ministry of Water and Irrigation, Jordan, 2009b). Base flow is estimated to have dropped to 2 cubic meter per second in 2000, and to 0.9 cubic meter per second in 2008, compared to 5-7 cubic meter per second in the 1950s (Haddadin, 2006; Ministry of Water and Irrigation, Jordan, 2009b; Namrouqa 2009). Despite several efforts to regulate water allocations, Syria has refused to provide Jordan with its water share of the Yarmouk River (Ministry of Water and Irrigation, Jordan, 2009b) arguing that river flow reductions come from lack of rain (Ministry of Water and Irrigation, Jordan, 2009b).

3.2 Population Increases

The population growth rate of Jordan is considered to be one of the highest in the world and is exacerbated by regional problems of wars and instability. Approximately three million Palestinian refugees settled in Jordan after the Wars of 1948 and 1967 and half a million Jordanians returned after the Gulf War in 1990, with an additional half million Iraqi citizens fleeing to Jordan after the Gulf War of 2003. According to the Department of Statistics, the population of Jordan is doubling every twenty years, reaching six million in 2008 and potentially rising to 9.2 million by 2020. This increased pollution will put a large strain on already limited water resources and greatly increase urban sector water demand.

3.3 Governance and Policy Problems

There are three agencies responsible for water management in Jordan: the Ministry of Water and Irrigation (MWI), the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA). Many of Jordan's water experts and NGOs have argued that the overlapping responsibilities of these three agencies and lack of communication between them have resulted in a lack of cohesiveness and integration in water management efforts. Non-existent team work and limited communication between the agencies inhibits the implementation of an effective water demand management policy in Jordan.

Governance is also restricted by the lack of adequate information about available water resources stemming from an insufficient monitoring program. Data regarding water quantity and quality is vital for proper planning in water resource management, as are measurements of human and environmental impacts on the water resource. At present, monitoring emphasizes water quality, but needs to be expanded to include water quantity as a parameter in policy discussions.

The absence of proper metering is another major contributor to poor governance leading to overuse of the water resource. Often meters are entirely absent or are not monitored where they do exist. Problems also exist in the collection of water tariffs in metered areas.

More importantly, there are marked deviations between the prices paid by farmers and households and the actual cost of supplying the water. These deviations have resulted in a culture of waste and water overuse, particularly in the agricultural sector, where subsidized water has also imposed a cost on other water sectors and on the environment. Large-scale farmers in particular have disproportionate access to water at prices well below the actual cost of the water.

The current structure and composition of agricultural production includes a large number of water intensive products with low value added. This is a typical indicator of the deviation between the price of water and its marginal productivity.

3.4 Water Losses in the Municipal Sector

More than 78% of the population of Jordan lives in urban areas concentrated in the northern governorates of Amman, Irbid, Zarqa, and Balqa, all of which are substantially elevated above available water resources in the Jordan River Basin. Because of the distance to the water source, water needs to be transported to these urban centers, increasing the chance of water loss through leakage, and increasing energy costs of transport.

In fact, a large proportion of Jordan's water supply is lost because of inefficient and aging infrastructure (USAID, 2006). About 56% of the total production of water for municipal uses in Jordan is unaccounted for (USAID, 2006), which includes both administrative losses and physical network losses. Administrative losses result from illegal extraction, unbilled water provided to tankers and fire hydrant points, inaccurate or erroneous meter readings, non-operational meters and/or un-metered connections.

Mafrq has the most inefficient system with losses around 78% (figure 5), with Jerash and Tafilah showing losses on the low end that are still close to 40%. Other reasons for the extensive water losses in places like Mafrq include lack of law enforcement, very low penalties for use of illegal water, lack of individual responsibility or awareness for water wastage among citizens, low maintenance of the pipes, and poor quality of pipe repair materials.

3.5 Mismanagement of Water in the Agricultural Sector

Jordan's agriculture sector significantly contributes to the water crisis in Jordan through high water allocations to this sector, water overuse, and pollution of surface and groundwater. Over the last thirty years, there has been an increase in irrigated land area, along with a parallel increase in permanent crops such as fruit trees (Food and Agricultural Organization, 2008). Much of the estimated 888,400 ha of cultivatable land in Jordan (Food and Agricultural Organization, 2008) lies outside the zone of sufficient rainwater for rain-fed agriculture. Between 1994 and 2008, 78,501 ha of the 252,680 ha under cultivation were irrigated (Department of Statistics, Jordan, 2008). Rain-fed agricultural land is being lost as variable precipitation leads to unreliable production, and as urban expansion increases, with around 88,400 ha of rain-fed land converted to other uses between 1975 and 2000 (Food and Agricultural Organization, 2008).

Current irrigation methods are also responsible for significant water waste, partly due to the continued use of traditional flood irrigation systems, despite parallel widespread adoption of more efficient drip and sprinkler technologies. Irrigation water loss also arises from leakage in transport, percolation through soil, and evaporation during transport or on the field. In 2007, 32,607 ha (97%) of vegetable crops were irrigated in Jordan. In open fields, 1,768 ha were irrigated with sprinkler systems, 23,529 ha were irrigated with drip irrigation systems, and 2,960 ha were irrigated with flood irrigation methods. Almost all vegetables planted in plastic greenhouses were irrigated using drip irrigation systems (4,260 ha). Only 5,156 ha (7%) of field crop area was irrigated in 2007 in Jordan. Most of this was irrigated using flood irrigation methods (3,069 ha), while 1,482 ha was irrigated using sprinkler systems and 505 ha was irrigated with drip irrigation. Clover (2,156 ha), maize (792 ha) and sorghum (76 ha) were entirely reliant on irrigation. Finally, of the 81,305 ha of fruit trees planted in Jordan in 2007, 43,327 ha were under irrigation (Department of Statistics, Jordan, 2007). Data between 1994 and

2008 reflects that 88% of agricultural land is situated in the highlands, while only 12% is situated in the JRV (Department of Statistics, Jordan, 2008).

3.6 Waste Water Reuse and Challenges

Currently little attempt is being made in Jordan to use treated waste water or to develop other non-conventional water harvesting techniques to augment dwindling water supplies. Low investment in water infrastructure is a major cause for this, while low water recovery rates have also undermined the incentive to invest in this sector.

The effectiveness of treatment plants depends on the quality of incoming wastewater and reflects the quality of wastewater discharged into the sewer system. The current performance of many wastewater treatment plants is inadequate for handling the quantity of water that needs treatment and end up discharging low quality effluent (Ministry of Water and Irrigation, Jordan 2009a). This effluent can adversely impact public health due to pathogen contamination of crops or the accumulation of toxins in irrigated soils. Surface and groundwater are also adversely impacted due to runoff and seepage of polluted water, limiting their use for drinking water purposes. Further, septic water is not regulated and untreated water discharged into the watershed may be a health and environmental issue (Ministry of Water and Irrigation, Jordan, 2009a).

The salinity of municipal water is around 580 ppm of TD and the average domestic water consumption is low, which is why wastewater in Jordan, in comparison to other countries, tends to be highly saline and have high organic loads (Ministry of Water and Irrigation, Jordan, 2009a). Wastewater treated in waste stabilization ponds aggravates this problem as water is also lost through evaporation, increasing salinity levels in effluents. Nonetheless, water supplied through waste water treatment will likely become increasingly important for agricultural and industrial production in Jordan in the near future.

3.7 Threats from Climate Change

Climate change predictions for the Mediterranean region indicate that warming will be highest in the summer, with a 2.2-2.5 ° C temperature increase resulting in heightened risk of summer drought through enhanced evaporation. These rising temperatures will adversely impact soil moisture and water stored in reservoirs. Annual precipitation is also predicted to decrease by 4% to 27% of current levels, as will the annual number of precipitation days, particularly in the summer (Christensen et al., 2007). Rain-fed agriculture will become much less reliable, increasing the need for irrigation water. Extreme weather events are also predicted to increase, with greater inter-annual temperature variability and more extreme short-term precipitation events. Some consequences for Jordan's water supply include loss of surface water through evaporation, increased water salinity, greater inter annual variability in water supply, greater risk of flooding and soil erosion, and increased siltation of reservoirs, dams and runoff areas. Flow of the Jordan River is also predicted to decrease by up to 80%. All of these factors will contribute to issues of water and food security, human health concerns, and will impact local and regional economies (Tolba and Saab, 2009).

3.8 SWOT Analysis

SWOT stands for Strengths, Weaknesses, Opportunities and Threats. It is a tool that is used to formulate strategic alternatives from situation analysis. SWOT analysis involves looking at the strengths and weaknesses of a circumstance, as well as examining potential opportunities. Future water strategies need to build on existing situations, strengthening elements of the system

that are already strong, addressing present shortcomings and taking advantages of the opportunities available to Jordan.

To summarize areas of concern in the current management of water in Jordan, a SWOT analysis was prepared (see table 4, appendix 2 for full analysis) that will also be used to generate recommendations for improving water management. Major strengths and weaknesses include:

Strengths:

1. Forced adaptation to water scarcity
2. Use of scarcity prices in domestic sector (or for domestic uses)
3. Increased awareness in some key segments of society
4. Adaption of water-conserving drip irrigation methods in the agriculture sector

Weaknesses:

1. High leakages in the water supply network
2. High prices for domestic water use subsidizing agriculture water use
3. Inadequate coverage and monitoring of meters
4. Inadequate administrative and physical infrastructure
5. High administrative and physical water losses
6. Absence and/or lack of adequate water conservation programs and government subsidies to encourage conservation, and lack of introduction of water conserving technologies—for example aerators, low flow flush, water and energy conserving household appliances
7. Large amount of water unaccounted for in the system—as high as 60 or 70% in most governorates, 76% in Mafraq
8. Inappropriate product structure, including the growth of water intensive crops for exports, such as citrus fruit

Considering some of the threats such as climate change and less availability of water, the opportunities of Integrated Water Resources Management, working with neighbors to improve trans-boundary water management can be combined with strengths such as use of scarcity pricing in domestic prices to make future strategic water planning for Jordan. Also the current water management can also be strengthened through acting on opportunities such as the development of water management alternatives to increase water availability (i.e. rain water harvesting), potentials to change crop patterns, the willingness of international donors to fund local projects, and the awareness of some communities to conserve water.

