Treated Wastewater for Irrigated Agriculture in the Jordan Valley

Analysing Water Allocation and Willingness to Pay for Reused Water

Zur Erlangung des akademischen Grades eines

Doktors der Naturwissenschaften an der

Fakultät fur Bauingenieur-, Geo- und Umweltwissenschaften

des Karlsruher Instituts für Technologie (KIT)

vorgelegte

Dissertation

Von

Amani Alfarra, B.Sc., M.Sc.

Geboren in: Kuwait / Nationalität: Palästinensisch

Tag der mündlichen Prüfung: 15.01.2010

Referent: Prof. Dr. Heinz Hötzl

Korreferent: Dr. Ben Sonneveld

Abstract

Water-scarcity in the Hashemite Kingdom of Jordan seriously affects the social and economic development of the country. Water availability per capita ranks lowest in the world and all renewable water resources of suitable quality are fully exploited. The situation is likely to exacerbate as population doubles in the coming decades and climate change scenarios indicate a significant reduction in water quantity. Indeed, the threat of depleting water resources that can no longer meet the increasing demand might create political instability in the kingdom and wreak havoc on future generations. Inter basin transfers could provide the necessary relief, yet, the political situation in the region impedes a constructive solution in this direction. Hence, answers must be found at an intra-country level. This also is the motivation of the current thesis where we investigate the use of Treated Waste Water (TWW) in the agricultural sector as a key scenario to reduce the strain on water resources. This thesis focuses on the Jordan Valley (JV), an important regional supplier of crops and vegetables, where much of the freshwater resources are consumed. Yet, 40 percent of the Valley's potential remains untapped due to lack of water, while the expansion is urgently required to meet the growing food demand. This growth can only be realized with additional water volumes as the widely implemented drip irrigation leaves little room for efficiency gains at the farm level. A chemical water analysis showed that TWW in Jordan meets the national and international standards of water quality and can be a valuable contribution for irrigated agriculture. We also found using a new Water Reuse Index (WRI) that there still is considerable room for an increase of TWW volumes as currently only 34 percent of the waste water is being treated. A forward-looking evaluation of various water resource allocations with fresh and TWW sources, effectuated by the WEAP model, shows that historical reservoir water volumes could be reproduced with confidence and can be used for further scenario evaluation. The results of an extensive survey among 400 farmers showed that 96 percent are willing to accept the TWW. Furthermore, farmers are willing to pay four to five times more of the current water price. The results of our ordered logit model show that it is recommendable to make site specific pricing and extension programs when TWW is introduced or further expanded. Finally, we simulated various pricing regimes for four archetypes of farming systems considering nutrients in TWW for its cost saving effects on fertilizers and crop specific effect of salinity. The results show that additional TWW volume increases farmer incomes considerably and while fertilizer costs could be saved saline TWW levels affect citrus and banana production negatively. We also found that it is difficult to cover the costs of new TWW plants and sewage infrastructure with farmer contributions alone. This is also not necessary as the environmental and health effects of TWW will benefit the society as a whole. We conclude that there are good prospects for further agricultural development in the JV when the use of TWW in Jordan is expanded. A gradual increase in farmer contributions seems justified as additional profits per water volume outweigh the increase in costs by far.

Kurzfassung

Wasserknappheit hat in Jordanien einen erheblichen Einfluß auf die soziale und ökonomische Entwicklung des Landes. Der Wasserverbrauch pro Kopf zählt zu den niedrigsten weltweit, wobei die erneuerbaren Wasserressourcen geeigneter Qualität bereits komplett ausgebeutet werden. Vor dem Hintergrund einer drohenden Bevölkerungsverdopplung in den nächsten Jahrzehnten und verschiedenen Klimawandelszenarien die eine drastische Verringerung des verfügbaren Wassers vorhersagen wird sich die aktuelle Situation wahrscheinlich noch verschärfen. Die Gefahr, dass Wasserressourcen durch den steigenden Bedarf erschöpft werden können, könnte die politische Stabilität des Landes in Zukunft bedrohen. Hier könnten Wassertransfers aus anderen Einzugsgebieten für die benötigte Entlastung sorgen. Allerdings behindert die politische Situation in der Region eine konstruktive Lösung, weshalb die Antworten auf diese Frage wohl in den einzelnen Ländern gefunden werden müssen. Die vorliegende Arbeit befasst sich mit diesem Problem. Sie untersucht, inwieweit geklärtes Abwasser zur Entlastung der Wasserressourcen beitragen kann. Da im Jordantal ein bedeutender Beitrag zur regionalen Lebensmittelversorgung geleistet wird und dort darüber hinaus erhebliche Mengen an Frischwasser verbraucht werden, fokusiert sich die Arbeit auf dieses Gebiet. Alleine 40 % der Produktionskapazitäten im Jordantal sind aufgrund von Wasserknappheit bisher unerschlossen, obwohl sie zur Deckung der wachsenden Nachfrage dringend benötigt werden. Weiteres Wachstum ist aber eng an die Erschließung neuer Wasserressourcen gekoppelt und die weitverbreitete Tropfbewässerung auf den Feldern der Farmer bietet hier wenig Spielraum für eine Optimierung. Wasserannalysen vom Auslauf jordanischer Kläranlagen erfüllen sowohl nationalen als auch internationalen Qualitätskriterien an die Wiedernutzung. Somit kann dieses Wasser einen wertvollen Beitrag durch Nutzung in der Landwirtschaft leisten. Mit Hilfe des neuentwickelten Wasserwiedernutzungsindex (WRI) wurden erhebliche Potentiale bezüglich der bisher ungeklärten Abwassermengen aufgedeckt. Momentan werden lediglich 34% des Gesamtabwassers geklärt. Anhand einer Vorwärtsmodellierung mit WEAP wurde die günstigste Verteilung von verschiedenen Frisch- und Abwässern ermittelt und festgestellt, dass sich historische Wasserstände in Dämmen des Jordantals zuverlässig bestimmen lassen und damit in zukünftigen Szenarien zur Evaluierung herangezogen werden können. Eine ausgiebige Befragung bei 400 Farmern zeigte eine durchgehend positive Resonanz, demnach können sich 96 % vorstellen, geklärtes Abwasser zur Bewässerung ihrer Felder zu nutzen. Darüberhinaus erklärten sie sich auch bereit, ein vier- bis fünfaches des Wasserpreises für dieses Wasser zu bezahlen. Die Anwendung eines Ordinaren-Logit-Modells („ordered-logit-model") führt zu der Empfehlung, Preisgestaltung bei der Einführung von Klärwasser zur Bewässerung oder Ausdehnung des Programmes standortspezifisch durchzuführen. Zuletzt wurden anhand von vier Farmarchetypen verschiedene Preissyteme hinsichtlich Nährstoffgehalts des geklärten Wassers, Kostenreduzierung durch eingesparten Düngereinsatz und den Enfluß von Salz auf die Pflanzen simuliert. Die Ergebnisse zeigen, dass zusätzliches Wasser in Form von geklärtem Abwasser eine erhebliche Einkommenssteigerung für die Farmer bedeutet. Zwar hat das salzige Klärwasser negativen Einfluß auf das Wachstum von Zitrusfrüchten und Bananen, gleichzeitig sinken aber auch die Ausgaben für Düngemittel. Kosten für neue Kläranlagen und Abwasserkanäle sollten jedoch nicht allein durch Umlage auf die Farmer gedeckt werden. Dies ist allerdings gar nicht notwendig, da die gesamte Gesellschaft von den Folgen im Umwelt

und Gesundheitsbereich profitieren wird. Zusammenfassend gibt es gute Aussichten auf eine optimierte Nutzung der landwirtschaftlichen Ressourcen im Jordantal, bei einer weiteren Ausdehnung der Klärwassernutzung. Ein allmähliches Umlegen der entstehenden Kosten auf die Farmen scheint durchaus angebracht, da deren zusätzliche Einnahmen pro Wassereinheit die entstehenden Kosten mehr als ausgleichen.

خلاصة

ندرة المياه في المملكة الأردنية الهاشمية تؤثر تأثيرا كبيرا على التنمية الاجتماعية والاقتصادية لهذا البلد. حيث ان نصيب الفرد من توافر المياه يعد في المرتبة الأدنى في العالم . ان جميع موارد المياه المتجددة من نوعية مناسبة مستغلة استغلالا كاملا في الأردن. كما ان الموقف من شأنه أن يتفاقم نتيجة تضاعف عدد السكان خلال العقود المقبلة وسيناريوهات تغير المناخ اللتي تشير إلى وجود انخفاض كبير في كمية المياه . خطر استنفاد موارد المياه التي لم تعد قادرة على تلبية الطلب المتزايد لها قد يؤدي إلى عدم الاستقرار السياسي في المملكة الأردنية ويؤثر سلبا على الأجيال المقبلة.

ان اعادة توزيع المياه ضمن الحوض المائي لوادي الأردن يمكن أن يوفر الإغاثة اللازمة ، ومع ذلك ، فإن الوضع السياسي في المنطقة يمكن ان يعرقل التوصل إلى حل بناء في هذا الاتجاه . وبالتالي ، لا بد من إيجاد أجوبة ضمن المستوى القطري. هذا أيضا هو الهدف من دراسة الدكتوراة هذة حيث أننا نريد تحسين استخدام المياه العادمة المعالجة (TWW) في القطاع الزراعي باعتباره السيناريو الرئيسي للحد من الضغط على الموارد المائية.

هذا البحث يركز على وادي الأردن ، كمورد إقليمي هام للمحاصيل والخضر ، وحيث ان الكثير من موارد المياه العذبة يتم استهلاكها في قطاع الزراعة. حتى الآن . ان 40 في المائة من امكانات الوادي لا تزال غير مستغلة بسبب قلة المياه، في حين أن هناك حاجة ملحة إلى التوسع لتلبية الطلب المتزايد على الأ غذية. هذا النمو لا يمكن تحقيقه إلا بتوفر كميات إضافية من المياه ، ان استخدام الري بالتنقيط على نطاق واسع لا يترك مجالا يذكر لتحقيق مكاسب في الكفاءة على مستوى المزرعة . أظهر التحليل الكيميائي للمياه العادمة المعالجة في وادي الأردن أنه يفي بالمعايير الوطنية والدولية لنوعية المياه ويمكن أ ن يشكل مساهمة قيمة في الزراعة المروية . وجدنا أيضا انه باستخدام المؤشر الجديد لاعادة استخدام المياه العادمة المعالجة (WRI)، أنه لا يزال هناك مجال كبير لزيادة كميات المياه العادمة المعالجة حيث انه المستخدم حاليا فقط هو 34 في المائة من مياه الصرف الصحي والتي يتم معالجتها. كما تم تقيم مستقبلي لتوزيع المخصصات المختلفة للمياة حسب نوعيتها المياه العذبة و المياه العادمة المعالجة تم استحدثها باستخدام نموذج WEAP: Water Evaluation and Planning ، حيث تمكنا من محاكاة واستحداث المخزون المائي للسدود باستخدام المعلومات التاريخية للمخزون كميات المياه بالسدود وبذلك يمكن استخدامها لتقييم مستقبلي لسيناريو هات مختلفة.

أظهرت نتائج دراسة استقصائية واسعة النطاق ل 400 المزارعين أن 96 في المائة منهم على استعداد لقبول استخدام المياه العادمة المعالجة في الزراعة. وعلاوة على ذلك فان المزارعين على استعداد لدفع اربع الى خمس اضعاف السعر الحالي للمياه.

اوصت نتائج تحليل نموذج ordered logit بأنه عندما يتم إدخال أو زيادة كميات المياه العادمة المعالجة من عمل برامج منفصلة حسب الموقع لتحديد سعر المياه المستخدمة بالزراعة. وأخيرا فإننا قمنا بمحاكاة نظم التسعير المختلفة لأربعة نماذج من نظم الزراعة آ خذين بعين الاعتبار الاسمدة المتوفرة بالمياه المعالجة والتوفير في التكلفة وتأثر المحاصيل من الملوحة. كما أظهرت النتائج أن استخدام المياه العادمة المعالجة يؤدي الي زيادة دخل المزارعين إلى حد كبير ، في حين أن مستويات الملوحة تؤثر على إنتاج الحمضيات والموز سلبا. ووجدنا أنه من الصعب تغطية تكاليف محطات المعالجة الجديدة والبنية التحتية للمياه المجاري من مساهمات المزارعين وحدها و هذه أيضا ليست ضرورية لأن تقليل الآثار البيئية والصحية سيعود بالفائدة على المجتمع ككل.

نخلص إلى أن هناك احتمالات جيدة لمزيد من التنمية الزراعية في وادي الأردن عند استخدام المياه العادمة المعالجة . ان الزيادة التدريجية في مساهمات المزارعين يبدو مبررا لانة يؤدي الي زيادة في الربح للمتر المكعب تفوق الزيادة في التكاليف إلى حد بعيد.

Acknowledgment

First of All I would like to thank the almighty Allah for His endless Grace and Blessing on me during all these years here at Karlsruhe University and all my life.

I would like to thank all the people who have helped and inspired me during my doctoral work and study.

I heartily thank my advisor, Prof. Dr. Heinz Hoetzl, first of all for giving me the chance to do my PhD study under the umbrella of the project “the Sustainable Management of Available Water Resources with Innovative Technologies (SMART)”, which is funded by the German Federal Ministry for Education and Research in Germany an investigation that has been carried out in the Jordan Valley. Also I am addressing my gratefulness for his continuous supervision and guidance during my research and study at Karlsruhe University. I would like to extend this thanks and gratitude to the Federal Ministry for Education and Research in Germany for financially supporting my study.

In addition I was delighted to interact with Dr.Ben Sonneveld from the Centre for World Food Studies – Free Amsterdam University who became my co-advisor, for his perpetual energy and enthusiasm in research which motivated my work. In addition, he was always accessible and willing to help me with my research. As a result for his endless support, research life became smooth and rewarding for me.

I would like to convey my sincere and special thanks to Dr. Wasim Ali who has been a constant source of encouragement during my study. Dr Wasim has encouraged me to continue my PhD when we met at the conference” Water for life, 2004” in Antalya, Turkey. His guidance and support from the initial to the final level enabled me to develop my research capacity and overcome the hard time.

Another person I owe special thanks for his continuous cooperation, support and input for my WEAP model is Dr Eric Kemp-Benedict from Stockholm Environment Institute in Boston; I can say that we developed a good friendship through this cooperation.

From my institute still I have to thank some people for their advice, support and being there—some times for listening—mainly I would like to mention my colleague Dr. Leif Wolf for allocating time for our discussions helping to widen my thinking, as well for his input in the reviewing process. Further appreciation is expressed to my colleges at Karlsruhe University for their support and friendship especially I would name Petra Linda, Antje Pöschko, Maren Rapp, Miriam Leicht , David Riepl and Moritz Zemann. My time in Karlsruhe is considered as a turning point in my life, I treasured all precious moments we shared and extend my most heartfelt thanks.

During my field work in Jordan I had good support from the people in the Ministry of Water and Irrigation—mainly the Jordan Valley Authority, represented by Eng Nayif Sader who facilitated my work.

For this I want to direct special thanks to him and others who helped me there like Ms. Hind Diab, Eng Sameer Abdel-Jabbar, Ahmad Suboh, and Eng Husain Balawnah. Without these people I could not have done my field work.

From the German Technical Co-operation (GTZ), I would like to thank Jochen Regner, who allowed me to use their office facility during my field work. Furthermore special gratefulness and thanks to a very special person at the GTZ Dr. Andreas H. Lück for many issues, directing me to the fund for printing this research by GTZ, continuous discussion, exchanging information and giving me the chance to chair a key note speaker at the round-table discussion on climate change in Jordan organised by GTZ "national water planning" (Management of Water Resources - "German-Jordanian Water Programme") in cooperation with the Ministry of Water & Irrigation, Amman, Jordan.

Other special thanks addressed to my friend Didacus Ramos in the US, who volunteered to review and edit my work proving that distance is no limit when supporting friends.

y deepest gratitude goes to my beloved husband Anees Aldahyyat, for his unflagging love and support throughout my work. As will my two boys in Gaza: Ahmad and Nader.

Finally, I would like to address special thanks for every person I met in Karlsruhe. Last but not least, a special thanks to my thesis committee members and advisors.

Table of Contents

List of Tables

List of Figures

Abbreviations:

ASL: Above Sea Level

BSL: Below Sea Level

DA: Development Area

DOS: Jordanian Department of Statistics

FU: Farm Unit

GTZ: German Technical Cooperation (GTZ)

JISM: Jordan Institution for Standards and Metrology

JV: Jordan Valley

JVA: Jordan Valley Authority

KAC: King Abdallah Canal

KTD: King Talal Reservoir

KTR: King Talal reservoir

MoA: Ministry of Agriculture

MoP: Ministry of Planning

MWI: Jordanian Ministry of Water and Irrigation

RSS: Royal Scientific Society

TWW: Treated wastewater

WTA: Willingness to Accept

WAJ: Water Authority of Jordan

WTP: Willingness to Pay

WWP: Wastewater Plant

Abbreviations: Units

du: dunum (one dunum is equal to 0.1 ha)

JD: Jordanian Dinar (one JD is equal to € 0.99569 or to $1.42142 US)

Fls: Jordanian Fils , 1000 fils = 1 JD

Mm^3: Million of cubic meter

m^3: cubic meter

m^3/s: cubic meter per second

yr: year

1 Introduction

صورة الحجر: الآية 22 (وأرسلنا الرياح لواقح فأنزلنا من السماء ماء فأسقيناكموه وما انتم له بخازنين) .

Surah 15, the Stone, Aya 22. “And we send the fecundating winds, then cause the rain to descend from the sky, therewith providing you with water (in abundance), though you are not the guardians of its stores”.

“And the Lord will be your guide at all times; in dry places he will give you water in full measure, and will make strong your bones; and you will be like a watered garden, and like an ever-flowing spring. (Isaiah 58,11).”

The Middle East is one of the most water scarce regions in the world and pressure on water resources is likely to increase with exploding populations, expansion of the agricultural sector and soaring demands of a more affluent society. Water scarcity in the region dates from ancient times as clearly shown in the quotes above from two of the most important books from this region. Water scarcity is increasingly affecting the economic and social development of the region’s countries where 5% of the world population accesses less than 1% of the world’s freshwater resources (WorldBank July, 2006).

The Hashemite Kingdom of Jordan is no exception and has been identified as one of the higher water stress countries defined as areas where more than 40% of total available water is withdrawn (UNEP 1999). Steve Lonergan (Lonergan 2003) from the United Nations Environmental Programme (UNEP) states that: “The Middle East provokes perhaps the greatest concern about water shortage. By 2025 most of the Middle East countries are expected to experience water stress or scarcity” (Figure 1-1). Next to the quantity it is also the quality of the available water which is of great concern in water scarce areas (UNEP 2002).

It is becoming clear that good water management can solve many of the problems of pollution and scarcity. Most of the citizens of Jordan and Israel, for example, two of the most 'water-scarce' countries in the world, have access to adequate supplies of safe water, largely as a result of an almost full control of the available water resources and an effective irrigation strategy in the agricultural sector, the largest water consumer in both countries.

Many of the water resources, surface and ground water, are shared among riparian states in the different watersheds in the region. A key aspect in these transboundary water discussions in the MENA region is connected to the emerging discussion on “hydro-hegemony”. Hydro-hegemony maintains a position in a basin in which it receives more than its equitable share of the water. In the Jordan River Basin, Israel is in such a position. The hegemonic position seems not to be related to riparian position but is a reflection of the relative economic, political and military power in the basin (Zeitoun 2005).

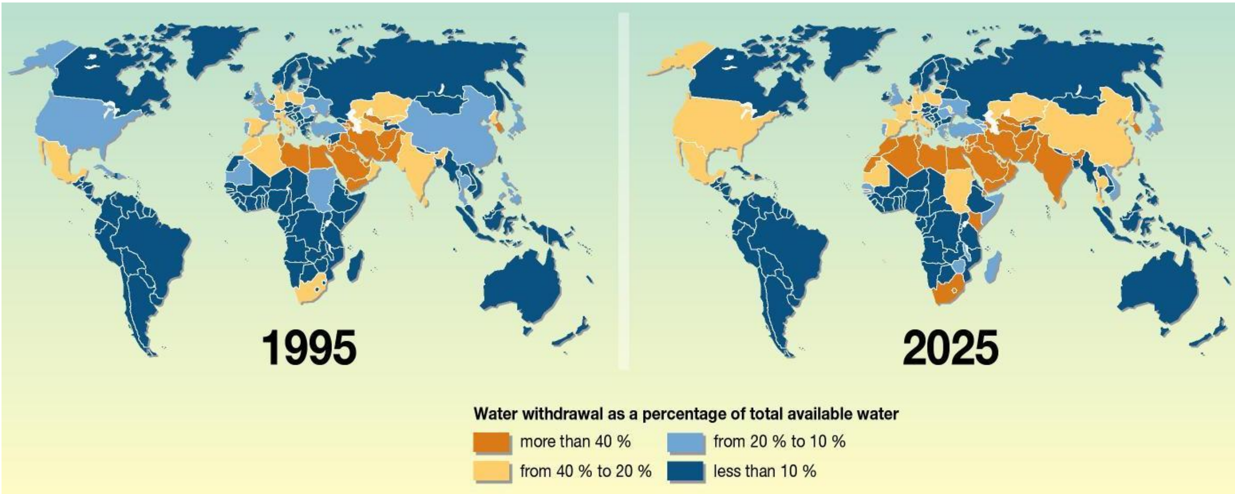


Figure 1-1: Global water stress countries (UNEP 2002).

A brief example, the total area of the Jordan River Basin is approximately 18,000 km^2, and the river is generally considered to have an average flow of approximately 1,400 million cubic meters (Mm^3)/year (Phillips et al. 2006). At present, five co-riparian's share the water resource of the basin. These are Lebanon, Syria, Israel, Jordan and the Occupied Territories of Palestine, of which only part of the West Bank is located in the Jordan River Basin. Most of these water resources are controlled but not equally distributed. Israel taps the upstream waters from Lake Tiberias with its National Water Carrier. Jordan and Syria built reservoirs in the Yarmouk River where part of the water is spent on agricultural sites of the Syrian Territory and the remaining part flows into the King Abdullah Canal that brings the water to the irrigated areas in the Lower Jordan Valley and to urban sites (Irbid and Amman). Israel also has access to groundwater resources under the West Bank. Currently Israel receives 44 percent of its water resources from the West Bank, Syrian territory and Lebanon (Keyzer et al, 2004). All these water interventions have two serious losers: the Palestinians on the West Bank and the ecology in the Lower Jordan Valley. The research of this study will concentrate on the Jordanian part of the area, what is known as the Jordan Valley (JV). It is a part of the long Dead Sea Rift system (420 km) that runs from the Lebanon Mountains in the north to Aqaba in the south. The northern part down to the Dead Sea is divided into eastern and western parts by the Jordan River itself. Bordered by a steep escarpment on both the eastern and the western side, the valley reaches a maximum width of twenty-two kilometres at points. The Jordan Valley Authority (JVA) identifies the Jordanian part from the Yarmouk River down to the Dead Sea as the JV area.

The Jordan Valley includes the west and east banks, where the east is located in Jordan and the west is shared between the Palestinian territory and Israel, Figure 1-2.

1.1 Research Problem

Water has the special characteristic that it does not disappear even when it evaporates. It just enters the water cycle. After use it still can be reused several times. This is also considered part of the solution to the growing water scarcity in Jordan, which makes it imperative to increase the practice of utilizing non-conventional water sources for irrigation such as treated wastewater and brackish water.

Indeed, wastewater in Jordan is a potential source of non-conventional water production with volumes rising and continuously available due to growing urban populations. Its reuse leads to savings in conventional primary water that could then be reserved for meeting the demand for higher-quality water (potable).

The Jordan Valley Authority (JVA) recognises that agriculture is important in its social, economic and environmental dimensions within Jordanian society. Intensive agriculture plays an increasingly important role in the region; yet, freshwater is vying for primacy in domestic use. So, the JVA developed a strategy and policy to increase the use of non-conventional water sources. Efforts were initiated to use treated wastewater for agriculture 26 years ago; subsequently adding brackish water for agriculture in 1985. This may have had a positive impact on the environment, crops and soil because few farmers have complained about declines in crop productivity while having the desired result of releasing a higher volume of conventional water for domestic uses.

The German Federal Ministry for Education and Research, considering Resolution 58/217 of the United Nations dated 20, December 2000 is supporting a research program for "Integrated Water Resources Management" (IWRM) in regions with water shortages. This includes the SMART project "Sustainable Management of Available Water Resources with Innovative Technologies" in the Jordan Valley. The SMART research project is targeting development of a transferable approach for Integrated Water Resources Management (IWRM) in the water-short Jordan Valley.

In this context this research is responding to the central question playing on the Jordan Valley: How can water availability be increased within the social and economic context of the Jordan Valley? Are farmers willing to accept and pay for treated wastewater? Could a pricing strategy be designed to cover part of the costs required for the implementation of TWW plants and sewage infrastructure?

This research, carried out under the umbrella of the SMART project, investigated the use of non-conventional water sources that could be used for agricultural purposes, as well as investigating farmers' acceptance of using treated wastewater in irrigation and how much they would be willing to pay. The results of this study will evaluate treated wastewater in relation to agricultural production capacity in the Jordan River Valley. This is also the foundation for decision makers in their weighing of various water pricing strategies that could meet or cover the additional costs for TWW plants.

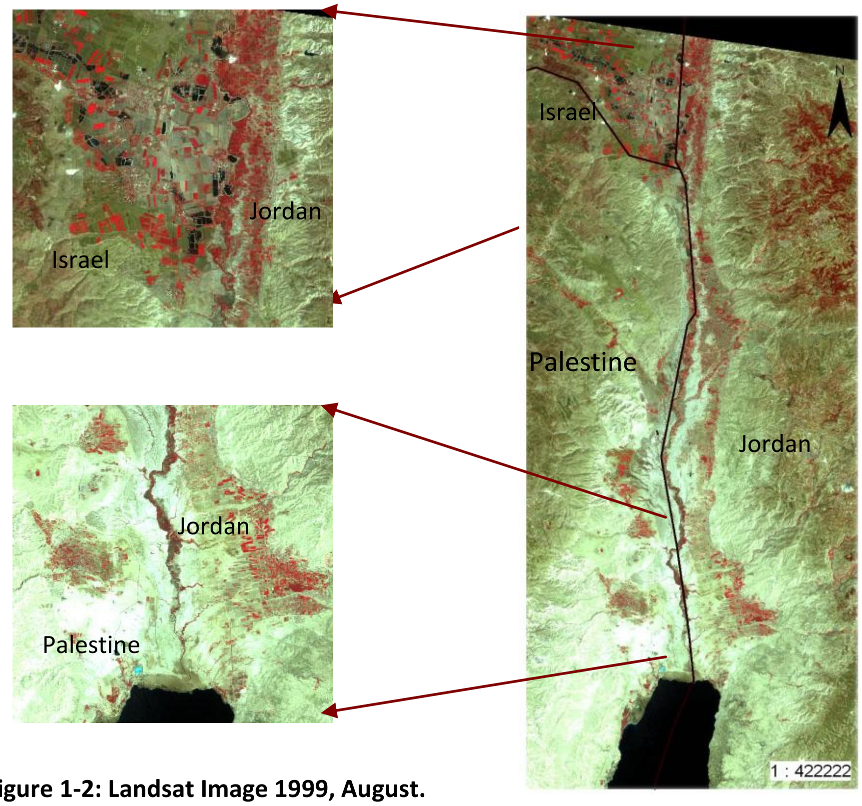


Figure 1-2: Landsat Image 1999, August.

The results of this study will assist decision makers and planners in considering a bigger view of water allocation by building different scenarios that could improve the water situation in the JV. WEAP21 program simulations will measure the impact of various water allocation scenarios on agricultural production in the JV.

The results also can be used to help the Palestinian farmers and decision makers in the "West Bank" to develop a similar program for reuse of treated wastewater and brackish water in the West Jordan Valley.

1.2 Introduction: State of the art IWRM

1.2.1 The Development of IWRM

In 1987 the World Commission on Environment and Development (WCED) defined sustainable development as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. A key factor in the elaboration of sustainable development is the integral view taken of central concepts that the interests of people, society, economy and environment need to be seen as an interconnected whole and trade-offs respecting all interests need to be made. Economic development has to be viable from a social and environmental point of view. Social development has to be viable in the light of the economy and the environment. And, environmental policies have to be attuned to social and economic development. The trade-offs are ultimately a societal and political choice (UNICEF 2003).

1. Introduction

The last three decades were notable because of the raising of the international community's awareness of the urgency of integrated water management. Wise water management is a direct corollary of improved quality of life.

The International Conference on Water and the Environment, held in Dublin in January 1992 developed issues for the Twenty-First Century again calling for new approaches to the assessment, development, and management of freshwater resources (UNCED 1992). The Dublin Conference was expected to formulate sustainable water policies and an action program to be considered by UNCED. The conference noted that water is a key to the achievement of national development goals and a baseline for economic development. It is crucial for strategic levels of investment in water management and infrastructure needed to achieve water security.

Moreover, the United Nations Conference on Environment and Development in Rio de Janeiro (June 1992) confirmed the widespread consensus that the management of water resources needs to be reformed. The conference stated, "The holistic management of freshwater as a finite and vulnerable resource, and the integration of sectoral water plans and programs within the framework of national economic and social policy are of paramount importance for actions in the 1990s and beyond." (World Bank 1993)

Integrated Water Resources represents a new approach to the assessment, development, and management of water resources emphasized at various global meetings. According to the United Nations Development Programme (UNDP 2000), integrated water resources management is based on the perception of water as an integral part of an ecosystem, a natural resource, and a social and economic good. Therefore, improving water resources planning, development, management and use is critical if countries are to achieve the Millennium Development Goals relating to poverty and hunger, human health, gender equality and environmental sustainability (UN 2008).

The Hague Forum carefully considered the outcomes of previous water initiatives and acknowledged water's social, environmental, and cultural values. The Forum suggested applying equity criteria along with appropriate subsidies to the poor when systematically adopting full-cost water pricing. The Forum further acknowledged that food security, ecosystem protection, empowerment of people, risk management of water related hazards, peaceful boundary and transboundary river basin management, basic water demands, and wise water management are achievable through IWRM (World Water Council 2000).

The German Government hosted the International Conference on Freshwater in Bonn, December 2001 in close cooperation with the United Nations. The aim of this conference was to contribute solutions for global water problems, to support preparations for the World Summit on Sustainable Development (WSSD) in Johannesburg, 2002, and the Third World Water Forum in Kyoto, 2003. The Conference developed Recommendations for Action in three important cross-sectoral areas: governance, management and partnerships; mobilizing financial resources; and, capacity building and knowledge sharing. The Bonn Conference points to the main areas of necessary political attention, thus making them more substantial for the public. What is required is awareness—political as well as public awareness—to meet the water security needs of the poor. (ICFW 2001)

The conference reviewed all previous water resources development principles and recognized that there was often a gap between policy development and practice. This lead the Bonn Conference to focus on practical implementation, not only identifying challenges and key targets, but also recommending action programs to implement policies in the field (ICFW 2001).

The *Bonn Keys,* which summarized the conference discussions, highlighted the key steps toward sustainable development through meeting water security needs of the poor, and promoting decentralization and new partnerships. To achieve these steps it suggested IWRM as the most capable tool. It recommended prioritizing actions in the fields of governance, mobilizing financial resources, capacity building, and sharing knowledge.

The *Bonn Recommendations for Action* addressed at the lowest appropriate level issues such as poverty, gender equity, corruption mitigation, and water management. The Conference identified a set of actions necessary to mobilize financial resources: strengthening public funding capabilities, improving economic efficiency, and increasing official assistance to developing countries. In the field of capacity building it prioritized the need for education and training regarding water wisdom, research, effective water institutions, knowledge sharing, and innovative technologies.

The Bonn Conference should be commended by the water world for connecting the views of the developing and developed world and impartially revealing practical implementation problems. It also provided action programs—an historical milestone for making IWRM truly effective in the field. The key success of the Bonn Conference was the adoption of the Bonn Recommendations in the WSSD Plan of Implementation (Rahaman et al. 2004).

The later conference, The World Summit on Sustainable Development (WSSD), held in Johannesburg South Africa, 2002 has been recognized as a success because it put IWRM at the top of the international agenda. The WSSD's Plan of Implementation includes IWRM as one of the key components for achieving sustainable development. It provides specific targets and guidelines for implementing IWRM worldwide including developing an IWRM and water efficiency plan by 2005 for all major river basins of the world; developing and implementing national/regional strategies, plans, and efficiency; facilitating public-private partnerships; developing gender-sensitive policies and programs; involving all concerned stakeholders in a variety of decision-making, management, and implementation processes; enhancing education; and combating corruption (UNEP 2002).

It is significant that the Bonn Conference recommendations were adopted within WSSD, and IWRM has now become the most internationally accepted water policy tool. The WSSD outcomes also encouraged major donors to commit themselves to implementing IWRM in the developing world.

The third World Water Forum held in March 2003 in Kyoto, Japan, also outlined safe, clean water for all, good governance, capacity building, financing, public participation, and various regional topics (TWWF 2003a).

A two-day Ministerial conference resulted in the release of a ministerial declaration on a range of water issues including water resource management, safe drinking water and sanitation, water for food and rural development, water pollution prevention and ecosystem conservation, as well as disaster mitigation and risk management (TWWF 2003b).

The forum recommended IWRM as the way to achieve sustainability regarding water resources. The ministerial declaration addressed the necessity of sharing benefits equitably, engaging in pro-poor and gender perspectives in water policies, facilitating stakeholder participation, ensuring good water governance and transparency, building human and institutional capacity, developing new mechanisms of public-private partnership, promoting river basin management initiatives, cooperating between riparian countries on transboundary water issues, and encouraging scientific research.

The ministerial declaration also vowed support to enable developing countries to achieve the UN Millennium Development Goals, and for developing IWRM and water efficiency plans in all river basins worldwide by 2005, the target set at the World Summit on Sustainable Development (TWWF, 2003b). Putting stakeholders and water ministers from around the world together in a Multi-Stakeholder Dialogue (MSD) for the first time in water history was another key achievement. In addition, a proposal to establish a network of Websites to follow the Portfolio of Water Actions received the fullest support of all participants. This will result in information sharing and promote cooperation between countries and international organizations (TWWF 2003a).

1.2.2 Definition of IWRM

Integrated Water Resources Management (IWRM) is a comprehensive water management concept. Beside other similar definitions the subsequent definition follows the concepts promoted by the Global Water Partnership (GWP 2000):

"IWRM is 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 eco-systems". A key concept of IWRM is the "Three E-pillars": "Maximizing Economic efficiency, social Equity and Environmental sustainability".

Sustainability has become a cogent paradigm for water resources. This headed the list of challenges for Integrated Water Resource Management to mitigate the inequitable and inefficient distribution of water resources, reduce their vulnerability to excessive demand, and limit the impacts on water quality of both land and water-based activities (Giupponi et al. 2006).

The World Bank defined IWRM as: "An integrated water resources perspective ensuring that social, economic, environmental and technical dimensions are taken into account in the management and development of surface waters (rivers, lakes, and wetlands) and groundwater." (World Bank 2000)) The World Bank identifies the Key Challenges associated with developing and managing water resources as population growth and economic development, water in ecosystems, water quality, water rights and climate change. The inability to predict and manage the quantity and quality of water and the impacts of droughts, floods and climatic variability imposes large costs on many economies in the developing world. On the other hand, water development and management could be based on a participatory approach, involving users, planners and policy makers at all levels.

One of the central aims of IWRM is to promote coordination and integration as a means of achieving a more holistic water management system improving water resource sustainability (Jønch-Clausen et al. 2001).

IWRM also could be defined as “a sustainable approach of water management that recognizes its multidimensional character—time, space, multidiscipline (science/technology) and stakeholders (regulators/ users/providers/neighbours)—and the necessity to address, embrace and relate these dimensions holistically so that sustainable solutions can be brought about” (Thomas et al. 2003).

The **time dimension** mainly refers to sustainable development: actions made now should be in harmony with the long term to protect the interests of future generations.

The **space dimension** recognizes that the natural unit for all water management efforts is the river basin or the watershed, and therefore it is necessary to “think globally” before “acting locally”.

The **multidiscipline dimension** requires a large number of parameters to be considered in the decision making process:

- Economic, environmental/ecological and social impacts,
- Legislation and health issues,
- Technique and technology,
- Political and institutional issues,
- Socio-economic impacts,
- Historical and cultural issues.

The **stakeholders dimension** qualifies that stakeholders have to be involved in the decision process in order to incorporate all the conflicting aspirations of the different decision participants.

The generally accepted definition of sustainable development ‘’is development which meets the needs of the present, without compromising the ability of future generations to meet their own needs’’ (Bebbington 2000; Cook et al. 2005).

Different authors (Jewitt 2002; Jonker 2002) found that there are a number of difficulties with such general definitions:

- the standard definition assumes a common understanding of what development means;
- it assumes the present generation knows what the needs of future generations will be;
- it does not explicitly link society and resources—the two elements in development;
- it is impossible to measure at what stage of development future generations are being compromised;
- it does not seem to consider the different time spans between human lifecycles and natural cycles.

Considering the above points a better definition of sustainable development might be “the improvement of people’s livelihoods without disrupting the natural cycles”. Based on this approach a more appropriate definition of IWRM would be “managing people’s activities in a river basin in a manner that promotes sustainable development (improves livelihoods without disrupting the water cycle)”.

A new paradigm is encapsulated in the Integrated Water Resources Management (IWRM) concept defined by GWP as: ‘‘Integrated Water Resources Management is 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’’ (GWP 2006).

Within the development of the IWRM concept managing water has became more complex, where there is a huge competition between water uses (such as drinking, versus other uses as recreation area, agriculture, industry and hydroelectricity generation). In addition water uses within the watershed can lead to the degradation and contamination of water quality. All these factors need to be considered in the planning process for water management uses.

Integrated Water Resource Management needs to look over the entire basin and include all the elements in the basin that can be affected and influenced by water.

There are three major water resource planning approaches as discussed by (Sharifi 2003) which are utilized today in the water industry. They are: traditional supply-side planning, least cost planning, and integrated resource planning.

- Traditional supply-side planning assumes that the problems associated with the provision of a safe and adequate supply of potable water can be solved by developing additional capacity as it is needed. It narrowly focuses on the supply side, excludes non-utility interests, and does not allow the utility to be flexible in meeting competing demands and satisfying regulatory policy goals. It also does not take into account conservation, industrial water reuse, or reasonable assumptions about future trends in customer consumptions and demands.
- Least-cost planning includes a comprehensive evaluation of all supply and demand alternatives, where the end result is an attempt to minimize the cost while creating a flexible plan allowing for uncertainty and a changing economic environment. It includes externalities such as cost and inclusion of non-utility participants’ goal’s to ensure the success of the planning process.
- Integrated resource planning (IRP) is a concept based on participation (customers and other resource users as stakeholders). It provides for formal integration and coordination among the several government institutions that have regulatory responsibilities for water resource matters.

Integrated Water Resource Management explicitly seeks to identify and manage risk and uncertainty and provides for coordination of planning between water utilities in a specific region.

The main challenge for IWRM is how to integrate the development in management and planning, and sustainability concepts with the growing number of disciplinary qualitative and quantitative models, and the advances in information technology; how to achieve sustainable methods of making use of resources in particular, sharing limited water resources; and, how to implement an adaptive co-management concept.

Understanding the concept of IWRM on different levels (Jianzhong et al. 2008) The first level is systematic consideration of the various dimensions of water, such as surface water and ground water, different quality of the water, the water within the basin and the water used outside the basin, etc. The key issue is that the water system is formed by many interdependent components such as floods, pollution, wet land, fishery, irrigation, etc. The second level of IWRM focuses on the interaction between water, land and environment, such as floods, pollution, wet land, fishery, irrigation, etc. Finally, the third level emphasizes the interaction between water, society and economic development. IWRM tries to promote the social economic development through efficiency of water resources management, to achieve the objective of sustaining water utilization and social economic development, which makes the implementation of IWRM a complex and huge system process.

Many countries, developing or developed, are trying to find their own way to solve their water problems using the IWRM concept to deal with water shortage, water pollution and ecological system degradation, etc.

The shift in water resources management forms the expression Integrated Water Resources Management (IWRM) and its definition identifying IWRM as meeting human requirements for the use of freshwater, whilst maintaining hydrological and biological processes and biodiversity which are considered essential for the functioning of ecosystems, the sustainable use of water resources and the maintenance of goods and services provided by them. Worldwide, this is a concept that is being increasingly put into practice and incorporates much of the philosophical framework of ‘‘ecosystem management’’ (Jewitt 2002).

This research paper tries to apply the concept of IWRM as defined in this and the following chapter by studying the water allocation and valuing the water in the Jordan Valley as it appears in the following diagram (Figure 1-3).

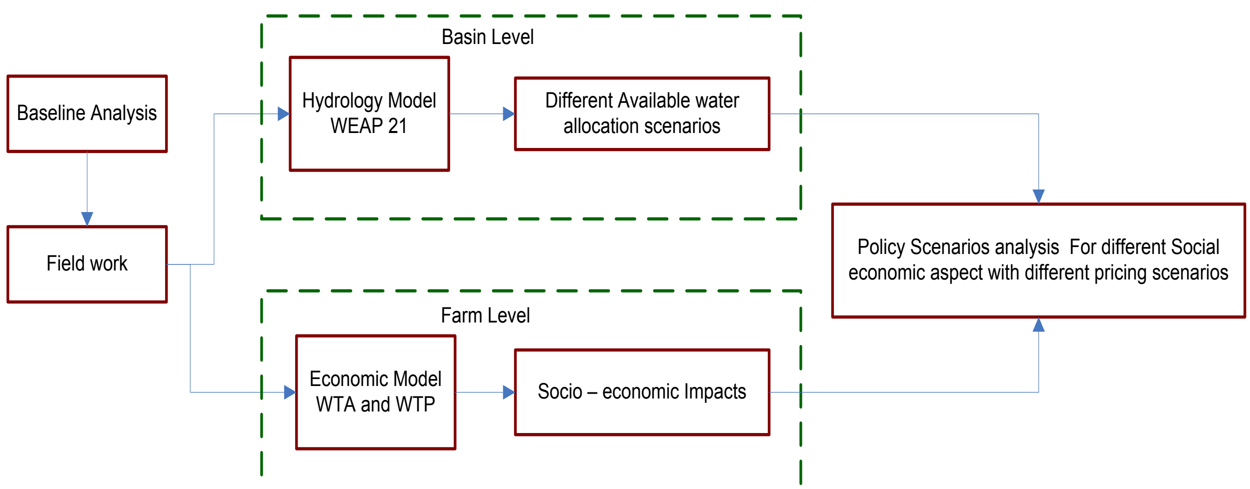


Figure 1-3: the Conceptual Framework for the research study applying IWRM model in the JV.

1.3 Objectives

The study addresses Integrated Water Resources Management challenges in the region by generating, synthesizing and disseminating useful information and knowledge on basin level water resource management for use by practitioners, planners, policy makers, and donors.

To achieve this goal the study included in-depth analyses and comparisons of the historical development and present status at the Jordan Valley Basin. The intention is to create a generic understanding of how societies manage water resources with limited renewable water resources to meet growing demand outlining which problems are faced and which solutions are available for a given physical and social context. The following objectives achieve this goal:

- Simulation of the Jordan Valley (JV), by presenting the water allocation schema using the WEAP model to evaluate the impact of various water allocations scenarios on agricultural production;
- Introduction of a framework for Wastewater Reuse in Jordan as a monitoring tool;
- Investigation of the Water Reuse Index (WRI) in Jordan to calculate the gap between achievements at different junctures, and identify water saving efforts;
- Employment of the Continge|nt Valuation (CV) method to investigate the farmers Willingness to Accept (WTA) and the farmers willingness to pay (WTP) for treated wastewater for agricultural use in the Jordan Valley (between the Yarmouk River and north of the Dead Sea);
- Analyse the socio-cultural opportunities (incentives) and constraints (disincentives) that influence the adoption of wastewater treatment and reuse for agricultural irrigation;
- Investigation of the cost of TWW per cubic meter for each wastewater treatment plant (WWTP) to be evaluated with willingness to pay (WTP); and,
- Development of a methodology for an Irrigated Water Price in the Jordan Valley according to water quality, taking in to consideration the incentives to change farmers' applied fertilizer practices when using TWW.
- We will analyze the possibilities for expanding the TWW volumes and covering the costs under various price water tariffs.

1.4 Methodology

This section describes the methodology that was used in this study.

1.4.1 Data collection

Verifiable information is crucial to good policy making and this study, therefore, relies on two types of data which quality is assured by various sources. The primary data in the research have been collected through a structured questionnaire that has been completed by face-to-face interviews with farmers in the study area. The collected data from the field questionnaire will provide the necessary information for estimating the willingness to accept (WTA) using TWW and willingness to pay (WTP) by the farmers for the treated wastewater in agriculture in addition to other useful information that will be used in the quantitative analysis. This will be done by employing a Contingent Valuation Method (CVM) that is used to estimate economic values for all kinds of ecosystem and environmental services. It can be used to estimate both use and non-use values, and it is the most widely used method for estimating non-use values (King et al. 2000).

The secondary data were collected from sources such as departments of statistics and several institutes such as the Ministry of Agriculture, the Ministry of Water and Irrigation and the Ministry of the Environment. Secondary data were further obtained from published reports and studies prepared by other researchers or institutions or donor agencies assuming that the data have been peer reviewed for accuracy.

1.4.2 Analytical Procedure

Data processing will be done at three stages to fulfil the requirements of each stage:

Stage one:

Simulating water supply and demand in the Jordan Valley Region to evaluate the use of treated wastewater in relation to agricultural production. The study capitalizes on extensive primary and secondary spatial data sets to accommodate a production function that reproduces geographically-specific agricultural production. The information is processed in a WEAP model to evaluate the impact of various water allocation scenarios for agricultural production.