4. Water Policy Options for Jordan: An Integrated Water Resources Management (IWRM) Approach

Securing a reliable supply of water that is adequate in both quantity and quality is one of the most challenging issues facing Jordan today. Although no single action can remedy the water shortage, taking actions in concert that target both the supply side and demand side of water use in Jordan are necessary to meet Jordan's future water needs. Increasing efficiency of water use, conservation, re-allocation between users and sectors, establishment of good water governance and the implementation of IWRM are among the measures that could be applied to reduce the imbalance between water demand and supply in Jordan.

Within any water management regime, it is imperative to shift focus from a sectoral approach to defining and solving management issues to a watershed approach accounting for the physical, biological, chemical, societal, and political features of a region. Emphasizing management of

both the ecosystem and the hydrological cycle are also important to maintaining the interdependence between water and other ecosystem functions and services. Increasingly, academics and policy makers are achieving this through taking an IWRM approach to water management, which has the added benefit of moving away from the sectoral approach to management that has been so plagued with problems. IWRM also moves away from the traditional emphasis on the agricultural sector and instead addresses the various sectors including domestic, waste-water, industrial, along with agriculture in a more holistic approach (Babel et al., 2008).

IWRM has been defined by the Technical Committee of the Global Water Partnership (GWP) as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems". Further, IWRM goes beyond managing water resources within a political or manmade boundary and instead looks at more natural boundaries such as the watershed or catchment level, and often requires both regional and local stakeholder cooperation to do this. The ability of IWRM or any integrated management to improve water management has been questioned (Butterworth et al., 2010), but advocates indicate that the concept will be better implemented if the focus is on local and adaptive management and not just on institutional and governance reforms. Research and education on interactions between natural resource systems and human activities, the state of the physical resource in a *wadi* system, socio-economic analyses of different water users, integration and coordination of meteorological and hydrological data, and institutional and legal reforms all play an important role in IWRM in Jordan, as outlined in the following sections.

An IWRM plan should involve aspects of the hydrologic cycle, land use, climate, geography and pollution, economics, social interactions and institutional aspects relating to water management. It should also deal with the issues of water withdrawal, quality, conservation and legislation, monitoring and regulation, as well as the physical aspects of flood control, dams and water and waste treatment engineering works. The confluence of all of these aspects, usually at a river basin or watershed level, is central to the practice of effective IWRM. Of course, there are many external impacts on IWRM such as the effects of global climate change, water transfer between watersheds, movement of populations and the consequent changes in human activities and the effect of atmospheric transfer of pollutants—sometimes occurring on a continental or even global scale.

Based on the above discussion, the various reforms for water management in Jordan are recommended below, under different headings. The idea is to have a bigger plan and implementation in smaller steps. Some of the major changes that will need to occur would involve institutional and economic reforms in the water sector (which includes improving infrastructure and water tariffs among other things); involvement and education of all the stakeholders (i.e. ministries, industries, farmers, non-governmental sectors, universities, and even the general population) and some technological advancements and adjustments to help reduce water usage, rain water harvesting, improvements in irrigation, and improvement in crops that need less water. The following discussion divides policy recommendations into sectors, although in implementation of IWRM, a holistic approach is necessary that accounts for diverse interactions between water users and water demands.

4.1 Institutional Reforms within Jordan

As water management within Jordan is currently undertaken by three different agencies, it is important that a consolidated institutional and legal framework be established with clearly delineated responsibilities. A regulatory body also needs to be established for controlling and operating water and waste-water systems in Jordan. The aims of the regulating body should include that of controlling water losses, setting tariff rates, and other reforms that improve water and wastewater management from the utility level to the governance level.

There are some important institutional considerations in IWRM that should be taken into account. Firstly, there should be a hierarchical context. Stress should be on the systems perspective, which means that while working on a problem at any level or scale, managers must seek the connections between all levels. Management should go beyond the administrative and political boundaries and defining ecological boundaries at appropriate scales, for example basin level or watershed level. IWRM plan should also consider ecological integrity so as to protect total native diversity and the ecological patterns and processes that maintain that diversity. The use of ecological boundaries necessitates cooperation between federal (national), provincial (state) and local management agencies as well as private parties (including NGOs)—thus calling for inter-agency cooperation. Therefore, managers must learn to work together and integrate conflicting legal mandates and management goals.

Another consideration for a good IWRM plan is good data collection. IWRM requires more research and data collection on habitat inventories, disturbance regime dynamics, baseline, and population assessment as well as better management and use of existing data. Monitoring is therefore necessary because the data gathered during the monitoring sessions provides feedback to the managers on the progress of the action items and allows the manager to keep track of the changes. Relevant, affordable, and accessible information exchange is the key starting point for integration activities, because relevant information is appropriate to the tasks, has been tested, is reliable and is of sufficiently high quality. Affordable and accessible information encompasses not only the cost of the data and information but also refers to the means and processes that the users already have to fully apply such information. New systems and software should not be required to view or use data unless absolutely necessary. Equitable information access is also critical: users should not be discriminated against because of geography (distance), gender, economic, cultural or social issues. With data collection and monitoring, it also important for management to be adaptive (especially in the initial stages), which means knowledge is provisional and management is both a learning process and continuous experiment.

In general, implementing IWRM requires changes in the structure and operation of management agencies. This may range from a simple change such as forming an interagency committee, to complex changes such as modifying professional norms and altering power relations. Regardless of the role of scientific knowledge, human values play a dominant role in setting IWRM goals, so people (stakeholders) should be an integral part of the IWRM (Grover et al., 2005).

4.1.1 Improving infrastructure

Improving water management in Jordan will involve reforms at different levels of the management hierarchy. At the utility level, reforms need to improve the performance of both physical and human infrastructure. In terms of physical infrastructure, water losses occur through deteriorating pipes, treatment plants, and metering devices. Deteriorating infrastructure impacts urban water distribution through leakage problems, and rural/ agricultural distribution through wastage in transport of irrigation water. Wastewater treatment plants are also in need of

renovation to reach optimal functioning. Investment in aging infrastructure is extremely important in Jordan's water demand management program, but due to the high costs involved will likely need to be achieved through a public-private partnership. In terms of human infrastructure, utilities will be greatly improved with upgrades to the quality of customer service, human resource management, finance and accounting.

At the sector level, improvements will need to be made by building the competence and capacities of different ministries and regulatory authorities. Education and capacity building will also be necessary to develop a core group of operators for proper management of water resources. Further, the government will need to develop indicators to measure change that allows it to respond to environmental and economic trends impacting water supply or demand. This will require the proper selection of indicators, and the establishment of databases for storing collected information and monitoring data. Some of the key indicators will include the percentage of non-revenue water, water production, meter coverage, meter readings, as well as billing and revenue collection.

4.1.2 Improving the water tariff system

Poor conservation occurs within all sectors, but is of greatest concern with agriculture due to the overwhelming demand for water in this sector. Poor conservation is linked primarily to the fact that water prices do not reflect the true cost of providing this scarce resource. It is imperative to understand and estimate the relationship between the demand for water in agriculture and the price charged per cubic meter. It is also crucial to estimate the marginal product of this water in different agricultural uses. Restructuring agricultural production may result from a price regime more reflective of water scarcity and productivity than the current one.

Currently, the Water Authority of Jordan does not charge farmers anything for pumping from private wells for the first 150,000 cubic meters, and charges only JD0.005 per cubic meter between 150,000 and 200,000 and JD0.060 for every cubic meter over 200,000 cubic meters consumption (Namrouqa, 2010). At this time, water prices cover less than 60% of the operation and maintenance costs of water supply for irrigation (Food and Agricultural Organization, 2008). If current water tariffs are increased, the farmers will be encouraged to adopt more efficient irrigation methods and switch to higher-value crops (Namrouqa, 2010). Water tariffs in the JRV have been raised a number of times. The current tariff is designed to accommodate crop water requirements, which are highest for trees. The average collected rate is around \$21 USD per 1,000 m³, but should be increased to around \$38 USD per 1,000 m³ to cover all water supply costs. In the highlands, the average cost of irrigation water is significantly higher at \$70-\$80 USD per 1,000 m³ and rises with fuel costs (Food and Agricultural Organization, 2008).

Tariffs should be set to reflect the full cost of investment. Short-term aims for tariffs should at minimum be the recovery of operational and maintenance costs, and long-term aims should be a strategy for full cost recovery. The prices for water should be at least set at \$1.75 (US dollars) for the agricultural sector, \$2.52 for the residential sector and \$ 1.10 for the industrial sector (Based on results of modified Harvard Fischer model described in appendix 3 and private communication with Dr. Atif Kubursi, May 2010). There are different rates for each sector depending on their productivity.

However, adoption of water tariffs becomes difficult because water is not only a desirable commodity, its availability is also critical for life. There are little or no substitutes for it. Furthermore, it is a well-entrenched principle that no matter how scarce water is, every person is

entitled to a minimum quantity that is considered consistent with human dignity (Kubursi, to be published).

Water is a scarce resource (asset), a scarce commodity and a scarce input. Economics is particularly suited for dealing with such a resource as economics after all is the study of how scarce resources are or should be allocated to various uses and users. It is generally accepted however, that water is not bought and sold in competitive markets. This is because in the case of water at least five of the basic properties of competitive markets are absent. These five properties include the following: First, free markets lead to an efficient allocation of scarce resources if these markets are characterized by competitive structures, that is, these markets include a large number of independent small sellers and a similarly large number of independent small buyers that no single supplier or buyer is significant enough to influence the price. Each and every buyer and seller in this market is a price-taker. Second, competitive markets require freedom of entry and exit, with no barriers existing to preclude easy entrance or exit. Third, the product must be homogeneous enough that each unit is quite similar to any other unit. Fourth, for a free market to lead to an efficient allocation, externalities must be absent. In economics, an externality or spillover of an economic transaction is an impact on a party that is not directly involved in the transaction. An efficient allocation can emerge from a free market when social costs coincide with private costs. Water production, however, involves many "externalities". In particular, extraction of water in one place reduces the amount available in another. Further, pumping water from an aquifer in one location can affect the cost of pumping elsewhere. Such externalities do not typically enter the private calculations of individual producers and drives a wedge between private cost and social costs. Fifth, in a free market that allocates efficiently scarce resources, social benefits must coincide with private ones. If not, then (as in the case of cost externalities) the pursuit of private ends will not lead to socially optimal results. In the case of water, many uses have social benefits that exceed the private ones. The use of water in agricultural may result in benefits that exceed the private returns to farmers. Among these are food security, border security, and national interest. These conditions are often violated in the case of water, where water sources are relatively few, barriers to entry are real and high (high cost of infrastructure), a large gap exists between private and social costs, and benefits and water units are not homogeneous with a large spectrum of different qualities are observed. This is perhaps why water production facilities are often owned by the State. In many respects water is not a private good; it has, as we alluded to above, many of the characteristics of quasi public goods (Kubursi, to be published).

4.1.3 Controlling water conservation through economic incentives

Another way of increasing water conservation efforts in Jordan is to provide incentives to prevent overuse of water, such as subsidies for increasing the use of water-saving appliances in domestic and industrial sectors. Economic incentives and financing opportunities that encourage farmers to employ new irrigation technologies also need to be put in place. To achieve an incentive program, the government could use the revenue gained from higher water prices.

Moving from an emphasis on food self-sufficiency by limiting subsidies of high water-consuming crops, and instead relying on importation of these products from abroad as "virtual water," may also provide an important incentive for water savings and could significantly reduce national water demand in agriculture. Nonetheless, evaluating the need to import "virtual water" crops must weigh the impact of this measure on both the water footprint and the carbon footprint of production and transport.

There is currently little correlation between the water requirements of crops and crop production in Jordan, indicating how little water prices currently impact crop choices in the country. Table 2 shows correlation coefficients based on the ranking done in terms of their intensity, efficiency and their values and volumes. The results are very indicative of a major mismatch between water intensity or efficiency with crop prices (a proxy for value) and volumes of production. The correlation coefficients are either negative or fairly low, which shows that current crop prices do not guide scarce water allocations in crop production. Equally relevant is the divergence of volume of production of crops with water intensity. There is a marked divergence between the ranks of crops by volume with water intensity. This could be an indicator that some concern about water scarcity is driving this economizing behavior.

Nonetheless, drip irrigation systems are more efficient systems than surface irrigation, with a direct correlation between water intensity and efficiency. However, negative correlation between water efficiency and productivity depicts that water is not being used efficiently and effectively to grow right crops. High value but high water intensive crops are being irrigated which essentially means that water use is inefficient to irrigate high value crops (table 2).

Rising water prices could result in less land area being used for crop production, with high-water consuming crops dropping out of production and land-use. For example, the Interseasonal Agricultural Water Allocation System (SAWAS) model developed by Water Economics Project (Fisher et al., 2005) shows that certain agricultural activities become unprofitable due to the relationship between their water requirements, cost of production and their market price. Winter crops have been shown to be the most unprofitable in this water scarce region, followed by fish ponds, maize, certain orchard fruits, sunflowers, and high water consuming vegetables.

Raising water prices could alternatively result in necessary changes in production patterns from water-inefficient crops to more water-efficient crops instead of merely abandoning land previously used for unprofitable in inefficient crop production.

Replacing high water-consuming plants with high market-value crops that have low water requirements may initially require some government subsidy where there is the need for initial infrastructure development to produce these foodstuffs. Key changes in agricultural production should focus on the following relationships between crops and water-use efficiencies:

- Wheat and barley are the two main field crops produced in Jordan, with wheat considerably more water intensive than barley (Shatanawi et al., 1998). Increased barley production over wheat may prove a more water-efficient use of field areas. Other water intensive field crops include maize and clover, and finding alternatives for both of these crops may prove helpful in increasing the water efficiency of field areas.
- 95% of land-area used for vegetable production in Jordan is irrigated. Tomatoes are the most commonly grown vegetable but require significantly more water than crops such as potatoes, squash, cauliflower, eggplant and watermelon, highlighting opportunities for water conservation through crop replacements. Tomatoes are currently subsidized for export to the Gulf region. Finding markets for less water-intensive alternatives could open up opportunities for crop-switching and water savings.
- Expansion of fruit tree production, particularly citrus, apples, peaches and bananas, should be highly discouraged since these are very water intensive to produce.
- Annual crops, already in production in Jordan, that have lower water requirements include barley, vetch, squash, cucumber, sweet peppers, string beans, turnips, radish, and carrots

(Shatanawi et al., 1998). Perennial olives also have relatively low water consumption compared to the other tree crops, and are mostly unirrigated in Jordan.

4.1.4 Other economic approaches available for water management

As a general economic rule, a scarce resource, such as water in Jordan, should go to the sector which can maximize the economic return. Yet water is also a human right (recently recognized by UN General Assembly resolution, emphasizing the basic rights of access to safe drinking water and sanitation) and complicates the economic approach to water allocation as basic needs must be met. Therefore, it is often necessary to subsidized water use to meet basic societal needs, regardless of economic return.

Nonetheless, pricing strategies and demand side management is extremely important to meeting increased water demand in Jordan. Demand can be controlled by pricing since demand is not fixed and can be modified by changes in prices. Some economists have argued that prices can correct behavioral patterns in water use and demand, while some authors think price is one of the several factors that influence demand and use of water. Literature has also suggested that domestic and agricultural water use is relatively inelastic (Espey et al., 1997; Hanemann, 1998; Renzetti, 2002; Garrido, 2002) while industrial use is more elastic. Yet, even when the sector is in-elastic, economic instruments have been used to correct inefficient use of water and to control water demand.

Four different economic instruments/approaches are particularly helpful in managing water demand in conjunction with modifications to the policy instruments. Some of these economic instruments have been previously described in this paper. The first one is the use of water allocation models to calculate water pricing, the second is to examine the correlations between water efficiency and production and their value added, the third is to calculate shadow prices; and the fourth is the use of a life cycle assessment tool to determine the best options for domestic water conservation methods (described in appendix 3). Essentially, all instruments highlight the importance of full cost-accounting in the development of water prices. Nonetheless, although full cost accounting should reflect all the costs associated with operation, maintenance, replacing the infrastructure, opportunity costs and cost of externalities including environmental degradation and damage, it is not easy to capture all the externalities.

Finally, one of the other serious challenges to implementing economic instruments/approaches in water demand management is the need to clearly establish and define property rights and resolve the issue of common property rights, particularly with a resource such as water. Other challenges include the impact of water markets on equity and the environment, and also the impact that high costs of water can have on other market functions.

4.2 Greater Involvement of Stakeholders and the Public in Water Management

To improve water conservation efforts and reduce water demand in Jordan, it is crucial to take steps to improve public awareness on water scarcity in the region, particularly regarding the costs incurred in extraction, provision and maintenance of the water supply infrastructure. It is also crucial to build capacity within Jordan to properly monitor and manage water, and also to involve stakeholders more seriously in decision-making processes.

4.2.1 Education and capacity building

Since IWRM will involve a shift in paradigm thinking of present water professionals in the country it will be imperative to build the capacity among the water professionals. Public education on the value and scarcity of water resources in the country will help foster individual

conservation efforts within all sectors of the economy. Education is also important for generating support for policy changes to increase water conservation and protection. Education in schools is an important part of the package, since it is easy to change the behavior at earlier ages and children may also influence their parents to change. Public awareness campaigns help communities deal with water allocation problems between competing water-interest groups. To be effective, awareness programs should also target policy makers and private sector interests.

Capacity building is also an important step needed to be taken by the Jordanian Government, and involves improving linkages between researchers, policy makers and end users. In the agricultural sector, these linkages should include connecting market research on product demand to scientific and technological research on crop water needs and water dispersion possibilities. For instance, farmers currently overproduce water-consuming crops such as tomatoes, and should instead focus their production on crops that use less water and have higher economic value. In addition to capacity building and education, this might need some incentives to change the behavior of farmers.

4.2.2 Stakeholder participation

Stakeholder participation is an important component of implementing IRWM or any policy change. Involvement and understanding of local stakeholders, their culture and deeply-rooted practices, interests, and power relations (especially in hierarchical societies like Jordan) is necessary to reduce feelings of mistrust or threat to changing policies (Zeitoun, 2009). Some of the major stakeholders in the water sector in Jordan are farmers, the higher agriculture council, the Royal Committee on water, ministry of agriculture, ministry of environment, ministry of water and irrigation, ministry of finance, ministry of planning and international cooperation, and the civil society in general.