Stage two:

The CVM is based on a questionnaire that reveals respondents' personal reluctance or propensity to consider the use of treated waste water instead of freshwater. Moreover, the questionnaire includes topics that provide the necessary information for farmers to enable them in informed decision making and to identify and reveal their monetary valuations of TWW. We distinguish the following five steps in this stage of the research.

- **Step 1:** Defining how to value the issue. Is using treated wastewater as a farming decision determined as a worthwhile service that farmers are willing to purchase?
- **Step 2:** Making preliminary decisions about the survey itself, including whether it will be conducted by mail, phone or in person by face-to-face interviews, how large the sample size will be, who will be surveyed (the targeted population), and other related questions.

  Interviews face to face are generally the most effective for complex questions—even though they can be more expensive—because it is often easier to explain the required background information to respondents in person, and people are more likely to complete a long survey when they are interviewed in person. The drawback is that the sample is restricted by the available budget.

This in fact was the chosen method for conducting this survey. In the JV, the face to face interview was the most reliable method since farmers there have their own social cultural structure (as education level, accessibility, trust of others, fluency in English, etc.).

- **Step 3:** The actual survey design. This is the most important and difficult part of the process requiring several months to complete. It is accomplished in several sub-steps: initial interviews or focus groups with the types of people who will be receiving the final survey. Then, the questions get more detailed and specific to help develop specific questions for the survey, as well as to decide what kind of background information is needed and how to present it. This requires learning about the farmers' awareness regarding the use of treated wastewater.

  After a number of focus groups have been conducted, an idea of how to provide background information is developed to describe the hypothetical scenario for asking the valuation question, and to start pre-testing the survey.

  There are many elicitation formats that could be used for the questionnaire: open-ended, bidding game, payment card, single-bounded, one and a half bounded and double bounded dichotomous choice and randomized card storing procedure. There are no scientific principles that guarantee a single optimal questionnaire design despite the many attitude-behavioural studies by cognitive psychologists and sociologists (Bateman et al. 2004).

  For the purpose of this research two types of techniques have been implemented. The first is dichotomous choice (Yes/No) used to obtain WTA. The bidding game is used for WTP, whereby the values are presented in ordered classes from: 0.008 – 0.02 JD per cubic meter.

- **Step 4:** The actual survey implementation. The first task is to select the survey sample. The sample of this survey was selected randomly by using standard statistical sampling methods, then the actual implementation. The sample size of this survey was (400) farm units would have been needed in order to select a 0.05 size sample of all the area under study. In considering both, the final total sample was (401) farm units, which is distributed as (122) farm units in the North, (127) farm units in the Middle, and (152) farm units in the South.
- **Step 5:** Analyze and report the results. The data were entered to the computer and analyzed by using the appropriate statistical techniques for the type of the survey questions. A descriptive analysis was carried out to analyse the farmer Willingness to Accept (WTA) using treated wastewater in agriculture and the farmer Willingness to Pay (WTP) by employing a statistical package (SPSS) for analysis.

<u>Stage three:</u>

Wastewater is a valuable resource as an agricultural water source. Further, the rich nutrient stock contained in wastewater provides a major benefit for agricultural and other purposes.

The challenge faced by policymakers is how best to minimize the negative effects of wastewater use, while at the same time obtaining the maximum benefits from this resource.

The potential benefits of wastewater use in agriculture may be summarized as follows:

- provides a reliable source of water supply to farmers for crop production;
- conserves nutrients thereby reducing the need for artificial fertilizers;
- increases crop yields and returns from farming;
- provides source of income through its use in other enterprises such as aquaculture; and,
- is a low-cost method for sanitary disposal of municipal wastewater.

Wastewater could also have harmful impacts in agriculture, with potential costs attached to its use such as:

- increased exposure of farmers, consumers and neighbouring communities to infectious diseases;
- lead to groundwater contamination;
- long-term wastewater use could damage soil resources, e.g. build-up of salts and heavy metals in the soils, which might reduce soil productive capacity;
- lower property values in the vicinity; and,
- other unforeseen negative impacts on socio-ecological systems.

Taking into consideration all incentives and disincentives a framework for pricing agricultural water at Jordan Valley will be proposed at the end of this chapter.

1.5 Thesis Structure

Chapter 1: Introduces the problem, objective, scope, and approach of the research. It emphasizes that the growing water scarcity in Jordan makes it imperative to increase best practices and dependency on non-conventional water in irrigation such as treated wastewater and brackish water. This made the government of Jordan recognize the importance of reclaimed wastewater as a non-conventional water resource. Indeed, in Jordan substantial amounts of the wastewater that are collected are still discharged into water courses or in the underground without treatment. Moreover, not all wastewater generated is treated or connected to a sewage system—being discharged through septic tanks and the like. The research objective is to analyze the socio-cultural opportunities and constraints that influence the adoption of wastewater treatment and reuse for agricultural irrigation in the Jordan Valley.

Chapter 2: Study area – case study in the Jordan Valley, presents a background on the Jordan Valley at the Hashemite Kingdom of Jordan where this research was carried out introducing the socio economic characteristic of the JV.

Chapter 3: Framework for wastewater reuse in Jordan, presents a conceptual framework for wastewater reuse, identifying Jordan as a pioneer in wastewater treatment and reuse in the Middle East.

Reducing the gap between supply and demand in the reclaimed wastewater market entails increasing the rates of wastewater treatment and reuse. The currently used indicators to quantify achievements in wastewater reuse account only for the reused amounts of wastewater from urban treatment plants while omitting that from rural disconnected communities. These indicators are reviewed and a new indicator called the Wastewater Reuse Index (WRI) is introduced quantifying the amounts actually reused as a percentage of total wastewater production (urban and rural).

Chapter 4: Modelling water allocation in the Jordan Valley. Simulations of water supply and demand in the Jordan Valley Region are used to evaluate the features and benefits of treated wastewater in relation to agricultural production. The study capitalizes on extensive primary and secondary spatial data sets. The information is processed in a WEAP model to evaluate the impact of various water allocations scenarios for agricultural production.

Chapter 5: The socio-economic situation of the farmers in the JV affects the willingness of those farmers to accept and pay for reclaimed wastewater (WTA and WTP). A regression model was developed to correlate farmers' decisions with financial stimuli as inducement. Also, factors (incentives and disincentives) were analyzed and assessed that promote or discourage the use of reclaimed wastewater in irrigated agriculture. This analysis will help explain the fundamental driving forces for wastewater reuse, as derived from existing field experiences.

Chapter 6: The implementation of additional TWW and related water way infrastructure will increase the available water volume for the farmers in the JV. We analyze the water quality of the TWW in relation to the water prices. Furth more, TWW investments are costly and we evaluate in a scenario setting whether various water tariffs can cover the costs of new TWW plants.

Chapter 7: this chapter includes the story line and the out finding of this research. TWW is a new source of water known as unconventional water. Using this water in agriculture sector will help to reduce the stress on the freshwater that can be allocated to domestic uses. At the end the study we are proposing pricing scenarios which take into consideration the quality and the cost analysis for TWW versus the freshwater.

2 Study Area: Case Study Jordan Valley

2.1 Jordan Valley Background

2.1.1 Geography

The Jordan Valley Authority (JVA) is responsible for that part of the long Rift Valley on the Jordan side that runs from the Yarmouk River in the north to Al Aqaba in the south, with the Jordan River extending from Lake Tiberius in the north to the Red Sea in the south, over a total length of 380- kilometre. The northern part, from the Yarmouk River to the Dead Sea, is known as the Jordan Valley (JV). It is divided into eastern and western parts by the Jordan River. Bordered by a steep escarpment on both the eastern and the western side, the valley reaches a width of twenty-two kilometres at its widest points (THKJ 1998).

The Jordan Rift Valley altitude varies from 200m below sea level (in the north) to 400 m below sea level (in the south). Temperatures are moderate during winter (on average between 15°C and 22°C between November and March) and reach record levels during summer commonly exceeding 45°C during the day in the months of June, July and August. The climate is semi-arid in the north (precipitations of 350 mm/year) and arid in the south (50 mm/year near the Dead Sea).

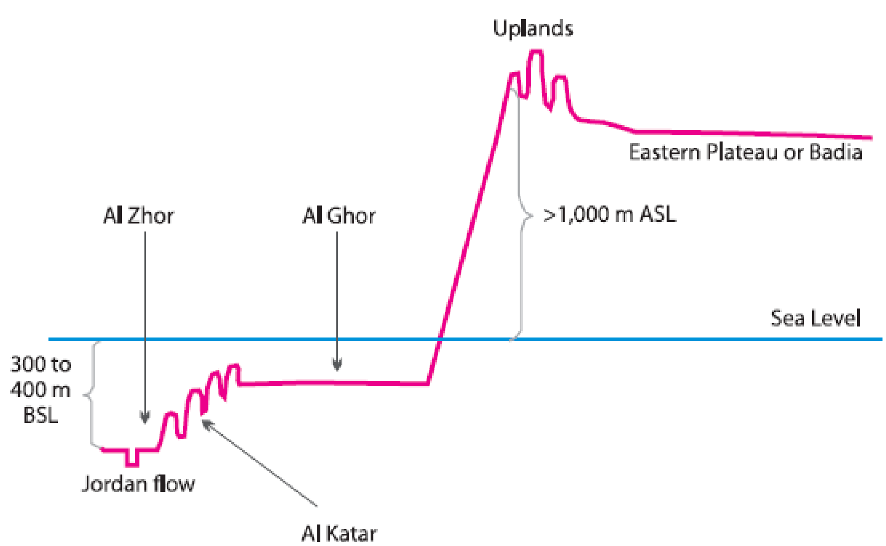


Figure 2-1: Topographic cross section of the Jordan River Basin in Jordan.

The Jordan River (Figure 2-1) flows in a 30m to 60m deep gorge through a narrow alluvial, fertile plain locally called "Al Zor" from 200m to 2km wide. The rest of the valley, called "Al Ghor[1]" in Arabic, is a fertile area formed by colluviums coming from neighbouring mountains and alluvial fans lying on the lacusturie sediments of Lake Lisan, which covered the area 14,000 years ago. Gently sloping (1.5% to 2.5%) from the mountains, it is 10km wide in the north, narrows down to 4km in the middle, finally widening to 20km in the south. In these two areas, soils are deep and of good quality but, because of the climate, only a steppe and some grassland existed before the reclamation of the valley, with the notable exception of small areas irrigated by the side-wadis[2] and springs (Courcier et al. 2005).

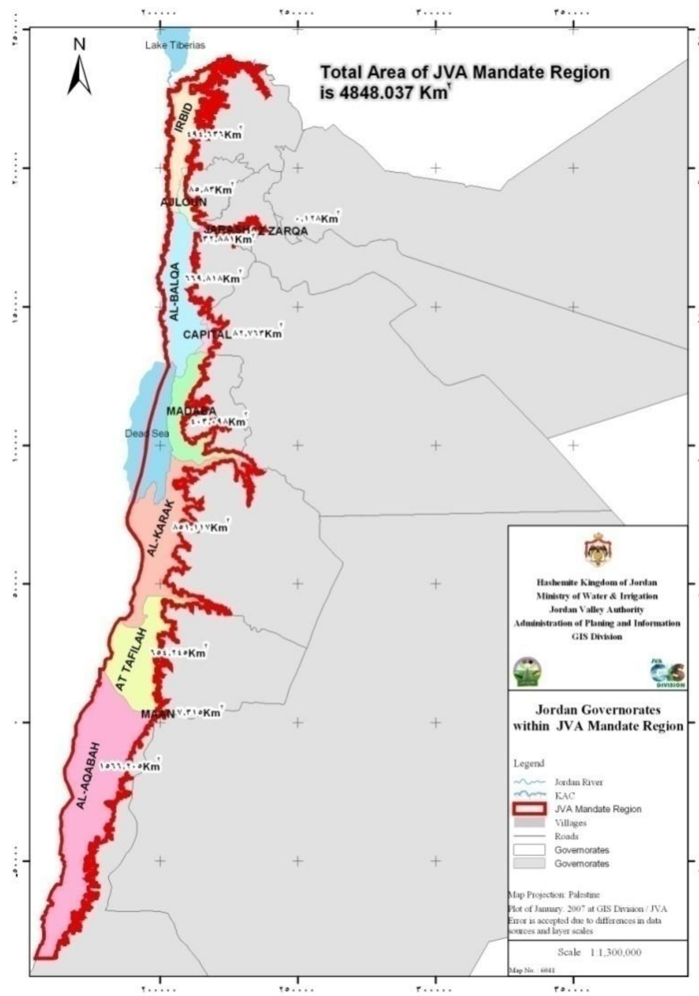


Figure 2-2: The Jordan Valley Authority boundaries by Jordan law.

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

The Jordan Valley Development Law No. 19 of 1988 (amended in 2001) identifies the area of JVA responsibility as extending from the Yarmouk River in the north to the Red Sea in the south (Figure 2-2). The eastern extension of the area is limited by the contour line at 300m above mean sea level (a.m.s.l.) north of the Dead Sea and the contour line at 500m a.m.s.l. south of the Dead Sea. The JVA service area comprises JV North, JV South, Southern Ghors and Wadi al Araba. The total geographical area of JVA's responsibilities is about 4,800 Km^2 Figure 2-2, distributed through eight governorates (JVA 2008): Irbid

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

[2] **Wadi**(Arabic: وادي) is a narrow valley with a dry riverbed that contains water only during times of heavy rain—flash floods.

(494.6 Km^2), Ajloun (85.8 Km^2), Jerash (32.8 Km^2), Salt (669.8 Km^2), Madaba (403 Km^2), Karak (851.1 Km^2), Tafeeleh (654.2 Km^2), and Aqaba (1566.2 Km^2).

2.1.2 Climate and Water Supply

Variations in temperature, humidity, and rainfall produce distinct agro-climatic zones. Annual rainfall starts in October and ends in May. Precipitation reaches 350-400mm/year in the north JV and drops down to 50mm/year in the south. The warm winter of the valley allows the production of off-season crops and enables a kind of large green house.

The annual available water in the valley is around 250-300 Mm^3, while the annual demand for irrigation exceeds 500 Mm^3. Around 60 Mm^3 of water is pumped up to Amman city and 20 Mm^3 to Irbid for domestic uses from ground water and the KAC (THKJ 2004; JVA Sep, 2004).

The JVA over comes the gap between demand and supply by reducing the quantities delivered to farmers with a variable percent proportional to water availability.

The research area in the Jordan Valley is between the Yarmouk River and the north Dead Sea. It is been divided into three main parts corresponding to the JVA divisions and the Ministries of Statistics and Agriculture (Figure 2-7): Northern JV, Middle JV and Southern JV. Each of these regions has its own climatic and agro-ecological characteristic constituting a base for dividing the agricultural land, total land area and irrigated area of the four zones (summarized in Table 2-1):

Table 2-1: Geographical and irrigated areas in the JRV

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

1 square kilometre = 1, 000 dunum

Agriculture is one of the primary economic activities of Jordan in general and of the Jordan Valley in particular. Traditional farming practices including irrigation techniques have been deeply rooted in the farmers for many decades.

Figure 2-3: King Abdullah Canal (KAC) in the north of JV.

2.1.3 The Northern JV

The farming system in the north of the Valley is homogeneous and is irrigated with water from the northern part of the King Abdullah Canal—a freshwater source (Figure 2-3). This section is divided into two zones described as follows:

Figure 2-4: Open Field cultivation.

The extreme north of the Valley is a citrus zone where most of the lands have been cultivated with a variety of citrus for more than 40 years and are run by large Jordanian families (extended families from the region such as Ghezawi, Al Waked families, etc. (Philippe 2004).

Areas located around the villages of Wadi Ryan and Kreymeh are studded with greenhouse vegetables and open field crops.

The citrus zone has been reduced by regulation enforced by the JVA stemming from water shortages.

2.1.4 The Middle JV

The Middle JV is situated between the villages of Kraymeh and Dah-Rat Al Ramel, and can be described as follow:

The irrigation water is blended from treated wastewater (TWW) from King Talal Reservoir water and freshwater from the northern part of King Abdullah Canal (Figure 2-5). This mix is used in the Middle and South JV, while King Talal Reservoir receives both (1) treated wastewater from greater Amman and Zarqa and (2) rain runoff from catchment areas.

In the extended zone from Kraymeh to Dah-Rat Al -Ramel the main cultivated crop is vegetables (around 70%). Greenhouse cultivation is the preferred format for the main crops of tomatoes, paprika and cucumbers. Open field cultivation (Figure 2-4) of mostly eggplants and potatoes is considered second in importance.

The Middle Jordan Valley mainly consists of orchards—fruit trees and palms with some citrus. Also a limited number of small vegetable farms can be found with open field crops. There are also some larger farms with greenhouses. Small farms with open fields lie more to the south while large farms with greenhouses lie in the area of Kraymeh and Al Muaddi.

Figure 2-5: Mixing point for treated wastewater from King Talal Reservoir (right) and fresh surface water from the Yarmuk river deviated in the King Abdullah Canal (left).

2.1.5 South JV

The South JV is the area that lies between Dah-Rat Al-Ramel and Swaemeh (north of the Dead Sea) including Karameh and the South Shouneh villages. Most of the farms are planted with vegetables (Plastic greenhouses and open fields) and bananas in the South Shouneh area.

The southern part of the Valley stretches along the 18 km extension project of the King Abdullah Canal, Hisban-Kafrein irrigation project and 14.5 km extension. This last section of the canal is presently not in operation because of the limited water supply reaching Karameh—the end of the operated canal. As a result some farmers in the 14.5 km extension project depend on ground water (tube wells). The JVA delivers some water via the canal to help farmers with irrigation due to ground water salinity. More than 35 farmers in the South JV operate desalination plants for cultivating cash crops.

The South JV can be described as follows:

Around South Shouneh, many farmers have water rights from Wadi Shuaib Reservoir and they have planted 2,500 dunums. The water flows in an open channel free of charge with each farm owning a share. The main cultivation type is open field and greenhouse vegetables and bananas.

Many farmers depend on private tube wells to irrigate their crops but are required to pay fees to WAJ.

Around the Karameh area farmers receive blended irrigation water through the King Abdullah Canal and are growing particular vegetable crops such as tomatoes, eggplants, squash, parsley and mint in open field farms or greenhouses.

The most southern parts of the South JV depend on irrigation from the Kafrein Reservoir and Wadi Hisban—a non-controlled wadi. Water usage is charged at the same mean fee used in other places in the JV.

The ground water in the area is brackish (EC is more than 2,000 ppm). So, farmers mix this water with freshwater from the Hisban–Kafreen irrigation project (that have water rights from Wadi Shuaib) or plant directly with ground water. Here also, some farmers have their own desalination units.

2.2 Water Distribution Responsibility

The official Jordanian body charged with water jurisdiction is the Ministry of Water and Irrigation (MWI). This ministry is represented by two authorities: the Water Authority of Jordan (WAJ) and the Jordan Valley Authority (JVA). The WAJ mandate comprises the distribution of municipal water and the collection and treatment of wastewater; while the JVA takes responsibility for the development of the water system and irrigation water specifically in the JV. In the past, WAJ issued user-licenses to farmers in the As Samra WWTP vicinity, resulting in the reduction of water for downstream farmers in the Jordan Valley. This practice is questionable as the government strategy is NOT to extend areas for irrigated agriculture according to the National Water Master Plan (NWMP).

2.3 Jordan Valley Water Allocation

The Jordan Valley is Jordan's most productive and sustainable agricultural area. The water sector is the focal area for development and aims at integrated water resources management sustainable in economic, ecological and social terms. In particular the national aim is for an increased use of treated wastewater (reclaimed water) and brackish water as substitutes for fresh water.

2.3.1 Land Ownership and Management

The ownership of farm units in the Jordan Valley is a result of the government redistribution policy. Ownership and management depend on the financial situation of the farmer. A unit may be owned by more than one farmer and a farmer may own more than one unit

Managing the farm can be carried out either by the owner, a lessee or as a shared responsibility between owner and farmer—sharecroppers. Some sharecroppers in the JRV are non-Jordanian labours.

In the JRV sharecropping is practiced through non-formal agreements between the owner and a landless person. The owner usually makes most of the important decisions with regard to crop selection as well as inputs to be used. The sharecropper provides labour—sometimes with family members and, when necessary, hired labour. This ownership and management arrangement is most commonly found in the Middle JV.

2.4 Cropping Patterns

Several cropping patterns exist in the Jordan Valley with 98% of the crops irrigated. The major crop types (Table 2-2) are vegetables (62%) then fruit trees (29.7 %) (Ministry of Agriculture in Jordan, 2006).

Table 2-2: General cropping pattern of the Jordan Valley,(Ministry of Agriculture, 2006).

	Cultivated area at the Jordan Valley (2006) in thousand Dunum							%of total irrigated
Crops	**Northern JV**		**Middle JV**		**Southern JV**		**JV (du)**	
	Irrigated	Rain fed	Irrigated	Rain fed	Irrigated	Rain fed		
Field Crops	6	3.7	2.8	0	0.72	0	13.22	5.6
Vegetables	31	0	65.2	0	50.6	0	146.8	62.5
Citrus trees	35.9	0	8.3	0	2.2	0	46.4	19.8
Other trees	6.3	0.94	4.83	0	16.31	0	28.38	12.1
Total (du)	79.2	4.64	81.13	0	69.83	0	234.8	100
%	33.7	2	34.6	0	29.7	0	100	

2.4.1 Currant Water Pricing System in Jordanian Agriculture

The first water tariff in the Jordan Valley was implemented in 1961. Farmers paid 1 fils/m^3 independent of the amount of the water consumed. In 1966, this tariff was redefined to 1 fils/m^3 for the first 1,800 m^3 consumed, and 2 fils/m^3 for additional volume (JRIDI 2002).

In 1995 agricultural water in Jordan was repriced by the Ministry of Water/ Jordan Valley Authority and Irrigation to support the small farmer (Table 2-3).

Table 2-3: Agricultural water price in Jordan

Amount of consumed water (m^3 / Farm Unit / month)	Price JD / m^3
0-2500	0.008
2501 -3500	0.015
3501 – 4500	0.02
Over 4500	0.35

The law priced all water in the Jordan Valley equally using a government subsidy. Subsequently, the Jordan Water Strategy and Policies 2002, Article 43, declared that differential prices can be applied to irrigation water by quality. The new tariff is proportional to consumption—the more water consumed, the higher the tariff.

Usually farmers pay a fraction of the operational, maintenance costs and capital costs of irrigation water. However, the real value of water should reflect the cost to gain access to 'new' sources of water of same quality. But, this is a point for further research since it involves economics, morals and politics.

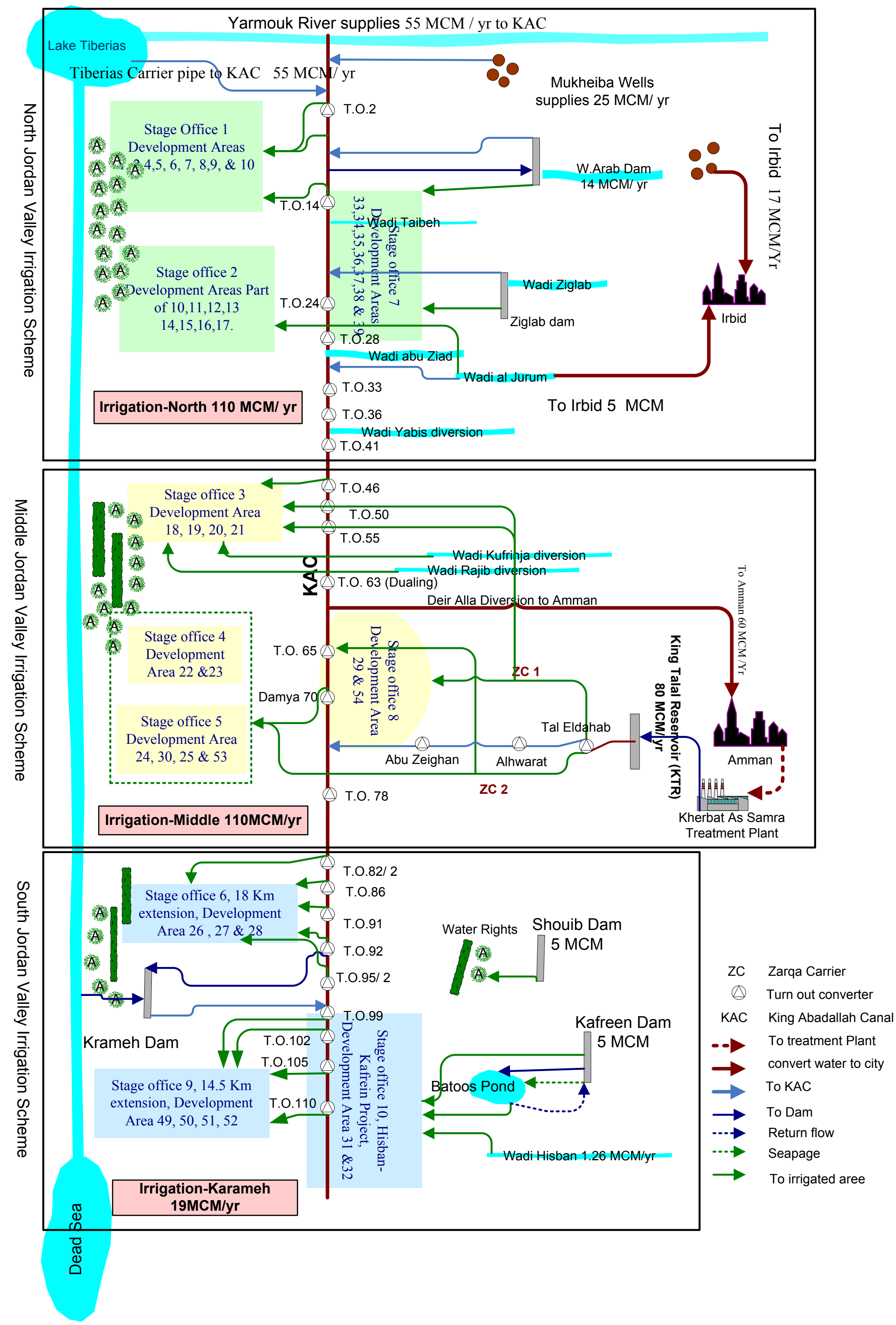


Figure 2-6: Graphic depiction of Demand–Supply water allocation for Jordan Valley 2007- developed for the purpose of this research.

Studies in the Indus Valley between India and Pakistan in the mid-twentieth century suggest that local control and investment—even sweat equity—made the Indian protocol more successful than the Pakistani model that was a top down entitlement. The latter was not internalized by local farmers who regarded it as a project by a detached far off government body, yet the farmers regarded the water as an entitlement to be used as they pleased leading to much over drafting. The Indian farmers by contrast built the system with government assistance but much less involvement and they understood the system including its limitations (Merrill et al. 2002). It is regarded as a prime example of water management.

2.5 Irrigation in the Jordan Valley

The Jordan Valley irrigation scheme emanates from the distribution points from and to the King Abdullah Canal (KAC)[3], the main water carrier for the valley. The canal receives water from different tributaries then is distributed to farms for irrigation and to Amman for drinking. The main water use areas and water flows in the Jordan Valley are shown schematically in Figure 2-6. This scheme was developed to serve this research and to graphically understand the Supply and Demand water allocation plan for the Jordan Valley for 2007. The JVA is the responsible body for redistributing water from KAC to farmers via Stage Offices.

The water of the Yarmouk River downstream of the confluence with the Jordan River at the northern end of the valley is fed into a concrete canal called King Abdulah Canal (KAC) that runs parallel to the river on the eastern bank. All flows from side wadies have been re-channelled to feed the KAC.

In 2006 the KAC was supplied with approximately 55 Mm^3 from the Yarmouk River and another 55 Mm^3 from the Tiberias Carrier in compliance with the 1994 Jordanian-Israeli Peace Treaty (Treaty 1994). Another 25 Mm^3/year comes from Mukhyba wells to the KAC with additional inflows from several wadis cutting through the mountain ranges bordering the valley providing another 8 Mm^3/year (JVA 2007).

While the Al-Arab Reservoir supplies the KAC with 14 Mm^3 of freshwater, Ziglab reservoir provides another 4 Mm^3/year of fresh surface water. Meanwhile the King Talal Reservoir (KTD), Shueib Reservoir, and Kafrein Reservoir supply the irrigation in JV with 90 Mm^3 /year of blended water for agriculture.

The total water that flowed into the KAC during 2006 was 250 Mm^3 of which 45 Mm^3 was conveyed to Amman city and another 17 Mm^3 to Irbid city in the north and another 25 Mm^3 was stored at Karameh Reservoir.

[3] KAC: is a construction at the East Ghor Canal by Jordan in 1960, which runs down the east bank of the Jordan Valley for 69 Km, has brought new areas under irrigation.

The North Jordan Valley up to the conveyance to Der Alla receives freshwater from KAC for agriculture purposes. While the Middle North Jordan Valley receives blended water (treated wastewater mixed with freshwater) mainly from King Talal Reservoir (KTD) via KAC and Zarqa and Zarqa Carrier (ZCI and ZCII). The North and Middle JV's agricultural water demand is approximately 240 Mm^3/year.

The Jordan Valley receives blended water from different sources such as the King Talal Reservoir (KTD) and Kafrein Reservoir and the Shueieb Reservoir farmers' possess water rights; these reservoirs receive TWW from different plants. Some farmers in the South JV have their own wells and desalination units.

2.6 Irrigation with TWW at the JV

2.6.1 Wastewater Reuse Terminology

Wastewater reclamation involves the treatment or processing of wastewater to make it reusable.

Wastewater reuse or **water reuse** is the beneficial use of the treated water. Reclamation and reuse of water frequently require water conveyance facilities for delivering the reclaimed water and may require intermittent storage of the reclaimed water prior to its reuse.

Indirect use includes mixing and dilution by discharge into an impoundment, receiving water or groundwater aquifer prior to reuse (Asano, 1998 cited in (GTZ 2006)).

Irrigation is defined as the application of water to soil for the purpose of supplying the essential moisture for plant growth. Irrigation plays a vital role in increasing crop yields and stabilizing production. In arid and semi-arid regions, irrigation is essential for economically viable agriculture, while in semi-humid and humid areas, it is often required on a supplementary basis (Pescod 1992).

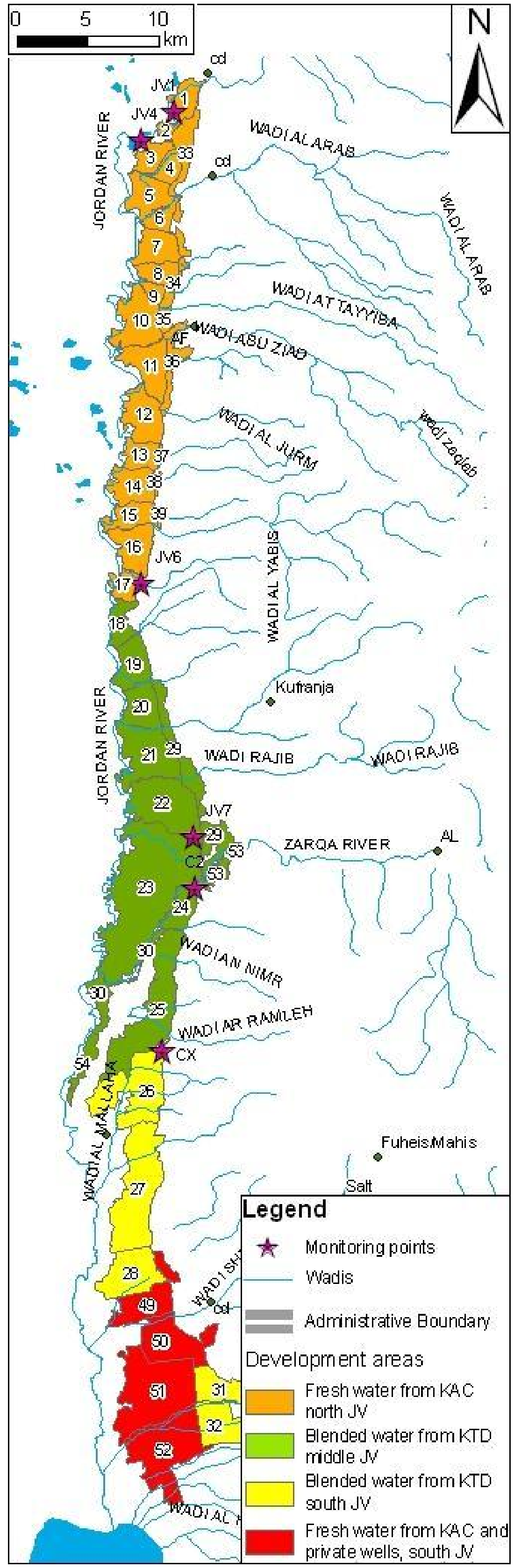


Figure 2-7: Development area in the JV and the sampling point.

At the farm level, the following basic conditions should be met to make irrigated farming successful:

- the required **amount** of water should be applied;
- the water should be of acceptable **quality;**
- water application should be properly **scheduled**;
- appropriate irrigation **methods** should be used;
- salt accumulation in the root zone should be prevented by means of **leaching**;
- the rise of water table should be controlled by means of appropriate **drainage**;
- plant **nutrients** should be managed in an optimal way.

The above requirements are equally applicable when the source of irrigation water is treated wastewater. Nutrients in municipal wastewater and treated effluents are a particular advantage of these sources over conventional irrigation water sources and supplemental fertilizers are sometimes not necessary. However, additional environmental and health requirements must be taken into account when treated wastewater is the source of irrigation.

2.6.2 Irrigation System in Jordan Valley

King Abdullah Canal (KAC) is the main carrier body of water in the JV. It begins with a concrete section of 20 m^3/s capacity then declines to 3.2 m^3/s at the end. The canal was built in four stages the completion of the final phase in 1987 with a total length of 110 km beginning from the Al Adasiya in the southern steeply inclined part of the Yarmouk River to almost the shores of the Dead Sea with a maximum width of 11.30 m and a maximum (water) depth of 2.80 m.

Table 2-4: The amount of water that fed the KAC from various tributaries in 2006 (MWI 2006)

Source	**Amount of Water (Mm^3)**	**Percentage (%)**
Yarmouk River	14.25	9.42
Tiberias carrier	53.12	35.13
Sharhabeil Reservoirs	1.12	0.74
Wadi Arab Reservoir	4.45	2.94
Mukheiaba Wells	34.66	22.92
Wadi Jurum	1.82	1.2
Wadi Rayan	0.002	0.001
Wadi Yabis	0.59	0.39
Wadi Rajeb	0.21	0.14
Abu Alzhighan channel	41	27.11
Total	**151.22**	

2.7 Water Quality at Jordan Valley Monitoring Points

In the Jordan Valley there are two main types of water used in irrigation: freshwater at the North part; and TWW in the Middle and part of the South.

KAC water is monitored by the Jordan Valley Authority (JVA) by sampling water from several locations along the KAC. The sample points indicated by stars at Figure 2-7 have preinstalled electronic sampling machines. These points are as follows: one at the exit of the Yarmouk River (JV1), next point at Tiberias Carrier (JV4 of Figure 7), next Abu Habeal (JV6), and at the channel around the town of Deir Allah (JV7). These sampling points are at the North JV where surface freshwater is used. Another point is next to Ma'adi site (C2). And, the last point is at Dahrat al Raml (CX). These two locations are the sampling points after TWW from the KTD is mixed with KAC water.

TWW used in the Central and Southern JV comes from the country's largest WWTP, As-Samra, which treats the domestic water of the capital, Amman and the city of Zarqa. On its course to the JV the TWW is diluted by surface run-off water from adjacent catchments areas of Wadi Duleil, Wadi Zarqa and the KTR, where it is stored temporarily. Therefore, TWW in the JV can also be addressed as TWW for indirect use.

2.7.1 Irrigation system

In the Jordan Valley reclaimed water is used for agricultural irrigation in the central and southern parts using the blended reclaimed water. In addition to the freshwater coming from KAC, the Middle JV receives extra water from KTR at the mixing point. An estimated 70-80 Mm^3 are used annually for irrigating farms in the Middle JV. Thus, the irrigation water quality is strongly connected to the principle irrigation system and the amount of available freshwater and the volume of TWW used.

2.7.2 Quality of water to be applied

Important agricultural water quality parameters to be monitored include a number of specific properties of water that are relevant in relation to crop yield and quality, maintenance of soil productivity and protection of the environment as recommended by the Food and Agriculture Organization of the United Nations (FAO). These parameters mainly consist of certain physical and chemical characteristics of the water.

Table 2-5 presents a list of some of the important physical and chemical characteristics used in the evaluation of agricultural water quality.

During the monitoring of irrigation water at all locations in the Jordan Valley, all these parameter values have fallen within the guidelines and are suitable for all crops.

It was noted that during the dry seasons some parameters became high but still remained within the guidelines and accepted values.

Water Salinity representative for Electric Conductivity (EC):

Electrical conductivity indicates the total ionized constituents of water. It is directly related to the sum of the cations (or anions), as determined chemically and is closely correlated with the total salt concentration. Electrical conductivity is a rapid and reasonably precise determination and values are always expressed at a standard temperature of 25°C to enable comparison of readings taken under varying climatic conditions. The symbol ECw, is used to represent the electrical conductivity of irrigation water (Pescod 1992).

Table 2-5: parameters used in the evaluation of agricultural water quality (source (Pescod 1992))

Parameters	**Symbol**	**Unit**
Physical		
Total dissolved solids	TDS	mg/l
Electrical conductivity	EC	S/m
Temperature	T	°C
Colour/Turbidity		NTU/JTU2
Hardness		mg equiv. CaCO3/l
Sediments		g/l
Chemical		
Acidity/Basicity	pH	
Type and concentration of anions and cations:		
Calcium	Ca++	me/l
		me/l
Magnesium	Mg++	me/l
Sodium	Na+	
Potassium	K	me/l
		me/l
Carbonate	CO_3--	me/l
Bicarbonate	HCO_3-	me/l
Chloride	Cl-	me/l
Sulphate	SO_4--	me/l
Sodium adsorption ratio	SAR	
Boron	B	mg/l
Trace metals		mg/l
Heavy metals		mg/l
Nitrate-Nitrogen	NO_3-N	mg/l
Phosphate Phosphorus	PO4-P	mg/l

Water salinity is one of the most important criteria of water for irrigation through its impact on the ability of plants to absorb water through roots. High salinity could lead to the salts accumulation in the soil (Figure 2-8). These are the average rates of salinity by EC at KAC during the period February 2006 to February 2007 (AL-Sharieda et al. 2007) where it is clear that salinity values have increased significantly in both locations (CX and C2) due to the mixing of water from KTD – (a high salinity source) and the water from the main channel coming from the north—a less salty source. Figure 2-9 shows the seasonal rates of the EC at the observation points.

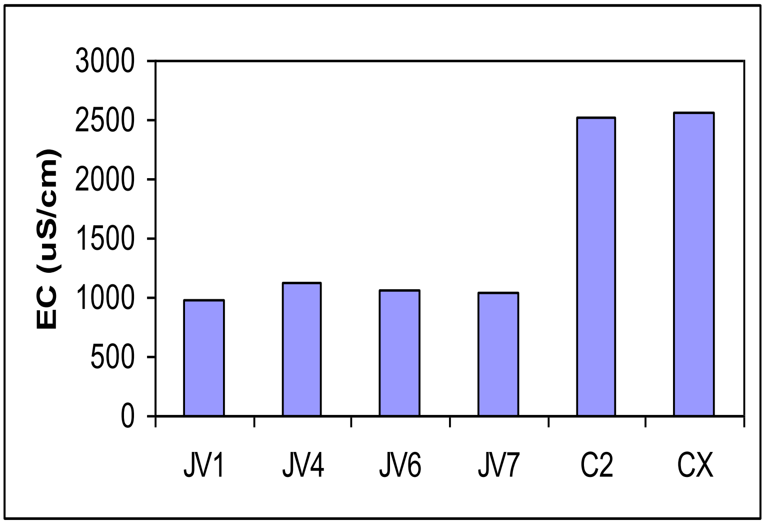


Figure 2-8: EC at the Monitoring points (RSS 2008).

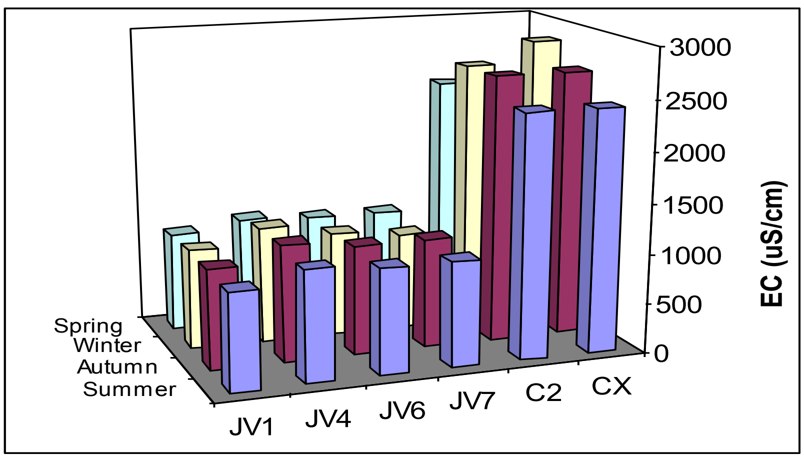


Figure 2-9: Seasonal EC at monitoring points (RSS 2008).

Total Suspended Solids (**TSS**) is the solids in water that can be trapped by a filter. TSS can include a wide variety of material such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life (Murphy 1998). TSS gives a measure of the turbidity of the water.

TSS at the JV may cause the blockage of the irrigation pipes and pumps and disable filters. It is clear from Figure 2-10, that the value of TSS was high at the site JV1 because of the nature of drifts that occur during the flow of water in the Yarmouk River, while TSS is very low in the water from Tibierias Carrier because of water being transferred is in a closed pipeline.

Note further that the value of TSS has declined during the flow of water into site JV7 due to deposition while the rise at C2 and CX because of mixing the water with water from KTD contains a significant amount of suspended material.

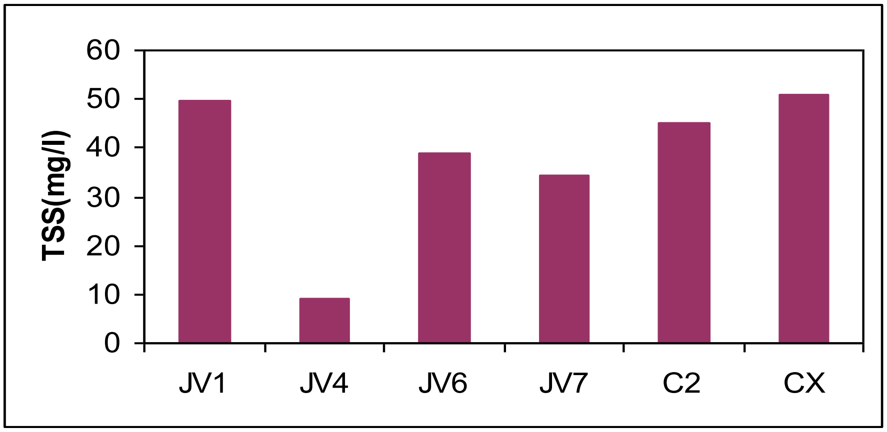


Figure 2-10: the Average TSS at the Monotoring points.

Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)

COD is the total measurement of all chemicals in the water that can be oxidized.

BOD5 measures the amount of substances that bacteria can oxidize in 5 days.

It is clear from Figure 2-11 that the high value for COD-BOD_5 raises only after the water at KAC was mixed with Blended water from KTD.

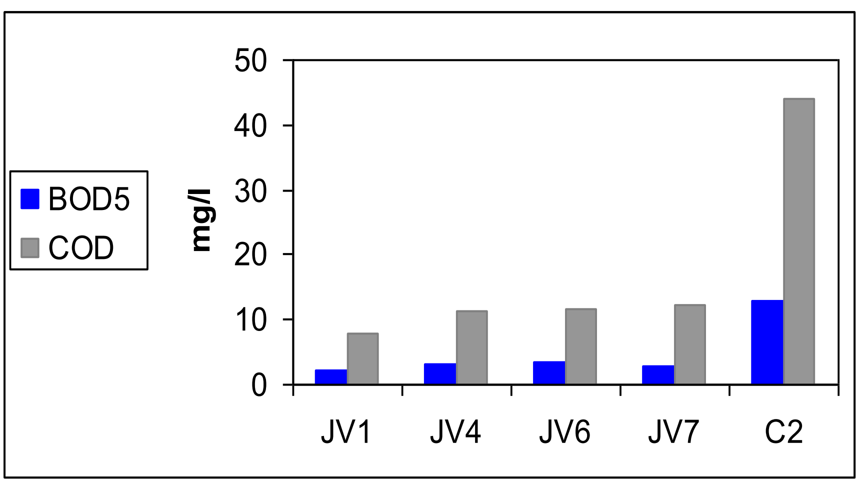


Figure 2-11: COD and BOD_5 concentration at monitoring points.

Nutrient Content

At the locations along the JV where blended water is used a considerable amount of plant macro-nutrients [(nitrogen (N), phosphorous (P) and potassium (K)] can be considered as a low-strength multi-nutrient fertilizer (GTZ 2006).

Nitrogen: The total **N** concentration in RW is generally between 10 to 60 mg/l. In the JV, the majority of N in the RW is in the form of NH_4^+-N and to a lesser extent in the form of organic-N and NO_3 -N.

Phosphorus: **P** is present in RW in the form of (1) organic bound phosphate and (2) phosphate from soaps and detergent residues. The concentration of phosphate in RW is variable but, according to Ryden and Pratt (1980), in most cases is below 30 mg/l.

Potassium: **K** is present in RW in the form of the dissolved K-cation, K^+. The concentration in RW is in general 30 to 60 mg/l.

The concentration of the nutrients fluctuates according to the water source, the degree of wastewater treatment, the seasons and the degree of dilution with rainwater.