Different stakeholder groups have more power in decision making than others, as indicated in figure 6 (based on Zeitoun, 2009). Although figure 6 examines water demand management (WDM), it can also apply to stakeholder interest in water supply management policies, and may also be expanded from a sectoral consideration of water management to a more integrated approach. Within the agricultural community, large scale farmers have much more power to influence policy than small scale farmers. Civil society has little impact on WMD, while the two most influential stakeholders in Jordan are the Royal Committee and the Higher Agricultural Councils.

Zeitoun (2009) describes differences in the ability to influence change by different stakeholder groups in terms of soft and hard forms of power. Soft forms of power include bargaining power and the power to frame issues that may not be contested, whereas hard forms include economic and military power, or at least the threat or ability to yield these forms. In Jordan, support for changes in WDM often conflicts with the ability to implement change, with strong proponents of WDM within civil society and Ministry of Environment (MOE) having little ability to influence change in the system. In contrast, the most influential groups do not or do not fully support changes to WDM policies. It is therefore likely that the middle-of-the-line groups will be important and useful for consensus-building and dialogue creation, as well as for introducing any changes in the policies. The Royal Committees should also play an influential role in such changes. Other ways to address power asymmetries between water stakeholders in Jordan include:

- Focus on positive-sum outcomes including improving use of appropriate technology (where both land and water are limiting factors), and the creation of rural-urban water transfers to meet demands in both sectors.
- Encouraging transformation within existing institutions from the Royal Court downwards, with more effective communication among stakeholders.
- Leveling the playing field by improving governance of institutions, using effective WDM mechanisms, and improving education levels of soft-power stakeholders. Leveling the playing field also includes implementing decision-support systems and improving lawmaking and enforcement to ensure that power dynamics do not slide into greater asymmetries.

To reach and involve all the stakeholders, it is important to build dialogue platforms using neutral facilitators to most effectively engage and involve everyone in working towards necessary change in WDM. Engaging local groups may also involve bringing in traditional conflict resolution methods. Focus will also have to be directed at the dynamic between the more powerful players in the water sector, with emphasis on improving negotiation and negotiation skills between the Water Utility Authorities, large-scale farmer organizations, and the water authorities. Nonetheless, bringing in any change in policy and implementing them will require strong political will and long-term vision for sustainable regional/national water policies.

Yet, at the same time, part of water management will have to be decentralized to reduce costs and placate small-scale users. Many decisions will need to be discussed and made at the local level, which will have the added benefit of increasing the efficiency and effectiveness of water demand reduction projects. In fact, studies have shown that stakeholder participation at the community level for planning, funding and implementing projects has led to increases in both sustainable use and sustainable management of water (Lundqvist and Gleick, 1997; Faruqi, 2001). Decentralization of control is already an objective of the Jordan Government, as the MWI indicates that it plans to reduce the role of government in irrigation management to regulation and supervision, while stakeholders and the private sector will be encouraged to expand their role in all other areas (Ministry of Water and Irrigation, Jordan, 2009a).

4.2.3 Moving subsistence farmers into alternative livelihoods

Unfortunately, as a result of rising water prices brought on by increasing water shortages and potential reductions in government subsidies, some stakeholders will be unable to continue to participate in the agricultural sector. Small farmers and subsistence farmers will be most affected by an increase in water tariffs and the high costs of new technologies that reduce water use on farms. This group will also consist of women and economically underprivileged. In general, increased water prices will have a large impact on the rural economy and will likely result in increased rural to urban migration and associated social problems. The policy change should include participation by these stakeholders, but should also involve building the capacity of small farmers to enter alternative and less water intensive activities so that they can earn a livelihood instead of using limited resource for undependable agriculture.

4.3 Other Interventions

4.3.1 Development of non-conventional water resources to increase water supply

1. Desalination of water from the Red Sea through the establishment of the Red Sea Dead Sea Canal (RSDSC) is considered to be a long-term solution to cope with imbalance between water demand and supply in Jordan.

- The RSDSC entails pumping one billion cubic meters of water through a 200-kilometer canal from Aqaba on the Red Sea to the Dead Sea (Ministry of Water and Irrigation, Jordan, 2009b; Namrouqa, 2009), with 850 million cubic meters of this delivered for desalination (Ministry of Water and Irrigation, Jordan, 2009b). The rest of the water will be used to stabilize Dead Sea levels.
 - The desalination plant will be located near the Dead Sea and will be powered mainly by hydroelectric energy generated by utilizing the elevation difference between the Aqaba Gulf and the Dead Sea (Asmer and Ergenzinger, 2003).
 - Two-thirds of the desalinated water will be delivered to Jordan and one third to Israel and the Palestinian Territories (Ministry of Water and Irrigation, Jordan, 2009b). It is hoped that this project will also help enhance peace and stability through economic development of the Jordan Valley (Ministry of Water and Irrigation, Jordan, 2009b; Namrouqa, 2009).
2. Treated wastewater will become extremely important for the continuation of agriculture in Jordan as freshwater sources become more limited and more expensive to provide (Ministry of Water and Irrigation, Jordan, 2009a; Food and Agricultural Organization, 2008).
- This treated wastewater can be used more easily in the JRV due to existing infrastructure, with wastewater generated in urban areas above the JRV, mixed with freshwater, and subsequently released into watercourses that flow into the JRV through gravity. Currently, about 60 MCM per year of treated wastewater is used for JRV irrigation purposes (Ministry of Water and Irrigation, Jordan, 2009a).
 - Wastewater use in food products always involves the risk of contamination, yet the level of consumer exposure to these contaminants depends on the quality of the water used, the irrigation method, the time between irrigation and subsequent consumption, and on how the product is consumed. Sprinkler or spray irrigation should be avoided with treated wastewater as these methods deposit water and micro-organisms directly onto the leaves and fruits of a plant and do not conform to Jordan health standards (Food and Agricultural Organization, 2008). Drip irrigation is the ideal method for depositing treated wastewater. Conversely, drip irrigation can significantly decrease health and environmental risk by depositing water at low pressure directly into the soil.
 - Treated wastewater has the additional economic benefit of adding effluent nutrients to plants and soil, therefore reducing reliance on synthetic fertilizer, although wastewater also tends to have higher salinity levels than fresh water which needs to be periodically leached from the soil.
 - Gray water reuse systems can be used on a smaller scale to capture untreated household water from showers, washbasins, washing machines etc, and can then be reused for flushing toilets.
3. Rainwater harvesting systems provide a means of increasing the efficiency of rainwater use and reducing water costs. Currently only 5% of rainwater can be used as 85% is lost through evapotranspiration and 10% is lost through runoff.
- Rainwater harvesting can be used to collect rainwater on rooftops or off of concrete or rock surfaces. Water can then be stored in cisterns or water storage devices for future use.
 - For agricultural practices, rainwater can be harvested using terraces, rippers, contour ridges and other type of water collection methods that store water directly in the soil for crop production. However these methods are not always effective and depend on the infiltration rates of soil and climatic conditions that impact evaporation. Experiments have shown that

the best way to harvest rain water for crop production is to store it deeper in the soil in sand ditches (since it also reduces evapotranspiration) (Abu-Zreig et al., 2000).

4.3.2 Technological solutions to reducing water wastage

Small changes to management practices in the agricultural sector by local farmers can lead to significant water savings. These practices can and are being implemented at the farm level, and can be encouraged to be expanded through economic incentives or subsidies for new technologies. Implementation also depends on education of local stakeholders about water management options, and capacity building for implementation and maintenance of these technologies. Water saving technologies are also available for the municipal and industrial sectors, and can be similarly encouraged through economic incentives, education and capacity building. General infrastructure changes in the efficiency of water networks and metering systems are also an important step to reduce water wastage, and are generally constrained by government inefficiency or economic concerns. Some specific examples of technological options for improved water management are listed below.

1. Irrigation wastage can be improved by implementing new irrigation technologies and scheduling.
 - Night-time irrigation can substantially reduce water losses due to evaporation. Soil moisture probes can also be helpful in optimizing irrigation through proper scheduling.
 - Sprinkler irrigation systems apply water overhead using high-pressure sprinklers or guns and are much more water efficient than flood irrigation methods. Yet, drip irrigation systems are the most water-efficient as they deliver water directly to the root zone. Although this is an expensive technology and might need initial government or private investment, investment will pay off since drip irrigation is very effective at saving water, reducing evaporation and increasing crop yield.
2. Laser-leveling and land grading of fields can significantly reduce runoff, particularly in agricultural areas that use flood irrigation which often results in an uneven distribution of water.
3. Conservation tillage methods in agriculture, which leave a minimum of 30% of crop residue on the soil surface, can be very helpful in reducing water flow rates across the field, improving water infiltration by reducing water loss through runoff, and preventing soil erosion.
4. Greenhouses and natural or plastic mulches are used in agriculture to reduce evaporation, and their use can be expanded, particularly with vegetable production.
5. Governments can improve water conservation in municipal and industrial uses by subsidizing or providing water conservation and water saving technologies such as faucet aerators and low-flow shower heads, dual flush toilets and dry toilets.
 - Rebate programs have provided incentives to customers in places like Canada to invest in efficient appliances like washing machines and toilets and have helped in saving water and energy in many countries around the world.
6. Technical solutions should include maintenance and replacement of many of the water networks in Jordan to achieve the highest possible efficiency in water conveyance, distribution, and use (Abdel Khaleq and Dziegielewski, 2006).
 - Detecting and repairing leaks can largely minimize the amount of lost water and reduce the amount of water pumped, saving water and energy. Leak detection and repair is the most practiced conservation activity in the North America (Great Lakes Commission, 2004).

7. Installation of universal water metering is an essential element in conserving waters because it leads to a change in behavior by allowing customers to better track their consumption and thereby reduce water use.

- As an example, installation of universal water metering in Canada has proven to reduce overall residential, industrial and commercial water consumption by 15 to 30 percent (Great Lakes St. Lawrence River Cities Initiative, 2008).

Life cycle analyses of different options for domestic water management, based on increasing the use of non-conventional water sources and implementing technological solutions, were carried out to calculate reductions in use and the environmental and financial implications of the different management options (tables 5, 6 and 7 in appendix 4). Table 5 calculates the annual water and energy savings for domestic water management under different water management options and shows that increasing the use of non-conventional water sources such as rainwater harvesting and gray-water are able to save maximum resources. Nonetheless, Table 6 shows that the production of rainwater harvesting vessels incurs an environmental cost, but overall this option still appears to be environmentally sound as it reduces the energy cost involved in abstraction and transportation of water from more conventional sources. The production of the tables involved multiple assumptions about the system, but they are nonetheless a useful tool for policy makers to weigh different options for combining water and energy savings.

4.4 Issues with Implementation of IWRM

IWRM should be used as an approach to balance the use of water in various sectors – the main problem arises when an attempt is made to integrate everything at the same time. One of the problems with IWRM is the definition of “integration”. It can mean differently to different people. For instance, there can be “technical integration”, where scientific descriptions of the environment being studied are reported in a compatible manner and where each report should be useful to other groups involved. There can be “procedural integration”, where an agreed set of protocols is used for all the aspects of the IWRM to try and make all the information accessible to others in a standard or known format or “imposed integration”, where one or a few agencies drive the process and define the scope, methods, format and reporting of the various aspects of the study. Lastly, there can be “reporting integration”, where the various aspects are summarized, analyzed and reported by an appointed group or unit (and they integrate the various aspects) (Grover et al., 2005).

Another problem related to IWRM arises because of the various disciplines involved. This leads to issues such as no common vocabulary and no common understanding of IWRM. Another problem is that the possible solutions are rated differently by different interest groups. For instance, the role of the local community and regional experts will have different priorities, as will policy and technical stakeholders. The key is to strike a balance between the technical community and local participation, and between top-down and bottom-up approaches. Scaling up is not just replication of technologies or approaches, but expansion of principles and knowledge, such that people build capacity to make better decisions and influence decision-making authorities. Thus, scaling-up has power and development dimensions (Grover et al., 2005).

5. Conclusion

Jordan needs to shift towards an integrated policy for water management, where the policy will include all sectors (i.e. domestic, industrial and agricultural), where the focus is on the watershed or catchment scale, and where cooperative management between regional partners is used to

define equitable and efficient shares. Jordan may wish to examine the possibility of establishing a Jordan River Basin Commission to accomplish this.

A more rational allocation algorithm of scarce water is needed. This is primarily true in the agricultural sector where reducing the production of highly water-intensive crops can be accomplished by moving to more economically viable low water consuming plants. For food security, Jordan therefore needs to explore the possibility of trade in “virtual water” through importation of high water consuming crops from countries that are more water-endowed. Also, fresh water use in agriculture should be reduced by implementing incentives that encourage more efficient water applications through adopting water-saving irrigation technologies and other farming techniques and strategies. Increased reliance on treated wastewater in agriculture will also free up fresh water for use in other sectors. There is an obvious need for more efficient and effective water policies, metering of water use, and collection of water tariffs. Enforcement of the Water Strategy Policy of 1997 and Groundwater policies and Bylaw # 85 of 2002 are particularly critical for achieving these objectives.

As shown in the correlation coefficients (table 2), the results are very indicative of a major mismatch between water intensity and efficiency with crop prices (a proxy for value) and volumes of production. Water prices need to be based on the actual full costs of supplying the water to different sectors. Therefore, block rates need to be increased, but charges also need to be increased to dissuade water waste in activities including the production of high water consuming crops.

Stakeholder and civil society participation in water management and water conservation efforts can and must be encouraged through education and capacity building, and through making the political process more transparent and cooperative.

It is not an exaggeration to suggest that IWRM be incorporated as a critical component of any efficient and effective strategy to deal with water scarcity, and particularly for achieving high efficiency from using this increasingly scarce resource in Jordan.

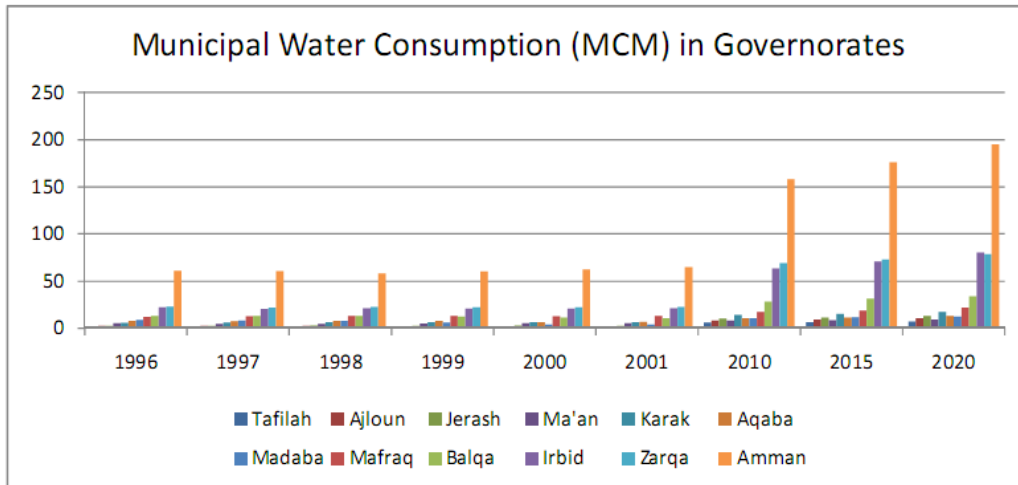
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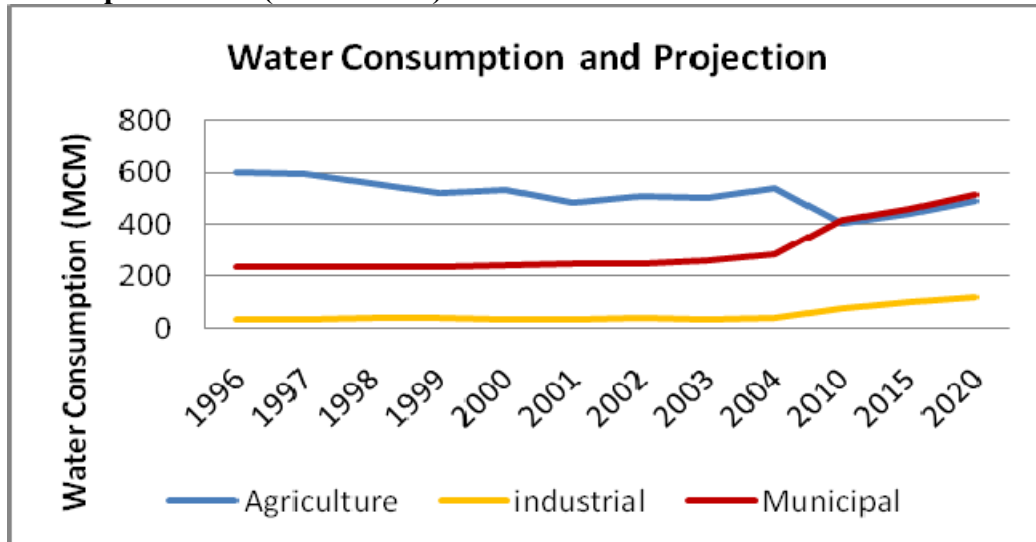
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Figure 1: Past and Projected Municipal Water Consumption (MCM) per Governorate (1996 – 2020)



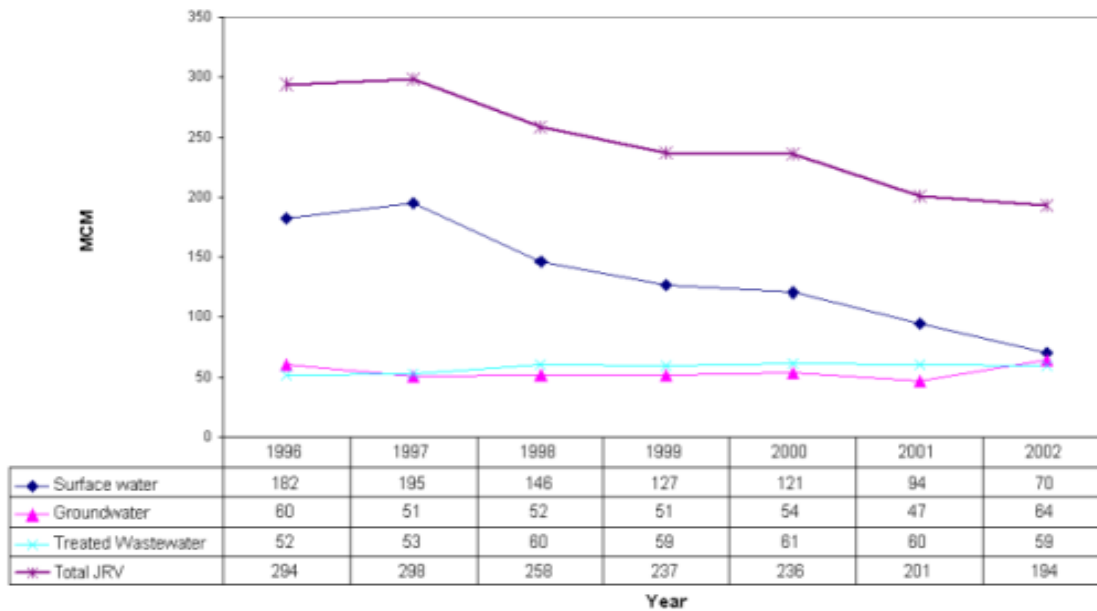
Source: National Water Master Plan- Ministry of Water and Irrigation 2007