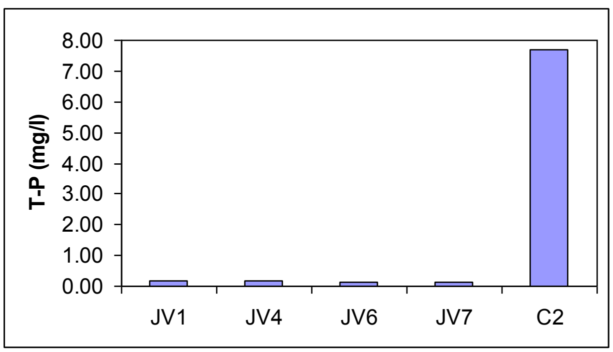


Figure 2-12: P concentrations at monitoring points (RSS 2008).

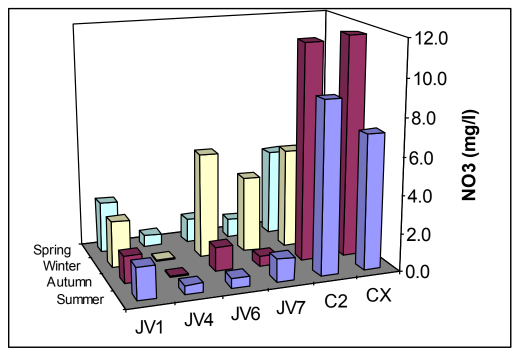


Figure 2-13: NO3- N seasonal average concentration at monitoring points (RSS 2008).

Nutrient content of applied irrigation water is important since it provides part of the nutrients required by the crop. Additional application of nutrients can cause nutritional imbalances in the soil solution and in the crop and has the potential to reduce crop yield and quality if farmers don't take it into inconsideration.

Similar to elements, the nutrient content after the mixing point on the monitoring points C2 and CX gets high values due to receiving TWW from KTD.

Also other secondary nutrients required for plants such as calcium (Ca), magnesium (Mg), chlorine (Cl) and Sodium (Na) are monitored. The level of these nutrients varies widely throughout the year according to the Royal Scientific Society report (2007).

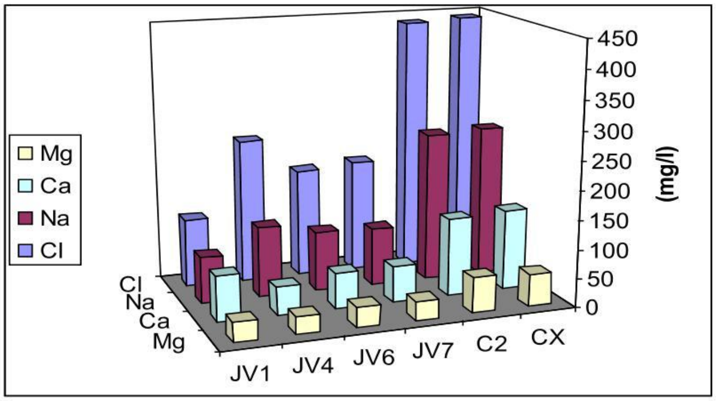


Figure 2-14: average rates for chloride, sodium, calcium, magnesium at the observation point along the KAC.

High sodium (Na^+) content in irrigation water can cause severe soil problems. The cation replaces Ca^{++} and Mg^{++} ions at the negatively charged exchange complex and leads to dispersion and the deterioration of soil structure. This, in turn, reduces the permeability of the soil for infiltration of rainfall and irrigation water as well as exchange of air, thus causing unfavourable growing conditions for plants.

With regard to possible soil problems, the ratio between the concentration of Ca^{++} plus Mg^{++} vs. Na^+ is important. The Na^+ hazard is reduced if Ca^{++} plus Mg^{++} is high compared to Na^+. This relation is reflected in the formula of the sodium absorption ratio (SAR)(GTZ 2003):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} \text{ (mg/l)}$$

2.7.3 The impact of the above parameters on the agriculture sector

TSS: As a physical parameter may reduce the permeability of the surface soil layer or cause clogging of micro irrigation systems. Other impacts are related to the composition of substances causing turbidity or suspension.

Water collected in reservoirs (fresh or treated wastewater) suspensions and turbidity are caused by fine soil and rock particles which are not harmful to plants and can only have physical and maybe chemical impacts on irrigation system, such as pipes , canals, pumps, .etc. A farmer deals with this situation by installing filters at the water inlet to the farm.

BOD_5, COD: Oxygen is necessary for plant growth and it should be present at the root zone. However, anaerobic situation would occur only if irrigation water contained high organic matter concentrations and very low Dissolved Oxygen (DO) contents at the same time. When soils remain 100 % saturated with that water for long periods of time, it allows development of the described negative anaerobic conditions in the root zone (Al-Zboon et al. 2008).

Values of up to 60 mg/l for BOD_5 and up to 120 mg /l for COD cant be considered as harmful to plants or soils (EPA 1992), to the contrary, the oxidation of organic matter produces necessary nutrients for plants such as No_3 and PO_4.

Nutrient Content: the action of the cations Ca and Mg on soil and plants is directly connected to the pH value and concentration of Na.

It is recommended that the concentration of Ca are of less than 400mg/l and Mg of less than 150 mg/l in water irrigation (Ayers et al. 1994)

When the SAR value is less than 6 no problems are to be expected for soils or plants, while some problems may occur when the SAR is between 6-9 such as decreasing soil permeability. Soil clogging occurs when the SAR is more than 9 (Suarez et al. 2006).

The effects of Na and Cl are bound to the Ca content of the soil—the higher the Ca content the less the negative impacts of Na and Cl. Na and Cl are the major salinity parameters in irrigation water where the EC values reflect their concentration.

K is used as fertilizer only when k> 80 mg/l reduces the plant uptake of Ca (Suarez et al. 2006).

3 Framework for Wastewater Reuse in Jordan

3.1 Introduction

Jordan represents a typically water constrained economy daily confronted with challenging decisions on its water use. With a fast growing population and an expanding agricultural sector the demand for alternatives to freshwater resources remains imminent. An important strategy for the Jordanian government to meet the water demand for agricultural produce is to rely more on treated wastewater.

The basic principle is to use collected wastewater treated to adjust for quality to serve the following end-users: irrigation, artificial recharge, potable water supply, toilet flushing, and industrial water supply. The reuse of reclaimed wastewater is motivated by two strong economic incentives (Abu-Madi 2004): 1) to decrease the water scarcity in the region, and/or 2) avoid the cost of the deterioration of water resources and the environment caused by untreated or partly treated wastewater.

Reducing the agricultural demand for freshwater in the region is not easy, but non-conventional water sources can assist in reducing the overall amount of water utilized by the agricultural sector. Wastewater is therefore an important additional source as it can be treated and reused by the agricultural sector for crop irrigation but also for landscape irrigation, groundwater recharge, and even some recreational purposes (Aydın et al. 2002; Monte 2007; Mekala et al. 2008).

3.2 Wastewater Treatment

Conventional wastewater treatment typically consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment. In Jordan there are twenty two (22) treatment plants operating using different mechanisms as shown in the following Table 3-1:

Both treatment and post-treatment measures are available for the effluent of WWTP, which complies with WHO guidelines. It is important to mention that WHO in 2006 issued a new version of the Guidelines for the use of treated wastewater in irrigation. The difference between this version and the old version (1999) is that the current one is less stringent with regard to microbiological thresholds (E .coli). Whilst the old one determined that E.coli should be < 1000 parts per 100 ml, the current version leaves the decision to each and every country which might allow up to 100,000 parts per 100 ml.

Table 3-1: WWTP cost comparison and Description (MWI, 2006)

TREATMENT PLANT NAME	YEAR OF OPERATION	TYPE OF Treatment System	TOTAL CONSTRUTION COST(JD)	DISGN FLOW	DISGN BOD	REMARKS & Status
AQABA (old)	1987	W.S.P*	1494180	9000	900	Good
AQABA(NEW)	2005	Activated Sludge		12000	420	Good
AL- BAQA	1987	TRICKLING FILTER	2140000+ 5500000	14900	800	Good
FUHEIS	1997	Activated Sludge		2400	995	Good
IRBID (CENTRAL)	1987	TRICK.and ACT. SLUDGE	6769618	11023	800	Good
JARASH(EAST)	1983	Activated Sludge	180000 + 3180000	3500	1090	Good
AL KARAK	1988	TRICKLING FILTER	830000	786	800	Will be upgraded soon
KUFRANJA	1989	TRICKLING FILTER	888517	1800	850	Will be upgraded soon
MADABA	1989	Activated Sludge	630000+	7600	950	Good
MAFRAQ	1988	W.S.P*	885073	1800	825	Will be upgraded soon
MA'AN	1989	W.S.P*	649000	1590	970	Will be upgraded soon
ABU NUSEIR	1986	ACT SLUDGE and. RBC	1713405	4000	1100	Good
RAMTHA	1987	Activated Sludge	700000+ 7500000	5400	1000	Good
AS SAMRA	1985	W.S.P*	31000000+	68000	525	Will be upgraded soon
AS SALT	1981	Activated Sludge	1538000	7700	1090	Good
TAFILA	1988	TRICKLING FILTER	871304	7600	1050	Good
WADI AL ARAB	1999	Activated Sludge	18657763	22000	995	Good
WADI HASSAN	2001	OXIDATION DITCH	6900000	1600	800	Good
WADI MOUSA	2000	Activated Sludge	6135500	3400	800	Good
WADI ALSIER	1997	Aerated lagoons		4000	780	Good
ALEKEDER	2004	W.S.P*	4000000	4000	1500	Good
ALAJOUN	2005	W.S.P*	80000	1000	1500	Good
TELALMENTEH	2004	TRICK.and ACT. SLUDGE	3500000	400	2000	Good

*W.S.P : wastewater stabilization ponds

3.3 Reuse for agricultural irrigation

In both developed and developing countries treated wastewater is used for agricultural irrigation both directly and indirectly (Westcot 1997; Carr et al. 2004). In direct reuse the treated effluent is taken from the wastewater treatment plants (WWTPs) to the irrigation site, for example, to irrigate orchards (citrus, grapes, olives, peaches, pears, apples, and pomegranate), field crops (fodder, cotton, cereals), and recreational and domestic use (golf courses and lawns). In indirect reuse the treated effluent is discharged into surface water or groundwater aquifers. The effluents, thus, are blended with freshwater available from the wadis, reservoirs, rivers, and aquifers and used by downstream farmers (Hussain et al. 2002).

In most cases reclaimed wastewater is used for unrestricted irrigation in accordance with the Jordanian Institution for Standard and Meteorology established standardized at the JS 893:2002 under water-reclaimed domestic wastewater as distinguished from restricted and unrestricted irrigation.

Distinction should be made between restricted and unrestricted irrigation on the basis of irrigated crops and modes of operation. Crops for unrestricted irrigation include forests and areas where access to the public is not expected, fodder, industrial crops, pastures, trees (including fruit bearing trees, on the condition that during collection the fruits do not come into contact with the ground), seed crops, crops that produce products which are processed before consumption. With respect to irrigation methods, spray irrigation is not allowed. Restricted irrigation includes all other crops such as vegetables, vineyards, crops with products that are consumed raw, and greenhouses (Mara et al. 1999; JISM 2002).

In practice, it might be being used for all crops, even those consumed raw or uncooked since most of the treated wastewater in Jordan is blended with freshwater from the King Talal Reservoir (KTR)and used downstream in the Jordan Valley for unrestricted irrigation (Shatanawi et al. 1996).

Figure 3-1: As'samra waste stabilization pond, the new WWTP to the right and old to the left(Pictures taken on Nov,2007).

The Jordanian agricultural sector employs 4% of the country's economically active population and generates 11.4% of the country's exports. Structural adjustments have transformed the food sector from food subsidies and price and import control policies in the 1970s and 1980s to a gradual liberalization and the removal of food subsidies by the 1990s (El-Zabri et al. 2007). The contribution of the agricultural sector, including forestry and fisheries, to the total GDP slightly declined from 3.9 % of GDP in 2005, 3.6 % in 2006 and to 3.4 % in 2007 (Central Bank of Jordan 2008).

Although the agricultural sector contributes a relatively small amount to Jordan's GDP, the government recognizes that its economic and social dimensions are a fundamental factor of the national economy. It is the base for integrated rural development, a source of income and employment for rural and Badia (semi-desert) people and a generator of activities in the other economical sub-sectors, especially the industrial and service ones. It also plays a central role in food security and trade balance improvement

(AL-JALOUDY 2000). Moreover, with the high food prices and globally increasing demand for fodder and biofuel, the agricultural sector will only gain in importance in the coming years (Keyzer et al. 2005).

Jordanian society maintains strong cultural ties to an agrarian life style. Open-air markets and bazaars selling locally produced agricultural products are an important if diminishing economic institution. The environmental dimensions are in transition as urbanization spreads and traditional lifestyles retreat. Intensive agriculture with larger yields on less land plays an increasingly important role in regional water demand. Policy makers give priority to freshwater for domestic use and consequently have developed a strategy to increase the use of non-conventional water. Agricultural use of treated wastewater has been employed for the past 25 years and the use of brackish water in agriculture started in 1985.

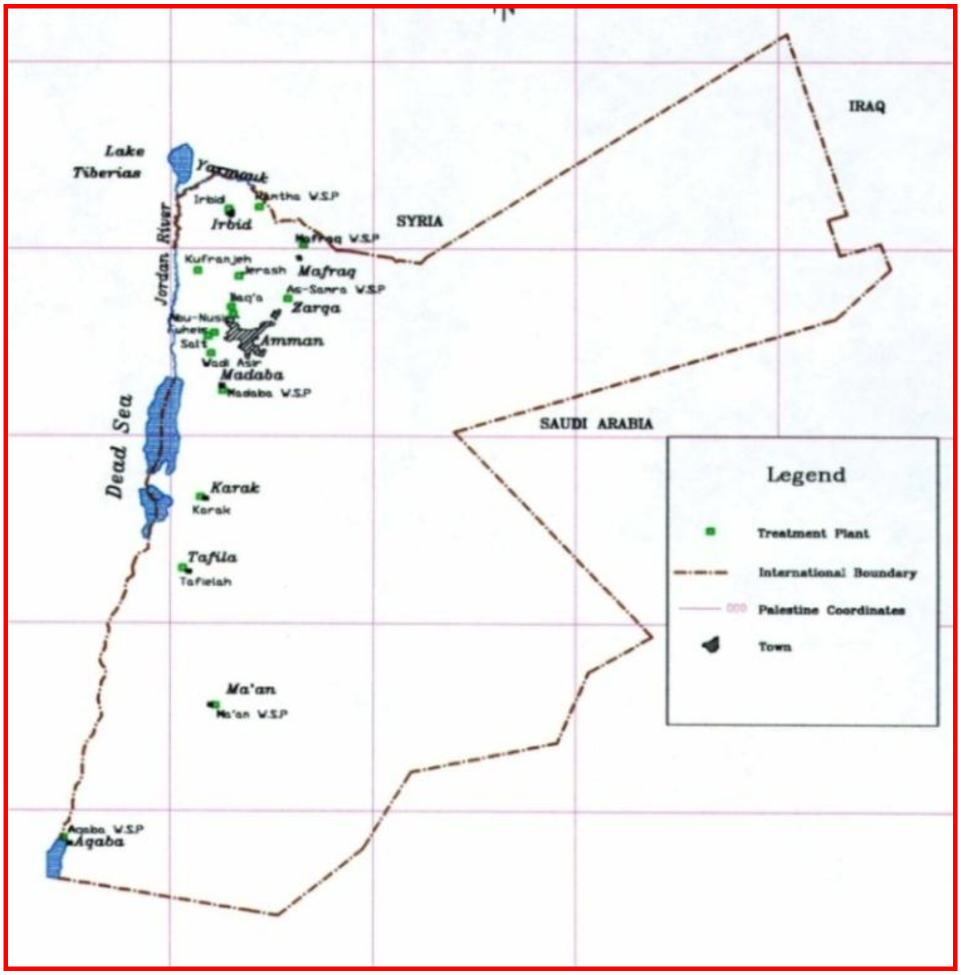


Figure 3-2: The location of WWTP in Jordan.

Wastewater treatment and improvement are required as had been emphasized by (Oron et al. 1999) to minimize the health and environmental risks and to elevate the utilization of wastewater as a solution to water shortage problems. Two major drawbacks can be identified when no central facilities exist:

- Lack of a collection system to accumulate all disposed wastes.
- Insufficient well-operated sewage treatment facilities.

3.4 Measuring wastewater reuse

Water scarcity has made wastewater reuse more prominent in technical and policy literature as well as in national and international professional meetings. Several indicators are being used to quantify achievements and progress in wastewater reuse. These include wastewater flow as a percentage of wastewater treated or wastewater produced, and as a percentage of urban, agricultural, or tap water supplied. Alternative indicators are based on the area of land irrigated with reclaimed wastewater (Scott et al. 2004; Gabriel 2005). However, no standard measure exists to measure overall reuse efficiency at a national level.

In this study we argue that an appropriate indicator should take into account all wastewater production, both collected and uncollected. Otherwise it does not provide a sufficient measure of potential – if nearly all collected wastewater is reused, but almost none of the wastewater is collected this means there may be considerable potential to expand reuse. This is, for example, shown in Figure 3-3, where an index is used that divides wastewater reuse by wastewater treatment, using AQUASTAT data, to make a regional comparison using the following equation:

$$Z = \frac{R}{T} \times 100.$$

where, *R* is total wastewater reused and *T* is the amount of wastewater treated,

There are two values for Jordan, the highest value, 90.1%, is calculated using the reported volume of treated wastewater, which is an important value to show how much of the effluents from WWTP are already used. However, the lower value, 39.7 %, is the ratio of wastewater reuse compared with the estimated generation of wastewater (assumed to be 80 % of water withdrawals; Nayef Sadir, MWI personal communication). As can be seen in the compared figures, using treatment in the denominator provides a misleadingly high estimate of the current reuse rate.

Given the potentially large gap between actual and apparent reuse, as shown in Figure 3-3, we argue that it is important to base measures of wastewater reuse on complete wastewater generation including on-site and low-cost means of reuse, in order to properly capture potential sources (FAO. et al. 2003). Figure 3-3 shows that most countries calculate their reuse as a percentage based on what is treated not the volume of water originally delivered to users.

Currently available measures of reuse are based on collected urban wastewater and typically omit wastewater that does not pass through conventional collection and treatment. This limits our ability to estimate potential, and makes international comparison difficult. A much more inclusive calculator is required; one that could be applied on a universal standard.

Therefore we propose to use the wastewater reuse index (WRI) that is defined as:

$$WRI = \frac{R}{G} \times 100, \quad 0 \leq WRI \leq 100$$

where, *R* is total wastewater reused and *G* is total wastewater generation, quantifying the total amount of reused wastewater as a percentage of the total hydraulic capacity of the wastewater resources (total production of wastewater). The WRI includes standard criteria enabling water resource managers and policy makers to put a figure on the gap between achievements at different levels, and recognizes water saving efforts such as low water consumption and reducing losses. The WRI can be used to quantify the gap between achievements in wastewater reuse at different stages thus, highlighting the way forward for improving reuses efficiency.

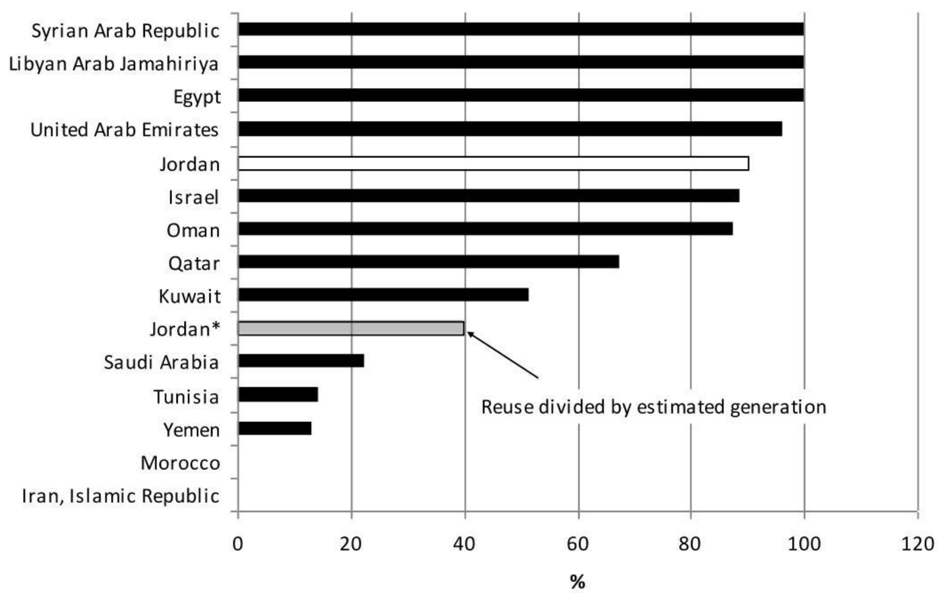


Figure 3-3: Wastewater reuse as percentage of treatment in the MENA region, (AQUASTAT - FAO 2003- 2007; AQUASTAT - FAO 2008).

In the following, all quantities are listed in Mm^3/year. The relevant variables are as follows:

G = total wastewater generation (urban, rural, commercial, and industrial)

C = amount of wastewater collected (by sewage and on-site systems)

T = amount of wastewater treated (as effluent from

WWTPs and appropriate on-site systems)

R = amount of wastewater reused in percentage of total treated wastewater

WRI = Wastewater Reuse Index (%)

x = collection as percentage of total production,

y = treatment as percentage of total collection,

z = reuse as percentage of total treatment.

Since the wastewater generation in Jordan is considered 80% of the water distributed to the municipals, then:

$$G = 80\% \times water\ distributed$$

In Table 3-2 calculated values for wastewater reuse for Jordan and the Jordan Valley in the years 2004 - 2007 are presented

$$WRI = f(R, G)$$

$$WRI = \frac{R}{G} \times 100 = \frac{z \times y \times x}{10^4} \quad , \quad 0 \leq WRI \leq 100$$

Table 3-2: Waste water generation, treatment and reuse in Jordan in the years 2004 to 2007 as well as for the Jordan Valley for the year 2006

Symbol	Waste water type	2004	2005	2006	2007	2006 For JV
G	Total wastewater generation (Mm^3)	220.62	225.6	229.04	240.7	200.4
C	Amount of wastewater collected(Mm^3)	101.79	107.364	110.91	113.8	103.5
T	Amount of wastewater treated(Mm^3)	74.2	78.99	86.79	77.87	79.49
R	Amount of wastewater reused(Mm^3)	67	72	79.778	90.97	72.69
X	Collection as percentage of total production (%)	46.14%	47.59%	48.42%	47.29%	64%
Y	Treatment as percentage of total collection (%)	72.90%	73.57%	78.25%	68.41%	77%
Z	Reuse as percentage of total treatment (%)	90.30%	91.15%	91.92%	116.80%	91%
	Water Reuse Index (%)	30.40%	31.92%	34.83%	37.79%	45%

The WRI for all of Jordan in 2006 was 34.8 % while it was 45% at the Jordan Valley research area. It is clear that the WRI is quite low in Jordan, even though it has increased slightly in subsequent years (Figure 3-4). We observe that important efficiency gains can be obtained in the production of reused waste water as currently only 50 percent of the total wastewater generated is being collected, of which 25 percent is lost in the process. In general the following measures are recommended to increase the efficiency of the process:

- To increase the WRI more dwellings would need to be connected to the sewer system. Currently approximately 61% of dwellings in Jordan are connected to the sewage network system, while the rest of dwellings depend on the cesspools.

- Decentralized WWTP could help to increase reuse since many rural areas and some cities have no WWTP due to hilly terrain and lack of investment and there is some unaccounted loss from the network.
- Finally, there is high evaporation from the stabilization pond and lagoons at the WWTP.

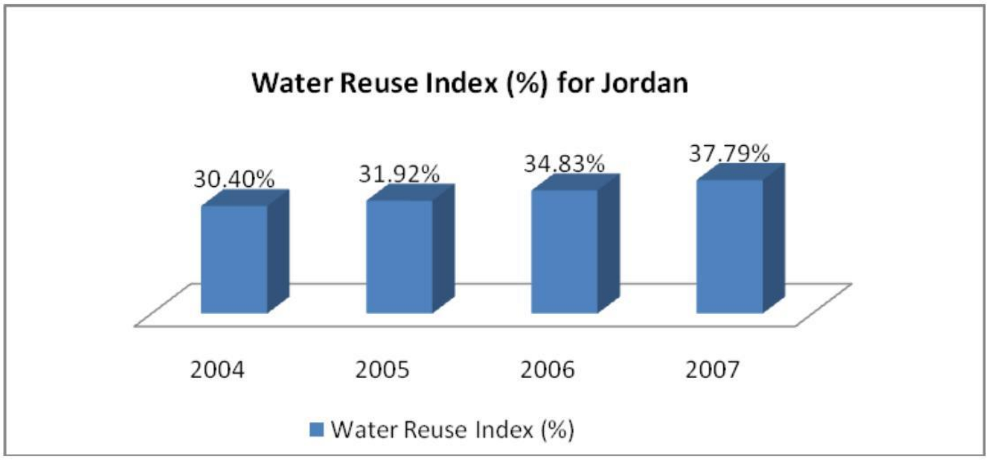


Figure 3-4: WRI for Jordan for the years between (2004-2007).

3.5 International comparison

Because of data paucity problems, it is difficult to carry out a true international comparison for the indicator we are proposing. As is clear from the method used here, if sensible estimates of wastewater generation can be constructed, then it is possible to improve on the estimates of wastewater generation and use those for a preliminary comparison. The discussion in this section will use the measures that have been adopted in the resources cited.

In the Middle East there is a significant increase in water reuse to meet an ultimate objective of reusing 50 to 70 percent at least of the total wastewater volume (EPA 2004).

In Israel during the drought year of 1990-91, agricultural allocations were severely cut and the proportion of wastewater reuse (which constituted a safe supply) rose to over 24 percent of total allocations (Shelef et al. 1996). In normal years, Israel reuses more than 65 percent of its total domestic sewage production (Friedler 2001).

Some nations evaluate reuse through the comparison of water reuse potential with total water use. In the United States municipal water reuse accounted for 1.5 % of total freshwater withdrawals in 2000. In Tunisia recycled water accounted for 4.3 % of available water resources in 1996. In Israel it accounted for 15 % of available water resources in the year 2000. The volume of treated wastewater compared to irrigation water resources is 7 % in Tunisia, 8 % in Jordan, 24 % in Israel, and 32 % in Kuwait. Approximately 10 % of the treated effluent is being reused in Kuwait, 20-30 % in Tunisia, 85 % in Jordan, and 92 % in Israel. (G. Kamizoulis et al. 1999)

3.6 Wastewater and Reuse in Jordan

In Jordan the agricultural sector consumes approximately 64% of available water per year with one-third of this amount consumed in the Jordan Valley and about 50% reclaimed water (TWW). All in all, agriculture consumes less than 35.5 % of the total amount of freshwater available in the Jordan Valley (Figure 3-5 and Table 3-3).

Table 3-3: Water supply for different demand, Ministry of Water and Irrigation data (2006/ 2007)

Demand Requirements	Ground Water	Surface water	Treated Wastewater	Total
	Mm^3			
Domestic	214.0007	79.75	0	293.751
Rural area	0.745	7		7.745
Industry & Remote Areas	44.894	3.527	0	48.421
Agriculture	244.81	176.366	90.97	512.146
Agriculture (High land)		77.46		77.46
Total Supply Demand	504.4497	344.103	90.97	939.523
Actual Demand				1512
Deficit				572.477

Of the 22 WWTPs in Jordan only three receive TWW (Figure 3-6, Table 3-4) from septic tanks and not through the wastewater network. In 2006 the total effluent was 87 Mm^3, of which 91.9% was reused by agriculture after mixing it with freshwater during its inflow in the wadis (blended water).

Table 3-4: the total effluent from WWTP and the actual amount of WWT reused in 2006

WWTP's	Effluent	Actual reuse	WWTP's	Effluent	Actual reuse
	Mm^3			Mm^3	
AS-SAMRA	58.775	58.775	TAFILA	0.333	0.125
AQABA	4.921	4.921	WADI AL SEER	0.892	0.892
RAMTHA W.S.P	1.23	1.23	FUHIS	0.577	0.577
MAFRAQ W.S.P	0.636	0.636	WADI ARAB	3.516	0
MADABA W.S.P	1.493	1.493	WADI HASSAN	0.388	0.388
MA'AN W.S.P	0.862	0.862	WADI MOUSA	0.631	0.631
IRBID	2.235	0	TALL – MANTAH	0.091	0
JERASH	1.179	1.179	AKADEER	1.152	1.152
KUFRANJA	1.058	1.058	AL- LAJJOUN	0.232	0
ABU-NUSIER	0.808	0.08	TOTAL M.C.M (per year)	86.787	79.778

Jordan wants to increase the amount of TWW by improving the sewer network since TWW is vital to the water balance, e.g. to reallocate the freshwater used in agriculture to domestic use.

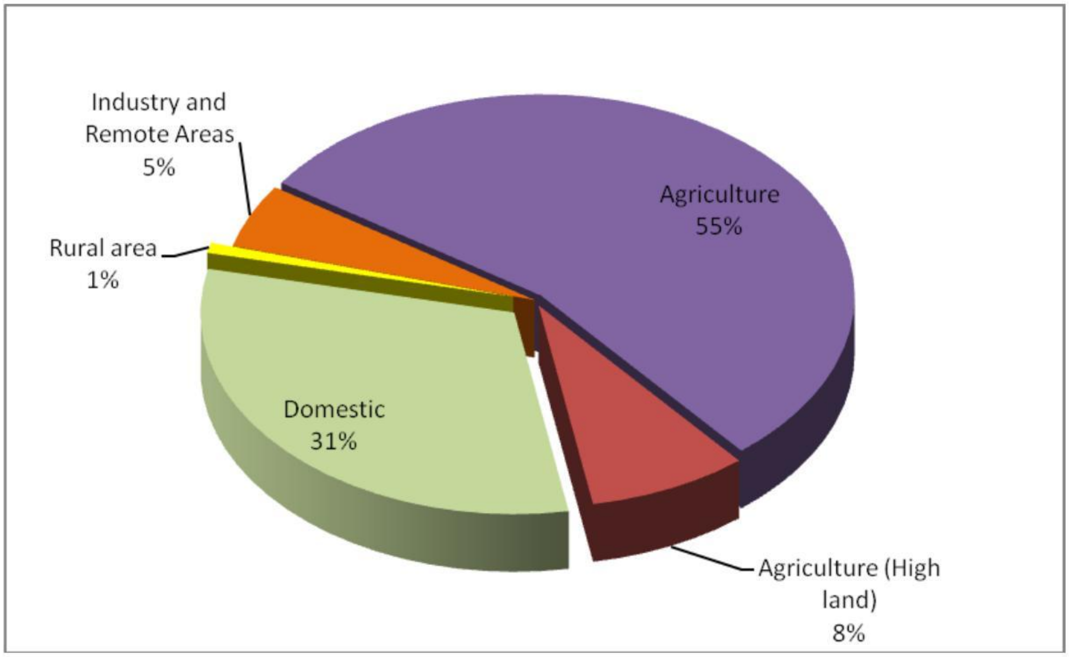


Figure 3-5: Water supply for different sectors in Jordan (Ministry of Water and Irrigation 2006/ 2007).

The effluent from the 22 operating WWTP in Jordan (Figure 3-2) is used primarily for agricultural purposes in the immediate vicinity, while surplus TWW flows along wadis where it either evaporates or is captured in water bodies like reservoirs and ponds (Table 3-9). Farmers alongside the wadis are illegally pumping the effluent to irrigate their crops thwarting the intended destination and intended reuse of that water. However, the volume of these illegal flows is unknown.

In the year 2006, the amount of water supplied was about 925 million cubic meters (Mm3) while the actual demand was 1512 Mm3, the municipal uses represented about 32 %, irrigation about 63 %, and industrial uses about 5% of the total consumption. According to MWI assumption "the wastewater (WW) generated is assumed to be 80 % of the total volume", that means WWG = 230 Mm3/year with only approximately 111 Mm3 reaching the WWTP. Several reasons are cited for this loss the most important being that only approximately 61 % of the total households are connected to the sewer system. This means that approximately 40 % of Jordanian households are not connected to the sewer network system (Table 3-5). In other words, there is a considerable amount of the influent lost without recycling or reuse. Most of the non-connected households depend on cesspools, which can lead to ground water contamination.

Table 3-5: Total Subscribers to water and sanitation system in Jordan, 2006

WAJ Directorate	Total Subscribers to water	Total Subscribers to sanitation	Served % Per Directorate	Served % Per Governorate
Amman	409222	328230	80%	80%
Irbid	78840	41581	53%	
Al Kourah	11475	0	0%	
Al Ramth	11466	4917	43%	
Bani Kinanah	10726	2	0%	
Bani Obiead	15644	5093	33%	
North Ghor	10768	0	0%	37%
Al Zraqa	83483	57675	69%	
Al Risyafa	33398	25580	77%	71%
Maádaba	15352	7336	48%	
Theiban	4388	2	0%	37%
Al Salt	21662	11765	54%	
Ain Albasha	16671	14399	86%	
Al Fuhis	5215	4290	82%	
South Shouna	6082	0	0%	
Maadi	6207	0	0%	55%
Al Karak	16238	4340	27%	
Ghor Al safi	3856	0	0%	
Al Qaser	4978	0	0%	
South Mazar	9622	45	0%	13%
Al Tafila	11990	2359	20%	20%
Maán	8939	1900	21%	
Wadi Mousa	6330	2059	33%	
Al Shoubak	2078	0	0%	23%
Al Mafraq	25368	4915	19%	
North Badia	7712	0	0%	15%
Ajloun	15202	4739	31%	31%
Jarash	20882	7252	35%	35%
Al Aqaba	23275	16904	73%	73%
Total	897069	545383	61%	61%

Source: MWI /WAJ, 2008

3.7 Water sources for irrigation in the JV

According to the data base at MWI in Jordan, the agricultural sector consumes around 512 Mm^3 water (MWI 2007), which around half of this amount (251 Mm^3) is consumed by the Jordan Valley where only approximately 76.6 Mm^3 (35.5 %) is freshwater and the rest is marginal (41.4% TWW , 23.1 Brackish). That mean cultivation in the JV consumes 22% of the fresh surface water whereas 78% fresh groundwater is consumed in the highland.

The objective of this chapter is to quantify the gap between achievements in wastewater reuse and real consumptions that could provide a better insight into the problem of reuse efficiency, through using the wastewater reuse index (WRI) to give a clear picture of the quantities of influents and effluents, as well as the potential reuse of effluents presently.

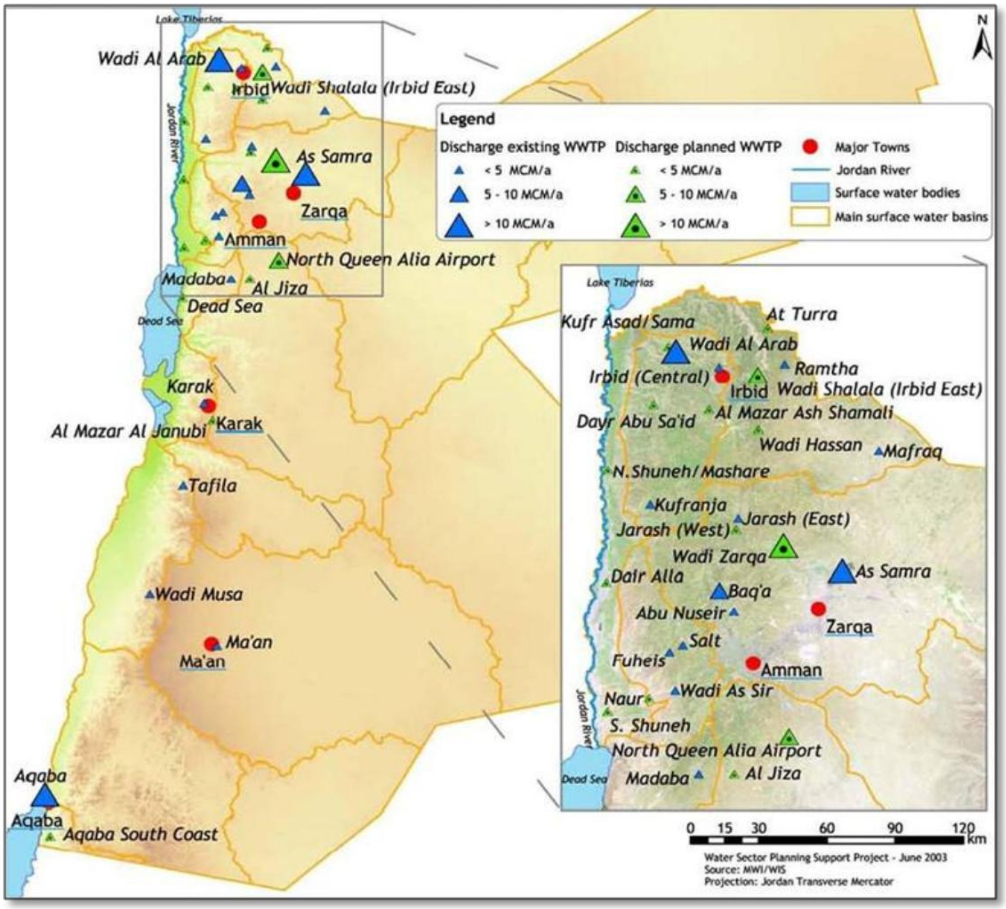


Figure 3-6: Centralized and decentralized WWTP in Jordan.

Generally there are two types of WWTPs in Jordan: one is the centralized WWTP recognised as a governmental institution; the other is the decentralized WWTP such as those installed at airports, universities and private companies. There are 22 governmental (87 Mm^3 in 2006) (Table 3-4) and 23 private WWTPs (less than 3 Mm^3in 2006) (Figure 3-6).

Governmental WWTPs receive sewage water from the public sewage network system that falls under Water Authority of Jordan (WAJ) jurisdiction. Private WWTPs handle wastewater drained from local premises with no connection to the public network and are not part of the WAJ mandate.

3.8 Sewage System in Jordan

There are around 39 % of households using private cesspools for discharging sewage water, which indicates a huge deviation in the share of dwellings connected to the public sewage network system among the governorates. The highest percent of connection (80 %) is in Amman governorate and the Karak governorate has the lowest percent (13 %). The Amman Governorate, which receives the biggest share of municipal potable water (more than 40 %), has almost 78 % of its dwellings connected to the public sewage network system (Table 3-5).

3.9 Influents and effluents of WWTP's

The total municipal water distribution for domestic use according to the data of MWI was approximately 286.3 Mm^3 in 2006 as shown in (Table 3-6), of which approximately 110.9 $Mm^3$was received as influents at the WWTPs.

Table 3-6: Municipal water consumption for each governorate in Jordan (MWI , 2006)

	2004	2005	2006	Consumption 2006
Governorate		m3/year		
Amman	118,536,066	119,869,739	121,953,318	42.6
El Zarqa	37,687,744	38,447,913	40,324,912	14.08
IRBID	32,754,703	34,376,280	34,195,729	11.94
MAFRAQ	16,903,277	17,482,806	17,604,297	6.15
El Balqa	20,177,343	21,274,250	21,168,767	7.39
KARAK	11,030,435	11,023,232	11,466,121	4
TAFILA	3,070,173	3,496,374	3,705,131	1.29
MA'AN	7,068,872	7,107,804	7,452,019	2.6
JERASH	4,362,633	4,081,985	4,135,507	1.44
AL- LAJJOUN	3,101,994	3,649,708	3,643,033	1.27
MADABA	6,057,704	6,172,765	6,369,242	2.22
AQABA	15,020,565	15,012,503	14,285,763	4.99
Total	275,771,509	281,995,359	286,303,839	

Source: Ministry of water and Irrigation(MWI) , Water Authority of Jordan (WAJ)

In contrast, the MWI assumed that 80 % (or 229 Mm^3) of domestic water will be generated as wastewater. This assumption by the ministry was made during the mid eighties. It means 48.42% of the generated wastewater from domestic uses does not reach WWPs due to the following reasons:

- Approximately only 61 % of dwellings (Table 3-5Table 3-5) in Jordan are connected to the sewer network system, while the remaining use cesspools;
- Some municipal water is lost to illegal water abstraction; and,
- Technical losses due to leakage in the water supply networks estimated around 25-40 %, according to WAJ.

As'samra WWTP receives a 73.8% of the total amount of influents and is the largest WWTP in Jordan and even of the Middle East; Al Zarqa and Amman are its largest suppliers (Table 3-7). The effluent of this WWTP is also the main supplier of reclaimed water for the King Talal Reservoir (KTR) that is used for the agricultural sector in the JV.

Table 3-7: Influents and effluents of WWT Plants, 2006

	Influent		**Effluent**	
WWTP	Mm^3**/Year**	**%**	Mm^3**/Year**	**%**
AS-SAMRA W.S.P	81.84	73.8	58.78	67.72
AQABA MECH	2.46	2.22	2.64	3.04
AQABA W.S.P	2.27	2.05	2.28	2.63
RAMTHA W.S.P	1.28	1.15	1.23	1.42
MAFRAQ W.S.P	0.68	0.61	0.64	0.73
MADABA W.S.P	1.67	1.51	1.49	1.72
MA'AN W.S.P	0.97	0.87	0.86	0.99
IRBID	2.32	2.09	2.23	2.58
JERASH	1.21	1.09	1.18	1.36
KUFRANJA	1.24	1.11	1.06	1.22
ABU-NUSIER	0.84	0.76	0.81	0.93
SALT	1.58	1.42	1.42	1.64
BAQA'	4.01	3.61	3.81	4.39
KARAK	0.59	0.53	0.55	0.63
TAFILA	0.37	0.33	0.33	0.38
WADI AL SEER	0.99	0.89	0.89	1.03
FUHIS	0.61	0.55	0.58	0.67
WADI ARAB	3.64	3.28	3.52	4.05
WADI HASSAN	0.4	0.36	0.39	0.45
WADI MOUSA	0.61	0.55	0.63	0.73
TALL – MANTAH	0.1	0.09	0.09	0.1
AKADER	1.05	0.95	1.15	1.33
AL- LAJJOUN+A25	0.18	0.17	0.23	0.27
TOTAL M.C.M (per year)	110.91		86.79	

Source: MWI, 2008

3.10 Effluents Outlet

The net effluents (Table 3-8) refer to the actual effluent passing through the WWTPs and equal the gross effluent of each WWTP minus the amount of water consumed by agriculture at the premises and vicinities of the WWTPs (licensed consumption).

Table 3-8: Net effluent at existing WT Plants.

WWTP	Effluent	Water consumption before the outlet	Net effluent*
	(Mm^3/ Year)		
As'samra	69.65	20	49.65
Aqaba	4.2	4.2	0
Ramtha	1.18	1.18	0
Mafraq	0.6	0.6	0
Madaba	1.57	1.57	0
Ma'an	0.87	0.22	0.65
Irbid	2.25	0	2.25
Jerash	1.22	0	1.22
Kufranja	1.22	0.63	0.59
Abu-Nusier	0.83	0	0.83
Salt	1.47	0.05	1.42
Baq'a	4.08	0.49	3.59
Karak	0.55	0.64	0
Tafila	0.37	0.12	0.25
Wadi Al-Seer	1.12	0.07	1.05
Fuhais	0.61	0	0.61
Wadi Arab	3.7	0	3.7
Wadi Hassan	0.27	0.27	0
Wadi Musa	0.71	0.71	0
Tall Al-Mantah	0.1	0	0.1
Al-Akader	1.16	1.16	0
Al-Lajjoun	0.17	0	0.17
Total (MM3/ Year)	97.9	31.91	66.08

* Net effluent is the effluent minus water amounts consumed in premises and vicinities of WT Plants

There is a significant amount of effluents that come from Assamra, Baq'a, Wadi Arab and Irbid as can be seen from (Table 3-9). But only effluents coming from Assamra and Baq'a are used in irrigation. This means that approximately 6 Mm3 per year is not utilized and the effluent from the northern treatment plants like Irbid have poor quality where it is diverted to the Jordan River.

There are three reservoirs (King Talal Reservoir, Shu'aeb, and Kafrain) that receive effluents from some WWTP. Since these effluents run through wadies and are mixed with fresh surface water they become blended water. All amounts of water stored in these reservoirs are designated for agricultural use in the Jordan Valley. The total effluent water draining into these reservoirs is around 58 Mm3 annually, of which 55 Mm3 is received by KTR alone. The following (Table 3-10) shows the contribution of effluents to these reservoirs.

Table 3-9: Effluents outlet

WWTP	Effluent outlet
As'samra	KTR
Aqaba	Completely used within the Aqaba Governorate
Irbid	Jordan River, but it is under consideration to be used in the future at JV
Salt	Shu'aeb Reservoir
Jerash	*Supposed to reach KTR
Mafraq	Completely consumed, exceed goes to KTR
Baq'a	KTR
Karak	no exceed TWW its used within WWTP vicinities
Al-Lajjoun	Wadi
Abu-Nusier	*Supposed to reach KTR
Al-Akader	Completely consumed
Tafila	Used along the wadi in agriculture
Ramtha	no exceed TWW its used within WWTP vicinities
Ma'an	completley used along the Wadi
Madaba	Completely consumed by surrounding area
Kufranja	Jordan River, to be used at the EU project Rajeb Farm
Wadi Al-Seer	Kafrain Reservoir, and used in Agriculture along the Wadi
Fuhais	Shu'aeb Reservoir, under consideration to be used in Agriculture
Wadi Arab	Jordan River, but it is under consideration to be used in the future at JV (Shatanawi and Fayyad December 1996)
Wadi Musa	Completely consumed by the Red Reservoir Association
Wadi Hassan	Completely consumed, by the University of science and technology
Tall Al-Mantah	Completely consumed within WWTP vicinities

* Officially, water should enter KTR but actually it is used locally before reaching the KTR.

King Talal Reservoir (KTR) is considered a vital water source for agriculture sustainability in the middle Jordan Valley, since it is the principal recipient of effluents (53 Mm^3 /year) mainly from As'samra, Baq'a, Jerash and Abu-Nusier WWTP's. In addition, many springs and stormwater runoff accumulate in the KTR.

Farmers at the middle Jordan Valley depend entirely on the KTR as a source of irrigation water, and they do not receive any surface water from King Abdulla Canal (KAC). Furthermore, they have to share this limited resource with new Development Areas (DAs) recently connected to the KTR system (DA 19, 20, 21) Figure (6-2)

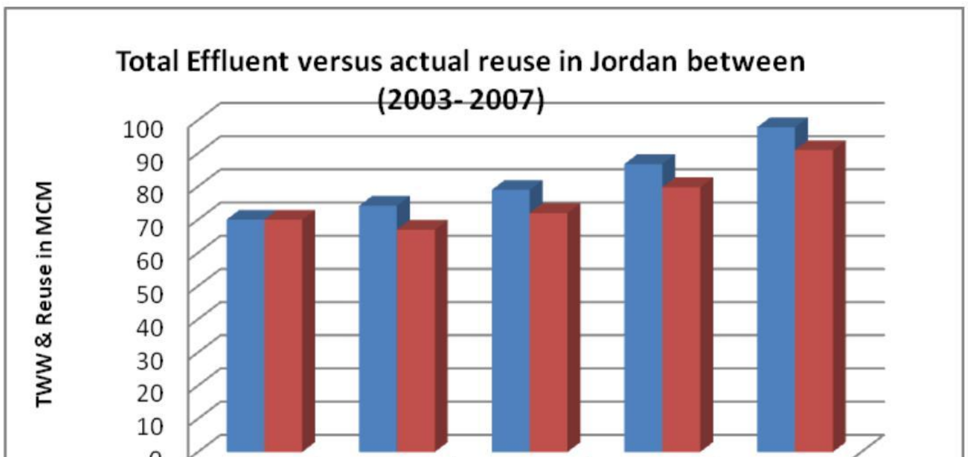
In addition, farmers alongside Wadi Al-Zarqa' use TWW for uncontrolled cultivation. Unfortunately, no data and relevant information about the cultivated areas along Wadi Zarqa, crop pattern, and the actual consumption of water amounts is presently available.

Table 3-10: Effluents of WWT Plants flowing into reservoirs

Reservoir	WWT Plant feed reservoir	Effluent of WWT Plant (MM3/ Year)
KTR	As'samra	49.65
	Baq'a	3.59
Total		53.24
Shu'aeb	Salt	1.42
	Fuhais	0.61
Total		2.03
Kafrain	Wadi Al-Seer	1.05
Total effluents (Mm^3/ Year)		56.32

3.11 Wastewater Reuse

The collected wastewater must be treated to adjust its quality to the following end-users: irrigation, artificial recharge, potable water supply, toilet flushing, and industrial water supply. Reuse of wastewater has been practiced in many areas worldwide for thousands of years.



	2003	2004	2005	2006	2007
Effluent	70	74.19	78.99	86.79	97.86
Reused	70	67	72	79.78	90.97

Figure 3-7: Total Effluent versus actual reuse in Jordan between (2003- 2007) in Mm^3/year

3.11.1 Reuse for agricultural irrigation

Most of the treated wastewater in Jordan considered as blended water is mainly used downstream in the Jordan Valley for unrestricted irrigation where reclaimed wastewater can be used for all crops even those consumed raw or uncooked (Shatanawi and Fayyad 1996).

The reuse of TWW in agriculture has been practiced worldwide in developed and developing countries such as Australia, Federal Republic of Germany, India, Mexico, Tunisia, China, Guatemala, India and the United States of America (Buechler et al. 2006).

Sewage treatment plants of main cities carry out collection, treatment and disposal which usually are expensive to build and maintain, collection accounting for about 80 % of the cost. This is known as a centralized WWT system, where volume of the sewage becomes very large and the distance of conveyance long, as the sewage treatment plants are generally located outside of the cities. This type of treatment system is difficult to maintain in small remote towns or dispersed suburban areas. In some older cities, storm water is carried in the same sewers as wastewater. Heavy rainfall then may inundate treatment plants and send untreated sewage into buildings or streams.

Rural and suburban areas without large-scale wastewater collection and treatment systems commonly depend on septic systems. Wastewater is collected in a tank, and then distributed to the surrounding soil through perforated pipes. Septic systems work effectively only in very low density development. In higher-density developments, septic systems can severely impair groundwater quality. The main governorates in Jordan are served better than rural areas that belong to those governorates (Table 3-5). Mainly the highland and rural areas rely on septic systems. Groundwater is contaminated there.

Compared with conventional systems (centralized WWT), alternative collection systems such as available new technologies are less expensive and require less excavation. Reduced excavation means that less polluting sediment is disturbed into streams of small wadis. Such a system could work as a decentralized treatment system. Specific treatment technology should be selected as per the prevailing ground situation such as the availability of the land etc. This location-specific technology tends to resist leakage better than conventional gravity collection systems.

Introduction of such systems could lead to increase the amount of treated wastewater in Jordan through applying new technologies such as decentralized wastewater treatment systems (on-site and/or cluster systems used to collect, treat, and disperse or reclaim wastewater from a small community or service area) or by using composting toilet systems (a technology that uses a biological process to degrade human waste into a humus-like end product, sometimes called biological toilets, dry toilets and waterless toilets) which contain and control the composting of excrement, toilet paper, carbon additive, and, optionally, food wastes. Unlike a septic system a composting toilet system relies on unsaturated conditions (material cannot be fully immersed in water), where aerobic bacteria and fungi break down wastes, just as they do in a yard waste composter. Sized and operated properly, a composting toilet breaks down waste to 10 to 30 percent of its original volume. The resulting end-product is a stable soil-like material called "humus", which legally in some countries such as United States must be either buried or removed by a licensed seepage hauler. In other countries, humus is used as a soil conditioner on edible crops. The primary objective of the composting toilet system is to contain, immobilize or destroy organisms that cause human disease (pathogens), thereby reducing the risk of human infection to acceptable levels and to avoid contamination of the immediate or distant environment and harming its inhabitants. A secondary objective is to transform the nutrients in human excrement into fully oxidized, stable plant-available forms that can be used as a soil conditioner for plants and trees. So that means it will be directly used in the surrounding area for house garden and agriculture.

3.12 Conclusion and Recommendation

In this paper we have presented a wastewater reuse index, defined as the total volume of wastewater reused divided by the total wastewater generation. We demonstrated with data from Jordan that using treated wastewater as a proxy for wastewater generation results in misleadingly high values for the reuse index. Instead, we estimate wastewater generation as a proportion of water withdrawals, as described above, assuming that the ratio of wastewater generation to water withdrawals is 80% for Jordan.

We argued that the wastewater reuse index is a useful measure for estimating the potential for wastewater reuse in Jordan and that it could be used for policy guidance. Concerning its application in Jordan, the WRI indicates that there is considerable scope for expanding wastewater reuse, which prompted a more detailed look at the constraints on wastewater treatment and reuse in different areas in the study area within the Jordan Valley. The appropriate approach to increasing wastewater treatment depends on local conditions. In some cases the appropriate response would be to increase the connection of dwellings to a sewer system. In others, particularly in hilly or rural areas, a better option would be to adopt technologies such as composting toilets or decentralized wastewater treatment plants.

The decentralized approach to wastewater collection and treatment offers a new means of addressing wastewater management. Common to all of these options is on-site wastewater treatment by means of low-cost treatment systems combined with direct use of the treatment products (water, compost, and biogas). This approach could sustainably meet wastewater management requirements.

4 Modelling water allocation in the Jordan Valley

4.1 Introduction

The Hashemite Kingdom of Jordan has extremely scarce water resources. As shown in Table 3-3, in 2006 Jordan faced a deficit of nearly 600 million m^3 of water or 39 % of the total demand. Water plays a significant role in the country's economic development making water of crucial strategic importance. Water, therefore, features prominently in peace negotiations with neighbouring states.

The fertile Jordan Valley, in particular, is an extensive water user as one of the most productive agricultural areas in the Middle East. The agricultural sector can be expected to be most strongly affected by water scarcity since presently 63% of Jordan's water resources are used for irrigation. Treated wastewater is therefore an important additional source constituting 25 % of the surface water, about 90 Mm^3 that is used to meet irrigation demand. In the future the demand for new unconventional water resources can be expected to rise considerably to mitigate the impact of water scarcity on the socio-economic well being of Jordan (Alfarra et al. 2009).

Despite the clear need for unconventional water supplies the government does not employ appropriate tools to evaluate the ramifications of wastewater development in relation to the prevailing cropping patterns and rainfall regimes in the JV. Therefore, a methodology is required that explicitly evaluates the use of treated wastewater resources as a potentially viable source of water available for crop irrigation in the JV. To address this concern, this study makes a first attempt to simulate water supply and demand in the Jordan Valley Region. The model described in this paper evaluates the use of treated wastewater as a source for agricultural irrigation.

First, it is necessary to develop a better understanding of how the water supply and distribution system operates in the JV. Indeed, there is considerable opportunity for policy change and investment that could affect positively the future of water availability for agricultural, industrial, and domestic use. However, there are no systematic studies of possible future scenarios concerning changes in demand and supply that take into account the spatial dimensions of water resources and their uses. Yet, an understanding of the spatial features of the water supply system in the JV is essential for evaluating the impact of changing water demands in different parts of the JV, changes in distribution rules, shifting agricultural production patterns, and the introduction of demand-side initiatives. This also is an impetus for the present study presenting initial steps in the development of a water supply and demand model that can aid decision makers to form their plans for water allocation by comparing the effects of different assumptions and variables on water allocation and availability in a spatially explicit manner.

For our study we selected the Water Evaluation and Planning (WEAP) software (Yates et al. 2005). WEAP is particularly suitable for the intended research objective because it incorporates a demand priority and supply preference approach to describe water resource operating rules that function as system demands driving the allocation of water from surface and groundwater supplies to the demand centres (Yates et al. 2005). WEAP can be integrated with groundwater models and water quality data and is easily extendable to other sub-catchments and larger areas. Furthermore, WEAP's data structure maps the information in spatial and temporal dimensions. The development of its structural equations allows a statistical evaluation while its visual mode provides a practical interface for decision making processes by policy makers and stakeholders alike. Concerning output, WEAP simulates various water management scenarios to evaluate the impact on water availability and water quality for different client groups in a spatially explicit manner.

The Jordan River has been well studied providing a rich source of primary and secondary data sets for the analysis described in this paper. Using these data sets, WEAP reproduces geographically-specific agricultural production along the north-south flow of the River. Furthermore, WEAP allows the user to develop supply and demand scenarios allocating water for different demands based on user-supplied demand and supply priority weights. Therefore, the design and calibration of the WEAP model is presented in this paper. In subsequent work it will be used for scenario analysis to evaluate different water allocation scenarios and supply options for their effectiveness in meeting agricultural demand.

One focus of this Chapter is first calibrating reservoir volumes from data recorded by the Jordan Valley Authority. The reason for studying reservoir (dam) levels is the crucial role reservoirs play in regulating the supply of water in the JV. The high rainfall variability in the JV is ameliorated by storing the water in reservoirs; and, decisions on water allocation are based on those reservoir levels at the end of the wet season. Designations of reservoir levels —that are, the recorded level of stored water—and flows therefore contribute to the larger objective of this study, namely, analyzing the use of non-conventional water sources for agricultural irrigation. Additionally, it will be necessary to model the current water allocation decision-making process. As this is currently based on reservoir levels, the attribution of reservoir flows also contributes to this goal. Modelling water allocation rules allows for the simulation of alternative rules that can take re-used wastewater and other non-conventional water sources into account.

4.2 Current water supply and demand

Demand and supply in the JV area is discussed in detail in the following section.

4.2.1 Water Supply

King Abdallah Canal (KAC) and Tributaries: King Abdallah Canal (KAC) is a concrete canal and the main water carrier for the valley; it receives water from different tributaries starting from the Yarmouk River, upstream of the confluence with the Jordan River at the northern end of the valley. The KAC runs parallel to the Jordan River on the eastern bank for 69 kilometres. All flows from side wadis are rechanneled to feed the canal, and water from the canal is subsequently distributed to farms and subsequently to Amman, as shown schematically in Figure 2-6.

In 2006 the Yarmouk River supplied the KAC with 55 Mm^3/year while a further 55 Mm^3/year was provided by the Tiberias carrier[4] according to the peace treaty on October 26, 1994 (Treaty 1994). In addition to these surface flows, 25 Mm^3/year are pumped from the Mukhyba wells to the KAC. Additional inflows come from several wadis that cut through the mountain ranges bordering the valley providing another 6 Mm^3/year (JVA 2007). The North Jordan Valley up to the conveyance to Der Alla receives freshwater from KAC for agricultural purposes, while the Middle Jordan Valley receives blended water (treated wastewater mixed with freshwater) mainly from the King Talal Reservoir (KTD) via KAC, Zarqa River and Zarqa Carrier (ZC1 & ZC2). Presently in the North and Middle JV the agriculture water requirement is 110 Mm^3/year each.

The major water source allocation for farmers in the Jordan Valley is provided via the JVA stage offices—offices that interact with farmers. Stage offices receive and process daily water requests, manage and regulate the supplies to farms, process billing and accounting, and register the cropping areas for a group of development areas. There are ten stage offices in the Jordan Valley from the north to the Dead Sea, and two stage offices in the Southern Ghors.

Water flows both from the Wadi Arab Reservoir to the KAC and from the KAC to the Wadi Arab Reservoir. The KAC-to-Wadi Arab back pump is represented in WEAP as a diversion with a minimum flow requirement that is set to the historical flow.

Monthly water accounts have been created for the years 1990-2006, using proprietary data from the Reservoirs Control Department of the Jordanian Ministry of Water and Irrigation (MWI 2006).

Reservoirs **(Dams) in the JV** Reservoirs play an important role as they are the main storage reservoir supplying various water demands. Water allocation in the JV is decided based on how much water is available at the end of each rainy season in April. Six reservoirs are represented within WEAP: from north to south, the active reservoirs are Wadi Arab, Ziglab (also called Sharhabiel Reservoir), King Talal, Karameh, Shueib, and Kafrein. The WEAP model accounts for inflows, outflows, releases, evaporative losses, and groundwater interactions

King Talal Reservoir is the main storage body for blended water (freshwater mixed with treated wastewater) supplying the irrigation needs of the middle JV, while Wadi Arab Reservoir provides freshwater. These two reservoirs are the largest reservoirs in the JV. King Talal has a gross storage volume of 86 Mm^3, and a live storage volume of 75 Mm^3. Wadi Arab Reservoir has a gross storage volume of 20 Mm^3 and a live storage volume of 16.8 Mm^3. It is mainly used to provide freshwater to Amman city and the North JV agricultural area.

The JVA develops an annual plan at the beginning of every irrigation water supply season to determine the availability of water resources and to estimate the upcoming supplies for the season. The JVA calculates the available resources in the reservoirs at the end of the wet period (i.e. end of March). To

[4] The Tiberias carrier is a water conveyor transporting water from Lake Tiberias in Israel to the KAC in Jordan that was constructed just after the signing of the Israeli-Jordanian Peace Treaty of 1994.

develop the Annual Water Plan the JVA predicts the resources then estimates the expected demands for water and finally computes the minimum target levels in the reservoirs using April as the start of the irrigation water supply period. The JVA recognizes two seasons of supply and demand—summer and winter. The summer season runs from the beginning of April to September 30th, while the winter season runs from the beginning of October to the end of March of the following year.

Table 4-1: Annual average of water inflow to KAC (1990-2006) in m³/s (MWI 2006)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Yarmouk River	23.57	36.42	63.01	45.29	37.81	41.14	38.37	37.92	38.31	23.94	20.84	11.64	8.73	21.14	26.52	16.45	22.76
From Tibiria	0.00	0.00	0.00	0.00	0.00	8.24	11.67	17.97	21.20	15.89	20.57	17.22	19.39	20.21	19.02	17.81	20.15
Wadi Arab Reservoir Inflow	0.12	0.88	7.97	0.22	0.72	0.23	0.36	0.51	0.57	0.14	0.62	0.07	0.04	4.02	0.24	0.00	0.12
Ziglab Reservoir inflow	1.56	2.18	4.16	3.80	3.29	2.30	2.46	2.38	2.38	2.38	1.97	1.69	1.60	3.15	3.18	2.81	0.34
King Talal Reservoir Inflow	13.87	35.82	78.01	41.66	43.49	30.95	31.56	39.32	28.15	25.90	29.84	28.08	33.76	45.32	31.82	34.37	29.43
Kafrein Reservoir Inflow	1.98	4.98	14.72	10.06	6.34	3.67	3.58	5.65	2.83	0.79	3.11	2.54	5.71	8.96	3.30	4.59	2.87
Shueib Reservoir Inflow	0.80	2.98	7.98	5.97	4.13	2.97	2.38	2.11	1.24	0.34	1.80	1.70	3.01	5.37	1.72	1.81	1.52
Wadi Yabis	0.09	0.20	6.42	3.63	1.53	0.73	0.36	0.53	1.13	0.05	0.22	0.03	0.05	5.38	0.43	1.65	0.77
Wadi Abu Ziad	0.09	0.23	0.49	0.64	0.76	0.47	0.43	0.43	0.25	0.16	0.17	0.02	0.04	0.37	0.31	0.21	0.20
Wadi Jurum	1.22	1.73	2.85	4.11	4.07	2.99	1.93	1.91	1.88	1.05	1.74	1.07	0.97	1.41	1.56	1.24	1.27
Wadi Kufranjah	0.39	2.17	6.89	3.08	2.17	2.38	1.74	3.79	3.42	0.75	1.95	1.05	1.41	6.68	1.61	2.51	1.60
Wadi Rajeb	0.37	1.36	8.05	3.49	1.73	1.70	1.41	1.91	2.51	0.66	1.36	0.66	1.02	4.54	1.08	1.21	0.90

4.2.2 Water Demand

There are two main demands that are represented in the model: urban demand in Amman city and agricultural demand separated into the three agricultural areas North JV, Middle JV and South JV. It is important to distinguish the three agricultural areas because each region has different water quality available and uses a different source of water for irrigation.

The annual crop areas and water requirements for 1990 are shown in Table 4-2 and Table 4-3Water requirements are calculated by the MWI based on records collected by the JVA stage offices.

Table 4-2: Agricultural Area in 2006, area in dunum (MoA 2006)

Zone	Veg. GH	Summer Veg.	Winter Veg.	Winter Seeds	Citrus Trees	Banana	Palm Trees	Other Trees	Total
North JV	2162.5	8845	22198	6003	53885	3349	370	2714	99526.5
Middle JV	9899.5	35536	29668	2811	8285	80	3051	2694	92024.5
South JV	1614.5	16488	34156	721	2211	11700	3040	1678	71608.5

*1 Dunum = 1,000 m^2 = 0.1 ha.

In Jordan, agriculture consumes around 600 Mm^3 of water per year with one-third of this amount (200 Mm^3) consumed by the Jordan Valley. Almost 50 % of this 200 Mm^3 is reclaimed water. All in all, agriculture consumes less than 20 % of the freshwater resources available to the JV.

Table 4-3: Annual crop water requirements for different crops in the JV (JVA 2006) in Mm^3

Zone	Veg. GH	Summer Veg.	Winter Veg.	Winter Seeds	Citrus Trees	Banana	Palm Trees	Other Trees	Total
North JV	360	444	314	622	1177	1752	688	1177	6534
Middle JV	359	447	327	626	1187	1790	688	1187	6611
South JV	439	454	344	676	1243	1854	688	1243	6940

In 2006, the total municipal water consumption was approximately 290 Mm^3. Of this, almost 42.6% was pumped into Amman Governorate while Ajloun received the smallest allocation, around 1.27 %. Out of the total, only approximately 110 Mm^3 was treated in wastewater treatment plants because only 61% of households have wastewater connections. This means that approximately 40% of all households are not yet connected to the sewer network system. In other words, there is considerable amount of the influent lost without recycling or reuse since many households depend on cesspools. Aside from the lost opportunity to reuse the wastewater, the cesspools are likely sources of groundwater contamination.

Within Amman city, the population according to Department of Statistic (DOS) in Jordan was 1.6 million in 1994, and 1.9 million in 2004, corresponding to an average annual growth rate of 2.0%. The population growth prior to 1994 (between 1979 and 1994) was 4.4 % per year, while since 2004 it has been growing at 3.7% per year (DOS 2008). The total population of the Amman region is estimated at about 2.173 millions in 2006 (DOS 2007). An official estimation of the annual water demand is 51 m^3 per person per year in the city. However, using this figure reveals significant discrepancies between estimated demand and supply, suggesting that not all water supplies are measured due to net work losess. Within the WEAP simulation it is assumed that 15% of the delivered water is not captured. Accordingly, WEAP assumes an annual rate of 60 m^3 per person per year.

4.3 Representation in WEAP

WEAP, the Water Evaluation and Planning software is intended to be an effective tool for integrated water resource management (IWRM). The design goals were that it be useful to planners, easy to use, affordable, and readily available to the broad water resource community. WEAP is designed around a water accounting and allocation framework that balances demand and installed infrastructure. It also allows for hydrologic processes to be incorporated in models using a lumped-parameter hydrologic model. As a planning tool, WEAP supports scenario analysis as part of its core features. Examples of possible scenario variations include alternate water supply and demand options, climate scenarios, and changing land use. WEAP's strength is addressing water planning and resource allocation problems and issues (Yates et al. 2005). WEAP has been enhanced so that it is relatively easy to link MODFLOW groundwater models and QUAL2K water quality models to a WEAP model. As discussed below, most of the calculations in WEAP are carried out automatically within a water allocation framework. In addition, WEAP offers spreadsheet-like capabilities for implementing algorithms. Finally, WEAP models are extensive in other ways as well, e.g., by linking to dynamic link libraries, or DLLs, and can be combined with other models.

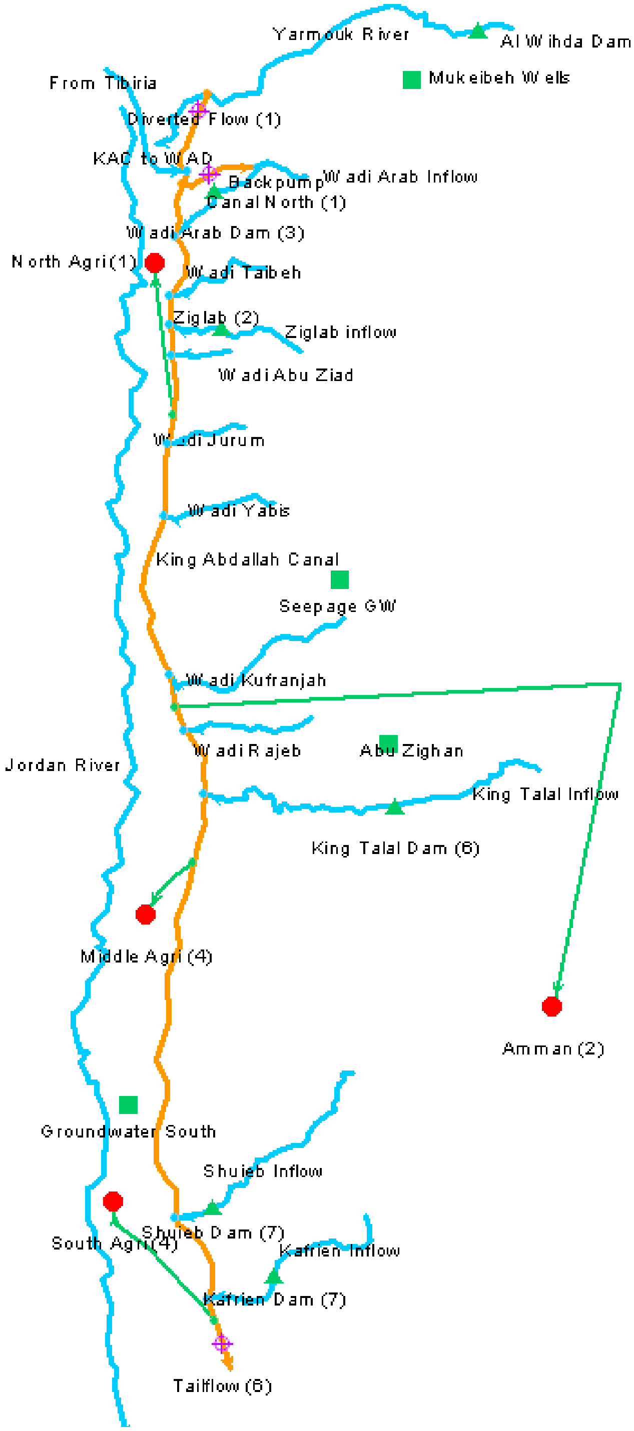


Figure 4-1: Study area represented in WEAP.

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

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

Data within the MWI are located in different departments. Therefore, enhancing the model requires a great deal of cooperation between departments to include groundwater and water quality.

The major components of the water delivery system shown in Figure 2-6 have been represented in the WEAP software model for water allocation and planning. The elements of the model system are shown in Figure 4-1. In the application described in this paper, demands and supplies are represented on a monthly basis for the years 1990-2006 for purposes of calibration. The calibrated model will be used later to evaluate scenarios of alternative water supply.

In designing the schematic representation of the study area in WEAP, the objective was to include as much detail as was needed to properly characterize both demand and supply sources, subject to the availability of field data. The representations consist of the following main elements:

Distribution Systems: A distribution system represents water users in a common geographic area with shared water sources. In the current representation, distribution systems are identified either with irrigation systems or municipal demands (Amman city) – the same categories used by the MWI for allocating water in the Jordan Valley. The water demand in each distribution system for Amman city is aggregated, while irrigation demand is partitioned by crop type, cultivated area and crop demand. Within WEAP, distribution systems are represented by demand sites.

Municipal water demands are estimated as described in the previous section 4.2.2. Irrigation demands are estimated by multiplying the area under different crops by an irrigation rate determined by the ministry.

King Abdallah Canal (KAC) and Tributaries: These are the primary water conduits in the region. Stream flows from the 13 wadis and tributaries flowing to the KAC are estimated on a monthly basis.

Water flows in both directions from the Wadi Arab to the KAC and from the KAC to Wadi Arab. The KAC-to-Wadi Arab backpump is represented in WEAP as a diversion with a minimum flow requirement that is set to the historical flow.

Reservoirs: Five reservoirs are represented within WEAP, from north to south the active reservoirs are Wadi Arab, Ziglab (also called Sharhabiel Reservoir), King Talal, Shueib, and Kafrein. Account is taken of inflows, outflows, releases, evaporative losses, and groundwater interactions.

The gross storage capacity of the reservoirs is shown in Figure 5 showing the storage capacity of Kafrein reservoir increasing during the 1990-2006 period. In WEAP, this was represented by a step increase between 1995 and 1996. The most important reservoirs by volume are King Talal (86 Mm^3 gross storage; 75 Mm^3 live storage) and Wadi Arab (20 Mm^3 gross storage, 17 Mm^3 live storage) (Page 57).

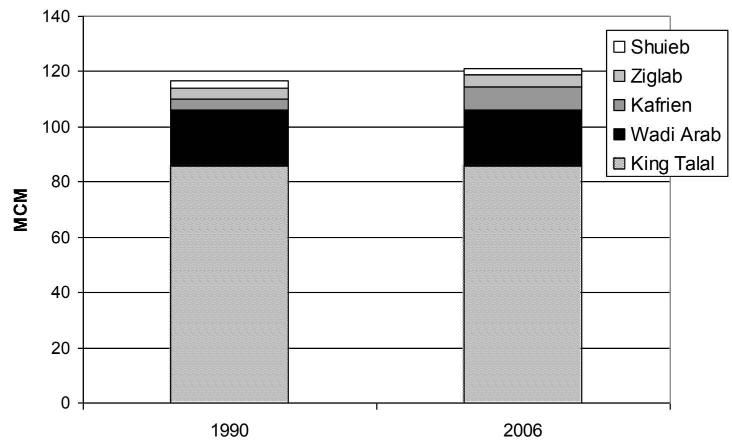


Figure 4-2: Gross storage capacity of JV reservoirs (Mm^3).

4.4 Simulation and Calibration

A major focus of the work described in this section is to represent reservoir operating rules in the JV. Rather than making an attempt to capture the decision processes carried out by the MWI, which are somewhat ad hoc, some simple rules were assumed that to a large extent captured the measured water allocation.

Note that two allocation decisions are taken by the MWI:

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

The focus of this section is on the agricultural demand. For this reason, the water actually supplied to each distribution system (the “coverage” for the system) was set to its historical value, and then the reservoir operating rules were simulated to meet that supply.

WEAP provides a constrained distribution of the total available water. Water allocation within a time step is carried out by using user-specified priorities for different demand sites and sources. At each time step, the coverage of highest-priority demands is set to as high a value as possible given constraints on water availability and other constraints specified in the model. Then those coverages are frozen, and the coverages for the next highest-priority demands are set. This process is repeated until all coverages are calculated, consistent with the demands and available volumes of water. Water is then supplied to each demand site, with the volume supplied being equal to the coverage multiplied by the demand.

The WEAP algorithm is implemented as a series of linear programming (LP) problems, iterated over demand and supply priorities. The algorithm can be written in the following way. Suppose that there are

N demand sites and *M* sources. Denote the demand at demand site *i*, with priority *p*, by $D_i^{(p)}$. The amount of water actually supplied to the demand site from source *r* is $x_{i,r}^{(p)}$, while the total amount of water available from source *r* is $S_{r,t}$. (Sources are given a time label, *t*, because they can represent storage as well as transient flows. For other variables, the time label is suppressed.) Note that a source can also have a demand, for example, a reservoir accepts inflows and has targets for storage. Then, starting with priority *p* = 1, and looping over supply preferences to the demand sites at that priority, the following linear program is solved:

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

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

and

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

Where either

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

or

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

Additionally,

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

$$x_{i,r}^{(p)} \geq 0$$ for priority *p* and supply *r* at specified supply priority

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

also, $x_{i,r}^{(p)} = 0$ if the supply priority is higher than the one currently being evaluated

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

After observing the patterns of reservoir releases and volumes over time, the following priorities were specified within the JV WEAP application, where a priority of 1 is the highest priority:

Priority 1: KAC headflow, Wadi Arab backpump, North Agriculture

Priority 2: Ziglab reservoir , Amman city

Priority 3: Wadi Arab reservoir

Priority 4: Middle Agriculture, South Agriculture

Priority 5: King Talal reservoir, KAC tailflow

Priority 6: Shueib reservoir, Kafrein reservoir

The flow in the King Abdallah Canal as it exits in the study area (the tailflow), is modeled as an instream flow requirement that is tied to the volume of water within the King Talal Reservoir. It is given the same priority as the filling priority for King Talal Reservoir. The flow requirement is set in the following way: when live storage in the Talal reservoir is less than 25% of the capacity, the tailflow requirement is set to zero. When live storage in the Talal reservoir is 100% of capacity, the tailflow requirement is set to 1.5 m^3/ second. Between those two limits, the tailflow requirement increases linearly with the volume in the Talal reservoir.

In addition to the priorities listed above, the Wadi Arab, Ziglab, Shueib, and Kafrein reservoirs have works as a “buffer” that slows down releases as the reservoirs gets empties. The rate of release from the buffer zone is set by a buffer coefficient. The levels of the buffers and the coefficients were used as calibration parameters. The calibration parameters were constrained to lie between minimum and maximum values, as shown in Table 4-4. Otherwise, WEAP imposes constraints that reflect water availability.

Table 4-4: Calibration parameters

Parameter	Minimum	Maximum	Initial Value
Top of Buffer (million m^3)			
Wadi Arab- High	10	100	100
Wadi Arab- Medium	10	100	85
Wadi Arab- low	10	60	40
King Talal – High	10	100	100
King Talal – Medium	10	100	85
King Talal- low	10	60	40
Top of Buffer as fraction of storage capacity (dimensionless)			
Wadi Arab Reservoir	3.1	20	9.1
King Tala	0.1	1	0.7
Ziglab	0.1	1	0.75
Buffer Coefficient (dimensionless)			
Wadi Arab	0.1	1	0.55
Ziglab	0.4	4.3	2.4

After modeling the JV using WEAP by integrating required data from 1990 to 2006 for both demand and supply, the model was calibrated in a two-step process using the PEST parameter estimation software version 1.1 (Watermark Numerical Computing 2004).

In the first calibration run, observed reservoir levels for all five reservoirs were compared to their modeled values. In the second run, the calibrated values from the first run were set as the initial values, and observed reservoir levels for all reservoirs except for King Talal reservoir were compared to their modeled values. The reason for this two-step process is that, the volume in King Talal reservoir is sufficiently large so that, if it is included, it dominates the total volume. By carrying out the second calibration run, a better fit was obtained for the smaller reservoirs. The results are shown in Table 4-4.

The measured and estimated reservoir volumes for the three largest reservoirs (King Talal, Wadi Arab, and Kafrein) are shown in Figure 4-3, Figure 4-4 and Figure 4-5. As can be seen on the figures, the relatively simple simulation operating rules and priorities reproduce the historical reservoir levels quite well.

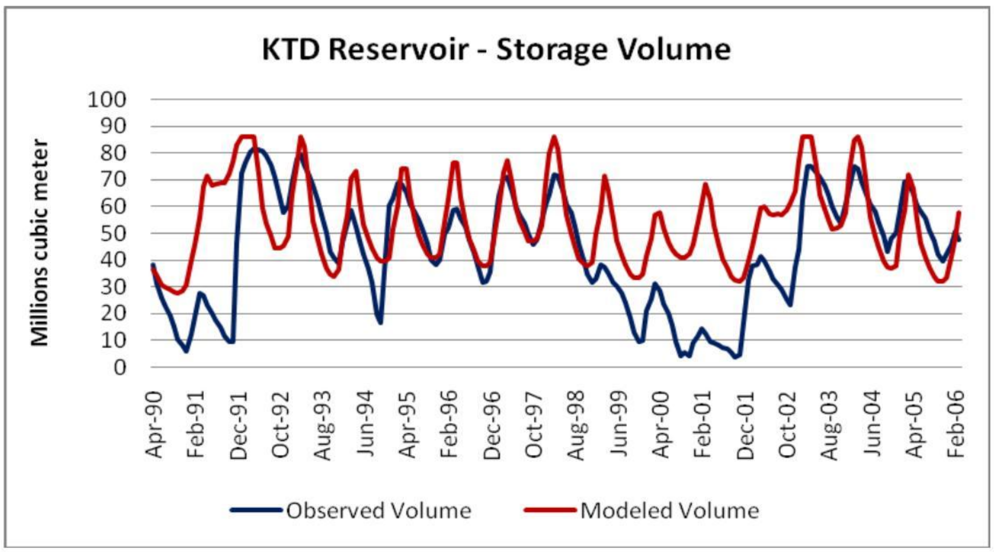


Figure 4-3: King Talal Storage, measured and WEAP estimation for the period (1990 -2006).

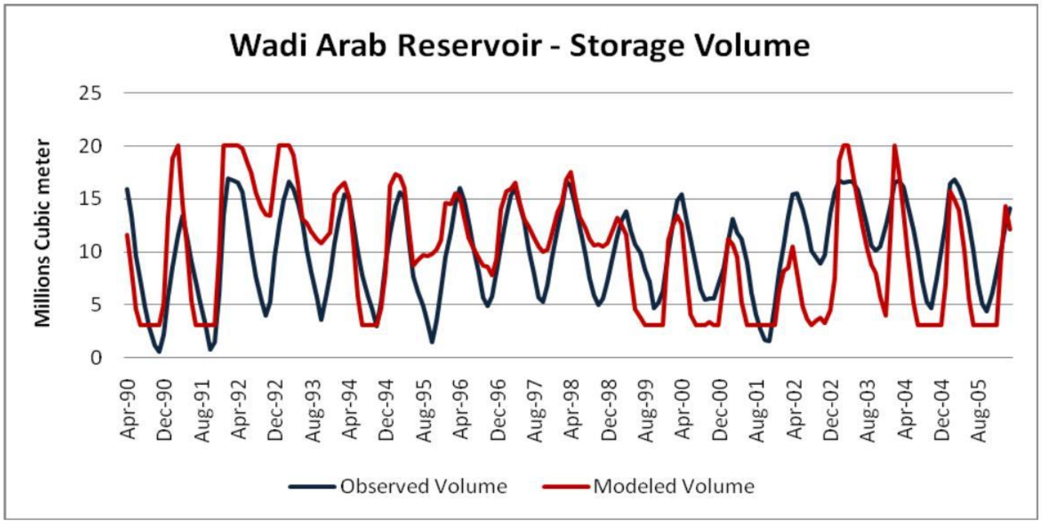


Figure 4-4: Wadi Arab Reservoir storage, historical data and WEAP calibrated data.

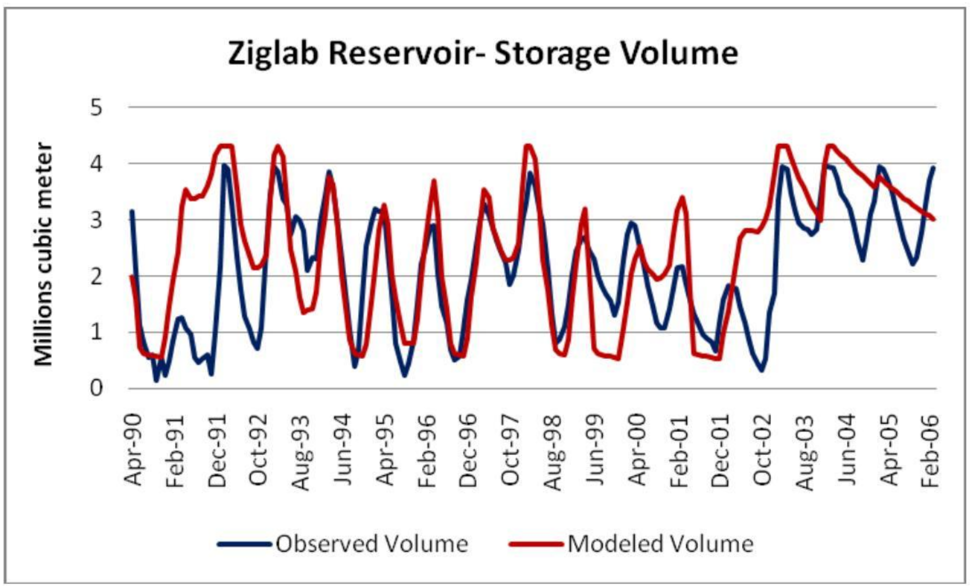


Figure 4-5: Ziglab Reservoir storage, historical data and WEAP estimation.

4.5 Demand Scenarios:

In this section we project the demand in the model for the purpose of forecasting and management, which could help in analyzing various scenarios output as variations, uncertainties and sources of risk.

The model uses the term "annual activity" which means the annual amount of water required by each demand.

As explained above, the model takes into account two types of demand: domestic (urban presented by Amman city) and agricultural demand within the JV. For domestic demand in the period 1991-2050, we kept the historical population growth trend obtained from the Department of Statistics (DOS) in Jordan and extended that same population growth to 2050. The population growth rate has changed in the past: before 1994 it was 4.4 % per year, then 2.02 % per year, and in 2004 to 3.7 % per year. In the scenario we assumed continued growth at 3.7% per year.

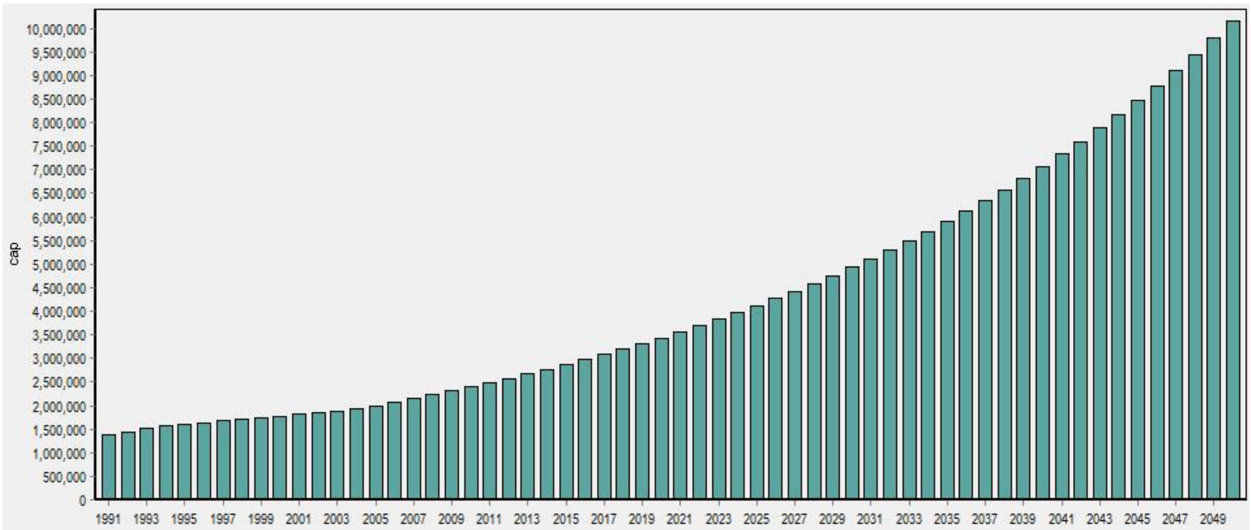


Figure 4-6: Calculated population growth assuming increase 3.7 annually from 2004 -2050.

For agriculture all scenarios assumed a small increase in the cultivated area. This was considered to be reasonable given the limited water resources in the Jordan Valley. The change in agricultural area is shown in the following figures for North, Middle and South JV:

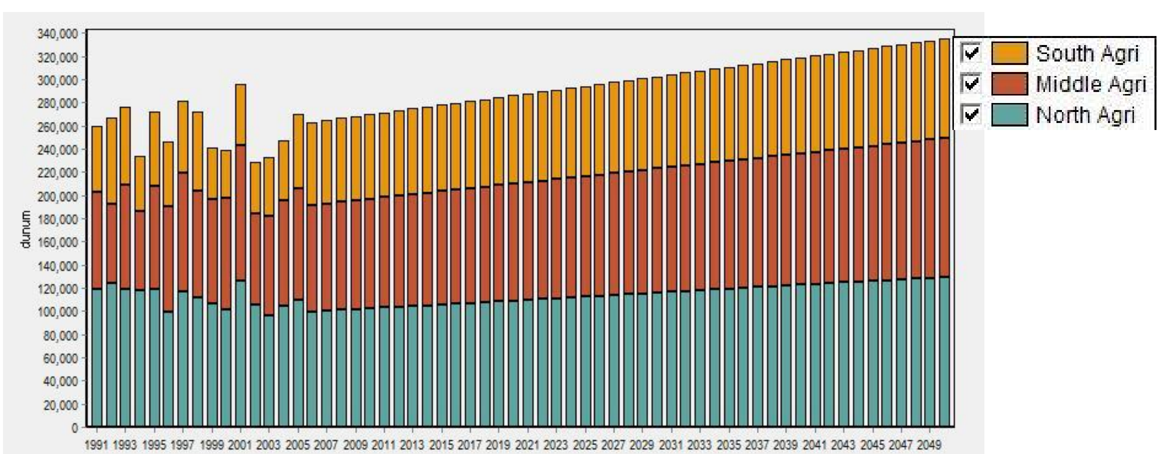


Figure 4-7: Increase of agricultural area by region up to 2050

4.6 Supply Scenarios

An important aspect of modeling the water system in the JV is to understand how it operates under a variety of hydrologic conditions. Natural variations in hydrology from year to year, which are large in the JV, can have major effects on the results of the scenarios.

WEAP’s Water Year Method allows the use of the historical data to explore the effects of future changes in hydrological patterns. In the Water Year Method, a typical flow pattern is specified for a “normal” year and then scaled up and down for very wet, wet, dry, and very dry years. A scenario is then characterized by a Water Year sequence. Hydrologic fluctuations are therefore simulated as departures from a normal Water Year, which for this study was calculated as the average across the available historical data, from 1991 to 2006. In the model, the starting year (1991) year was a dry year. The non-normal water year type (very dry, dry, wet, very wet) were defined, following a statistical analysis of historical flows, by using a scaling factor of 0.65 for very dry, 0.75 for dry, 1.30 for wet, and 1.70 for very wet.

The Water Year method is a useful tool to project the future years in the scenarios, so we kept the same definition for the “business as usual” scenario, sampling the historical inflows, 1990-2006, to give characteristic “very dry”, “dry”, “normal”, “wet”, and “very wet” years. For the scenarios, a random sequence of water years was generated using the same frequencies as for the Historical Climate.

4.7 Scenario Development

A scenario approach is a useful technique for water sustainability assessment, as it allows a wide view over a long time horizon that considers futures with fundamentally different development and environmental assumptions and policies. This paper evaluates different scenarios that were tested by the model to support planners in their water allocation decisions. The projected year for the scenarios was 2050. Based on a variety of economic, demographic, hydrological, and technological trends a "reference" or "business-as usual" scenario projection was first established and called the Reference Scenario. We then developed four alternative scenarios with different assumptions about future developments. These scenarios were: Business-as-Usual, Increase Treated Wastewater North JV, and Climate Change, combining the Climate Change scenario with increasing the reuse of TWW and finally altered patterns of agriculture.

Alternative scenarios can examine vulnerability of water supplies to different demographic, technological, climatalogical, and hydrological futures. As well, scenarios can explore alternative policy for demand and supply management options for adapting to future vulnerability. By running the model for each of the scenarios, competing demands under different policies and rules can be evaluated for the effectiveness in meeting management goals.

Scenario analysis aims to answer "What if…?" questions. Data are essential to evaluate the current and past situation, while models are indispensable in exploring options for the future. This section deals with the result of the scenarios.

4.7.1 Business as Usual

The Business as Usual scenario is the base scenario that extrapolates historical trends to provide a baseline for the studied period. The objective of a reference scenario is to help in learning what could occur if the current trend continues and to understand the opportunities, pressures, and vulnerabilities that this might bring. Reference scenarios can also be useful for identifying where knowledge is weak in analyzing likely trends and where more information needs to be collected. They can be useful for designing contingency plans where there is a lot of risk and uncertainty.