Figure 2: Water Consumption and Projection in the Agricultural, Industrial and Municipal Sectors (1996 – 2020)



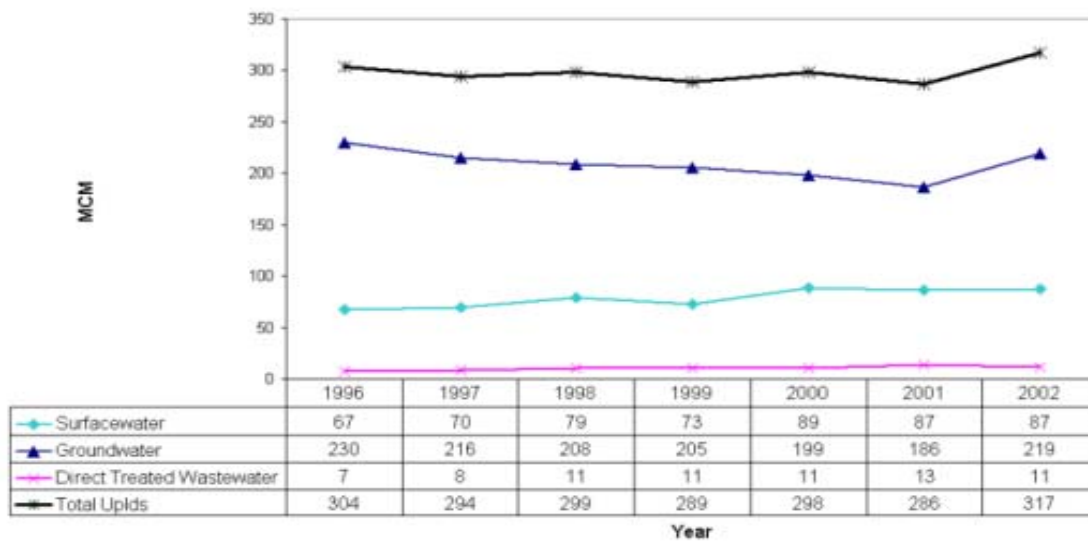
Source: National Water Master Plan- Ministry of Water and Irrigation 2007

Figure 3: Water Use for Irrigation in the Jordan Valley from 1996 to 2002



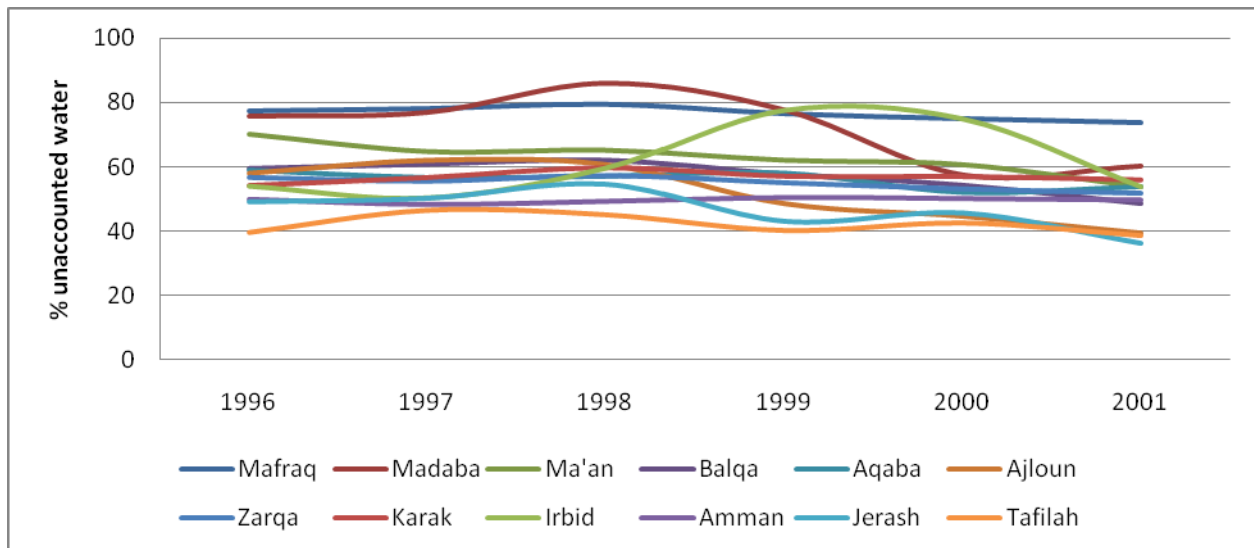
Source: National Water Master Plan- Ministry of Water and Irrigation 2007

Figure 4: Water Use for Irrigation in the Uplands from 1996 to 2002



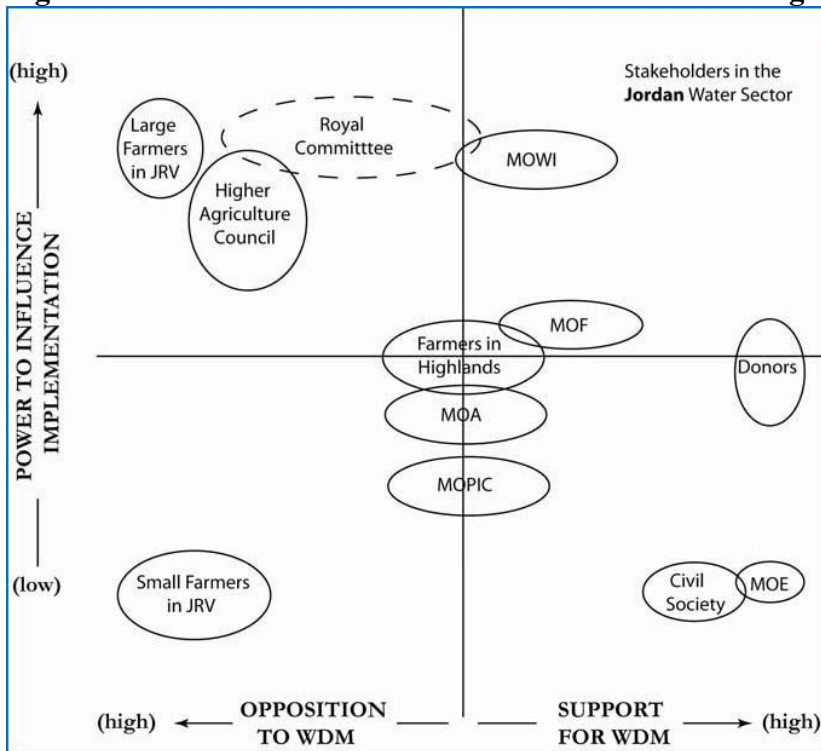
Source: National Water Master Plan- Ministry of Water and Irrigation 2007

Figure 5: Percentage Unaccounted Water per Governorate



Source: National Water Master Plan- Ministry of Water and Irrigation 2007

Figure 6: Stakeholder Influence on Water Demand Management



Source: Zeitoun 2009

Table 1: Water Footprint of Jordan

Population	Domestic Water with-Drawal Gm3/yr	Domestic Water Consumption				Foreign Water			Water Footprint		Domestic Internal Water Footprint M3/cap/yr	Agriculture Goods		Industrial Goods	
		Crop Evapotranspiration		Industrial Water with-Drawal		National		For Re-Export of Imported Produce	Total Gm3/Yr	Per Capita M3/Cap/Yr		Internal Water Footprint M3/Cap/Yr	External Water Footprint M3/Cap/Yr	Internal Water Footprint M3/Cap/Yr	External Water Footprint M3/Cap/Yr
		National Consumption Gm3/yr	Export Gm3/yr	National Consumption Gm3/yr	Export Gm3/yr	Ag	Ind								
4,813,708	0.21	1.45	0.07	0.035	0.00	4.37	0.21	0.22	6.27	1,303	44	301	908	7	43

Source: www.waterfootprint.org

Table 2: Correlations between Water Efficiency, Intensity, Crop Production and Prices

	Drip Irrigation	Surface Irrigation
CORR Intensity and Productivity	-0.102	-0.087
Corr Efficiency and Productivity	-0.102	-0.082
Corr Value and Productivity	-0.030	
CORR Intensity and Value	0.015	0.024

Appendix 1

Table 3: Summary of the Water Allocated to Jordan, Syria, and Israel in MCM/Yr from the Jordan and the Yarmouk Rivers According to the Johnston Plan and to the Agreements of 1987 and 1994.

Water allocated to Jordan, Syria, and Israel from the Jordan and the Yarmouk Rivers according to the Johnston Plan of 1953 (Mm ³ /yr)			Water used by Jordan, Syria, and Israel from the Jordan River basin after refusal of the Johnston Plan and before signing the Agreement of 1987 between Jordan and Syria and before signing the Water Agreement of 1994		Water that should be allocated to Jordan, Syria, and Israel from the Jordan and the Yarmouk Rivers after signing the Water Treaty between Jordan and Israel and after assuming that the provisions of the Agreement of 1987 have been implemented (i.e. Al-Wehda Dam was filled with water)	
	Jordan River	Yarmouk River	Jordan River	Yarmouk River	Jordan River	Yarmouk River
Jordan	343*	377	243	120	273**	305****
Israel	375	25	552	100	522	25
Syria	42	90	0	170	0	160*****

Notes: * The Jordan water share from the Jordan River is divided as follows: 100 MCM/yr from the Lower Jordan River, and 243 MCM/yr from the side wadis that feed the river from the Jordanian territories (Elmusa, 1998). ** Before signing the Agreement of 1994, Jordan received nothing from the Lower Jordan River but after signing the Agreement, Jordan was able to get 30 MCM/yr from the Lower Jordan. *** 305 MCM/yr includes the amounts of water, 75 MCM/yr, that returned to Jordan because of signing the Water Agreement with Israel in 1994 and also includes the amounts of water that should be provided to Jordan if Al-Wehda (the Unity) Dam has been filled. **** 160 MCM/yr represents the approximate storage capacity of 26 dams that Syria was allowed to build on the tributaries of the Yarmouk River according to Jordan-Syria Agreement of 1987.

Appendix 2

Table 4: SWOT Analysis (Strengths, Weaknesses, Opportunities, Threats)

<p>STRENGTHS:</p> <ol style="list-style-type: none"> 1. Forced adaptation to water scarcity 2. Use of scarcity prices in domestic sector (or for domestic uses) 3. Increased awareness in some key segments of society 4. Adaption of water-conserving drip irrigation methods in the agriculture sector 	<p>THREATS</p> <ol style="list-style-type: none"> 1. Climate change 2. Increased desertification-water scarcity – inadequate water 3. Water use equality among countries and among users 4. High salinity of water 5. Political instability and water conflicts in the region 6. Dwindling foreign aid for water projects
<p>WEAKNESSES:</p> <ol style="list-style-type: none"> 1. General: <ol style="list-style-type: none"> a. Low water availability b. Administrative insufficient c. Inadequate technical services d. Inappropriate awareness and low priority accorded to water services e. Insufficient use of treated waste water (lack of awareness and education) although it complies with WHO and Jordanian government standards f. Fragmented and insufficient regional approach g. Inadequate coordination/management of shared resources h. Poor or limited implementation of some provisions of regional water treaties i. Lack of availability of data and sharing between countries j. High population growth k. Low community awareness and participation and engagement in water programs l. Fragmented water institutional arrangements m. Multiplicity of institutions dealing with water and inadequate harmonization and streamlining of authorities and responsibilities n. Inadequate preparation for climate change and high evaporation rates in the region o. Annual recharge is lower than discharge p. High rate of depletion of ground water q. Water Quality issues – more concern is about quantity than quality (deteriorating water quality) r. Lack of infrastructure – lack of use of indigenous technologies 2. Domestic water use: <ol style="list-style-type: none"> a. High leakages b. High prices – higher than marginal costs (subsidizing agriculture) c. Metering - inadequate coverage and monitoring d. Inadequate administrative and physical infrastructure e. Administrative and high physical losses f. Absence and/or lack of adequate water conservation programs and government subsidies to encourage conservation and the introduction of water conserving technologies– for example aerators, low flow flush, water and energy conserving household appliances machines g. Large amount of unaccounted water use – unaccounted water is as high as 60 or 70% in most governorates, 76% in Mafrqa 3. Agriculture water use: <ol style="list-style-type: none"> a. Low prices way below marginal product and cost recovery – e.g. for first 150 m3 nothing is charged and very little charged for the greater use. b. Inappropriate product structure, water intensive crops for exports are grown e.g. fruit c. Irrigation water is highly subsidized d. Inadequate legal, management, institutional governance structure (too much corruption) e. Insufficient or limited use of treated waste water for agriculture despite the fact that it meets WHO and Jordanian standards f. Inappropriate technology for irrigation (for example, drip irrigation is not available for all the parts in the country) g. Insufficient research and inadequate research capacity and institutions for appropriate crops for the region h. Poor communication of information between farmers and policy makers 4. Inappropriate time scheduling of irrigation 5. Industries: <ol style="list-style-type: none"> a. Lack of waste water treatment for industrial water uses 	<p>OPPORTUNITIES</p> <ol style="list-style-type: none"> 1. High potential for IWRM 2. Potential change in pricing to reflect scarcity 3. Greater coordination among sectors and neighbors 4. Improved research capacity and communication of research to users 5. Improved expertise in water mgmt. 6. Improved infrastructure 7. Adequate statistics/data

Appendix 3

A3.1 Water Allocation Model

Structure of the Model

We begin by specifying the demand for water in each location. Three sectoral demands are defined: Agriculture demand, industrial demand and urban demand. Agriculture demand receives special attention because farming is the dominant water user in the region and because important national policies typically relate to it.

The rate at which water is demanded by each sector depends upon the price of water (US\$/m³) in that sector. The relationship between the rate of water use and the price of water is expressed by the sector's demand for water. These curves are all from the constant elasticity family.

$$Q_d = \left(\frac{P_{w_d}}{\beta_d} \right)^{\frac{1}{\alpha_d}}, \quad \beta_d > 0, \quad \alpha_d < 0$$

where

Q_d = rate at which water is demanded in sector d and

P_{w_d} = price of water in sector d

β_d = the demand for water intercept in sector d

α_d = inverse of the price elasticity of water for sector d

There is no compelling empirical or theoretical warrant for using constant elasticity demand curves, but they have theoretically plausible qualitative characteristics and are easy to estimate and convenient to apply. But this convenience comes at a price. This price is high when the elasticity estimate is not accurate or real.

The objective function to be maximized is the sum of the net benefits from fresh water and recycled water.

$$\begin{aligned} \text{Max } Z = & \sum_i \sum_d \left(\frac{\beta_{id} \times (QD_{id} + QFRY_{id})^{\alpha_{id}+1}}{\alpha_{id}+1} \right) - \sum_i \sum_s (QS_{is} \times CS_{is}) - \sum_i \sum_j (QTR_{ij} \times CTR_{ij}) \\ & - \sum_i \sum_d (QRY_{id} \times CR_{id}) - \sum_i \sum_j (QTRY_{ij} \times CTRY_{ij}) - \sum_i \sum_d ((QD_{id} + QFRY_{id}) \times CE_{id}) \end{aligned}$$

Subject to:

$$\sum_s QS_{is} + \sum_j QTR_{ji} - \sum_j QTR_{ij} = \sum_d QD_{id} \quad \forall i$$

$$\sum_s QRY_{id} + \sum_j QTRY_{ji} - \sum_j QTRY_{ij} = \sum_d QFRY_{id} \quad \forall i$$

$$QRY_{id} = PR_{id} \times (QD_{id} + QFRY_{id}) \quad \forall i, d$$

$$(QD_{id} + QFRY_{id}) \geq \left(\frac{P_{MAX}}{\beta_{id}} \right)^{\left(\frac{1}{\alpha_{id}} \right)} \quad \forall i, d$$

Equity Constraint

$$\sum_d (Qd_{id} + QFRY_{id}) \times POP_j = \sum_d (Qd_{jd} + QFRY_{jd}) \times POP_i$$

Bounds:

$$QS_{is} \leq QSMAX_{is} \quad \forall i, s$$

$$QD_{id} = QDL_{id} \quad \forall i, d$$

$$PR_{id} \leq PRMAX_{is} \quad \forall i, d$$

All Variables ≥ 0 ;

The inverse demand function can be expressed as a constant elasticity function:

$$P_{id} = B_{id} \times (QD_{id} + QFRY_{id})^{\alpha_{id}}$$

Where:

s = Supply sources or steps {S1,S2,S3,S4,S5}

d = Demand types {URB,IND,AGR}

i = Region or district

Z = Net benefits of water supply in 10^6 \$ (objective function variable)

QS_{is} = Water supplied from source s (of steps S1,S2,S3,S4,S5) to district i in Million Cubic Metres (MCM)

QD_{id} = Water demanded for sector d (URB,IND,AGR) at district i in MCM

QTR_{ij} = Water transported from district i to district j in MCM

QTRY_{ij} = Recycled water transported from district i to district j in MCM

QRY_{id} = Water recycled from use d in district i in MCM

QFRY_{id} = Recycled water supplied to use d in district i in MCM

QSMAX_{is} = Upper bound of water supplied from source s to district i in MCM

PR_{id} = Percent of water that can be recycled from use d in district i in MCM

PRMAX_{id} = Upper bound on the percent of water that can be recycled from use d in district i in MCM

CS_{is} = Unit cost of water supplied from source s to district i in \$US/m³

CE_{id} = Unit environmental cost of water discharged by use d at district i in \$US/m³

CTRY_{ij} = Unit cost of transporting recycled water from district i to district j in \$US/m³

CTR_{ij} = Unit cost of fresh water transported from district i to district j in \$US/m³

P_{id} = Price of water at district i in \$US/m³

POP_j = Population in region j

A3.2 Shadow Prices

The calculation of a shadow price of water is sketched in a simple example below by way of illustrating its derivation and interpretation. We start with postulating the following optimizing problem:

Minimize cost of production:

$$\bar{w}L + \bar{e}K + \bar{r}W$$

Where

w = wages

e = rental cost of capital

r = rental price of water

L = labor

K = capital

W = water

The bar over the prices is meant to denote competitively determined prices.