4.7.2 Increase Treated Wastewater for North JV

The actual treated and reused water from the total consumed is identified as the Wastewater Reuse Index (WRI) defined as:

$$WRI = \frac{R}{G} \times 100, \quad 0 \leq WRI \leq 100$$

Where *R* is total wastewater reused and *G* is total wastewater generated.

As fully discussed in chapter three, the WRI for all of Jordan in 2006 was 34.8 % and 45% at the Jordan Valley research area. The amount of wastewater reused in Jordan was 80 Mm^3 in 2006, and in the Jordan Valley was 73 Mm^3 in 2006 (Alfarra et al. 2009).

For this scenario an assumption to increase the WRI to 70 % based on wastewater in 2006 meaning that the increase of treated wastewater reused will be 114 Mm^3, the total increased amount will be located to North region. Our start up year will be 2012 meaning that while we will be using the interpolation function the increase of the reused water will gradually reach the specified amount by 2112.

4.7.3 Climate Change

Climate change dynamics have significant consequences on water resources on a watershed scale. With water becoming scarcer and susceptible to variation, the planning and reallocation decisions in watershed management need to be reviewed.

Climatologists are predicting that climate change will cause alterations in the patterns of rainfall, drought, floods, and desertification. So for the Climate Change scenario we adapted the output of GLOWA -Jordan Valley research project to indicate that under plausible climate drivers (IPCC B2 scenario), (Kunstmann et al. 2007) by the period 2070-2099

- Temperatures in the JV region could increase up to 4.5 °C;
- Precipitation could fall by 25% (Watson et al. 1997); and,
- Runoff could fall by 23%.

These results are consistent with the latest report by the Intergovernmental Panel on Climate Change (IPCC) in which declining precipitation and rising temperatures could lead to water shortages and increased competition for increasingly scarce water resources (Peters et al. 2007; Bates et al. 2008). The Jordan region is likely to face increased drought and decreasing resources of freshwater. As a result, the

Jordan region will face increased demand, more frequent and intense drought, and decreasing availability of freshwater.

To apply their prediction at our WEAP model using the water year method (section 4.6) to apply climate change and reduce the water inflow by 30 % and increase the dry in the region.

4.7.4 Combining the above two scenarios (Increased TWW Reuse and Climate Change)

This scenario combines the above two scenarios to evaluate the impact on demand and resources. We had studied earlier and separately each scenario to investigate effect each one has on demand and resources in the JV.

By applying the Climate Change scenario we see the predicted reduction of water flow to the area increasing stress on resources and increasing unmet demand. Counteracting this trend is the trend emerging from the TWW reuse scenario where we introduced extra unconventional sources of water to northern agriculture presently using freshwater from Wadi Arab Reservoir.

Combining both scenarios allows us to see how the reuse of TWW can help in reducing unmet demand by allocating unconventional water for agriculture. This releases the stress on freshwater to be allocated for domestic uses.

4.7.5 Altered patterns of agriculture

In Jordan date palm farms have been encouraged by the Ministry of Agriculture who introduced high quality varieties such as Barhee, Medjoul, Dejlet Noor, and Khalas.

The date palm tree has low water consumption and is potentially a highly profitable crop. This makes it an attractive alternative crop both to traditional crops with lower profitability and other highly profitable crops with potentially higher water consumption such as citrus and bananas.

Knowing that the average annual water requirement per dunum for Banana is 1750 m^3, citrus is 1170 m^3, Palm trees is 700 m^3 and vegetables are 400 m^3.

This scenario assumed changed patterns of agriculture in which total palm tree cultivation was expanded and that of bananas and citrus were reduced. The range of these changes was between 20 to 40 percent.

4.8 Scenario Analysis and Results

The following graphs were directly obtained from the WEAP software and were exported to Excel for comparison with other studies.

4.8.1 Business as Usual analysis

By projecting the past situation to the future we can see that unmet demand for different sectors increases mainly for Amman city because population growth continues. The Unmet Demand is defined as: Demand – Supply = Unmet Demand.

Figure 4-8 shows that the demand for Amman city is increasing over time due to an increase in population while the agriculture demand in JV remains almost constant due to the fact that the agricultural area is restricted and cannot be extended.

The demand of Amman city illustrated in the Business as Usual scenario reaches around 600 Mm^3 annually. (Amman city is partly supplied from the King Abdallah Canal).

In contrast to Amman city, there is not much increase in the agriculture sector due to the assumption that the agricultural area cannot increase very much above the current area. This assumption was justified by the constraint that the Jordan Valley is near maximum size. The other factor affecting agricultural is the specific water demand for the crop area. The specific water demand was kept constant throughout the scenario (until 2050), assuming no technological change.

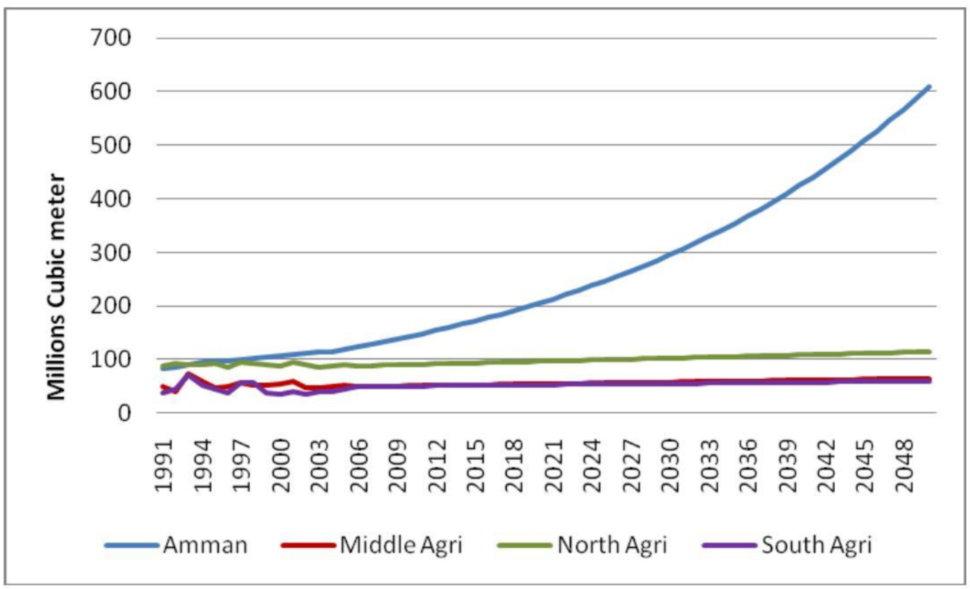


Figure 4-8: Comparison of the agriculture water demand with the demand of the Amman city for the period 1991- 2050, baseline scenario.

The unmet demand can be noted in the following Figure 4-9. Clearly, there is a continuous unmet demand for all agriculture sectors and also for Amman city, which will be the main challenge of future planning.

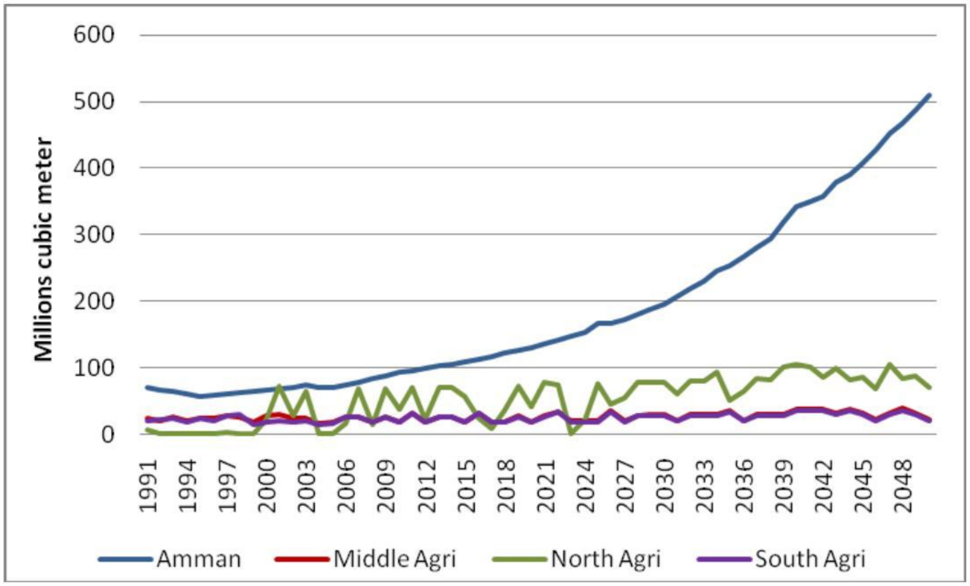


Figure 4-9: The unmet water demand for the period 1991- 2050, Business as usual scenario

Figure 4-9 for Amman city giving only the unmet demand required from KAC. However The KAC is not the only water supplier to Amman city. In ordered to cover the unmet demand in the future the Ministry of Water and Irrigation is planning to supply additional water from the following Basins / resources (Seder et al. 2009):

- DISI Project will provide 105 Mm^3 for Amman and Aqaba starting after 2011.
- Additional nonrenewable GW: Will provide an additional 7 Mm^3 from Jafer and Lajoun.
- Red Sea–Dead Sea Water Conveyance Project: Will provide 570 Mm^3 from 2022.
- Surface Water Resources: (30 Mm^3 from Wehdeh Reservoir, 24 Mm^3 storage in 2020 due to new reservoirs (Reservoirs yield=15 Mm^3), 5 Mm^3 from rainwater harvesting).
- Non-Conventional Water Resources in 2022:
  - 176 Mm^3 from planned wastewater treatment plants and an increase in demand from existing waste water treatment plants
  - 10 Mm^3 from desalination of Red Sea water (Aqaba)
  - 72 Mm^3 desalination of brackish water (47 Mm^3 from ZARA & Mujib and 25 Mm^3 from Kafrein –Hisban and Deir Alla)
  - 30 Mm^3 as stated in the peace treaty

Figure 4-10 shows the simulated storage in the reservoirs (Kafreen, KTD, Shueib , Wadi Arab Reservoir and Ziglab) for the years 1990 - 2050.

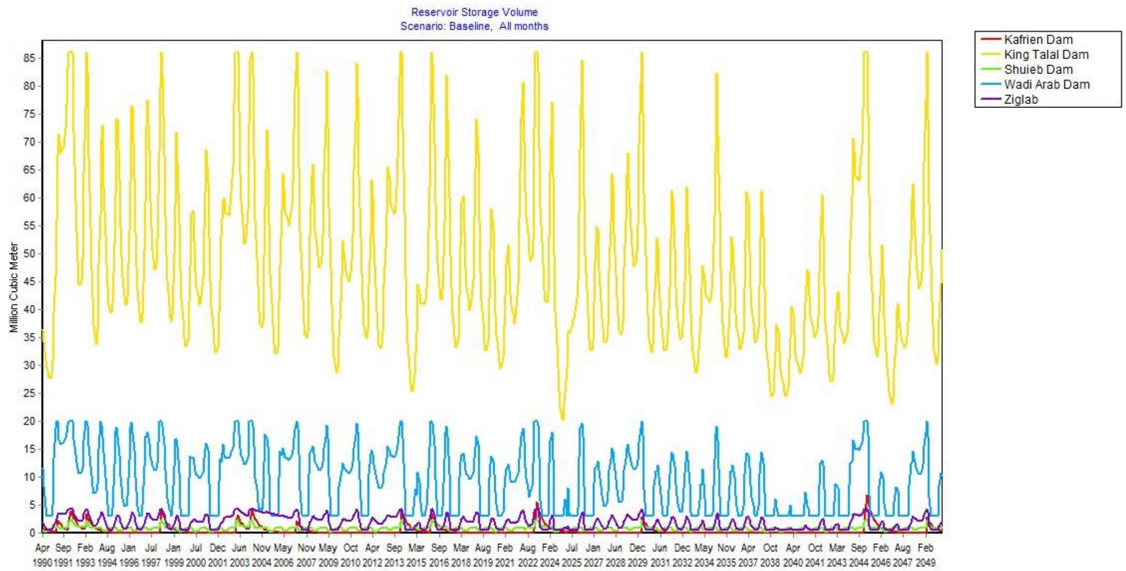


Figure 4-10: Reservoir storages in Business as usual scenario

From this scenario it is clear that there is an increasing big gap between water supply and demand. The Ministry of Water and Irrigation is dedicated to closing this gap by either reducing demand or increasing the effective supply. To reduce the demand we explored other scenarios in the Jordan Valley trying to answer what if …..? questions.

4.8.2 Increase Treated Wastewater North JV

In this scenario the effective supply of water for the agriculture in the northern JV is increased by raising the amount of reused wastewater gradually to 114 Mm^3 by 2012 starting in 2007. This used an interpolation relation in the model using the following (Interp(1990,0,2007,0,2015,114) * 1e6/(12 * 30.5 * 24 * 3600)) where the second part of the relation is to change it to cubic meters per second Figure 4-11).

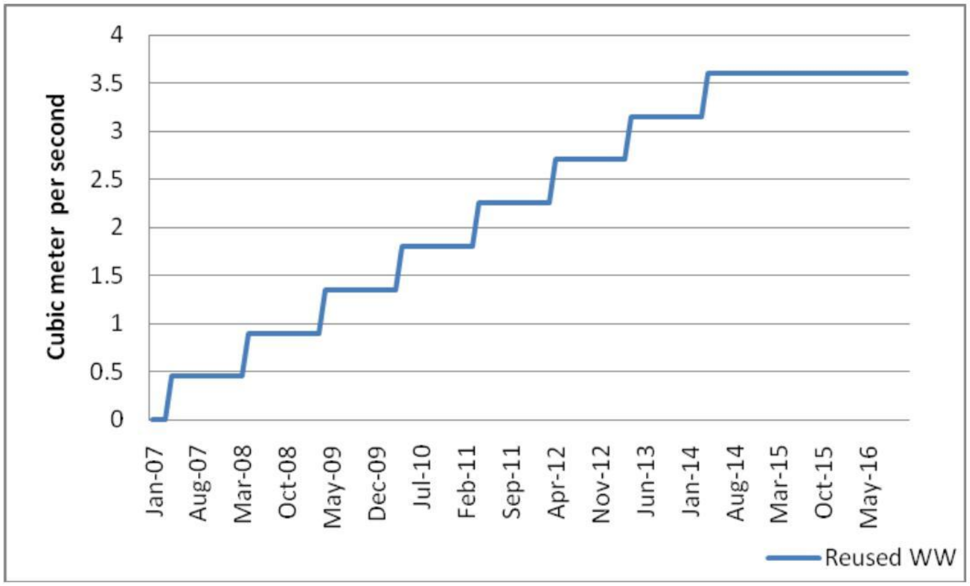


Figure 4-11: The interpolation to increase the reuse for north agriculture area.

The impact on the northern agriculture sector can be seen in the following figures (Figure 4-12). In particular, it can be seen that the unmet demand in the northern agriculture has been reduced tremendously.

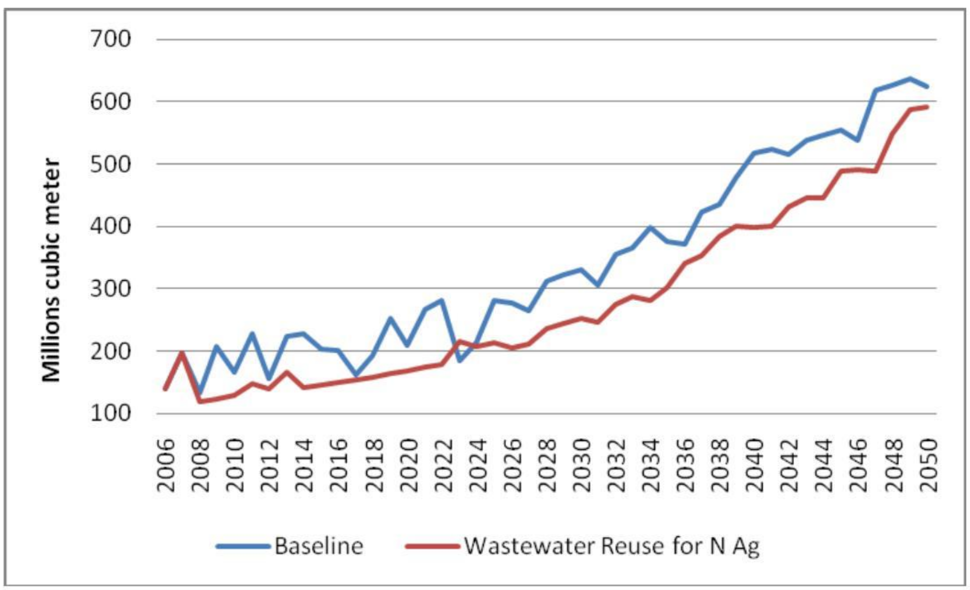


Figure 4-12: The unmet demand in North Agriculture sector, comparison between in the base line scenario and increase the reuse.

4.8.3 Climate Change

The assumptions behind the Climate Change scenario were discussed earlier in this chapter. Figure 4-15 shows that under the Climate Change scenario a reduction in total inflow to the JV is assumed. The Impact of the reduction is an increase in unmet demand, as seen in Figure 4-14.

Since Jordan is already an arid to semi-arid region, the climate change did not have a major influence on the reservoir storage volume Figure 4-13.

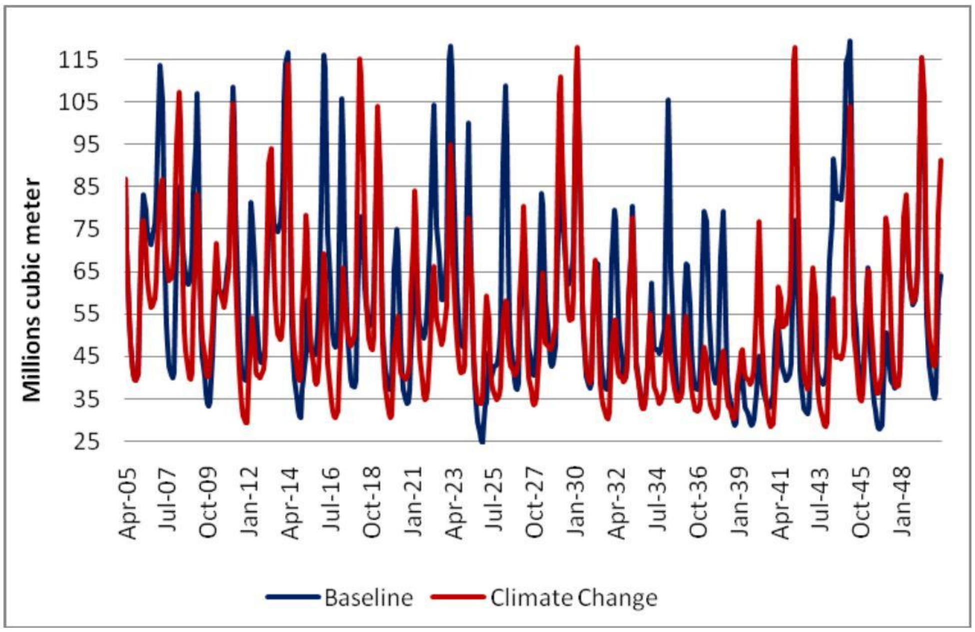


Figure 4-13: Comparison between the reservoir storage volume in the base line scenario and climate change

This is due to the fact that officials who are managing the reservoirs are already dealing with this limiting situation by releasing water at the end of the rainy season reducing the demand part of their requirement but not meeting the full requirement.

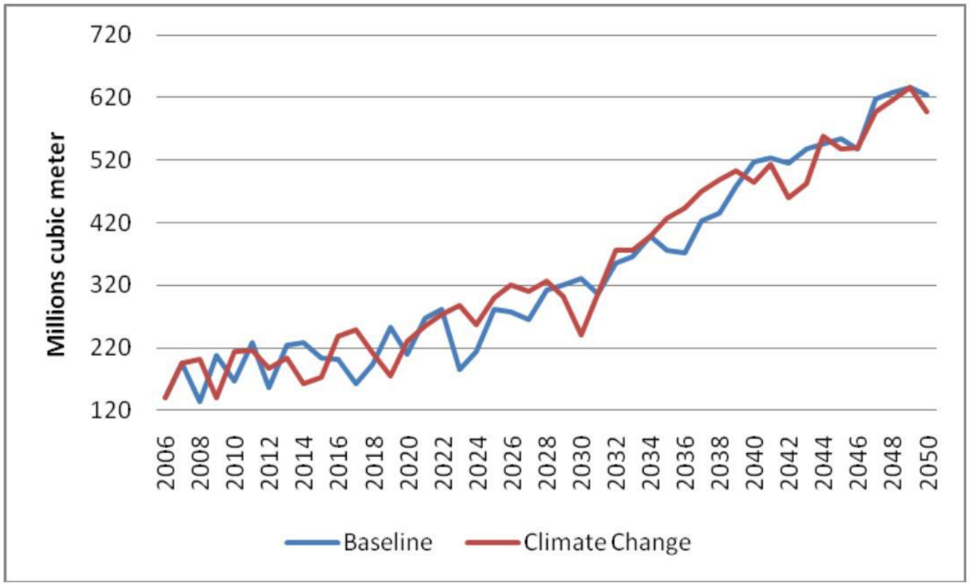


Figure 4-14: Unmet demand comparison between the baseline scenario and the climate change over the projected period (2006-2050)

Still the climate change which applied here by reducing the inflow by 23% could potentially affect the region negatively and tax already limited water resources Figure 4-15.

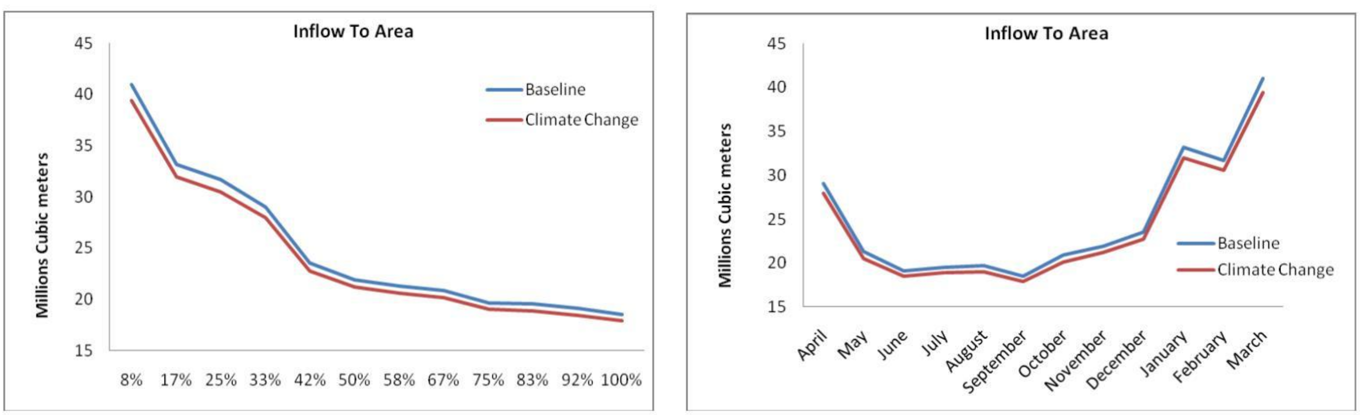


Figure 4-15: Inflow to the area, a comparison between Baseline and Climate Change scenario

The policy question that remains is how to reduce the stress on the region due to either increasing demands or climate change, and what sources of water and management options are available to manage drought.

4.8.4 Combining the above two scenarios (Increase TWW Reuse and Climate Change)

This scenario combines the above two scenarios—reuse of the treated wastewater and climate change—to see how this will influences the situation in the JV.

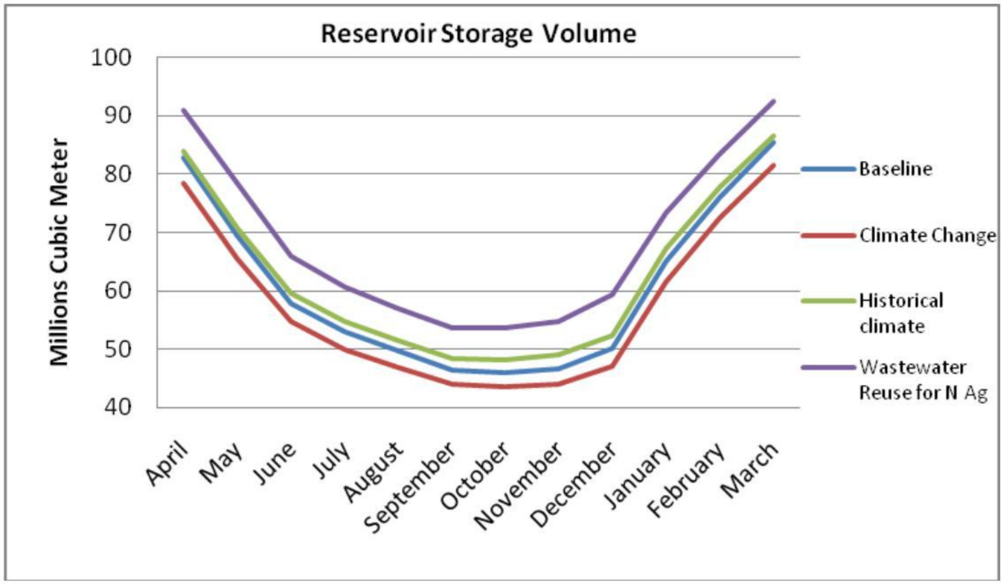


Figure 4-16: Reservoir storage

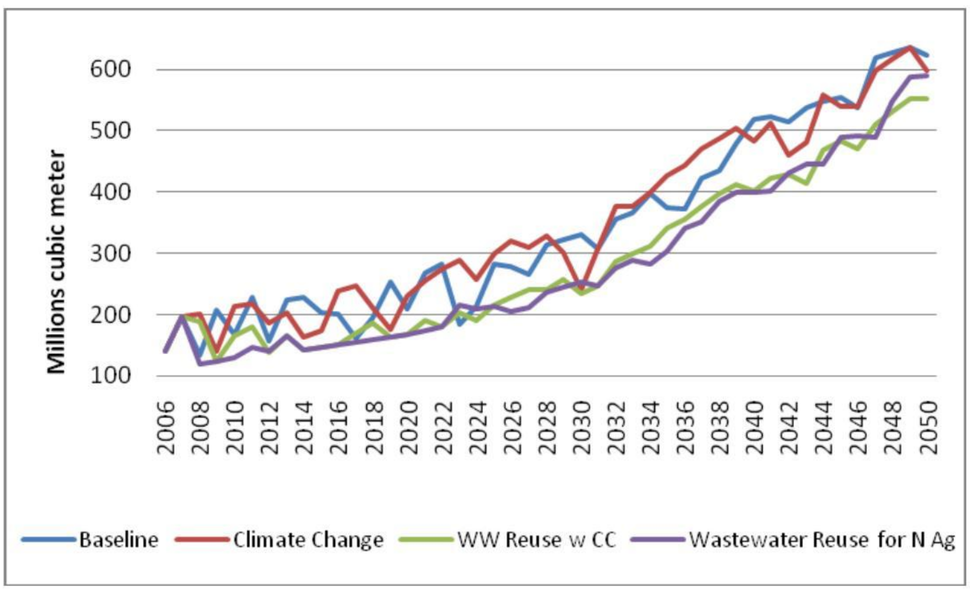


Figure 4-17: Unmet demand – comparison for the unmet demand for different scenarios

It can be seen from the above figures (Figure 4-16 and Figure 4-17), when we compare the unmet demand for different scenarios that the Climate Change scenario is very close to the Business as Usual scenario, which means if things continue as is without change while increasing reuse the additional treated wastewater in agriculture reduces the unmet demand even when climate influences the area. Where in average the difference in the unmet demand between baseline and this scenario is around 56 Mm^3, the difference between this scenario and the Climate Change on average is $61.3 Mm^3$.

That means to overcome the influence of climate change on the region it will be necessary to increase the use of unconventional water (TWW) in agriculture. This will help to reduce the stress on freshwater, which then could be allocated for domestic uses.

4.8.5 Altered patterns of agriculture

As discussed earlier in this chapter, in the model we reduced the cultivated area for banana and citrus tree and increased the area cultivated with palm trees, meanwhile maintaining the total cultivated area the same. The main objective of this scenario is to analyze the impact on the storage reservoir when cultivated crops with less water demands. Figure 4-18 shows that this leads to reduce the stress on the reservoir since the agricultural demand has been reduced with average about 185 Mm^3, compared to the baseline scenario.

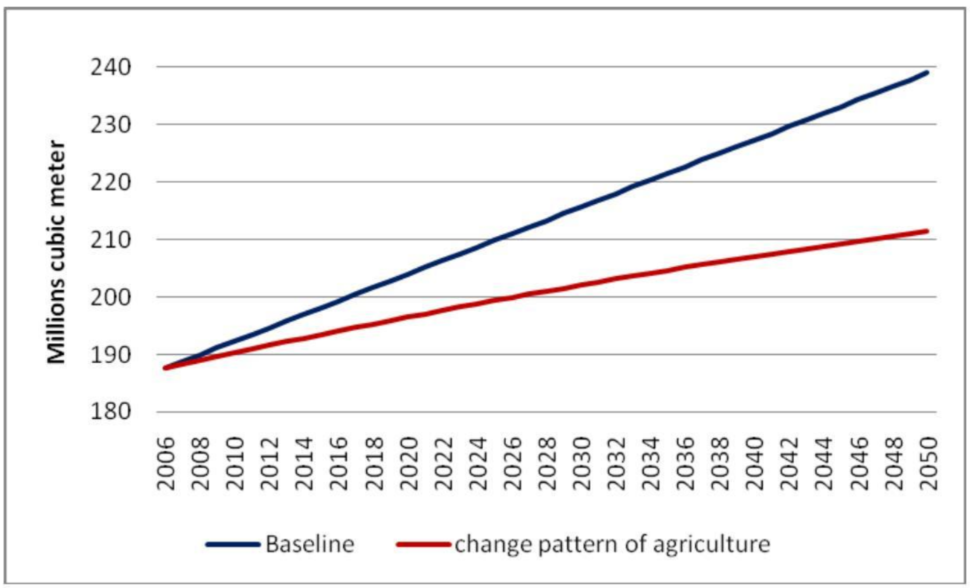


Figure 4-18: The demand reduced by change pattern of agriculture

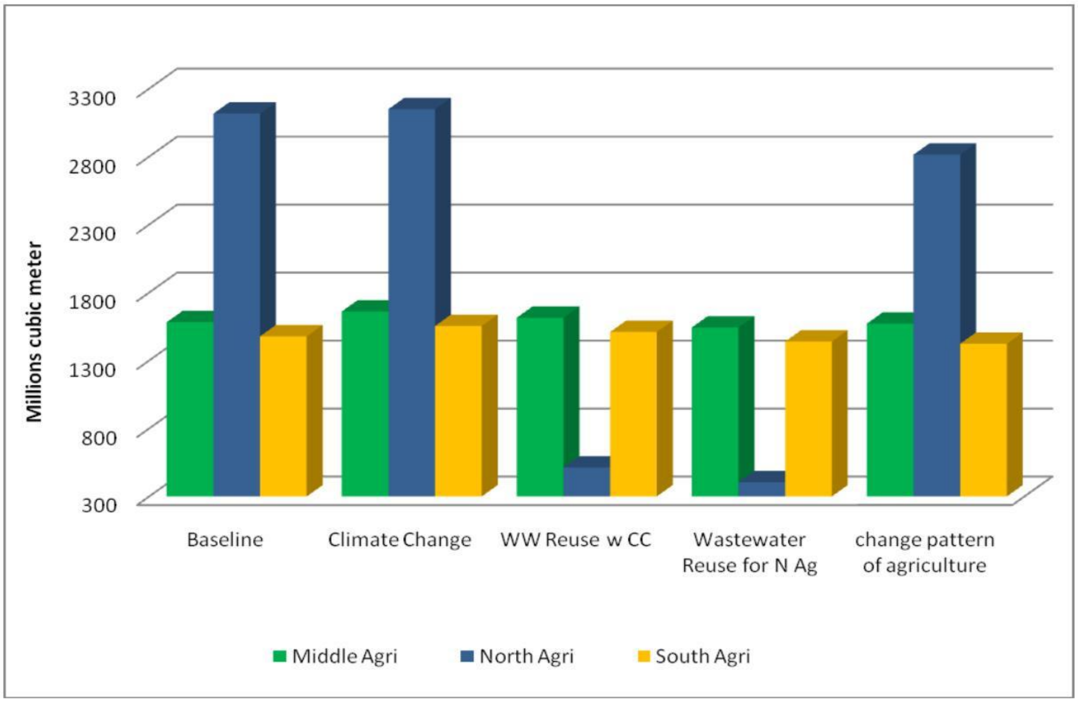


Figure 4-19: The unmet demand for the agriculture when applying different scenarios.

This scenario indicated that saving water can also be accomplished through demand reduction, when farmers adapt new crops that required less water to replace it with crops that required more water, in the same time this crops can be higher value as cash crop.

Table 4-5: Unmet Demand within different scenarios (Million Cubic Meters)

	Climate Change	WW Reuse w CC	WW Reuse for N Agr	Change pattern of Agr.
Middle Agri	1660.40	1609.11	1609.11	1571.01
North Agri	3148.94	1954.66	1954.66	2814.05
South Agri	1553.94	1503.71	1503.71	1423.02
Sum	6363.28	5067.47	5067.47	5808.07

4.9 Discussion and Conclusion

In this chapter we developed and calibrated a decision support tool (DST) that could support the efficient use of water resources for the Jordan Valley. The DST aims to improve the planning for water allocation according to different demands so as to reduce the stress on water resources. The DST considers various factors that can influence these decisions such as water quality, crop specificities and irrigation systems. As a basis for our DST we selected the WEAP model. The WEAP software simulates and models water allocations considering different demands and sources to analyze the past and current situation as well as exploring different future uncertainties. As such the DST can support decision makers in answering what-if questions and what should be done to avoid perilous situations.

The model was operationalized during a calibration stage where we aimed to reproduce monthly reservoir volumes against historical data, covering the period from 1990-2006. The simulated volumes of the main big reservoirs showed a good fit and gave a reliable picture of the previous period. Calibration of smaller reservoirs was more complicated due to an unknown share of seepage that largely influences observed reservoir volumes. With the calibrated model we evaluated different scenarios to explore possible future water allocations in the Jordan Valley.

The baseline scenario shows what will happen if current conditions continue in the future. Population demand was projected at growth of 3.7%, agricultural area size and inflow of water resources into the area followed current conditions. The results showed that Amman city will have a bigger unmet demand and the agricultural sector retained its same output, as expected.

In another scenario we increased the share of TWW in the Northern Region of the JV as a new source. This resulted in a clear reduction of the stress in freshwater resources that could be allocated to Amman city. The unmet water demand was reduced by 18.3 %.

Climate change was simulated by reducing the inflow to the region by 23%. The reduction didn't have a big influence on the reservoir storage as the policy is to distribute only a share of the water storage and not absolute water demands. Which means agriculture will receive less water since Amman city has higher priority to receive water. When farmer receive less water this will influence his farm

Another scenario explored the combination of increasing TWW share in agriculture and the Climate change effect. The results showed that the use of TWW could compensate the negative effect of reduced water availability due to climate change: we found out that the unmet demand for agriculture was reduced significantly within average of 56 Mm^3.

Finally, a scenario explored the effect of changing cropping patterns in the JV. Crops that required more water were replaced with other less water demanding crops that were also less sensitive to reduced water quality. Replacing a small percentage (5- 10 %) of cultivated area with Banana and Citrus by Palm trees or Vegetables shows that stress in water resources can be reduced considerably while maintaining the size of the agricultural area.

We conclude that the calibrated WEAP model provides useful information for decision makers to evaluate various policy interventions. Future research could concentrate on further refining the spatial resolution of the model so as to provide more accurate geographical specific recommendations. Including more rural and urban areas would further improve the regional scope of water resource policies.

5 The price to pay for treated wastewater; a socio–economic analysis of Jordan Valley farmers

5.1 Why water pricing matters

Inefficiencies in water management are caused by absence of appropriate price signals that on one hand indicate the scarcity of the water resource and on the other hand constitute a major incentive for custodians to regulate its production. The reason for this failure is found in the public good nature of the water resources, which implies that water resources are not traded in the markets as other goods are, and hence they do not have readily available market prices, to enable their efficient and sustainable allocation (Birol et al. 2008). Moreover, the specific characteristics make it also difficult to trade water as if it were a normal good. First, water is not consumed entirely at a specific place but flows to lower lying areas. Second, it is difficult to determine inflow, consumption and outflow at a certain site and hence to determine the corresponding buy and sale prices of the water. And even if this water balance could be determined in detail it is difficult to establish an owner to whom payments of its use have to be made. Hence, exercising property rights is difficult for water resources, and, conversely, when property rights are not well established, few will have an interest to act when depletion and degradation occurs (Keyzer et al. 2009). Indeed, the use of water sources is often free and it is difficult to protect them against unpaid uses; this is known as the non-excludability issue.

Even though several of the water resources used for irrigation, such as groundwater, is not pure public goods, they are common-pool resources, where the access of several not paying users could result in a tragedy of the commons (Hardin 1968). In this case the benefits accrue to a single user whereas the costs have to be born by all stakeholders (Cornes et al. 1996; Gaube 2001). The price can also be influenced by government policies that might distort the correct value of water (e.g., subsidies) and no longer reflects the economic scarcity of the water resource. This is clearly shown in the JV where farmers pay a price of 0.008 JD/m^3 while households are paying 4.5 JD/m^3 and higher prices when the 20 m^3 is exceeded. The magnitude and gravity of the water scarcity problem highlight the urgent need for development and implementation of economic instruments and adoption of new technologies and resources for efficient and sustainable management. Thus, pricing water is increasingly seen as an acceptable instrument of public policy. Water-use charges, pollution charges, tradable permits for water withdrawals or release of specific pollutants, and fines are all market-based approaches that can contribute to making water more accessible, healthier and more sustainable over the long term.

One particular area of water policy that has become increasingly subject to pricing principles is that of public water supply and wastewater services. Efficient and effective water pricing systems provide incentives for efficient water use and for water quality protection. They also generate funds for necessary infrastructure development and expansion.

Indeed correct water price signals in the JV will also increase efficiency and encourage the development of unconventional water sources. Such policy interventions could lead to a spectacular increase in the cultivated area as the current water supply only can cover 40-70 percent of the valley's full potential. Admittedly, efficiency gains in the JV will be difficult to make as the partially subterranean drip irrigation system already secures a highly efficient water distribution system. Yet, the previous chapters clearly show that significant water volumes can be obtained from TWW and a correct price of the water can be used to cover the costs required to develop TWW plants and necessary infrastructure. The productivity levels in the Valley also justify an adjustment of water tariffs. Finally, the choice to pay a higher price for water is also justified by the profits that are gained when the JV develops its full potential. Information from (Venot et al. 2007), shows that the marginal contribution of water to the net production, varies from 1 JD/m^3 for entrepreneurial greenhouse farms to 0.08 JD for family absentee citrus farms. So, even for the less profitable farms the gains largely outweigh the current water tariffs. As such a higher price could also contribute to cover implementation costs of new TWW plants.

Therefore, it is important that water is properly priced. This also motivates the current research where we want to investigate the farmers' stance and individual preference to pay for the treated waste water for irrigation. To address the absence of a clear market mechanism we will rely on the Contingent Valuation Method (CVM) a surrogate, non-market valuation method that uses interview techniques to reveal the preferred price for treated wastewater. Consequently we will ask the farmers their Willingness To Pay (WTP) and analyze their factors that influence the decisions. In this study 401 farmers in the JV were selected for these interviews.

The results will assist policy makers in identifying, the potential incentives and disincentives that promote or discourage the use of reclaimed wastewater in irrigated agriculture. Hence, the data collected will help to analyze the basis on which the farmer decides the use of water and the psychological factors (public perceptions) governing their decision making processes. Accordingly, it is important to:

- Understand the judgement strategies used by farmer to make their decisions to accept or reject the use of TWW;
- Identify the factors influencing farmer's risk perceptions in using recycled water;
- Investigate the role of trust in the authorities in farmer's decision making processes to either accept or reject TWW;
- Examine the different ways and situations where factors such as health, environment, treatment, distribution and conservation issues can have an impact on the farmer's willingness to use TWW;
- Understand why different sources and uses of recycled water can influence the decisions of farmer to use TWW; and,
- Understand how perceived economic advantages in using recycled water can facilitate the decisions of farmer to use TWW.

This chapter is organized as follows: Section 5.2 introduces the CV method and discusses its strengths and restrictions; section 5.3 presents the questionnaire, sampling scheme and geographical allocation of interviewed farmers and the tools that were used to analyze the data; section 5.4 presents the results; and section 5.5 concludes.

5.2 The Contingent Valuation Method (CVM)

Contingent valuation is a method of estimating the value of environmental services, the price of which can not be directly determined by market mechanisms. The Contingent Valuation Method (CVM) requires that individuals express their preferences for some environmental resource or change in resource status by answering questions about hypothetical choices. The very nature of this methodology has therefore meant that CVM has been subject to criticism from both economic and psychological experimentalists whose growing research focus has been the problem of preference elicitation. Indeed, the CVM is criticized by some as unreliable because it depends on what respondents say rather than what they do. This criticism has in turn caused supporters of CVM to pay much more attention to a testing protocol in which questions of method reliability and validity are directly addressed (Bateman et al. 1992). In the last decade CVM has gained increased acceptance amongst academics and policy makers as a versatile and powerful methodology for estimating respondents' WTP (Cameron 1997; Venkatachalam 2004; Pearce et al. 2006). In this study three different levels of crosscheck were applied. The first deals with the structure of the questionnaire by having questions that have direct and indirect answers. The second was having side talks with the field worker either before or after interviewing the eligible person. The third was confirming parts of the quantitative data by staff of the JVA within the study area; and using previous studies of the JVA.

Natural Resources Valuation The value of natural resources is derived from the consumption of various environmental services, final and intermediate. Following Pearce and Turner (1990), who introduce the concept of Total Economic Value (TEV), one may distinguish even non-use values that refer to environmental assets that are currently not yet considered as a scarce resource but may become so in the future. Non market values of environmental goods can be further categorized into three components: existence, option and bequest values (Carson 2000). Existence value refers to specific environmental amenities that have to be protected against extinction or damage. Bequest value is the value that public is willing to pay for preserving the environmental quality for the next generations. Finally, the option value of any environment amenity is the value that the public is willing to pay to preserve it for future use but they are not sure when they are going to use it.

The respondents to a CVM questionnaire will be asked a variety of questions about how much they would be willing to pay (WTP) to ensure a welfare gain from a change in the provision of a non-market environmental commodity; or how much they would be willing to accept (WTA) in compensation to endure a welfare loss from a reduced level of provision. A basic question for the implementation of the CVM is therefore whether WTP or WTA is the most appropriate indicator of value in a given situation (Bateman and Turner 1992). These questions make clear that information issues are central to the design and application of the survey-based CVM for valuing environmental goods. While content is under the control of the analyst, how this information is accessed and used is ultimately up to the respondent. Further, questions of information access and use may be much different for a survey about a relatively simple and familiar good versus a highly complex environmental policy change involving a relatively unfamiliar good (Berrens et al. 2004). The acceptance of treated wastewater is also affected by many factors including the political context of a country, local history, the recycling terminology used with the public, the degree of public involvement in strategy development, and the degree to which potable recycling is pushed as the primary option (Menegaki et al. 2007).

Researchers have developed many approaches for eliciting WTA and WTP values in CV surveys. The data collected from these different elicitation formats can be classified into one these three basic categories (Bateman et al. 2004). Continuous data results when the survey elicits point estimates of WTP. Open-ended questions of the form 'What is your maximum WTP?' require respondents to reply with one figure that they believe best represents their WTP for the good being offered. Binary data result when respondents simply state whether their WTP is greater or lower than a value presented to them by the analysts.

In section 3, *Questionnaire Design and Implementation* we will explain the approach that we used to elicit the farmers' WTA, WTP and the factors that influence this decision.

5.3 Methodology

In this section we will discuss the questionnaire design and its Implementation and the sampling strategy to select the farmers to be interviewed.

5.3.1 Questionnaire Design and Implementation

The Work Plan for Implementing the Contingent Valuation method for this research had 8 steps, where each step indicated a full stage in this research as shown in the following chart (Figure 5-1).

The so-called direct face-to-face interviews were used as this has been the most reliable approach in contingent valuation studies (Carson et al. 1996; Carson 2000; Afroz et al. 2009). Before presenting the WTA and WTP questionnaires to the farmers, they were informed about the water situation in Jordan as well as on the negative and positive aspects of using TWW or blended water. Also it was made clear that respondent anonymity would be guaranteed. Simultaneously, farmers were informed about the consequence of water scarcity which could imply tougher laws that lead to higher prices for water used in irrigation, and the use of different types of water than for irrigation. Subsequently, farmers were asked to respond to sequential dichotomous questions; whether they would vote in favour of paying the proposed price (bid) for TWW or blended water.

Literature suggests that extreme bids should be avoided, since they can lead to efficiency losses; and, that the number of bids used should be six at a maximum (Hanemann et al. 1996). To cover possible water prices ranging from current water prices used in irrigation irrespective of its quality and average operational costs for TWW at Jordan we organized the price ranges in six ordered classes, the selection of which was based on the results of the pilot questionnaire in the Jordan Valley. Additional independent questions were addressed to farmers to study what can influence their readiness for using TWW or blended water and encourage a changing attitude to value water.