Subject to a production function relationship

$$\bar{x} = F(L, K, W)$$

And a fixed amount of water

$$W = \bar{W}$$

where X -bar is total output

The Lagrangian

$$\mathcal{L}(L, K, W, \lambda_1, \lambda_2) = \bar{w}L + \bar{e}K + \bar{r}W + \lambda_1[\bar{x} - F(L, K, W)] + \lambda_2(W - \bar{W})$$

Differentiate totally:

$$\bar{w}dL + \bar{e}dK + \bar{r}dW + \lambda_1\left[-\frac{\partial F}{\partial L}dL - \frac{\partial F}{\partial K}dK - \frac{\partial F}{\partial W}dW\right] + \lambda_2[dW] + [\bar{x} - F(L, K, W)]d\lambda_1 + [W - \bar{W}]d\lambda_2$$

Group terms:

$$\left(\bar{w} - \lambda_1 \frac{\partial F}{\partial L}\right)dL + \left(\bar{e} - \lambda_1 \frac{\partial F}{\partial K}\right)dK + \left(\bar{r} - \lambda_1 \frac{\partial F}{\partial W} - \lambda_2\right)dW + \lambda_1 d\bar{x} - \lambda_2 d\bar{W} + [\bar{x} - F(L, K, W)]d\lambda_1 + [W - \bar{W}]d\lambda_2$$

The first three terms are the first order conditions of minimizing costs and are set equal to zero

$$\frac{dL}{d\bar{x}} = \lambda_1 \text{ where } \lambda_1 \text{ is the influence on cost of producing one additional unit of output or}$$

marginal cost (MC) of output.

$$\frac{dL}{dW} = -\lambda_2 \text{ where } \lambda_2 \text{ is the shadow price of water as it depicts MC of one additional unit}$$

of water.

The first order condition for water implies the following.

$$\bar{r} = \lambda_1 \frac{\partial F}{\partial W} + \lambda_2 \quad \lambda_1, \lambda_2 \geq 0$$

but λ_1 = price of output under optimal competitive conditions therefore $\bar{r} = P \frac{\partial F}{\partial W} + \lambda_2$

Therefore the rental price of water would equal its value of marginal product plus a scarcity premium represented by λ_2 .

The shadow price is simply a Lagrangian multiplier in the optimization equation. It denotes the improvement in the Objective Function due to a relaxation of any given constraint.

In the case of the WAS model, the shadow price associated with a particular constraint shows the extent by which the net benefits from water would increase if that constraint was loosened by one unit. For example, where a pipeline is limited in capacity, the associated shadow price shows the amount by which benefits would increase per unit of pipeline capacity if that capacity were slightly increased. This is the amount that those benefiting would just be willing to pay for more capacity.

The central shadow price in the model is that of water itself. The shadow price of water at a given location is the amount by which the benefits to water users (consumers and producers) would increase were there an additional cubic meter per year available at that location. It is also the price that the buyers at that location who value additional water the most would just be willing to pay to obtain an additional cubic meter per year, given the optimal water flows of the model solution.

Appendix 4

Table 5: Annual Reduction per Capita in Resources Use Due to the Implementation of Domestic Water Management Options.

Option Type			New Resource	Water Saving Options					Reuse Option
Option		Do Nothing Alternative	Rainwater Harvesting System	Low Flow Shower Head	Faucet Aerator	Leakage Prevention	Dual Flush Toilet	Dry Toilet	Gray-Water Reuse System
Resource use after using the option	Groundwater use (m3/capita/year)	9.69	0.97	5.81	3.88	6.78	7.52	5.02	3.69
	Surface water (m3/capita/year)	36.97	3.70	22.18	14.79	25.88	28.84	19.22	14.05
	Desalination*	1.78							
	Energy Consumption (KWh/capita/year)	54.72	6.85	33.45	22.81	38.76	42.91	29.14	21.77
Reduction in use due to using the option	groundwater use (m3/capita/year)		8.72	3.88	5.81	2.91	2.17	4.67	6.00
	surface water (m3/capita/year)		33.27	14.79	22.18	11.09	8.13	17.75	22.92
	Desalination	1.78							
	Energy Consumption (KWh/year)		47.87	21.28	31.91	15.96	11.81	25.58	32.95

Assumptions

Family Size = 5

Energy consumption = energy used for water abstraction and transportation = 3.2KWh/m³ + energy needed for treatment (in case of chlorination = 0) + energy used for desalination (0.86Kwh/m³)+energy used to transfer surface water (0.6)

Desalination water is only used for drinking, so all these options will not change consumption

Reduction in water use has been distributed equally under different options from groundwater and surface water

rainwater harvesting - using a cistern to collect 80m³ and can save 30 - 90% water from other sources - for calculations here 90% is used

low flow shower head use reduces water usage by 40% than using normal shower heads (EPA 1995)

Faucet aerator reduces water usage by 60% (EPA 1995)

leakage prevention can go up to 75% and it is expected that due to system improvements and education can be up to 30%

Dual flush toilet = reduction of 22%

Dry toilet savings are 48%

Gray water reuse saves 62%

Source: JWU, 2007 (from thesis) and for desal <http://www.desware.net/Energy-Requirements-Desalination-Processes.aspx> and for transportation http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/DesalinationFNU41_revised.pdf

Table 6: Environmental Impact of Production, Annual Reduction and Net Reduction in the Environmental Impact for the Different Water Management Options Relative to Do Nothing Option (the Numbers Are All per Capita)

Option Type		New Resource	Water Saving Options				Reuse Option	
Option		Rainwater Harvesting System	Low Flow Shower Head	Faucet Aerator	Leakage Prevention	Dual Flush Toilet	Dry Toilet	Gray-Water Reuse System
Environmental impact due to production								
Total impact of production (mPt)		33,400.00	29.60	0.30		196.00	72.80	1,776.00
Expected life (yr)		50.00	10.00	10.00		20.00	20.00	10.00
Annual environmental impact of production (mPt/year)		668.00	2.96	0.03		9.80	3.64	177.60
Reduction of environmental impact due to implementation								
Groundwater use (m3/capita/year)	water use reduction (m3/year)		3.88	5.81	2.91	2.17	4.67	6.00
	chlorine reduction (kg/year)		0.00	0.00	0.00	0.00	0.00	0.00
environmental impact reduction (mPt/year)			0.00	0.00	0.00	0.00	0.00	0.00
Surface water (m3/capita/year)	water use reduction (m3/year)		14.79	22.18	11.09	8.13	17.75	22.92
	chlorine reduction (kg/year)		0.01	0.01	0.01	0.00	0.01	0.01
environmental impact reduction (mPt/year)			0.38	0.38	0.38	0.00	0.38	0.38
Desalination								
Energy Consumption (KWh/year)	Reduction (kWh)	47.87	21.28	31.91	15.96	11.81	25.58	32.95
environmental impact reduction (mPt/year)		1,244.62	553.17	829.75	414.87	307.15	665.10	856.78
Total reduction of environmental impact (mPt/year)		1,244.62	553.55	830.13	415.25	307.15	665.48	857.16
Net reduction of environmental impact (mPt/year)= total reduction of environmental impact (mPt/year) - annual impact of production		576.62	550.59	830.10	415.25	297.35	661.84	679.56
* Environmental Impact of do-nothing scenario is		1,422.76						

Assumptions:

The environmental impact of production was calculated using the Eco-indicator 99

The impact is given per year

It is considered that the only water treatment is chlorination and 0.6mg/l of it is used. Environmental impact is 38 mPt/kg chlorine.

Table 7: Annual Benefits, Costs and the Present Worth of Net Benefits for the Different Water Management Options Relative to the "Do-Nothing" Alternative

Option Type Option	New Resource			Water Saving Options			Reuse Option Gray-water Reuse System
	Rainwater harvesting system	Low Flow shower head	Faucet aerator	Leakage Prevention	Dual Flush Toilet	Dry Toilet	
Investment							
Initial investment (cost and installation)	800	3	9	2	40	180	140
Expected life of equipment	50	10	10		20	20	10
Investment for 10 years (I0)	160	3	9	20	20	90	140
Annual Operational Benefits							
From water savings (\$)	50.39	22.40	33.60	16.80	12.36	26.90	34.71
From energy savings (\$)	6.70	2.98	4.47	2.23	1.65	3.58	4.61
From using compost as a fertilizer (\$)	0.00	0.00	0.00	0.00	0.00	3.60	0.00
Total annual benefits (\$)	57.09	25.38	38.06	19.03	14.01	34.08	39.32
Annual Operations Cost							
Operation and Maintenance cost (\$)	-0.80	-0.02	-0.05	0.00	-0.10	-0.45	-0.70
Net annual benefits (\$) = Total benefits - total costs	56.29	25.36	38.02	19.03	13.91	33.63	38.62
Present Worth (PW)	274.69	192.83	284.57	126.96	87.44	169.65	158.21

Assumptions

Average cost for water for domestic use is 1.2US\$/m3

Average cost of energy 0.14 US\$/KWh

Annual operations and maintenance cost 5% of investment cost

annually US \$ 2 per capita will be spent on leakage prevention

PW is calculated based on equation $PW = (A((1+k)^n)-1)/(k((1+k)^n))-I0$

where PW is present worth

A represents net annual benefits (US\$/year)

k discount rate (taken as 5% in this case)

n is number of years

I0 is investment in year zero (US\$)