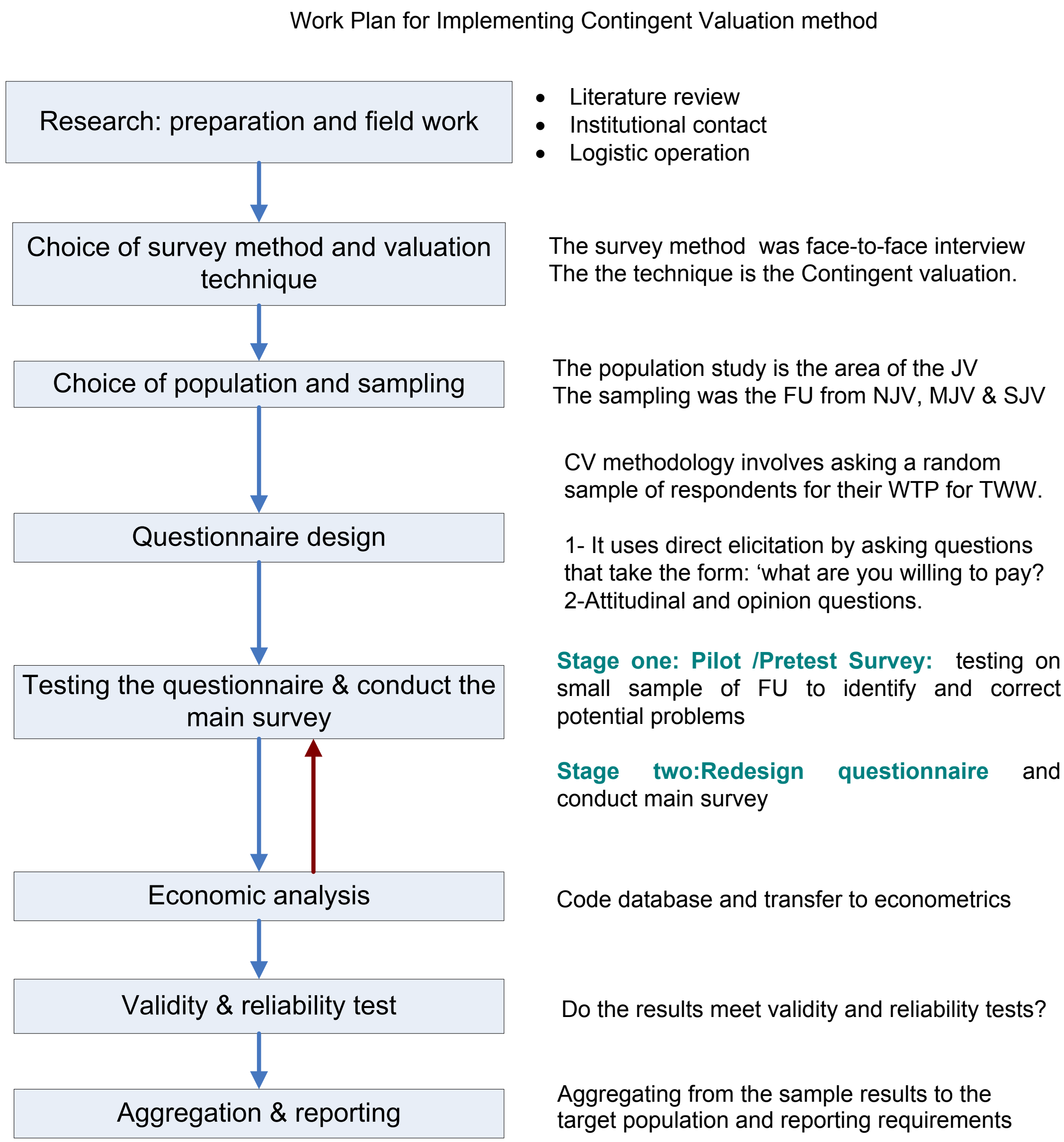


Figure 5-1: The Work Plan for Implementing Contingent Valuation method in JV (Bateman et al. 2004) modified by researcher.

A pilot survey was conducted for one month during 2007, to test the questionnaire in the field using 35 farms units. By the end of this stage the data were processed by computer system. The result of the pilot survey required some modifications on the formulation of some of the questions that were related to farmers WTP. Specifically the length of the bids was modified. It was also noticed that the English questionnaire made the farmer cautious in responding. So an Arabic translation was required for the survey to gain farmers' trust. The actual field survey was conducted in 2007/ 2008 during ten-months of fieldwork in the Jordan Valley.

In this study we opt for the dichotomous choice model to ask the WTA and use bidding techniques for the WTP. The bidding game is a repeated process that tries to bracket the respondent's maximum WTP by presenting higher values (bids). We noted the maximum WTP of the farmer for a cubic meter of TWW in agriculture and confirmed that any price less than his maximum acceptability will be accepted by him.

Finally, the farmers answered questions on different factors that influence the decision to use the specified TWW in irrigation. These factors are:

- Regulations and enforcement
- Availability or shortage of freshwater
- Water price and farming profit
- Cropping restriction or freedom
- Opinion of relatives
- Opinion of friends
- Farmers involvement in the planning and decision-making
- Potential fertilizers saving — fertilizers in reclaimed wastewater
- Reports, brochures, and studies
- Advice by specialists
- Media (TV, radio, newspapers, Public press use, etc.)
- Diseases out breaks
- Awareness and attitude change
- Crop marketing
- Acceptance of crop consumers
- Crop yield in reclaimed wastewater
- Cropping restriction
- Agricultural profit
- Farmers' involvement
- Health risks to farmers
- Health risks to crop consumers

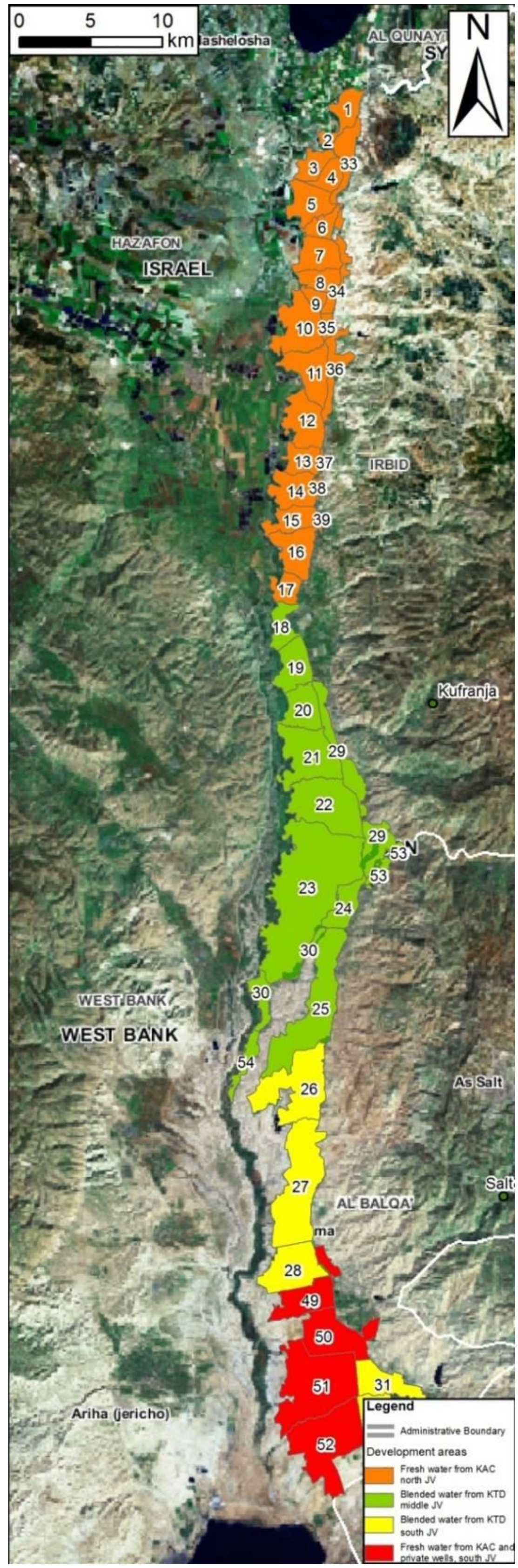


Figure 5-2: Development's area in JV.

- Impact on irrigation equipment
- Impacts on quality of soil
- Impacts on quality of crops
- Pricing of freshwater versus reclaimed wastewater
- Psychological aversion
- Quality standards and regulations
- Religious prohibition
- Dependence on water supply
- Water availability/accessibility at irrigation scheme level

In the following section we discuss the sampling scheme that was used to select the farmers for the interviews.

5.3.2 Sampling Strategy

This section discusses the sampling strategy. It starts by defining the target group, gives an overview of the sampling procedure, introduces the selection probabilities, sampling weights, and, finally, a discussion on the survey Mode

The sample to be selected should be representative for the farmers in the Jordan Valley and represent the distribution of most important factors that influence the WTA and WTP. We therefore sampled the population in three stages. First the study area of the Jordan Valley was divided into three regions based on: source of water and geographical location (North, Middle, and South of JV Figure 5-2).

Table 5-1: Irrigated area at the JV by region

Zone	Total Area (in Dunum)	Type of water irrigated
Northern JV	88284.81	Freshwater from King Abdulla Canal North, Hisban –Karen and south Ghor Wadis and Pumps
Middle JV	96201.02	Mix of King Abdulla Canal North and King Talal Reservoir Treated water (Blended water)
Southern JV	115374.57	Freshwater from King Abdulla Canal North and private wells (some wells has brackish
		Blended water

Next, each region was treated as a separate stratum in the sample. Each stratum consisted of several development areas (DAs). A selection of DAs was made from a list of all DAs in the stratum. No other stratification was used, but the ordering of clusters in the frame provided some implicit stratification, and in particular ensured that the sample was well spread out geographically. DAs were selected with a probability proportional to their size (PPS) using the same percent of the farm units to be selected in each cluster - (around 60% of the total development areas within each stratum). This resulted in the selection of 15 from the 24 development areas in the North, 7 from the 12 in the Middle, and, finally, 5 from 9 development areas in the South. This means that within each stratum the sample is approximately self-weighting. In selecting clusters the measure of size used was the number of farm units within each cluster as provided by the JVA 2006. Finally, within the selected DAs the selection of the farms followed a linear systematic sampling procedure: the farm units within the selected development areas were listed, and the sample was selected by taking farm units at fixed intervals from the list. The first farm unit was selected randomly. Thus, given the number- calculated by multiplying the weight of the development area size with the total number of the sample for the stratum - of the farm units were to be selected within each chosen cluster, the sampling interval was determined to be the number of farm units in the development area divided by that number. A random start between 1 and the interval was selected, and farm units were selected systematically at regular steps defined by the calculated interval. This kept the sample approximately self-weighting within each stratum.

5.3.3 Tools for data analysis

We used graphs and tables to analyze, in a univariate analysis the relation between WTP and WTA and individual explanatory variables. Next a multivariate analysis was performed to analyze the joint effect of the variables. As the bidding was done in classes we could not rely on conventional regression techniques with real valued dependent variables. Therefore, we selected a qualitative response model that reproduces discrete classes for a set of explanatory variables. The qualitative response model that was used in this exercise is an ordered logit model that will be briefly explained below.

The concept underlying the ordered logit model is to use an intermediate continuous variable **y** (for example, the bidding classes) in a regression with the set of independent variables **x** (site characteristics, type of irrigation and land use). The range of this (unobserved) **y** is subdivided into adjacent intervals representing the classes (e.g. 1 = 0-5 fils/m^3; 2 = 5-10 fils/m^3; etc.) of an observed discrete variable **z**. Thus, the ordered logit model assumes that there is a continuous process relating an unknown variable y to independent variables **x** by some function. In the logit model, additive error terms are used, so that the underlying process is given by:

$$y_i = \beta' x_i + \varepsilon_i, \qquad (1)$$

Where, $\boldsymbol{\beta}$ is the vector of parameters to be estimated; $\boldsymbol{\varepsilon_i}$ is the disturbance, assumed to be independent across observations; $\mathbf{y_i}$ can take any value and the subscript **i** refers to the observation number. Observed is the variable $\mathbf{z_i}$ given in ordered classes (1, 2,..,n). The relation between $\mathbf{z_i}$ and $\mathbf{y_i}$ is that adjacent intervals of $\mathbf{y_i}$ correspond with qualitative information $\mathbf{z_i}$. This relation is given by:

$$\begin{aligned} z_i &= 1 \quad \text{if} \quad y_i < \mu_1, \\ z_i &= 2 \quad \text{if} \quad \mu_1 \le y_i < \mu_2, \\ &\vdots \\ z_i &= n \quad \text{if} \quad \mu_{n-1} \le y_i. \end{aligned} \qquad (2)$$

The ordering requires the thresholds ($\mu_1,..,\mu_{n-1}$) to satisfy $\mu_1 < \mu_2 < .. < \mu_{n-1}$. Parameters $\boldsymbol{\beta}$ and the thresholds ($\mu_1,...,\mu_{n-1}$) are simultaneously estimated using the maximum likelihood method, which maximizes the probability of correct classifications.

We calculate the probability (Pr) that $\mathbf{z_i = 1}$ by:

$$\Pr(z_i = 1) \quad = \Pr(y_i < \mu_1) = \Pr(\varepsilon_i < \mu_1 - \beta' x_i) = F(\mu_1 - \beta' x_i),$$

the probability that $\mathbf{z_i = 2}$ by:

$$\begin{aligned} \Pr(z_i = 2) \quad &= \Pr(\mu_1 \le y_i < \mu_2) = \Pr(\mu_1 < \beta' x_i + \varepsilon_i < \mu_2) \\ &= \Pr(\varepsilon_i < \mu_2 - \beta' x_i) - \Pr(\varepsilon_i < \mu_1 - \beta' x_i) \\ &= F(\mu_2 - \beta' x_i) - F(\mu_1 - \beta' x_i) \end{aligned}$$

and the probability that $\mathbf{z_i = n}$ by:

$$\Pr(z_i = n) \quad = \Pr(y_i \ge \mu_{n-1}) = \Pr(\varepsilon_i \ge \mu_{n-1} - \beta' x_i) = F(\beta' x_i - \mu_{n-1}).$$

To meet the requirements of a probability model (monotonic-increasing CDF and results lie between 0 and 1), the disturbances ε_i are assumed to possess a logistic distribution, leading to a cumulative logistic transformation function Λ[5] (Figure 5.1). This function maps the admissible area of y, i.e. ($-\infty$,∞), to [0,1], with a first derivative that is always positive.

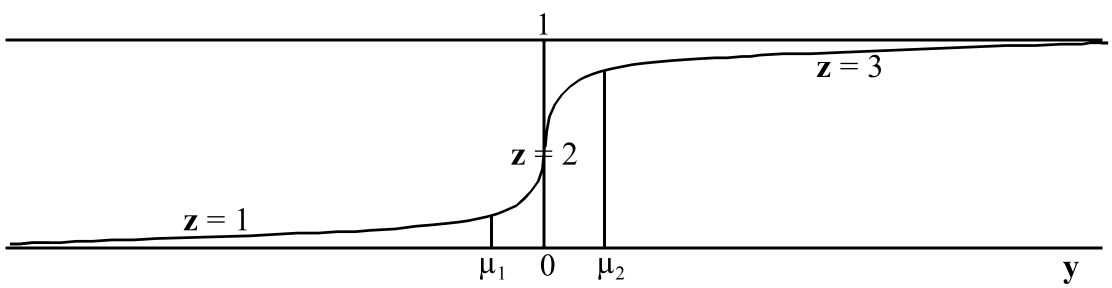


Figure 5-3 : Transformation curve for n = 3

Thus, the likelihood function for the ordered logit model that consists of (1) and (2) for n=3 is given by:

$$\ell(\beta, \mu_1, \mu_2) = \prod_{y_i=1} \Lambda(\mu_1 - \beta' x_i) \cdot \prod_{y_i=2} (\Lambda(\mu_2 - \beta' x_i) - \Lambda(\mu_1 - \beta' x_i)) \cdot \prod_{y_i=3} \Lambda(\beta' x_i - \mu_2).$$

(3)

The function ℓ is minimized with respect to the parameters β, μ_1 and μ_2.

---

[5] $\Lambda = \dfrac{1}{1 + e^{-(\bullet)}}$.

The significance of the estimated parameters are tested in this study with the χ^2-test. The **μ-s** are the constant terms of the model and their significance is not relevant. The overall quality of the estimation is given by the likelihood ratio test:

$$2\log(\ell(\beta,\mu_1,\mu_2)/\ell(\beta^*,\mu_1^*,\mu_2^*)). \quad (4)$$

In formula (4), $\ell(\beta,\mu_1,\mu_2)$ is the unrestricted likelihood, i.e. the likelihood of the estimated model, and $\ell(\beta^*,\mu_1^*,\mu_2^*)$ the restricted likelihood, i.e. the likelihood under the hypothesis $\mathbf{H_0}$ that $(\beta^*,\mu_1^*,\mu_2^*)=0$. If the data pass the test, the model is significantly different from the hypothesis $\mathbf{H_0}$. See (Maddala 1983), (Greene 1991) or (Davidson et al. 1993), for a more comprehensive description of discrete choice models.

In section 5.4 we use two tests to evaluate the model results. The first is the hit ratio, i.e. the percentage of correctly predicted observations by the model (e.g.(Kramer 1996), (Aldrich et al. 1984). The second, a tenfold cross-validation (Weiss et al. 1991), tests the sensitivity of the parameters for the inclusion or exclusion of observations. In this procedure, the data set is subdivided, at random, into 10 sets of about equal size. The model is estimated each time with 9 subsets of the data. The estimated parameters are applied to this evaluation set to compare model results with the accepted bids. In this way, 10 different parameter estimates are obtained, as well as the bid estimates of the entire set.

5.4 Results

This section discusses the results of this study. We start with a description of the WTA outcomes, followed by a univariate analysis to relate the individual explanatory variables to the WTP results. Finally we present the findings of the ordered logit model estimates.

5.4.1 WTA

An overwhelming 386 farmers out of the 401 showed a willingness to accept payments for the use of treated wastewater in irrigation. A closer look showed that farmers who refused payments had either access to fresh surface or ground water sources, obviously in abundant supply. These results are shown in Figure 5-4.

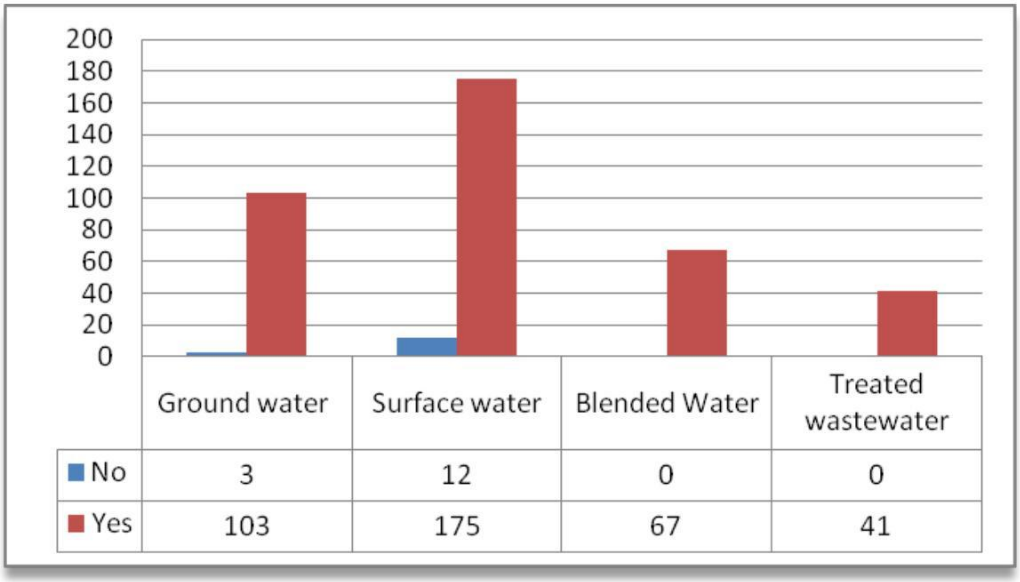


Figure 5-4: WTA associated with irrigated water type.

Remarkably, the farmers who refused the WTA were located in the North and Southern part of the JV Table 5-2, where freshwater sources are scarce. This confirms that farmers who refused the WTA are an exception in the region and that the vast majority is willing to pay for the TWW.

Table 5-2: A aggregation Farmer's WTA associated with each region.

Region	WTA		Total
	Yes	No	
North JV	113	9	122
Middle JV	127	0	172
South JV	146	6	152
Total JV	386	15	401

In a short separate exercise we performed a logistic regression on the full data set to analyze if the following variables did influence the WTA: ‘region’ in the JV, ‘Farmer Education’, ‘ownership of FU’, ‘kind of crop cultivated’, ’source of water’, ’irrigation type’, ’system of irrigation’, ’irrigation period’, ’tariff ’, ’farm total cost’, ’net profit’ and ’having a well’. The results show that only irrigation period and kind of cultivated crop had a significant effect with negative signs, indicating that farmers are willing to accept the TWW as irrigation periods are prolonged and cultivation of ‘Banana trees’, ’Other trees’ and ’Field crops’ do prevail.

The farmers’ acceptance to use TWW in irrigation is clear. During the field work they expressed that they were more concerned about the amount of water than water quality. Another important conclusion was that farmers indicated that in all cases using TWW in irrigation would be much cheaper for them than using or mining ground water.

5.4.2 WTP: a univariate analysis

Figure 5-5, shows the distribution of the accepted maximum bids by the farmers. Remarkably the price of freshwater was at the time of the study 0.008 JD/ m^3, while more than 55 percent of the farmers are willing to pay more than five times this amount for TWW. This clearly reflects the water scarcity problem but also the willingness of the farmers to invest in additional water sources.

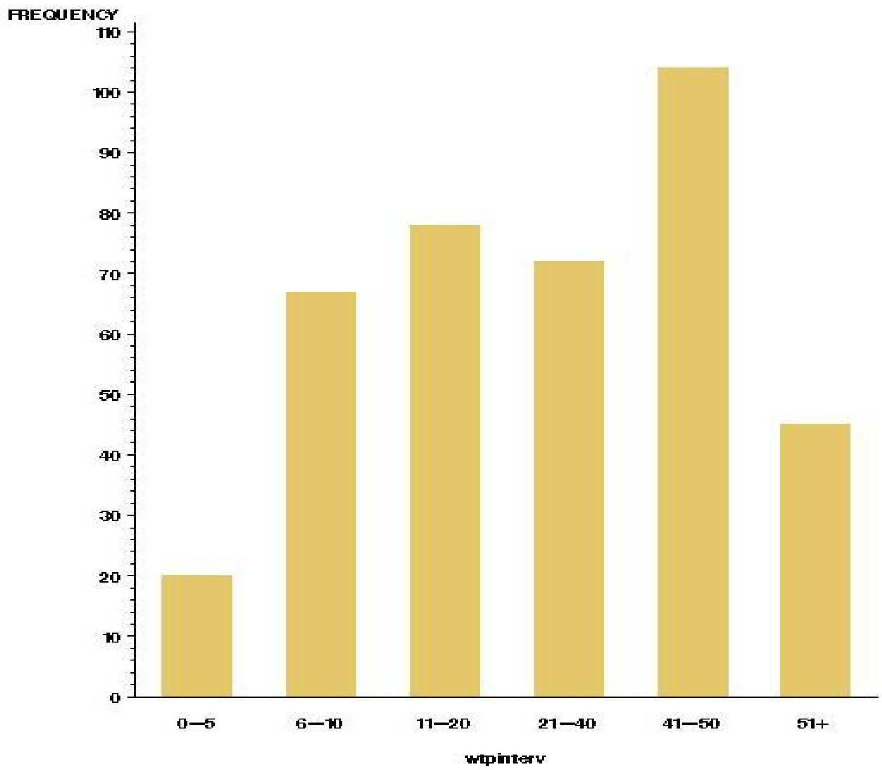


Figure 5-5: Farmers' WTP within interval (1-6) given in fils/ cubic meter for the whale JV.

Region. The distribution of the bid classes for the Middle region inclines to a lower value of WTP as compared to the other two regions. This can be explained by the long and widespread use of blended water (TWW mixed with freshwater) in this region. Many projects educated the farmers about the use and they are aware of the positive and negative effects, yet, they paid the same tariff for freshwater as for TWW or blended water, which is 0.008 JD/ m^3. So, these farmers are not willing to pay more as they are already using the TWW for the same tariff. The North region seems place WTP somewhere between bid 2 and 4, yet no more than that. Apparently in this least water scarce part of the region the guaranteed water supply makes that farmers are not willing to pay more as necessary. In the Southern part most farmers are willing to pay a high (bid 5) price for TWW. For releasing the prevailing water scarcity, even with TWW, farmers are willing to pay a high price.

It is now interesting to compare the distribution of the WTP for the different regions at the JV, as we separated these areas for their different characteristics concerning land use and source of water. The results are presented in Figure 5-6.

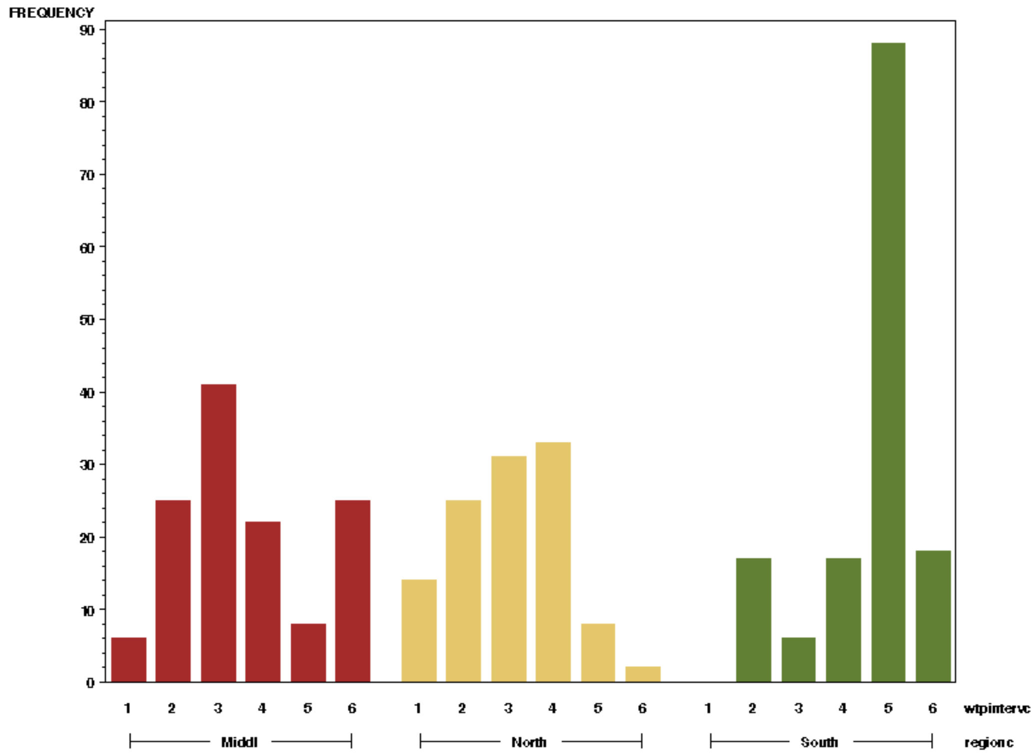


Figure 5-6: The Farmers WTP within regions in the JV by interval (1-6) given in fils/ cubic meter

Type of irrigation water. Possibly, farmers are willing to adjust prices according to quality, where freshwater should have a higher price. This became clear from farmers' responses when they were asked: Do you think the freshwater that is used in irrigation should have equal tariff as TWW? Table 5-3 shows the frequency distribution for the different types of water source. It is also clear that most of the farmers are rejecting the policy of giving the same tariff per cubic meter in agriculture for freshwater and TWW, where they do believe that the value of freshwater should be higher than the TWW.

Table 5-3: the farmers' perception regarding the water price for different water quality.

Type of irrigation water	Equal Tariff		Total
	No	Yes	
Groundwater	55	51	106
Surface water	144	43	187
Blended Water	51	16	67
Treated wastewater	40	1	41
Total	290	111	401

The above Table 5-4 indicates the following conclusions. Farmers who were using ground water gave the highest price cubic meter of TWW in agriculture at farm level even though almost half of them accepted the policy of asking same price for different types of water without taking quality into consideration. Of farmers who are using freshwater in irrigation 80 percent reject the policy of asking the same price for TWW as for freshwater and they believe that water should be priced according to quality. Of farmers who are using TWW 99 percent are of the opinion that it is not right to ask an equal tariff and they indicated that they wanted to buy freshwater in the JV. In case that they do not have enough water they would pay approximately one JD for each cubic meter.

The sample of 401 farm units was also representative for the use of four types of water used in irrigation: groundwater, surface water, blended wastewater, and treated wastewater as shown in Table 5-4.

Table 5-4: the Number of farmers WTP associated with respective to the current type of water type that is used in irrigation.

Bid No.	WTP Bid (fils/m3)	Current Irrigation Type, *Count and percentage*									
		Ground Water		**Surface Water**		**Blended Water**		**Treated Wastewater**		**Total**	
		Count	**%**	**count**	**%**	**count**	**%**	**count**	**%**	**Count**	**%**
1	0-5	3	0.75	27	6.73	0	0	5	1.25	35	8.73
2	6-10	9	2.24	37	9.23	10	2.49	11	2.74	67	16.71
3	11-20	3	0.75	57	14.21	6	1.5	12	2.99	78	19.45
4	21-40	17	4.24	43	10.72	11	2.74	1	0.25	72	17.96
5	41-50	59	14.71	12	2.99	20	4.99	12	2.99	103	25.69
6	51+	15	3.74	11	2.74	20	4.99	0	0	46	11.47
	Total	106	26.43	187	46.63	67	16.71	41	10.22	401	100

NB: 1 JD = 1000 fls.

Farmers who are using GW gave a higher price for using TWW in irrigation than other farmers in the JV, due to the high expense for mining GW and treating it if it was brackish water which is the prevailing situation in the south JV Table 5-4.

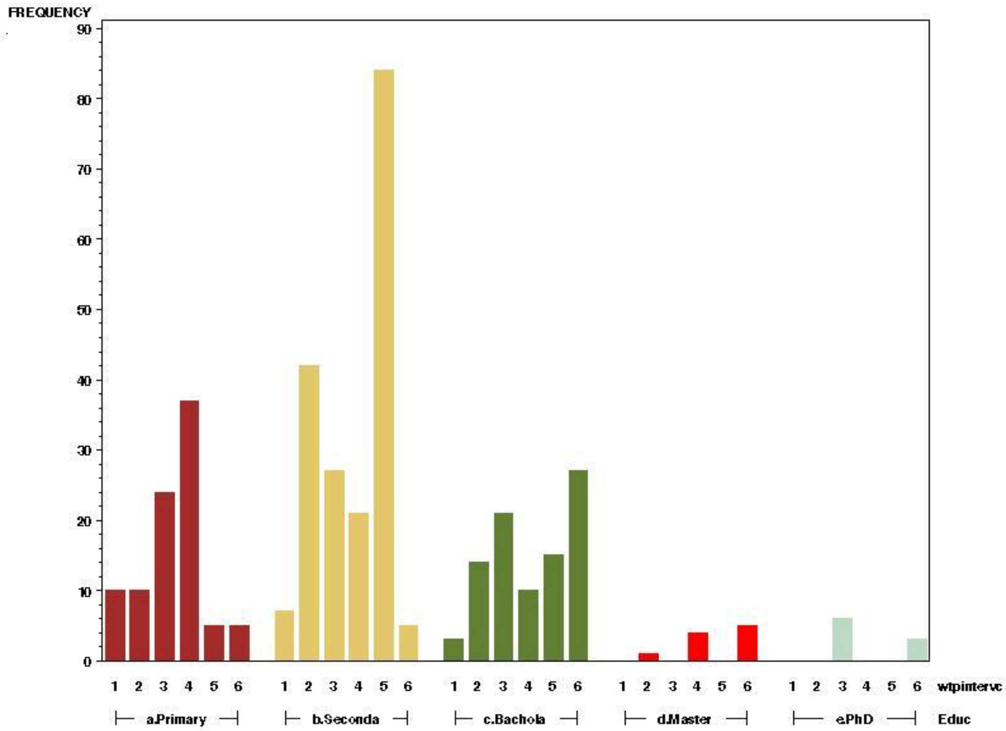


Figure 5-7: Education and its relation to farmers' WTP in the JV, the interval (1-6) given in fils/ cubic meter for the whale JV

Education. As can be seen from the Figure 5-7, Education affected the farmers' WTP choice slightly. Farmers with primary education only have a small tendency to pay less for TWW. Secondary educated farmers and bachelorettes give higher values to the water. The sample for higher educated farmers is too small to draw any conclusion for these categories.

Ownership. The effect of ownership of the land on the bid distribution is presented in Figure 5-8. The distribution of bids between owners and farmers who rent the land is more or less similar. Only a few are leasing the land but they are willing to pay a higher price for TWW. Obviously, the decision to pay for TWW is more or less independent from the form of ownership. This can be explained by the fact that the decision to buy water is not an in depth investment and pays back immediately with increasing yields.

Since irrigation in the JV is mainly drip irrigation, which means there isn't much that can be done in the area of improvements in irrigation efficiency. So drip irrigation can't be considered as a factor that influences farmer willingness to pay for TWW, Figure 5-8.

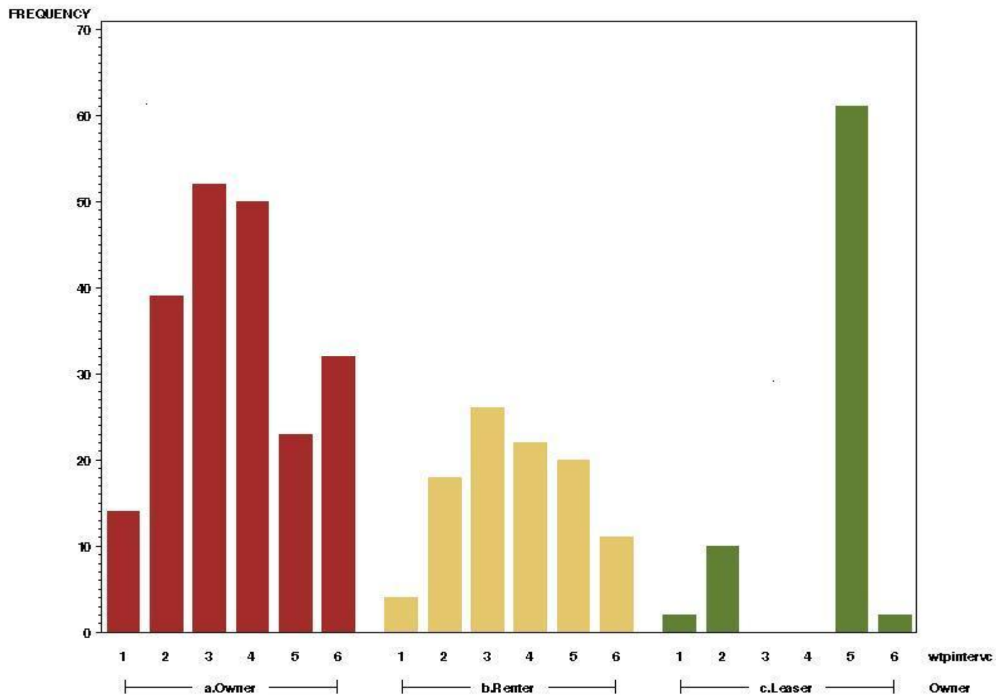


Figure 5-8: Land owner versus Farmers WTP in JV, the interval (1-6) given in fils/ cubic meter for the whale JV

Crops. Finally the farmers' WTP was correlated to the type of the crop that was cultivated. Figure 5-9 shows the results. We notice that farmers who are cultivating vegetables are willing to pay a high price for TWW. From the field surveys we observed that part of these vegetable farmers, mainly located in the Middle JV, have good experiences with TWW for the irrigation of vegetables and they practiced 'farmer to farmer' information exchange to convey their findings. So farmers who are cultivating vegetables in other regions of the JV knew that using TWW in irrigation will not affect their business negatively.

The results of the inventory on factors that would influence the farmers' opinion to use TWW are depicted in Figure 5-10. The results show that farmers have a professional attitude and will not only rely on 'opinions of relatives and friends', but prefer the expert judgements that are conveyed through 'advice by specialists, and 'reports, brochures and studies'. Furthermore, farmers indicated that their decision on TWW use is being influenced by 'water shortages', 'enforce regulation', 'water price and farm net profit', 'saving fertilizer', and 'crop restriction'. All these factors influence the net profit. And, as expected, farmer's decision is basically influenced by economic motives and not much by health and environmental issues.

Finally, it is interesting to note that approximately 70 percent of the farmers let their decision on TWW depend on the communication through mass media. This gives government extension services a powerful tool to reach many farmers to inform them about the use and regulation on TWW.

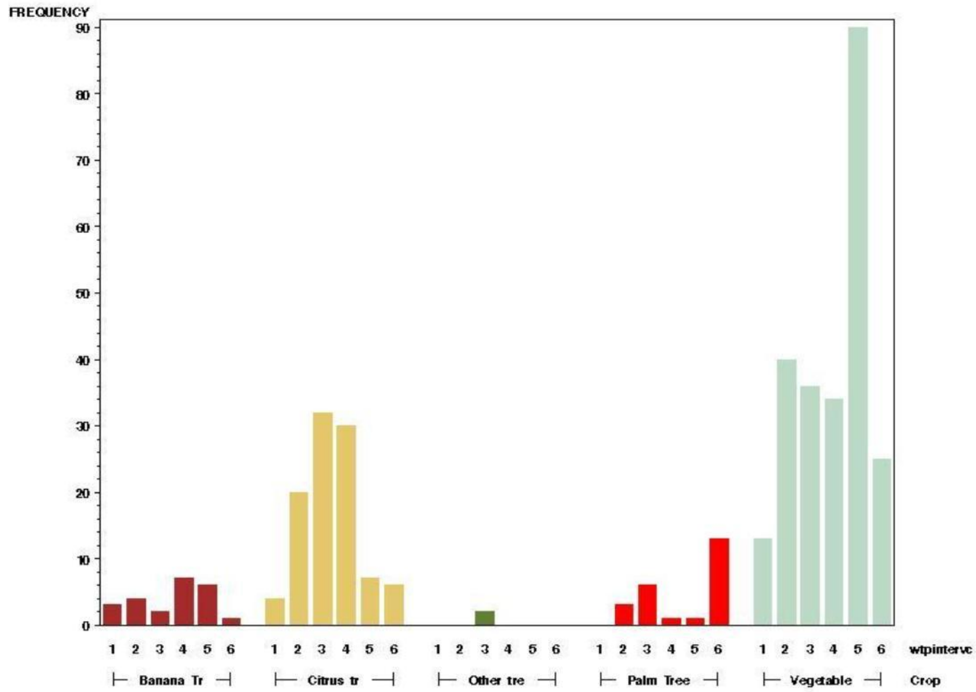


Figure 5-9: Crop type versus farmers' WTP.

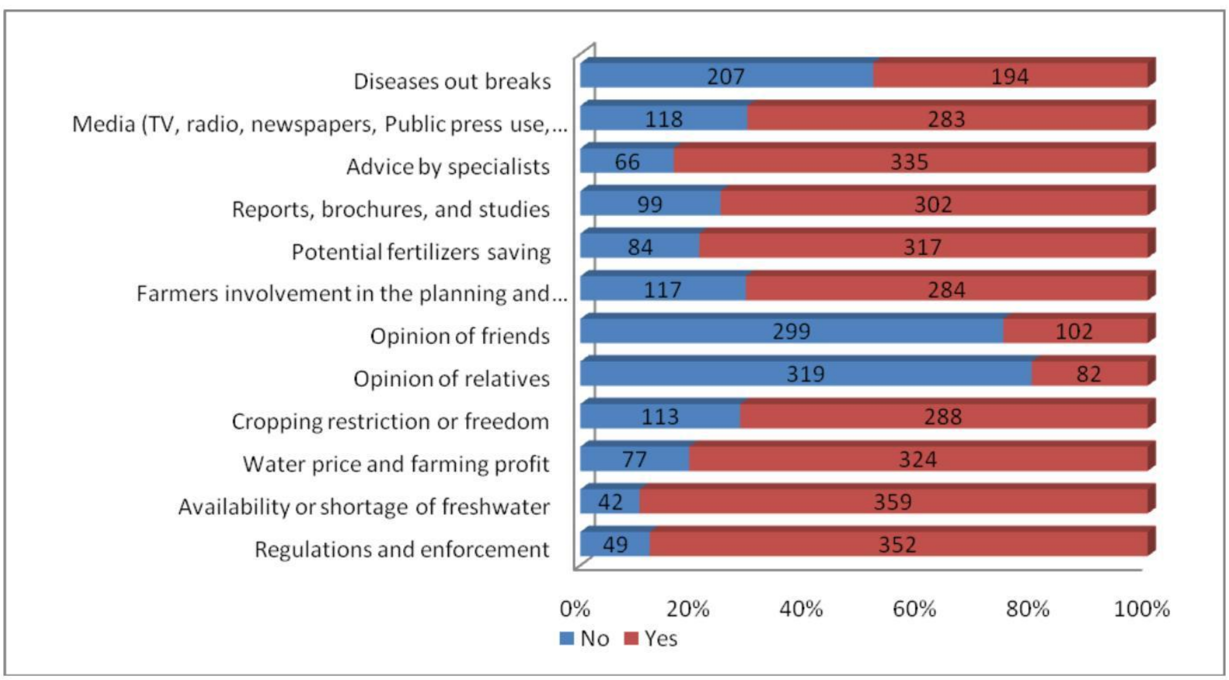


Figure 5-10: Farmers' respondent to the question "Which of the following factors influences your WTP for TWW?"

The questionnaire results depicted in Figure 5-11, show the responses of the farmers on the question which factors would influence their decision to use reclaimed wastewater in irrigated agriculture. The following findings stand out. First, 'increasing awareness and attitude change', is of large importance for

> The Council of Leading Islamic Scholars (CLIS), Saudi Arabia 1978 stated that impure wastewater can be considered as pure water and similar to the original pure water if its treatment using advanced technical procedures is capable of removing its impurities with regard to taste, colour and smell, as witnessed by honest, specialized and knowledgeable experts. Then it can be used to remove body impurities and for purifying, even for drinking. If there are negative impacts from the direct use on the human health, then it is better to avoid its use, not because it is impure but to avoid harming human beings. The CLIS prefers to avoid using it for drinking (as possible) to protect health and not to contradict with human habits.

acceptance of TWW and shows that farmers are familiar with the TWW and aware that this water source is different from freshwater supplies. This also explains why few farmers will not let themselves being influenced by psychological aversion, nor by 'religious prohibition' as most farmers were aware of the Islamic fatwa[6] permitting the use of TWW in agriculture (see box). Still old farmers don't like the idea even in spite of religious permission. Second, economic and marketing considerations like 'crop marketing', 'acceptance by consumers' , 'pricing of freshwater versus reclaimed wastewater', 'farm profit' influence to a large extent farmers' decision and confirms the trend observed in the previous paragraph. Therefore, their concerns on health ('farmers' and 'consumers') and environmental ('soils', 'crops') score somewhat lower than other factors that influence the decision on TWW. Third, interesting is the result that 'the existence of fertilizers in reclaimed wastewater' influences the farmers' decision. This is most likely a positive spin-off from the GTZ project where it was found that fertilizer application can be lowered by approximately 52 to 76 percent when farmers are using TWW in their agriculture (MWI 2004), resulting in considerable cost savings and a reduction of nutrients leaching to the groundwater (Hussain et al. 2002). Finally, 'impact on irrigation equipment', is by many (almost 60 percent) not considered a problem, most likely because farmers at Jordan valley hardly maintain their irrigation network but change the piping network every two to three years.

5.4.3 WTP: a multivariate analysis

After the univariate analysis of the previous section we now turn to investigate the joint effect of variables to test several hypotheses concerning the willingness of farmers in the Jordan Valley to pay for treated wastewater as an alternative to freshwater.

The WTP model is designed to explain farmers' responses to each mentioned bid. For this analysis we used the ordered logit model that was introduced in section 5.2. To make the results interpretable and avoid over fitting we aggregated some of the variables that referred to similar subjects. Table 5-5, lists the explanatory variables that were used to explain the WTP choices of the farmers.

[6] Fatwa: is a legal ruling on an issue of religious importance

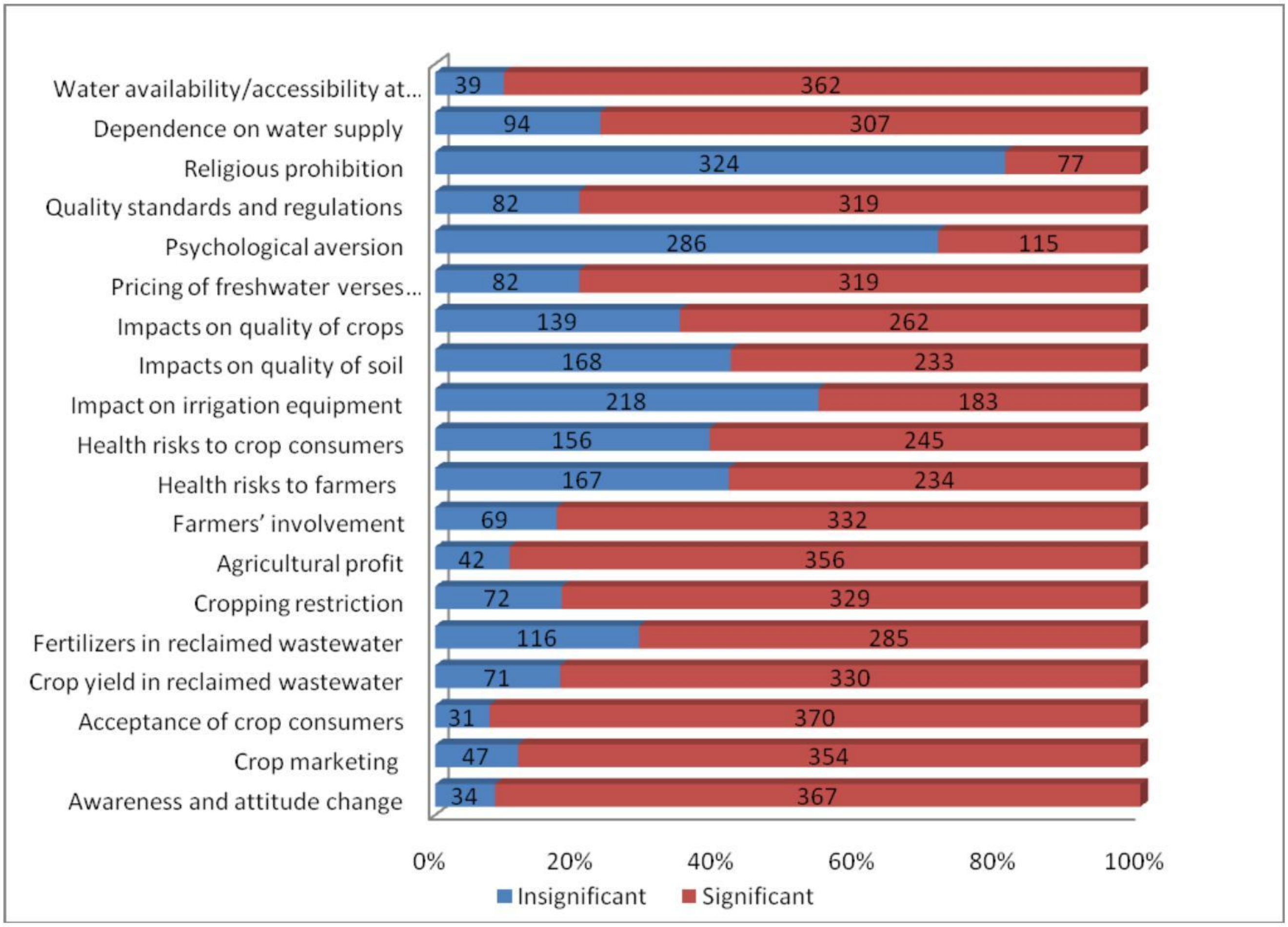


Figure 5-11: Farmers' ranking of the factors that potentially influence the use of reclaimed

The identification of significant variables for the model was done by a step-wise selection procedure (Kramer 1996). So, in this stage we let the statistical characteristics of the data set decide whether the variables are included in the model or not. The decision to include a variable is based on the log-likelihood of the estimation and χ^2-test statistics of the variables. In each selection round, the variable that leads to the largest improvement in the log-likelihood was included in the model. After a variable was included, it was tested whether the exclusion of a variable included at an earlier stage gave a further improvement. This process was terminated when the inclusion of an extra variable did not lead to a significant improvement of the model. The level of significance for acceptance in the step-wise selection is 0.05.

We will first model the WTP choices for the entire sample of all the farmers in the JV. Next we repeat the estimation rounds for the three different regions. After the first estimations we found that the few observations in class 1 could not be reproduced by any model and, for this reason we decided to aggregate class 1 and 2 in the first class. Hence, the estimation took place for five ordered bidding classes.

Table 5-5: Variable and its aggregation

Variables Single	Description	Meaning of value
Cultiv_Area	cultivated area (in dunum)	real value (15-180 dunum)
Age	Age of respondent	1=20-29; 2=30-39; 3 = 40-49; 4= over 50
Educ_est	Education	1= 'primary'; 2='secondary'; 3='higher education'
Own_est	Ownership	1=owner, 2=rent/lease
Crop_est	Crops cultivated	1=Citrus/Palm/Banana/Field Crops/Other 2=vegetables
Water type_est	Water type used for irrigation	1=Fresh (Groundwater, Surface), 2=Blended (including TWW)
systirr_est	Irrigation system	1= Furrow/Sprinklers/Flood, 2 = Drip
NetPro_Faryea	Net profit farm	real value (1500-126000)
Having Well	Well	0=no, 1 = yes
Conce_Wat_Tariff	Concerns about water tariff	0=no, 1 = yes
Ferti_ Saving	Possibility for saving fertilizer when using TWW	0=no, 1 = yes
Irrigat_Equipment	Concerns about Irrigation equiplen when using TWW	0=no, 1 = yes
Ava_Fresh	Availability of freshwater	0=no, 1 = yes
Awa_Attit_chan	Importance of awareness and attitude change	0=no, 1 = yes
Composed		
Organization	Member of farm association + Member of water association + farmers involvement	0=all answers no, 1= one 'Yes', 2= two times 'Yes', 3=three times 'Yes'. 4 =three times yes
Conc_water_qual	Concern about water type +Concern on water quality + Quality standards and regulations	0=all answers no, 1= one 'Yes', 2= two times 'Yes', 3=three times 'Yes'
Conc_impact	Concern crop quality + Concern soil quality	0=all answers no, 1= one 'Yes', 2= two times 'Yes'
OpinDirect	Opinion of relationships + Opinion of Friend + Farmers involvement in the planning and decision- making+ Media	0=all answers no, 1= one 'Yes', 2= two times 'Yes', 3=three times 'Yes'. 4 =three times yes
OpinGov	Reports, brochures, and studies+ Advice by specialists	0=all answers no, 1= one 'Yes', 2= two times 'Yes'
InfMarket	Crop Marketing+ Acceptance of crop consumers	0=all answers no, 1= one 'Yes', 2= two times 'Yes'
InfDev	Crop Yield + Fertilizers in reclaimed wastewater + Crop Restriction ;	0=all answers no, 1= one 'Yes', 2= two times 'Yes', 3=three times 'Yes'
InfEcon	Agricultural Profit + Pricing of freshwater	0=all answers no, 1= one 'Yes', 2= two times 'Yes'
InfHealth	Health RiskfFarmers + Health Risk consumer	0=all answers no, 1= one 'Yes', 2= two times 'Yes'
InfhEnv	Soil Quality + Crops Quality + Diseases	0=all answers no, 1= one 'Yes', 2= two times 'Yes', 3=three times 'Yes'
InfPsy	Psychology effects + Religious Prohibition	0=all answers no, 1= one 'Yes', 2= two times 'Yes'

Model for all JV farmers. The parameter estimates that were selected by the stepwise regression procedure at the 5 percent significance level for all interviewed farmers are presented in Table 5-6.

Table 5-6: Parameter estimates of the WTP model for all farmers at the JV.

Parameter	**Estimate**	**Standardized**
Intercept (1)	**-0.5329**	
Intercept (2)	**0.8895**	
Intercept (3)	**2.3612**	
Intercept (4)	**4.8237**	
Cultiv_Area___dunum	**0.0355**	**0.2681**
Age	**-0.2313**	**-0.1194**
educ_est	**-0.5028**	**-0.1994**
NetPro_Faryea	**-0.00014**	**-0.6256**
HavingWell	**0.7605**	**0.1627**
Conce_Wat_Tariff	**2.3732**	**0.5382**
Irrigat_Equipment	**-0.9647**	**-0.2658**
Ava_Fresh	**-0.9443**	**-0.1396**
organization	**0.3778**	**0.2003**
InfMarket	**-0.6254**	**-0.1335**
InfHealth	**0.7664**	**0.4014**
InfPsy	**1.1282**	**0.4834**

The intercept scales the probability model for the different class estimates. The negative sign indicates that for higher values the probability of a higher bid increases, and the reverse, when the sign is positive the probability for lower classes increases[7]. The standardized estimate gives the rescaled parameter (estimated value divided by its variance) and can be used to compare the relative strength of the various predictors.

The stepwise regression procedure selected 12 factors that affected the farmers' decision jointly. The highest impact has the size of the farm profit; higher farm profits are clearly a motivation to consider higher bids. Also higher age and higher education levels are likely to result in higher bids. This also holds for more marketing information and the concern about the quality of irrigation equipment when TWW is used. The latter can be explained by the farmers' habit to replace their entire irrigation equipment every two to three years to minimize possible negative effects of TWW use. Surprisingly, the presence of freshwater indicates a slight tendency to a higher bid. The concern about the water tariff is the second highest factor that influences the farmers' decision; more concern is likely to give a lower bid from the farmer. This lower bidding has also a higher probability when there is the presence of a well, most likely because it makes the use of TWW less urgent. Farmers with higher concerns about health and psychological effects also result in lower bids. A higher rate of organization means that farmers will bid less, most likely because they might negotiate for lower tariffs when organized as a group. Farmers with

[7] The results of ordered logit models were derived by the SAS package.

bigger farms tend to give a lower bid for increasing farm size, though the marginal contribution of this factor is low.

In Table 5-7 the class predicted by the model is compared with the farmers' bid. The diagonal shows the number of times that the model correctly reproduced the farmers bid. In total a 185 times (48 percent) the farmers' bid was correctly predicted by the model. The model under estimated the farmers' bid a 115 times (30 percent), but, more seriously, over estimated the farmers bid a 86 times (22 percent), indicating a higher price that the farmer is willing to pay and possibly discouraging his participation in TWW use if that price would have been used.

Table 5-7: Frequencies (and percentages) of observed and estimated Farmers' WTP classes for all JV farmers

Farmers respond		Model Estimated classes					
		1	2	3	4	5	Total
	1	45 (11.66)	18 (4.66)	10 (2.59)	13 (3.37)	1 (0.26)	87 (22.54)
	2	42 (10.88)	16 (4.15)	18 (4.66)	2 (0.52)	0 (0)	78 (20.21)
	3	14 (3.63)	15 (3.89)	19 (4.92)	24 (6.22)	0 (0)	72 (18.65)
	4	1 (0.26)	5 (1.30)	4 (1.04)	94 (24.35)	0 (0)	104 (26.94)
	5	0 (0)	0 (0)	0 (0)	34 (8.81)	11 (2.85)	54 (11.66)
	Total	102 (26.42)	54 (13.99)	51 (13.21)	167 (43.26)	12 (3.11)	386 (100)

5.4.4 Model of farmers' choice per region in the JV:

The selected factors changed when the model was estimated for the regions separately. For the Northern region the concern for water tariff had the highest influence on the farmers' bids; the more concern on water tariff the lower the farmers' bidding. This reflects the farmers' use and access to freshwater resources and the current lack of interest to use TWW. Possibly a lower price might be more convincing for the Northern JV farmers. The decision for higher bids is positively influenced by a more solid ownership, increased opinion of direct relatives and more information on environmental impacts. Higher concerns on psychological effects results in lower biddings.

Table 5-8: Parameter estimates of the WTP model for all farmers at the different regions in the JV.

	JV regions					
	North		Middle		South	
Factor	**Estimated**	**Standardized**	**Estimated**	**Standardized**	**Estimated**	**Standardized**
Intercept 1	3.1063		2.6753		2.1894	
Intercept 2	5.1347		5.2179		2.8765	
Intercept 3	7.5652		6.8389		4.9361	
Intercept 4	9.3847		7.5401		11.7405	
own_est	-1.5093	-0.3059	-1.0568	-0.2858	___	___
Conce_Wat_Tariff	4.0549	1.0019	___		___	___
Opin Direct	-0.6513	-0.346	___		___	___
InfhEnv	-0.8495	-0.411	0.9268	0.4608	___	___
InfPsy	1.0334	0.5126	1.268	0.5987	2.9005	0.6689
Cultiv_Area	___	___	0.0264	0.2761	___	___
Fertilizer saving	___	___	-5.2474	-0.9374	___	___
HavingWell	___	___	-3.7477	-0.504	2.0588	0.5573
Conc_water_qual	___	___	-1.1645	-0.3564	-0.8306	-0.3439
educ_est	___	___	___	___	-2.603	-0.8243
crop_est	___	___	___	___	-1.3714	-0.2812
NetPro_Faryea	___	___	___	___	-0.00021	-0.5557
Irrigat_Equipment	___	___	___	___	-4.047	-1.1185
Ava_Fresh	___	___	___	___	3.0235	0.4415
Conc_impact	___	___	___	___	4.1331	1.3149
InfHealth	___	___	___	___	1.6289	0.8467

Concerning the model results for the Middle JV, the highest influence is given by the factor that considers the saving on fertilizers. Farmers are WTP more if the effect of fertilizer saving is known. This is an interesting factor for policy makers as they can positively influence the use of TWW when they can make farmers aware of the positive effects of fertilizer saving. More concern about water quality, the presence of a well and the solidity of ownership increased the WTP for TWW, while higher concerns on health and psychological effects result in lower bids.

In the South JV, the major factor that influenced the height of the farmers' bid is the concern about crop and soil impact when TWW is used. This might be related to the fact that there main crop is banana which is a sensitive crop and to the recent high investments in palm tree cultivation in this part of the JV, and the unknown risks when TWW is used. Higher farm profits, higher education and cultivation of vegetables result in a higher bids. Concern on water quality and impact of irrigation equipment does not influence the selection of a higher bid negatively. Availability of freshwater, having a well, more information on health related issues and psychological effects all result in lower bids. It is remarkable that psychological effects were selected in all three estimation rounds, indicating that an increase in psychological effects will result in a lower bid.

Table 5-9: Frequencies (and percentages) of observed and estimated Farmers' WTP classes by region in JV farmers

	Jordan Valley Region		Model Estimated classes 1	2	3	4	5	Total
Farmers respond	North	1	30 (26.55)	6 (5.31)	3 (2.65)	0 (0)	0 (0)	39 (34.51)
	Middle	1	16(12.60)	15 (11.81)	0 (0)	0 (0)	0 (0)	31 (24.41)
	South	1	11 (7.53)	0 (0)	3 (2.05)	3 (2.05)	0 (0)	17 (11.64)
	North	2	7 (6.19)	18 (15.93)	6 (5.31)	0 (0)	0 (0)	31 (27.43)
	Middle	2	5 (3.94)	33 (25.98)	2 (1.57)	0 (0)	1 (0.79)	41 (32.28)
	South	2	3 (2.05)	0 (0)	2 (1.37)	1 (0.68)	0 (0)	6(4.11)
	North	3	0 (0)	4 (3.54)	29 (25.66)	0 (0)	0 (0)	33 (29.20)
	Middle	3	0 (0)	7 (5.51)	12 (9.45)	0 (0)	3 (2.36)	22 (17.32)
	South	3	7 (4.79)	0 (0)	5 (3.42)	5 (3.42)	0 (0)	17 (11.64)
	North	4	0 (0)	2 (1.77)	6 (5.31)	0 (0)	0 (0)	8 (7.08)
	Middle	4	1 (0.79)	2 (1.57)	0 (0)	0 (0)	5 (3.94)	8 (6.30)
	South	4	0 (0)	0 (0)	2 (1.37)	85 (58.22)	1 (0.68)	88 (60.27)
	North	5	0 (0)	0 (0)	2 (1.77)	0 (0)	0 (0)	2 (1.77)
	Middle	5	0 (0)	5 (3.94)	3 (2.36)	0 (0)	17 (13.39)	25 (19.69)
	South	5	0 (0)	0 (0)	0 (0)	5 (3.42)	13 (8.90)	18 (12.33)
	North	**Total**	37 (32.74)	30 (26.55)	46 (40.71)	0 (0)	0 (0)	113 (100)
	Middle	**Total**	22 (17.32)	62 (48.82)	17 (13.39)	0 (0)	26 (20.47)	127 (100)
	South	**Total**	21 (14.38)	0 (0)	12 (8.22)	99 (67.81)	14 (9.59)	146 (100)

In Table 5-7 compares the classes predicted by the model with the farmers' bid for all three regions. For the Northern region 77 of the bids (68 percent) were correctly estimated by the model, 21 (19 percent) was underestimated and 13 percent were overestimated. Yet, the model was not able to reproduce the higher bids in classes 4 and 5, possibly because of the few observations in these classes (8 and 2, respectively for class 4 and 5). For the middle region the model correctly estimated 71 (61 percent) of the bids, 23 times (18 percent) the bid was underestimated and 26 times (21 percent) the bid was overestimated. Class 4 was not reproduced by the model, most likely because it was mentioned only 8 times. The Southern region had a striking 114 cases (78 percent) correctly estimated. Only 17 cases (12 percent) were underestimated and 15 cases (10 percent) were overestimated. The model did not reproduce the class 2 which was mentioned only 6 times by the farmers.

We can conclude that the models for the regions had a better hit ratio as compared to the overall model. This confirms the heterogeneity among the farmers in the JV and the necessity to make tailor-made policies for the introduction of TWW.

5.5 Robustness of parameter estimates

We tested the models for their sensitivity to the inclusion or exclusion of observations and stability of its parameter estimations by a tenfold cross-validation procedure as described in Section 5. Figure 4.5 presents these estimates.

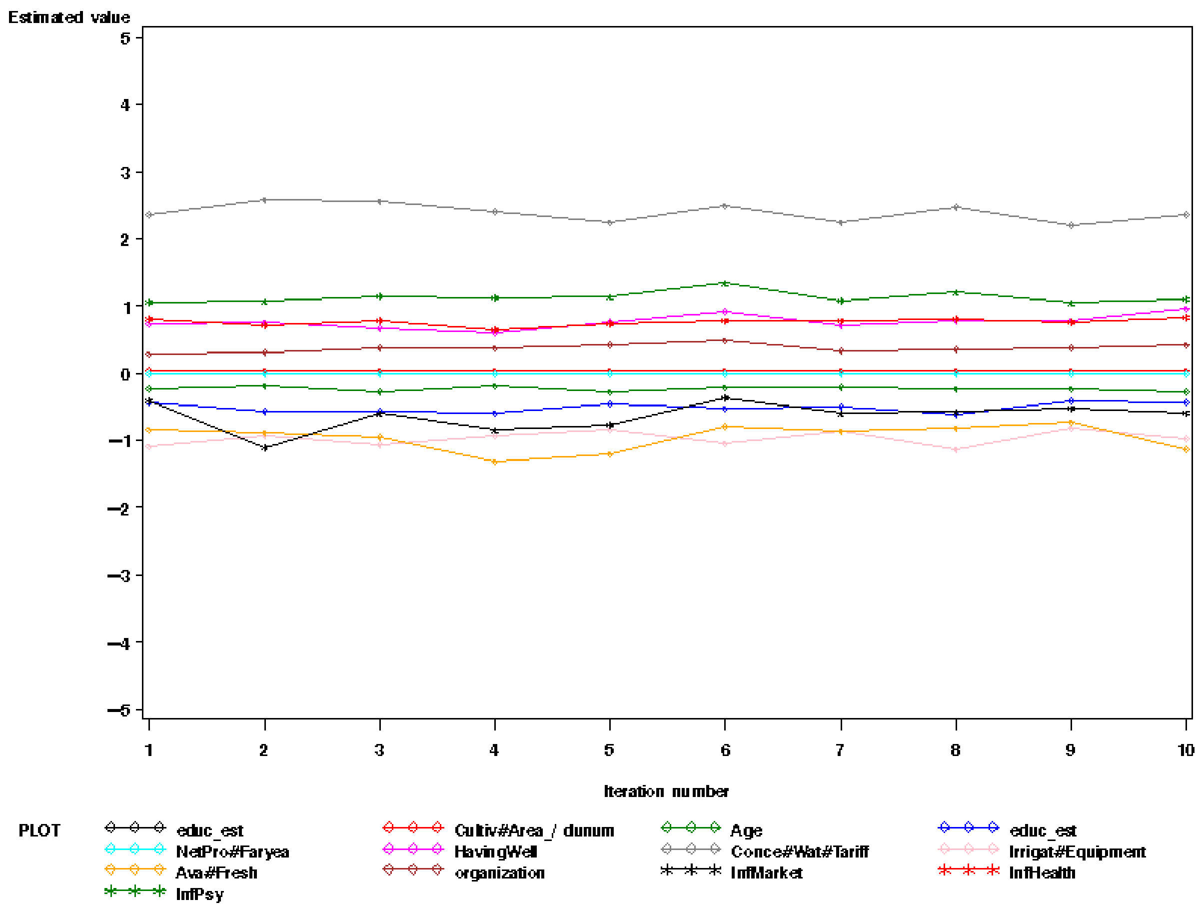


Figure 5-12: Tenfold cross validation for the entire sample.

Tenfold cross-validation procedure most parameters show minor fluctuations and all maintain their sign throughout the iterations. Only the Information of market and availability of freshwater factors are relatively sensitive, yet their standardized estimates are low and will therefore have minor influences on model results.

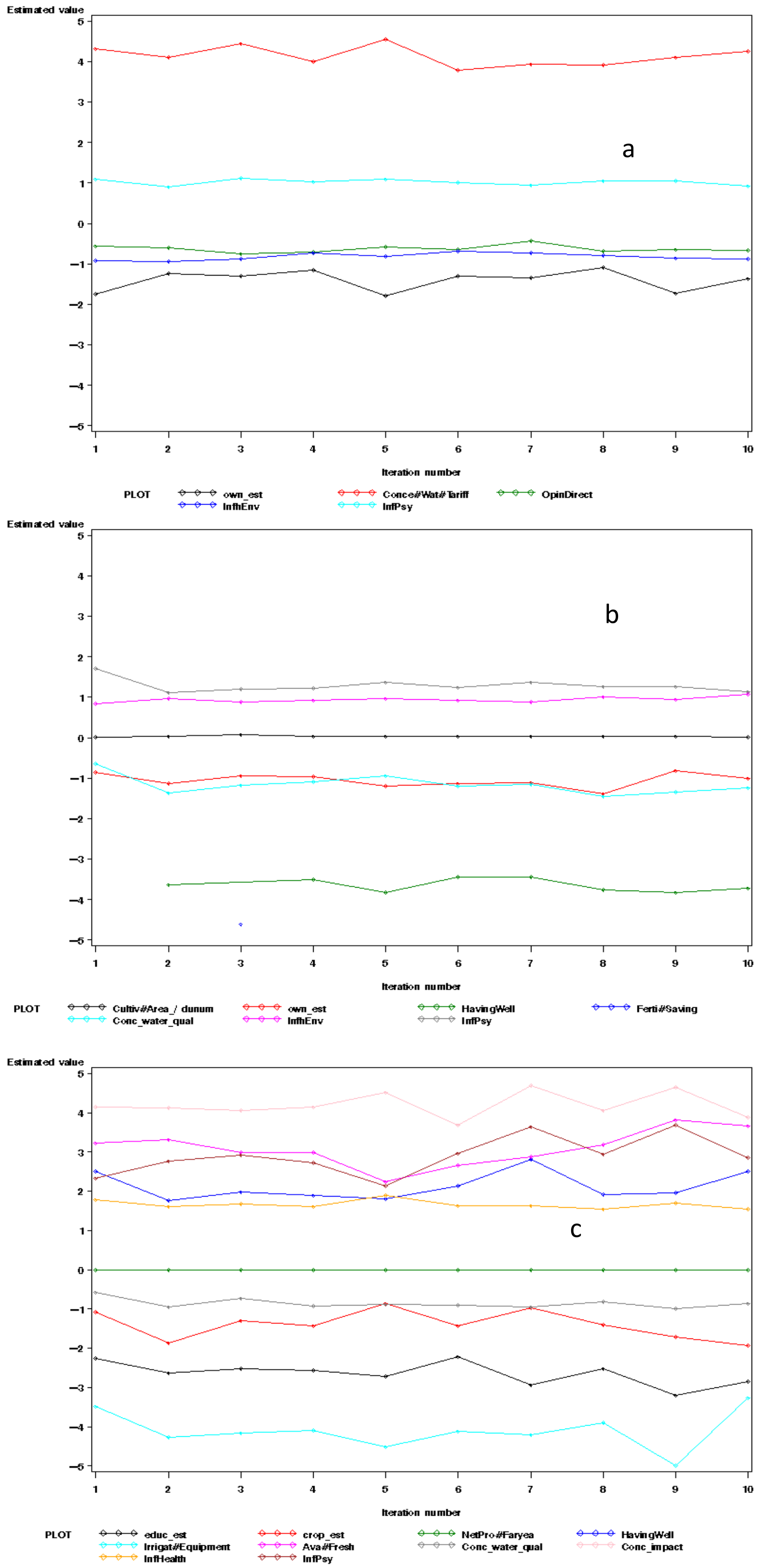


Figure 5.17. Tenfold cross validation for the northern (a), middle (b) and southern (c) region.

The same tenfold cross-validation procedure was repeated for the models that estimated the biddings for the three regions separately. Results are shown in the Figure 5-12 a-b-c for respectively Northern, Middle and Southern region.

Again most lines only show minor fluctuations, except for the southern region where availability of freshwater, having a well and psychological effects show a relative larger variability indicating that the magnitude of their parameter estimates has a higher dependence on the data as compared to other factors.

We can conclude from the results of the ten-fold cross validation that most parameter estimates show a relative stability and rather low dependence on the data. This means that the models can be applied with confidence for the large range of conditions used in this exercise.

5.6 Conclusion for the WTP model at the JV

Water scarcity is a dominant constraint for social and economic development in the Middle East. Irrigation water consumes about three-fourths of the available freshwater resources in Jordan and many other countries in the region. The ultimate objective is to manage irrigation water use under geographic, socio-economic and demographic constraints. The Jordan Valley is a typical case in point that sees its full agricultural potential blocked by the lack of water. However, water can be used several times and this specific characteristic has been seriously underutilized in Jordan as this study shows: The reuse index was only 34 percent for Jordan. A doubling of this amount would suffice to cover irrigation water requests in the Jordan Valley where current required/supply ratio is in the range of 40-80 percent. This study shows that farmers are willing to pay a much higher price compared to the current tariff. This choice is justified by the high profits that can be made for each additional cubic meter of water.

We found for the overall modelling of the farmers' WTP that higher farm profits clearly motivates higher bids; which shows the entrepreneurial spirit of the JV farmers and is in line with the same effect that we found for the factor 'marketing information'. The concern about the water tariff is the second highest factor that influences the farmers' decision; more concern is likely to give a lower bid from the farmer. Farmers with bigger farms tend to give a lower bid for increasing farm size. This was somewhat surprising as the reverse effect was expected, yet the marginal contribution of this factor is low and will, therefore, not be of much influence to the model results. The overall model results for all the farmers were moderate to low, with less than 50 percent correctly estimated. Classes had a serious overestimation of 22 percent—the model results should be interpreted with care. Yet, the parameter estimates are robust and the model will not easily be improved when more data are obtained.

The separate models for the Northern, Middle and Southern JV have a larger predictive power and present much better hit ratios. These outcomes also justify the separate analysis for these areas that might lead to different approaches for the introduction or expansion of TWW. Again the concern for water tariff had the highest influence on the farmers' bids in the Northern part of the valley. Since it is unlikely that a differentiated water tariff for different regions in the JV will be introduced extra efforts will be required to put in extension work to convince the farmers that there will be additional profits from TWW introduction. This is also not an easy task as the marginal contribution of water is smallest in the prevailing citrus farms found in this part of the JV.

In the Middle part where the use of TWW is common and awareness of additional fertilizer effects prevails farmers easily pay more for additional TWW. This is also interesting for policy makers as they can positively influence the use of TWW with farmers of the Northern region by making them aware of the positive effects of fertilizer saving. For example, farmer excursions to the neighbouring areas with appropriate extensions might have a convincing effect for hesitant farmers. The special impact of the newly and highly invested palm trees In the South JV also justifies a separate analysis.

Of special importance for extension workers is that the psychological effects were selected in all three estimation rounds as a positive sign. Obviously, the mind set of people is important. Recent evidence of this statement was obtained during a field visit when a farmer started complaining about his crop failure that he blamed on the newly introduced TWW. The further unverified story quickly spread around and other farmers were at the point of refusing the next supply of TWW, not withstanding the fact that adjacent farms with the same crops that received the same TWW were not affected.

In the previous chapter the water allocation model shows that there is a demand for using TWW, while in this chapter we found that there is a potential market for this water. In the coming chapter we will investigate the pricing scenarios based on quality and volume.

6 Alternative Proposal for Irrigation Pricing Mechanism in the JV

6.1 Introduction

Water markets are increasingly being relied upon as an instrument to reallocate water between competing users. Under conditions of water scarcity these water markets can also provide the required capital for additional investments in water infrastructure to tap from unconventional water resources as TWW. Indeed, without such additional water sources new irrigation developments in the JV cannot take place, as all water sources are fully committed in an advanced drip irrigation infrastructure that leaves little room for efficiency gains. (Venot et al. 2007) showed that water constraints impede a further exploration of the JV and that currently a large part of its full agricultural potential remains underutilized. During the field visits that were made in this study farmers in the JV often complained that the demand/supply ratios were even lower than Venot's assessment. Hence, without additional water volumes the economic development in the JV will be foregone, often times with a negative effect on the rural communities. This study shows in the previous chapter that Treated Waste Water (Hussain et al. 2002) is likely candidate to fill this gap.

The idea of water markets has been advocated by many scientists, e.g. (Howitt et al. 2005; Chong et al. 2006). Yet in 1992 the discussion on water pricing reached a turning point at the Dublin International conference on water and Environment where the fourth[8] principle underscored that "Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources." (WMO 1992). Similar to the adoption of a comprehensive policy framework on water markets and the treatment of water as an economic good, was the World Bank's core management approach on water resource management (World Bank 1993) to highlight that "waste and inefficiency have resulted from the frequent failure to use prices and other instruments to manage demand and guide allocation".

At the Jordan Valley the majority of the freshwater resources are transferred to the capital of Jordan - Amman city for municipal and domestic uses, thus reducing freshwater that is supplied for the agriculture areas. The used water is, in turn, sent back as treated wastewater (TWW) to the Jordan

[8] Principle No. 4 - Water has an economic value in all its competing uses and should be recognized as an economic good, Within this principle, it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price. Past failure to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is an important way of achieving efficient and equitable use, and of encouraging conservation and protection of water resources.

Valley, as a policy for reallocation. This is applied to Middle and part of South JV while the North JV is yet using freshwater. Meanwhile water distribution in JV depends upon the availability of water, i.e. if the rainy season was good and increases the availability of freshwater storage at the reservoirs then the percentage of water (fresh and blended) that the farmer is receiving will be increased.

Concerning the assignment of a price for TWW a balance must be achieved. If the price is too close to potable water, weary users will tend toward potable water for all purposes in order to avoid complications, regulations and market uncertainty. Furthermore, agriculture alone is unlikely to support the funding necessary for large scale recycled water schemes.

The provision of water irrigation pricing policies in Jordan are based on the assumption that water prices should cover at least the cost of operation and maintenance and should be used as an incentive to improve on-farm irrigation use efficiency. The price of irrigation water in the Jordan Valley was (0.008 JD) is clearly a form of subsidy to the farmers. Yet additional infrastructure is expensive and new water tariffs can be used to contribute to generate additional water volumes.

Yet, when introducing TWW we have to consider two qualities of this water resource. First, treated wastewater can be a rich source of nutrients that has advantageous effects on crop growth if nutrient concentrations are delivered in the correct amounts. If, for example, the total nitrogen delivered to the crop via treated wastewater irrigation exceeds the recommended dose, it may delay ripening and maturity, and cause yield losses. Second, the dissolved nutrients also cause rising levels of salinity that might affect sensitive crops negatively.

Several issues must be considered in order to appropriately value treated wastewater (TWW) especially when developing distribution mechanisms. Too low a price might encourage inefficient use and could lead to the perception that TWW is a cheap and unlimited resource. Our survey showed that 96 % of the Jordan Valley farmers have an interest in using TWW, provided that that water meets the Jordanian and International water quality standards. However, farmers did send out a double message. A majority answered negatively when asked if they want to pay the same price for TWW as freshwater. Yet, in the bidding exercises farmers showed a WTP much more that the current price. Meanwhile the current price is giving the same value for water beside its quality.

Gardner (1983, cited in (Fraiture et al. 2007)) states that if water prices rise to reflect its extra costs, , a rational farmer will have any or all of the four following responses: the farmer demands less water and leaves land fallow; applies less water to the crop accepting some yield loss; switches to less water-demanding crops; and/or invests in more efficient irrigation techniques. Literature provides evidence that farmers respond in all these ways.

From the survey and analysis in the previous section it has become clear that both water quantity and quality are important ingredients to value water resources as an economic good. A correct pricing mechanism will therefore encourage farmers in the JV to:

- increase the efficiency of water distribution where possible,
- invest in unconventional water resources as TWW
- save on fertilizer costs

This chapter is organized as follows. In section 6.2 we evaluate the effect of nutrients in TWW for its cost saving effects on fertilizers. Section 6.3 quantifies the effect of salinity levels on crop yields. Section 6.4 employs this information to evaluate the costs of producing additional TWW volumes and its impact on farmers' income under various water tariff scenarios. Section 6.4 concludes.

6.2 Proposal for Reform of the Pricing of TWW by added value for Nutrients

From an agricultural standpoint treated wastewater could have positive and negative impacts. The nutrient load in treated wastewater is a positive point for its nutrition value but also has to be considered for its salinity levels which have negative effects for sensitive crops. The following paragraph sheds light on both parameters in the use of treated wastewater in the Jordan Valley. Weighing the positive and negative points is very important before starting presenting proposals on water pricing.

6.2.1 Nutrients and Fertilization Management

TWW irrigation water in the central and south JV contains dissolved nutrients, which can be used by plants.

Table 6-1 shows the average values of three major nutrients (mg/l) for the years 2003-2005 for two major TWW sources, KTR and KAC-south. For comparison the nutrient content of (freshwater) King Abdullah Canal-north (KAC-north) is also shown (GTZ 2006).

Table 6-1: Average values (mg/l) for N, P and K in different water sources in the central and south JV.

Water source	NO_3-N + NH_4-N	PO_4-P	K
KTR	18.6	3.9	26.1
KAC-south	18.4	3.1	26
KAC-north	1.4	0.23	10.5

Source: JVA and RSS labs, 2003-2005 (GTZ 2006).

NB: due to the recently rehabilitation of Kherbit As-Samra treatment Plant which drain to KTR and KAC south, nitrogen (NO_3-N + NH_4-N)content is reduced to 15 mg/l

6.2.2 Calculating Nutrients in Irrigation Water

Table 6-2 shows the nutrients expressed in their weight equivalent of commercial fertilizers. The nutrients in KTR and KAC-South are close to the ratio of commercial NPK fertilizers where we find 10 kg N, 20 Kg P_2O_5 and 30 K_2O per 100 kg. The average commercial price in Jordan is 1500 JD per ton (see Table 6-3). As 1000 m^3 water equals the amount of 100 kg of commercial fertilizers, it is equivalent to a value of JD 150. Hence, one cubic meter of treated wastewater equals JD 150/1000 (0.15 JD/m^3).

Table 6-2: Amounts of nutrients in the irrigation water sources in the Jordan Valley

Water source	N (kg/1000 m^3)	P_2O_5 (kg/1000 m^3)	K_2O (kg/1000 m^3)
KTR	18.6	8.9	31.4
KAC-south	18.4	7.05	31.3
KAC-north	1.4	0.52	12.7

Table 6-3: Price of Fertilizer at the Jordan market for 2007

Name	**Formula**	**Percent of nutrient**	**Price/ ton (JD)**
Ammonium Sulphate	$(NH_4)_2 SO_4$	N (21%) S (24%)	380
Potassium nitrate	$KNNO_3$	K (46%) N (13)	1100
Urea-phosphate	$H_3PO_4 CO(NH_2)_2$	N (13%) P (44%)	1700
Urea	$(NH_2)_2CO$	N (46 %)	650
20-20-20	compound	N (20%), P_2O_5(20%), K_2O (20)	750-1200*
20-10-20	compound	N (20%), P_2O_5(10%), K_2O (20)	900-1500
20-10-30	compound	N (20%), P_2O_5(10%), K_2O (30)	1000-2000

NB: Source: GTZ, Reuse of marginal water, * the difference in prices due to differences in import country

The water quality as discussed earlier in Chapter two (Study Area), shows that up to now the freshwater and treated wastewater had the same prices. It is required to attach higher value to the freshwater taking into account its crucial importance as drinking water and for domestic uses. In Jordan the price of one cubic meter is 0.12 JD, for the first 22 cubic meters and increases with higher water deliveries.

We conclude that when the price of water should consider the added value for nutrition in the TWW, as this can help to reduce fertilizer costs. A GTZ project has proved from that farmers can save about 50% of farm fertilizer in each season.

6.2.3 Impact of salinity

A major degradation factor of re-used waters can be its high salinity levels that are caused by high ion concentrations that have a negative effect on the water intake of the plants as it competes with the plants' osmotic potential. Moreover, high ion concentrations might reach toxic levels that impede proper plant growth. Finally, high concentration of alkaline damages the structure of the soil, with a dramatic loss of water holding capacity as a result.

Yet, the reaction of yield performance on higher salt concentrations is typically crop specific; crops might be highly sensitive or highly tolerant to salinity. Therefore, TWW with higher salt levels requires an appropriate selection of crops. Moreover, to prevent an accumulation of salts in the root zone the water management should include a drainage system, regular leaching of the salts with freshwater, possibly with Calcium contents in case of high Alkaline concentrations. Below we will concentrate on the impact of salinity levels on the yields.

Table 6-4 : Relative crop salinity tolerance rating (FAO. 2002)

Relative crop salinity tolerance rating	**Soil salinity (ECe) at which yield loss begins**
Sensitive *Banana- Apple- Okra - Onion*	< 1.3 ds/m
Moderately sensitive *Citrus – Cabbage – Cucumber- Eggplant*	1.3 – 3.0 ds/m
Moderately tolerant *Olive trees Squash, zucchini*	3.0 – 6.0 ds/m
Tolerant (Date Palm- Tomato	6.0 – 10.0 ds/m
Unsuitable for most crops (unless reduced yield is acceptable)	> 10.0 ds/m

Source :(FAO. 2002)

6.2.4 Effects of salinity on crop growth and yield

There is a wide range in plant species response to salinity. Sugar beet, sugar cane, dates, cotton and barley are among the most salt tolerant; whereas beans, carrots, onions, strawberries and almonds are considered sensitive (Dajic 2006). In general, salinity decreases both yield and quality in crops and previous research has led to the development of large data bases on the salt tolerances of many crop species and varieties. Salt tolerance can be represented most simply based on two parameters: the threshold salinity (t) which is expected to cause an initial significant reduction in the maximum expected yield (Y); and the slope (s) of the yield decline. Slope is simply the rate that yield is expected to be reduced by for each unit of added salinity beyond the threshold value. The formula to calculate relative yields is (Allen et al. 1998):

$YR = Y - s (EC_e - t)$ where $EC_e > t$

Salts are added to the soil during each time of irrigation and accumulate in the root zone. In case that appropriate drainage systems are absent and insufficient freshwater is available for leaching soil salt levels might reach damaging concentrations. The crop removes much of the applied water from the soil to meet its evapotranspiration demand (ET) but leaves salts behind in the shrinking volume of soil water. The following table shows crop tolerance rating and their equivalent soil salinity.

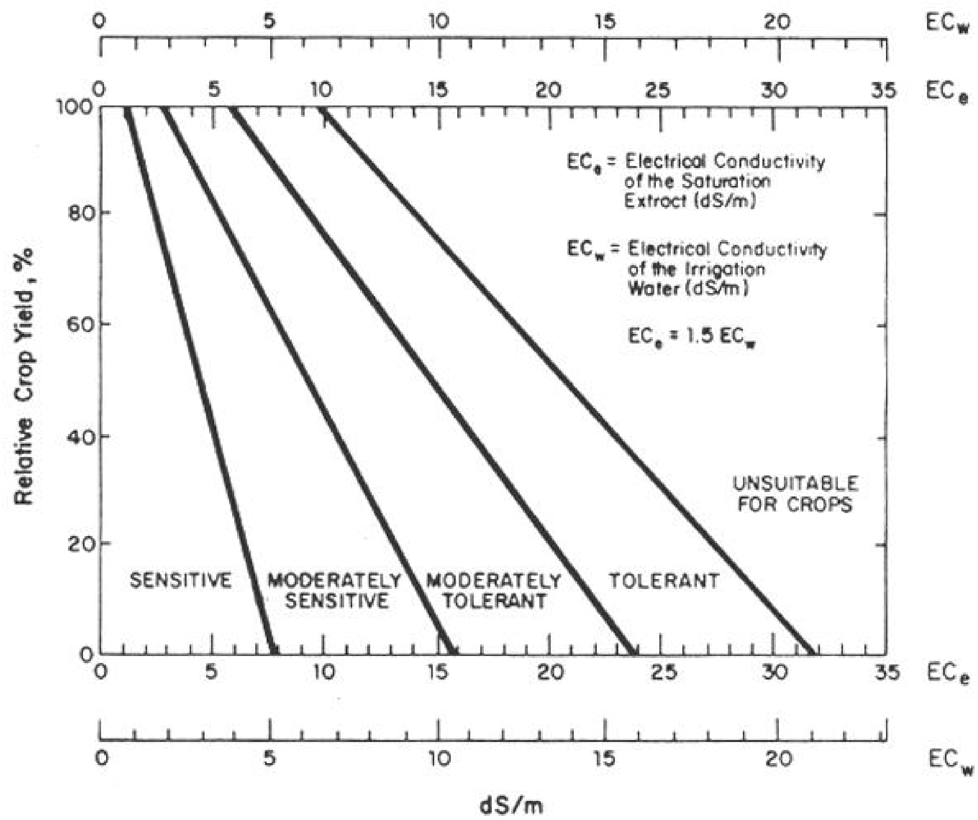


Figure 6-1: Effect of salinity levels for crops with different degrees of salt sensitivity. Source: (Ayers and Westcot 1994).

Figure 6-1 stylizes the yield reducing effects for crops with different sensitivity levels for salinity. We will use this relationship in the next section when we evaluate the introduction of additional TWW in the JV.

The average salinity for treated wastewater at King Talal Reservoir (KTR) used in the Jordan Valley is 2.7 whereas the average salinity for freshwater resources from King Abdalah Canal (KAC) is 1.1. So, significant yield loss can be expected for sensitive crops that are cultivated on treated wastewater.

6.3 Pricing scenarios to cover the costs of additional TWW

An important question that has to be resolved is who will bear the costs to generate additional TWW water volumes. Therefore, we will evaluate in this section various water pricing alternatives evaluate simultaneously the impact on 1) cost coverage for new TWW plants and 2) on farmers' income. In this assessment we will combine the information that has been derived from section 6.1 and 6.2. Our approach is to first estimate at the JV level the amount of water that is required to meet the full demand. This additional TWW water volume is related to different cost assessments. Next we will evaluate for four prevailing farm archetypes, which are considered representative for the majority of farm households in the JV, the impact of additional water volumes considering the impact of the goods (water quantity, fertilizer) and the bads (salt level). Finally, we will evaluate various water pricing scenarios and evaluate their cost coverage for additional TWW production and the impact on income under the four farm archetypes.

Cost of producing one CM TWW. According to the Ministry of water and Irrigation the average cost to produce one cubic meter TWW without including operation and maintenance (O & M) cost is 0.026 JD per cubic meter. If the cost of O & M is considered then the cost for each cubic meter is 0.63 JD. Including capital costs raise the price to 1.3 JD/m3 (MWI 2009). Currently the average total water volume that is supplied to the JV is 250 MCM, 87 MCM of which is TWW. The average demand/supply ratio in the JV is 64 percent, which means that 90 MCM of additional volume is required to let the JV occupy its total water requirements. Table 6.9 summarizes this information and shows the total costs for: Running; Running and O&M; Running and O&M and capital costs.

Table 6-5: Cost assessments of TWW per cubic meter.

Table of Scenarios		**Running Cost**	**Runnig + O&M**	**Running + O&M + capital cost**
Total volume TWW	MCM	87	87	87
Total supply JV	MCM	250	250	250
Efficiency (Req/supply)	%	64	64	64
Potential added volume of TWW	MCM	90	90	90
Cost of TWW / cubic meter	JD/m^3	0.017	0.63	1.3
Total costs for additional water	JD	15300000	56700000	117000000

Source: Ministry of water and Irrigation

In this section we are proposing to develop a pricing mechanism which removes the subsides gradually from water and increasing the price of irrigated water simultaneously with increasing gradually the amount of receiving water at farm level. This will be the incentive to farmers while price is increasing. Increasing prices will bring good revenue that can be used to establish more plants to treat wastewater as there is a huge potential for treatment and there is market for it.

Considering that the annual efficiencies which are defined as the ratio of crop water requirements to water supply in average is 64 percent. Meanwhile the efficiency in the Jordan Valley is 69 percent when the whole year is considered. (Venot et al. 2007).

Table 6-6 shows an agronomic-economic profile for four archetypes of farming systems that are considered to be representative for the JV. Water quota and net profits figures were derived from Venot (2007). Figures on fertilizer savings were obtained from (Meerbach et al. 2006). Current water tariffs were provided by the JVA. Yield losses due to the sensitivity of crops and prevailing salt levels were estimated using the relationships explained in section 6.2. For the citrus and banana farms were assume that additional TWW volumes are still blended with freshwater and that the final ECe level is around 1.5 ds/m.

Table 6-6: Four archetypes of farming systems in the JV: an agronomic-economic profile.

	Commercial vegetable farm	Citrus family farm	Commercial banana farm	Family farm, mixed
Before TWW				
water quota (m3/ha/yr)[1]	5050	10100	15000	5050
Fertilizer (JD/ha/year) [2]	695	496	993	298
net profit (JD/ha/year) [1]	5319	1550	8865	745
area ha[1]	8	4	4	7
Total water	40400	40400	60000	35350
Water costs (JD/farm)	323	323	480	283
Fertilizer costs (JD/farm)[2]	5560	2234	2979	596
Farm income JD/yr	42553	6200	35461	5213
After TWW				
Saving fertilizer (JD/farm)	2224	894	1191	238
Yield reduction: salinity	5	10	15	10
salinity losses (JD/farm)	2128	620	5319	521
Supply/demand ratio	64	62	87	64
Nett profit (JD/farm)	57969	8830	35943	6806
Nett increase	15416	2630	482	1594
%increase per farm	1,36	1,42	1,01	1,31

(Meerbach and Böning-Zilkens 2006; Venot et al. 2007)

We are now ready to run various water pricing scenarios and evaluate their impact on the cost coverage of new TWW infrastructure and on farmers' income. We will evaluate the scenarios over a period of twenty years. For each year an additional amount of TWW of (4.5 Mm^3) volume is generated resulting in the 90 Mm^3 after twenty years. The amount of money that is used to cover the cost of the TWW infrastructure is the difference between the total amount generated with the new and the old water tariff. The effect of farmers' income accounts for the effect of rising salinity levels on crop yields, savings made on fertilizer and costs incurred by water tariffs. When designing the scenarios we were aware that the prices can not be raised abruptly as farmers would protest against these water tariffs as was also shown in chapter 5. We, therefore designed a simple model that can vary the water tariffs as fixed amounts or with gradual annual increases. Of all the various possibilities we will run now five water pricing scenarios:

Scenario I. BUA, business as usual, the same water tariff that currently prevails.

Scenario II. FLAT. A flat water tariff that covers the Running costs of the TWW plants.

Scenario III. GRADUAL/LOW. A gradual increase of the water tariff with 1 percent per year

Scenario IV. GRADUAL/MODERATE. A gradual increase of the water tariff with 5 percent per year.

Scenario V. GRADUAL/HIGH. A gradual increase of the water tariff with 10 percent per year.

Their results are discussed below

BUA. The results of the first scenario are depicted in Figure 6.2. Especially vegetable farms benefit from the additional water volume, also because vegetable crops are less sensitive to salt water and save substantially on the fertilizer costs. Also Citrus and the mixed farm increase their income with almost 70 percent. Banana farms remain more or less the same, basically because they were already close to the maximum water level requirement (87 percent) and the salt levels affect crop yields negatively. Yet, the coverage of the cost for additional TWW infrastructure is extremely low. Under this scenario the entire implementation of TWW plants will be dependent on subsidy from the government or foreign donors.

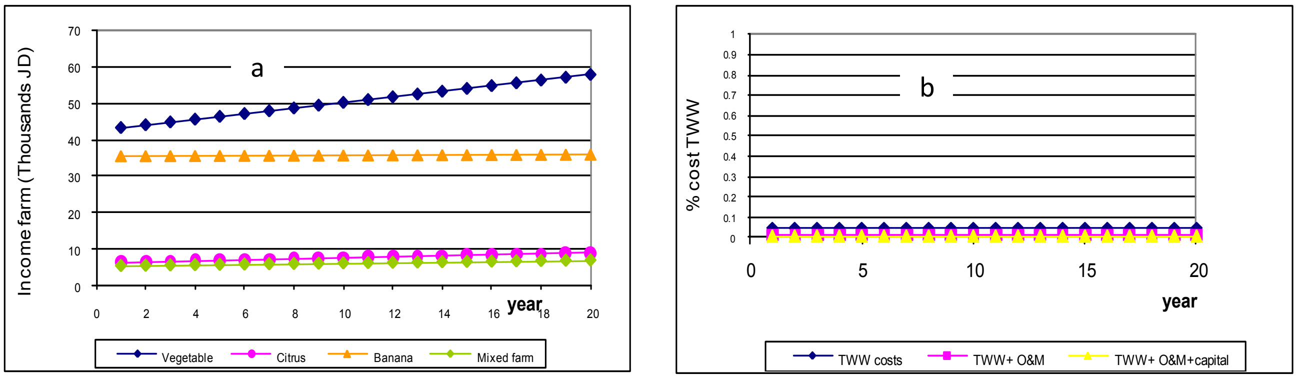


Figure 6-2: Effect on farm income (a) and cost coverage (b): scenario BUA

FLAT. **Error! Reference source not found.** shows the results of the FLAT scenario. The income of the farmers is hardly affected as water only makes up a small amount of the total farm costs and benefits from the additional water volumes are substantial, except for the earlier discussed banana farms. Cost coverage is high initially but decreases rapidly to lower levels especially when O&M and capital costs are included. Hence, also in this scenario the subsidies will have to cover substantial amounts.

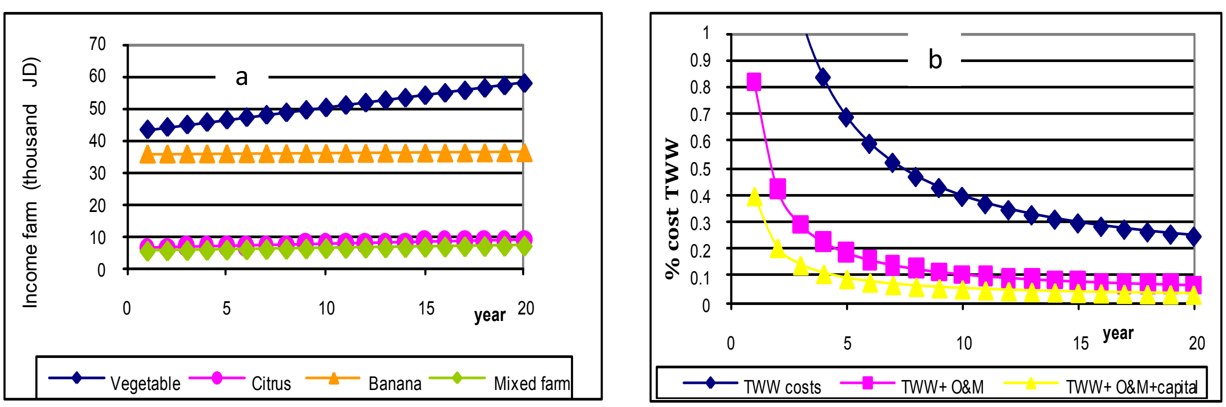


Figure 6-3: Effect on farm income (a) and cost coverage (b): scenario FLAT

GRADUAL/LOW. Figure 6-4 shows the results of the GRADUAL/LOW scenario. We can conclude that the trends on farmer income and cost coverage remain more or less the same as compared to the BUA alternative.

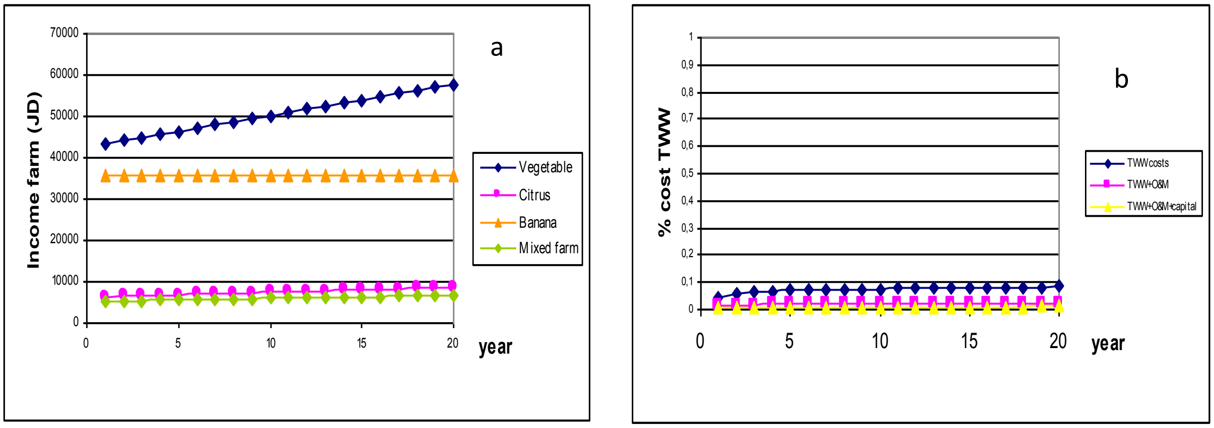


Figure 6-4: Effect on farm income (a) and cost coverage (b): scenario GRADUAL/LOW

GRADUATE/MODERATE. The results of the GRADUATE/MODERATE scenario are presented in Figure 6-5. The effects on farm income are noticeable. Banana farms are reducing their farm income while the increase in income for the citrus and the mixed farms is reduced. Cost coverage for the Running costs rise up to 30 percent. We conclude that the annual increase of five percent has on the long run some negative effects on income growth and slightly compensate the TWW costs.

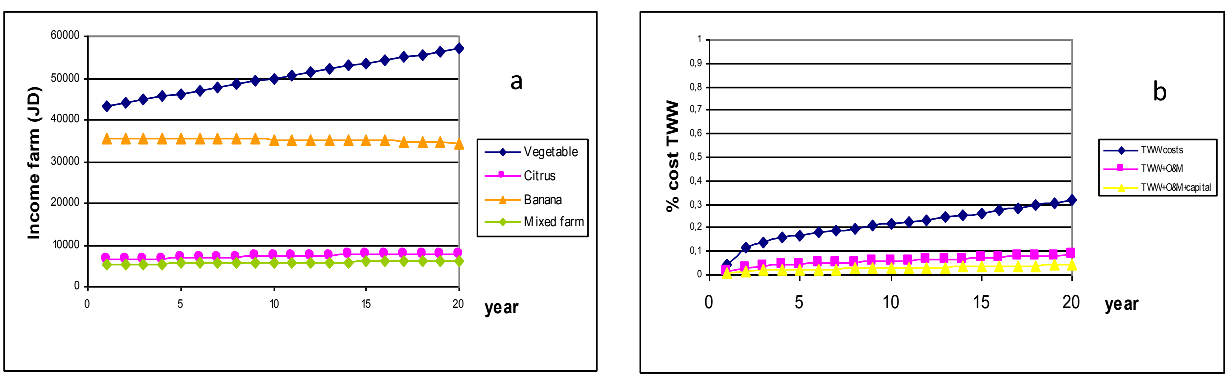


Figure 6-5: Effect on farm income (a) and cost coverage (b): scenario GRADUAL/MODERATE

GRADUATE/HIGH. Finally, Figure 6-6 presents the outcomes of the GRADUATE/HIGH scenario. Here we see that farm income is affected negatively after some 10 years or so. Especially the Banana farms have relatively a substantial decrease, bit also the lower income farms with citrus and mixed cultivation have negative net profits as compared to their starting year. Coverage of costs for running operations is almost a 100 percent but coverage of the costs including O&M and capital is still small, despite the high increase in water tariff.

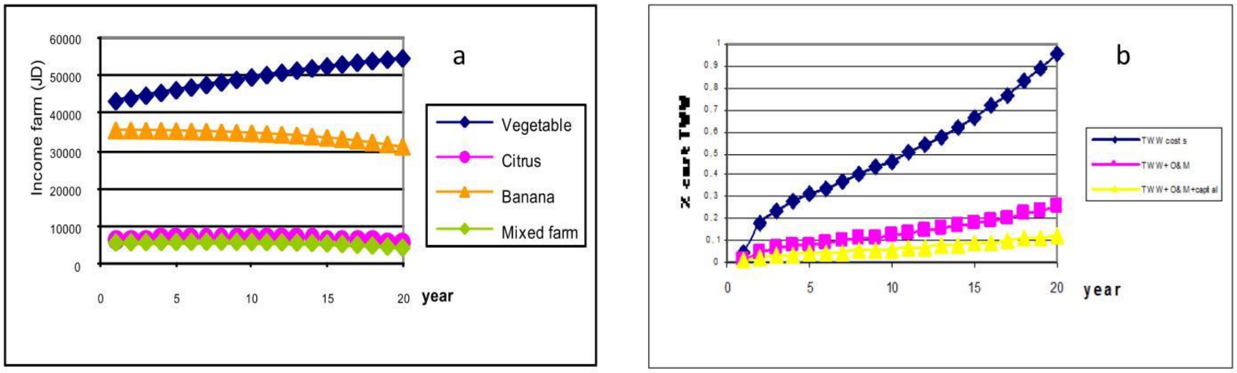


Figure 6-6: Effect on farm income (a) and cost coverage (b): scenario GRADUAL/HIGH

6.4 Conclusions

In this chapter we evaluated the effect of nutrients in TWW for its cost saving effects on fertilizers and quantified the crop specific effect of salinity levels on yields. This information was used to evaluate the impact of additional TWW volumes on farmers' income under various water tariff scenarios. Moreover, we also considered the costs that had to be covered for additional water volumes.

We found that a considerable amount of nutrients can be saved as the nutrient composition in the KAC has a remarkable similarity to the NPK ratios of commercial fertilizer. Meerbach and Böning-Zilkens 2006 also found that up to 50 percent of fertilizer costs can be saved when the TWW is used to frigate the crops. Yet, the negative side of the TWW water for irrigation is the sensitivity of the main crops—bananas and citrus—to its moderate salinity levels. We recommend that future water distribution schemes that supply TWW to these farms should be supplied with sufficient freshwater to mitigate the effect of salinity.

We found that farmers' income in general grows with additional TWW, except for bananas which are already supplied with almost 87 percent TWW and are also affected by the TWW salinity level. Only when the water tariff increases at a high pace do farmer incomes become lower as the total price for water starts to become a high share of the total costs. The coverage of cost for running costs, O&M and capital costs will be difficult to recoup from farmer contributions alone. This is also not necessary as the treatment of waste water also has environmental and health benefits that have a positive effect on the society as a whole. We conclude that there are good prospects for agricultural expansion in the JV when the use of TWW in Jordan becomes more efficient through an increase in WRI. Farmer contributions through higher water rates seem justified as the benefits of an additional m^3 TWW clearly outweigh its costs.

The objective of introducing a new pricing mechanism that includes different factors not only for cost recovery and benefit but also to account for farmers changing attitudes such as changing from crops sensitive to salinity and require high amount of water, such as bananas and citrus, to crops with less water demand and more tolerance to salinity is justified. Water scarcity in the region requires a more responsible behaviour from users to value water that they receive.

In addition pricing can help farmers' to understand the true value of receiving TWW in the region especially the coming era that will bring more drought to the Jordan Valley where freshwater will be considered more valuable for domestic uses.

We recommend a gradual tariff rise to slowly let the farmers become accustomed to the new water tariff situation. Field experience demonstrates that an appropriate extension program explaining the changes in water tariffs is indispensable. Finally, we suggest that water tariffs be differentiated with lower tariffs for the poorer farmers and their families in the JV.

7. Conclusion

Water scarcity has become a serious constraint for the economic and social development of the Hashemite Kingdom of Jordan. The last few decades witnessed a spectacular growth (2.6 percent (World Bank 2009)) of the population from less than one million in 1960 to 6.3 million in 2009, most of which are settled in urban areas. The pressure on the water resources is likely to exacerbate as a mounting population is expected to grow to a 10 million people in 2050 (Figure 7-1) and will demand water for food and feed as well as a guaranteed supply for their domestic use. Moreover, according to the latest reports climate change is expected to affect the country negatively as temperature increases while precipitation becomes more erratic and reduces on average by 30% (Harald et al. 2007; Bates et al. 2008). Hence, water scarcity will increase the competition for water between municipal, industrial and agricultural in Jordan. Following a Malthus vision the scarcity problem will wreak havoc on the society and create a political instability with people fighting over access to the few remaining water resources. Indeed to avoid this doom scenario becoming true Jordan faces an enormous challenge to manage its water resources. Inter basin transfers in the future might provide the necessary relief, yet, the political tense situation in the region impedes a constructive solution in this direction. After all, water infrastructure is a vulnerable target for sabotage and pipelines are easy to close down. Hence, the solution should be found at the national level.

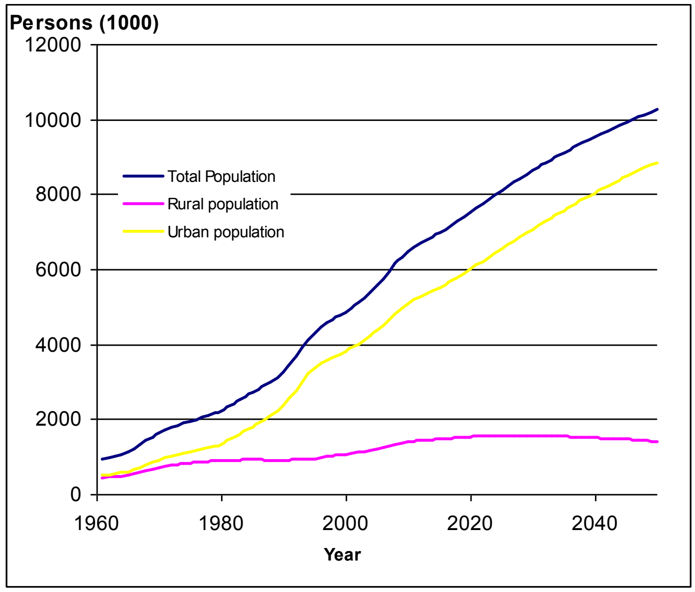


Figure 7-1: Population projection for Jordan (1960-2050).

This thesis employs the typical characteristic of water that once it is used it does not disappear from the system but can be treated and be prepared for re-use. As such the thesis discusses the role of Treated Waste Water (TWW) in Jordan as a likely candidate to re-use the water and reduce the strain on water resources. The thesis focuses thereby on agricultural development in the Jordan Valley (JV), an important regional supplier of crops and vegetables, where much of the freshwater in the Jordan Valley (65 percent) is being consumed — a resource that is urgently required to meet the demand of Jordan's fast growing urban areas. Moreover, Venot et al. 2007 showed that currently about 40 percent of the agricultural potential in the JV remains untapped due to water shortages. Furthermore, the sophisticated (sometimes subterranean) drip irrigation system in the JV guarantees a minimal loss of water and there appears to be little room for water use efficiency gains at the farm level. Hence, expansion of agriculture in the JV can only be realized by the creation of additional water volumes. Therefore, we enquire in this thesis the possibilities of using TWW in the JV as a substitute for freshwater resources and its potential contribution for further agricultural development. But, this is not an easy task, for the following reasons. First, the quality of TWW is a key characteristic that largely determines whether it will be accepted and successfully introduced as an additional water resource for the irrigated agriculture or be refused as an undesirable input. Second, we need to enquire if there is still a potential for TWW as a water source at the national level. This requires a suitable index that monitors the possibilities for further exploration of the TWW in solving the water scarcity problem. Third, TWW will have to be integrated in the national water management scheme and this requires a careful understanding of the supplies and demands in order to realize an efficient allocation of water resources. Fourth, there is insufficient understanding of willingness of farmers to accept (WTA) TWW, their willingness to pay (WTP) for TWW and the social and economic factors that influence these decisions (e.g. Scott, Faruqui et al. 2004). Fifth, WTP is an important contribution to cover the cost of the necessary infrastructure for sewage systems and TWW plants and should be weighed against the changes in farmers' income from the use of TWW. In this thesis we address these five issues as follows.

In chapter two we reviewed the quality of the TWW and found the following facts. Water collected in reservoirs (fresh or treated wastewater) has limited levels of *suspensions and turbidity* that are not harmful to plants. There is some risk of physical and chemical impacts on irrigation systems such as pipes, canals and pumps. Yet, farmers deal with this situation by installing filters at the water inlet to their farms. We found values of up to 60 mg/l for Biochemical Oxygen Demand (BOD) and up to 120 mg /l for Chemical Oxygen Demand (COD) — concentrations which are not considered harmful for plant growth (EPA 1992). The oxidation process of organic matter also has positive effects on plant growth as it produces valuable nutrients such as NO_3 and PO_4. According to the Jordanian Irrigation water quality guidelines, *EC* should be in the range of 1700-3000 $\mu S/m^3$, the average value of EC is 2386. The maximum reported value is 3026 which means that EC is always within the acceptable levels. Concentrations of *cations* Ca and Mg and *anions* like CL are directly connected to the pH value while high Na concentration might affect the soil structure. Yet, effects of Na and Cl are bound to the Ca content of the soil, the higher the Ca content the less the negative impacts of Na and Cl. We found that that levels of both Na and Cl sometimes exceed the upper maximum levels in the irrigation water (average recorded value for Na 363 mg/l and Cl 250 mg/l). Yet, the relatively high content of Ca and Mg limit their negative impact on soil. Indeed the average Sodium adsorption ratio (SAR) value for the reclaimed water in the Jordan Valley is 4.5 and oscillates between 3.2 and 5.6, all below the safe threshold level of a SAR value of 6. Where higher CL concentrations are found, no damage was recorded due to the low sensitivity of vegetables and the fact that Cl easily leaches. Finally, the analysis of KTR water showed that K levels are always less than 30 mg/l, far below the threshold level where it might damage the plants. Furthermore, K concentrations enrich the water with plant nutrients. So, we can conclude that the water quality of the TWW is suitable for irrigation.

In chapter three we introduced the Wastewater Reused Index (WRI) which is defined as the ratio of actual wastewater reused to total generated wastewater. We argue that WRI can better reflect the potential of wastewater reuse of a country compared with the more generally used indicator which is defined as the ratio of reuse to total treatment. The latter is of limited use for policy decisions as it does not reflect potentialities of wastewater use. With the information that we analyzed we detected that WRI in Jordan increased steadily from 30%-38% between 2004 and 2007. This indicates that there is still considerable scope for expanding wastewater reuse, which prompted a more detailed look at the constraints on wastewater treatment and its reuse in the Jordan Valley. In some cases the appropriate response is to increase the connection of dwellings to a sewer system. In others, particularly in hilly or rural areas, a better option is to adopt technologies such as composting toilet or decentralized wastewater treatment plants. The decentralized approach to wastewater collection and treatment offers a new means of addressing wastewater management. Common to all of these options is on-site wastewater treatment by means of low-cost treatment systems, combined with direct use of the treatment products (water, compost, and biogas). This approach can sustainably meet wastewater management requirements. We also found that doubling the amount of wastewater would suffice to cover the requests for irrigation water in the Jordan Valley where current required/supply ratio is in the range of 40-80 percent.

In chapter four the water demand and supply in the JV were modelled using WEAP software. The objective of this exercise was to investigate the allocation of fresh and treated wastewater resources to agricultural demand. We analyzed this situation by applying various scenarios to allocate water for different demands and alternative water sources. We calibrated the model using MWI data from 1990 to 2006 and simulated the coverage of the distribution networks. The results of the scenarios indicated a huge agricultural demand for treated wastewater and a simultaneously reduced stress on freshwater resources that could be allocated to domestic use. Improved coverage of agricultural water needs can be achieved by adopting different techniques, two of which were evaluated in detail: increasing wastewater reuse in agriculture, and changing the cropping pattern. These techniques can help to reduce the stress on reservoir volumes even under reduced water availability due to climate change.

Since there was a potential of WW to be treated and reused, we evaluated in Chapter five if this type of water is accepted by farmers and how much they are willing to pay for this resource. We found that 96 percent of the Jordan Valley farmers have an interest in using TWW, provided that Jordanian and International water standards are met. Furthermore, we found that farmers are willing to pay a much higher price than the current tariff which is only 0.008 JD/m^3. This choice is justified by the high profits that can be made for each additional cubic meter of water. Using an ordered logit model that reproduces the farmers bidding classes and includes all the farmers of the sample we found that higher farm profits clearly motivate higher bids. Yet, a higher concern about water tariff is likely to give a lower bid from the farmer. Model results when all farmers are included are moderate to low and should be interpreted with care. Yet, a tenfold cross validation shows that parameter estimates were robust. The separate models for the Northern, Middle and Southern JV show larger predictive power with better hit ratios, justifying a separate analysis for these areas that are characterized by different water sources and farming systems. In the Northern part of the valley the concern for water tariff had the highest influence on the farmers' bids. In the middle part where use of TWW is common and awareness of additional fertilizer effects prevails farmers easily pay more for additional TWW. This is also interesting for policy makers as they can positively influence the use of TWW when farmers of the Northern region can be made aware of the positive effects of fertilizer saving. The special impact of the newly planted and highly invested palm trees in the South JV also justify a separate analysis. Of special importance is that psychological effects were selected in all three estimation rounds with a positive sign. Obviously, the mind set of people is important and this sends a principal message to the extensions workers in that they have to convey the information on TWW in a complete and transparent way. We conclude that the outcomes of our study justify a specific extension program on TWW for the three regions in the JV.

Providing additional TWW can be considered highly expensive since it requires the establishment for extra treatment plants and sewage infrastructure. Hence, chapter six reviews the possibilities to recover these costs by evaluating various water pricing scenarios that includes the additional volumes of TWW. Several issues have been considered in order to give appropriate value for treated wastewater (TWW). Too low a price might encourage inefficient use and could lead to the perception of TWW being a cheap, unlimited resource. However, the majority of those farmers interviewed also said that they expected TWW to cost less than freshwater. This lower price could be necessary to encourage acceptance in the farming community. But, a balance must be achieved. If the price is too close to potable water, weary users will tend toward potable water for all purposes in order to avoid complications, regulations and market uncertainty. We decided to evaluate five water pricing scenarios that vary from the current water tariff to a flat water tariff that covers running costs of TWW plants and three scenarios where water tariff increases gradually though at a different pace. The evaluation includes a quality assessment of the nutrient content in TWW for its cost saving effects on fertilizers and its crop specific effect of salinity levels on yield. We evaluated the various scenarios for four archetypes of farming systems that are considered to be representative for the majority of the farms in the JV. We found that fertilizer costs can be saved because the nutrient composition in the blended water of the KAC has a remarkable similarity to the NPK ratios of commercial fertilizer. Yet, nutrient concentrations of TWW water affect salinity sensitive crops negatively. Farmers' income in general increases with additional TWW, except for bananas which are already supplied with almost 87 percent and is also affected by the TWW salinity level. Only when the water tariff does increase at a high pace do farmers income decline as water prices start to occupy a high share of total costs. We conclude that the cost to generate TWW will be difficult to cover by farmer contributions alone. We also think that this is not necessary as the treatment of waste water has also positive effects on the society as a whole as they benefit from improved environmental and public health conditions.

We conclude that that there are good prospects for agricultural expansion in the JV when the use of TWW becomes available through an increase in WRI. Farmer contributions through a moderate increase in price seem justified as the benefits of an additional cubic meter TWW outweigh this additional payment by far. We recommend a gradual tariff rise that is jointly presented with an appropriate extension program. We also suggest that water tariffs be differentiated with lower tariffs for the poorer farmers and their families in the JV. Finally, biophysical conditions of the neighbouring West Bank-Palestine areas along the Jordan River are very similar to the sites that we studied. Indeed future developments on the West Bank will to some degree meet the same problems that were addressed in this thesis and the lessons that we learned will then be valuable there.

Bibliography

Abu-Madi, M. (2004): Incentive Systems for Wastewater Treatment and Reuse in Irrigated Agriculture in the MENA Region: Evidence from Jordan and Tunisia. TU Delft / UNESCO-IHE Delft. Delft, Delft University. PhD: P.250.

Afroz, R., K. Hanaki and HK. Kiyo (2009): "Willingness to pay for waste management improvement in Dhaka city, Bangladesh." Journal of Environmental Management 90(1): 492-503.

AL-JALOUDY, M. A. (2000): "Country Profile - Jordan." Retrieved Dec, 2008, from http://www.fao.org/ag/AGP/agpc/doc/Counprof/Jordan/Jordan.htm.

AL-Sharieda, A., B. El-Hayiek and N. Al-Hamoud (2007): مشروع مراقبة نوعية مصادر المياة في منطقة وادي الأردن. التقرير السنوي عمان الجمعية العلمية الملكية .(2007 شباط 2006- شباط **RSS).**

Al-Zboon, K. and N. Al-Ananzeh (2008): "Performance of wastewater treatment plants in Jordan and suitability for reuse." African Journal of Biotechnology - Academic Journal Vol. 7 (15): P. 2621–2629.

Aldrich, J. H. and F. D. Nelson (1984): Linear Probability, Logit, and Probit Models. 07-045 , Beverly Hills, Calif. US., Sage Publications.

Alfarra, A., E. Kemp-Benedict, H. Hötzl, N. Sader, B. Sonneveld, W. Ali and L. Wolf, (2009): A Framework For Wastewater Reuse In Jordan: From Present Status To Future Potential, Applying the Wastewater Reuse Index (WRI) as Indicated. EWRA's 7th International Conference on Water Resources Conservancy and Risk Reduction Under Climatic Instability Limassol, Cyprus a Special Issue of the Journal of Water Resources Management (WARM); by Springer for the European Water Resources Association (EWRA). Scheduled for issuance by April 2010

Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998): Crop evapotranspiration - Guidelines for computing crop water requirements -Chapter 8 - ETc under soil water stress conditions. FAO Irrigation and drainage paper 56. Rome - Itali, Food and Agriculture Organization of the United Nations (FAO): 326.

AQUASTAT - FAO (2003- 2007): Aquastat - online database, Food and Agriculture Organization of the United Nations.

AQUASTAT - FAO (2008): Aquastat - Jordan online database, Food and Agriculture Organization of the United Nations.

Aydın, M. E. and K. Gür. (2002): "Using Reclaimed Municipal Wastewater for Irrigation ", 2008, from http://www.toprak.org.tr/isd/can_38.htm#sayfa.

Ayers, R. S. and D. W. Westcot (1994): Water quality for agriculture. FAO Irrigation and Drainage Papers - 29 Rome -Italy, Food and Agriculture Organization of the United Nations (FAO) - Agriculture and Consumer Protection P.234.

Bateman, I., R. Carson, B. Day,M. Hanemann, N. Hanley, T. Hett, M. Jones-Lee ,G. Loomes , S. Mourato, E. Özdemiroglu, D. Pearce, R. Sugden and J. Swanson (2004): Economic Valuation With Stated Preference Techniques: A Manual Edward Elgar Pub.

Bateman, I. J. and R. K. Turner (1992): Evaluation of the Environment: The Contingent Valuation Method. CSERGE GEC Working Paper 92-18, University of East Anglia, Norwich, U.K.: P.108.

Bates, B., Z. Kundzewicz, S. Wu and J. Palutikof (2008): Climate Change and Water: Technical Paper. Geneva, Intergovernmental Panel on Climate Change (IPCC): P.210.

Bebbington, J. (2000): Sustainable Development: A Review of the International Development, Business and Accounting Literature. WORKING PAPER 00-17, the University of Aberdeen: P.46.

Berrens, R. P., A. K. Bohara, H.C. Jenkins-Smith, C.L Silva and D.L. Weimer (2004): "Information and effort in contingent valuation surveys: application to global climate change using national internet samples." Journal of Environmental Economics and Management 47(2): 331-363.

Birol, E., P. Koundouri and Y. Kountouris (2008): "Evaluating farmers' preferences for wastewater: quantity and quality aspects " International Journal of Water Volume 4(Number 1-2 / 2008): P.69 - 86

Buechler, S., G. D. Mekala and B. Keraita (2006): Wastewater Use for Urban and Peri-urban Agriculture. CITIES FARMING FOR THE FUTURE -Urban Agriculture for Green and Productive Cities. R. v. Veenhuizen, IIRR/RUAF/IDRC P. 223.

Cameron, J. I. (1997): "Applying socio-ecological economics: A case study of contingent valuation and integrated catchment management." Ecological Economics 23(2): 155-165.

Carr, R. M., U. J. Blumenthal and D. Mara (2004): Health Guidelines for the Use of Wastewater in Agriculture: Developing Realistic Guidelines. WASTEWATER USE IN IRRIGATED AGRICULTURE ,Confronting the Livelihood and Environmental Realities. C. Scott, N. I. Faruqui and L. Raschid, http://www.idrc.ca/en/ev-68330-201-1-DO_TOPIC.html: P. 206.

Carson, R. T. (2000): "Contingent Valuation: A User's Guide." Environ. Sci. Technol. 34(8): 1413-1418.

Carson, R. T., N. E. Flores, M. Martin and L. Wright (1996): "Contingent Valuation and Revealed Preference Methodologies: Comparing the Estimates for Quasi-Public Goods." Land Economics 72(1): 80-99.

Central Bank of Jordan (2008): Annual Report 2007- the domistic economy. . Amman - Jordan, , Central Bank of Jordan (www.cbj.gov.jo): P.21.

Chong, H. and D. Sunding (2006): "Water Markets and Trading." Annual Review of Environment and Resources 31(1): 239-264.

Cook, D. and K. Prior (2005): Sustainable Development and Regulation. Green Separation Processes: Fundamentals and Applications. C. Afonso and J. P. Crespo. Weinheim, Wiley Interscience P.383.

Cornes, R. and T. Sandler (1996): The theory of externalities public goods and club goods. Cambridge, Cambridge University Press.

Courcier, R., J.-P. Venot and F. Molle (2005): Historical Transformations of the Lower Jordan River Basin (in Jordan): Changes in Water Use and Projections (1950–2025), French Regional Mission for Water and Agriculture of the French Embassy in Jordan (MREA) and the International Water Management Institute (IWMI): P.95.

Dajic, Z. (2006): SALT STRESS. Physiology and Molecular Biology of Stress Tolerance in Plants. K. M. Rao, A. Raghavendra and K. J. Reddy. Netherlands, Springer Netherlands: 41-99.

Davidson, R. and J. Mackinnon (1993): Estimation and inference in econometrics. Oxford University Press. Oxford, England.

DOS (2007): Jordan in Figures, The Hashemite Kingdom of Jordan Department of Statistics (DOS) (http://www.dos.gov.jo/dos_home_e/main/index.htm).

DOS (2008): The Hashemite Kingdom of Jordan Department of Statistics (DOS), Jordan Department of Statistics (http://www.dos.gov.jo/dos_home_e/main/index.htm).

El-Zabri, T. and D. McGrenra (2007): Hashemite Kingdom of Jordan Country strategic opportunities programme. E. 2007/92/R.16. Rome, International Fund for Agricultural Development (IFAD): p.51.

EPA (1992): Manual: Guidelines For Water Reuse. Washington, DC, U.S. Environmental Protection Agency, Washington, D.C., EPA/625/R-92/004 (NTIS 93-222180), 1992 Last Revised:2/2008: P.260.

EPA (2004): Guidelines for Water Reuse. EPA/625/R-04/108. Washington, DC, U.S. Environmental Protection Agency- Municipal Support Division Office of Wastewater Management Office of Water: P.478.

FAO. (2002): Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO Irrigation and Drainage Paper 61. Rome, Italy, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO): P.120.

FAO. and WHO. (2003): Expert Consultation for Launching the Regional Network on Wastewater Re-use in the Near East. Cairo, Food and Agriculture Organization of the United - Nations - Regional Office for the Near East and World Health Organization -Regional Office for the Eastern Mediterranean: P.160.

Fraiture, C. d. and C. Perry (2007): Why Is Agricultural Water Demand Unresponsive at Low Price Ranges? International Water Management Institute (IWMI). www.iwmi.cgiar.org, CAB International: Chapter 3, P.14.

Friedler, E. (2001): "Water reuse -- an integral part of water resources management:: Israel as a case study." Water Policy 3(1): 29-39.

G. Kamizoulis, A. Bahri, F. Brissaud and A.N. Angelakis (1999): WASTEWATER RECYCLING AND REUSE PRACTICES IN MEDITERRANEAN REGION: Recommended Guidelines, World Health Organization. Regional Office for the Eastern Mediterranean. Regional Centre for Environmental Health Activities (CEHA). 25.

Gabriel, B. (2005): Wastewater Reuse. Wastewater Microbiology (Third Edition): 589-607.

Gaube, T. (2001): "Group size and free riding when private and public goods are gross substitutes." Economics Letters 70(1): 127-132.

Giupponi, C., A. Jakeman, D. Karssenberg and H. Hare (2006): Sustainable Management of Water Resources: An Integrated Approach, Edward Elgar Publishing.

Greene, W. (1991): Econometric analysis. Macmillan, Collier Macmillan (New York, London).

GTZ (2003): Guideline for Brackish water irrigation in the Jordan Valley- Brackish water Project. Amman, Commissioned by German Technical Cooperation (GTZ) - Jordan Valley Authority (JVA) P.121.

GTZ (2006): Guidelines for Reclaimed Water Irrigation in the Jordan Valley - Practical Recommendations for Farmers and Extension Workers Ministry of water and Irrigation (MWI), Jordan Valley Authority (JVA) ,Commissioned by German Technical Cooperation (GTZ): P. 81.

GWP (2006): Global Water Partnership Toolbox on Integrated Water Resource Management. Stockholm, Global Water Partnership(http://www.gwptoolbox.org/).

Hanemann, W. M. and B. Kanninen (1996): The Statistical analysis of Discrete-Response CV Data Working Paper No. 798, California Agricultural Experiment Station Giannin Foundation of Agricultural Economics P.123.

Kunstmann, H., P. Suppan , A. Heckl and A. Rimmer (2007): "Regional climate change in the Middle East and impact on hydrology in the Upper Jordan catchment." IAHS-AISH publication P.9.

Hardin, G. (1968): "The Tragedy of the Commons," and Beyond." Science Vol.162(No.3859): P.1243-1248.

Howitt, R. and K. Hansen (2005): "The Evolving Western Water Markets " Choices , The magazine of Food , Farm and resources issues(1st Quarter 2005): P. 59-64. .

Hussain, I., L. Raschid, M. Hanjra, F. Marikar and W. van der Hoek (2002): Wastewater Use in Agriculture: Review of Impacts and Methodological Issues in Valuing Impacts. Working paper 37, International Water Management Institute (IWMI): p.62.

ICFW (2001): International Conference on Fresh water From Bonn to Johannesburg: Putting Water and Sanitation on Top of the Political Agenda, Bonn, Germany, http://www.water-2001.de/.

Jewitt, G. (2002): "Can Integrated Water Resources Management sustain the provision of ecosystem goods and services?" Elsevier - Physics and Chemistry of the Earth Parts A/B/C 27 (11): P. 887-895(889).

Jianzhong, Z., Z. Yinliang, W. zhongmei and H. Jinhui (2008): The Current Water Allocation Systems of Surface Water for Agriculture in Yellow River. The China Ministry of Water Resources, http://www.yrcc.gov.cn/eng/: P.15.

JISM (2002): Water: Reclaimed Domestic Wastewater -(JS 893:2002). Jordan Institution for Standards and Metrology (JISM). Amman - Jordan: P.12.

Jønch-Clausen, T. and J. Fugl (2001): "Firming up the Conceptual Basis of Integrated Water Resources Management." International Journal of Water Resources Development 17: 501-510.

Jonker, L. (2002): "Integrated water resources management: theory, practice, cases " Elsevier Science - Physics and Chemistry of the Earth 27 (11-22): P. 719-720

JRIDI, A. (2002): The Development Of The Jordanian Jordan River Basin: The Main Historical Steps. Amman, Jordan, French Institute for Forestry, Agricultural Regional French Mission and Water and Environmental Engineering for Water and Agriculture (MREA): P.35.

JVA (2006): Crop Water Requirements - Jordan Valley Ministry of Water and Irrigation - Jordan.

JVA (2006): Jordan Valley Development areas and farm unit data base, Ministry of Water and Irrigation - Jordan.

JVA (2007): المصادر المائية الطلب والمتاح, Ministry of Water and Irrigation, Jordan Valley Authority: P.4.

JVA (2008): The Jordan Valley Authorities: establishment and bylaws, Ministry of Water and Irrigation (MWI). (http://212.35.69.233/AboutJVA.htm).

JVA (Sep, 2004): The Third Country Training Programme For Water Resources Management. Amman, The Hashemite Kingdom of Jordan, Ministry of Water & Irrigation , Jordan Valley Authority: P.17.

Keyzer, M., B. Sonneveld and W. van Veen (2009): "Valuation of natural resources: efficiency and equity " Journal of Development in Practice Vol. 19(No. 2): P. 233-239. Oxford, UK. .

Keyzer, M. A., M.D. Merbis, I.F Pavel and C.F. van Wesenbeeck (2005): "ANALYSIS: Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? ." Science Direct: Ecological Economics 55(2): P.187-202

King, D. and M. Mazzotta. (2000): "Ecosystem Valuation." Contingent Valuation Method, 2008, from http://www.ecosystemvaluation.org/contingent_valuation.htm.

Kramer, B. (1996): "An ordered logit model for the evaluation of Dutch non-life insurance companies " De Economist, Springer Netherlands Vol. 144(No.1): P. 79-91.

Kunstmann, H., P. Suppan, A. Heckl and A. Rimmer (2007): "Regional climate change in the Middle East and impact on hydrology in the Upper Jordan catchment." IAHS-AISH publication (Publ. 313): P.9

Lonergan, S. (2003): "Water and War." Our Planet, the magazine of the United Nations Environment Programme (UNEP) Volume 15 (No 4): P. 32.

Maddala, G. (1983): Limited-Dependent and Qualitative Variables in Econometrics. Cambridge, UK., Cambridge University Press.

Mara, D. D. and H. W. Pearson (1999): "A hybrid waste stabilization pond and wastewater storage and treatment reservoir system for wastewater reuse for both restricted and unrestricted crop irrigation." Water Research 33(2): 591-594.

Meerbach, D. and M. Böning-Zilkens (2006): Analysis of Irrigation and Fertigation Practices Using Reclaimed Water in the Jordan Valley. Amman, Jordan., German Technical Cooperation (GTZ) and Ministry of Water and Irrigation (MWI): P. 112.

Mekala, G. D., B. Davidson, M. Samad and A.M. Boland (2008): A Framework for Efficient Wastewater Treatment and Recycling Systems. Working Paper 129, International Water Management Institute (IWMI: P.25.

Menegaki, A. N., N. Hanley and K. Tsagarakis (2007): "The social acceptability and valuation of recycled water in Crete: A study of consumers' and farmers' attitudes." Ecological Economics 62(1): 7-18.

Merrill, S., C. Adelman, L. Diamond, D. Esposito, J. Fox, B. Hannon, C. Ketels, S. Morris, M. Porter, S. Raymond, Y. Whee Rhee and P. Timmer (2002): Driving Economic Growth - chapter 2. Foreign Aid in the National Interest -Promoting Freedom, Security, and Opportunity. B. Ross-Larson, M. d. Coquereaumont, P. Holtz and A. Strong. Washington, D.C., U.S. Agency For International Development: P.169.

Metz, H. C. (Dec,1989): A Country Study: Jordan. Washington, D.C., Library of Congress, Federal Research Division.

MoA (2006): Annual Report. Information and Technology, Ministry of Agriculture - Jordan P.200.

Monte, M. H. F. M. d. (2007): Guidelines for Good Practice of Water Reuse for Irrigation: Portuguese Standard NP 4434 Wastewater Reuse–Risk Assessment, Decision-Making and Environmental Security. Netherlands, Springer Netherlands. 2007: P. 253-265.

Murphy, S. (1998): Water Quality Monitoring General Information on Solids Boulder, American Public Health Association: http://bcn.boulder.co.us/basin/data/BACT/info/TSS.html.

MWI (2004): Practical Recommendations for Nutrient Management under Irrigation with Reclaimed Water. D. Meerbach. Amman, Ministry of Water and Irrigation and Commissioned by German Technical Cooperation (GTZ): p.81.

MWI (2006): Data Base. J. V. Authority, Ministry of Water and Irrigation - Amman, Jordan.

MWI (2007): Data base for ministry of water and irrigation, Ministry of water and irrigation - Amman, Jordan.

MWI (2009): The operation report for the sewer system. S. department, The Hashemite Kingdom of Jordan, Ministry of Water & Irrigation.: P.22.

Oron, G., C. Campos, L. Gillerman, and M. Salgot. (1999): "Wastewater treatment, renovation and reuse for agricultural irrigation in small communities." Agricultural Water Management 38(3): 223-234.

Pearce, D., G. Atkinson and S. Mourato (2006): Cost-Benefit Analysis and the Environment: RECENT DEVELOPMENTS. Paris, France, Organisation For Economic Co-Operation And Development (OECD).

Pescod, M. B. (1992): Wastewater treatment and use in agriculture FAO irrigation and drainage paper 47. Rome, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO): P.156.

Peters, H. P. and H. Heinrichs (2007): "Legitimizing Climate Policy: The “Risk Construct” Of Global Climate Change In The German Mass Media." International Journal of Sustainability Communication(IJSC 3 (2008)): P.14-36.

Philippe, V. j. (2004): Reclamations history of the Jordan River Basin in Jordan, a focus on agriculture: past trends, actual farming system & future prospective. Farming Systems in the Jordan River Basin in Jordan agroeconomic and economic description. Amman, INA P-G Paris Grignon National Institute of Agronomy, French Regional Mission for water and Agriculture (MREA) French Embassy, International Water Management Institute (IWMI): P185.

Phillips, D., M. Daoudy, M**. McCaffrey, S. Öjendal, J. and A. Turton (2006):** Trans-boundary Water Co-operation as a Tool for Conflict Prevention & Broader Benefit Sharing, Ministry for Foreign Affairs Sweden.

Rahaman, M. M., O. Varis and T. Kajander (2004): "EU Water Framework Directive vs. Integrated Water Resources Management: The Seven Mismatches " International Journal of Water Resources Development 20(4): P. 565 - 575

RSS (2008): مشروع مراقبة نوعية مصادر المياه في منطقة وادي الاردن. قسم دراسات نوعية المياه - مركز بحوث البيئة - الجمعية العلمية الملكية A. m. Shurida, B. Alhayik and N. Alhamoud. Amman , Jordan, Royal Scientific Society: P. 98.

Scott, C., N. Faruqui and L. Raschid (2004): Wastewater Use in Irrigated Agriculture: Coordinating the Livelihood and Environmental Realities, International Water Management Institute (IWMI), International Development Research Centre (IDRC) ,International Water Management Institute (IDRC).

Seder, N., A. Uleimat and S. Rothenberger (2009): Water reuse - Jordan Case Study. Amman, Jordan, Arab Countries water Utilities Association (ACWUA)_ Working group on water Reuse: P.28.

Sharifi, M. A. (2003): Integrated Planning and Decision Support Systems for Sustainable Water Resources Management: Concepts, Potentials and Limitations. Water Resources

Management for Sustainable Agricultural Productivity, Lahore, Pakistan, Asian Productivity Organization.

Shatanawi, M. and M. Fayyad (1996): "Effect of Khirbet As-Samra treated effluent on the quality of irrigation water in the Central Jordan Valley." Water Research 30(12): 2915-2920.

Shelef, G. and Y. Azov (1996): "The coming era of intensive wastewater reuse in the Mediterranean region." Water Science and Technology 33(10-11): 115-125.

Suarez, D. L., J. D. Wood and S.M. Lesch (2006): "Effect of SAR on water infiltration under a sequential rain-irrigation management system." Agricultural Water Management 86(1-2): 150-164.

THKJ (1998): Jordan's Water Strategy & Polices – Water Utility Policy,. The Hashemite Kingdom of Jordan - Ministry of Water & Irrigation: P.100.

THKJ (2004): The Third Country Training Programme For Water Resources Management. The Hashemite Kingdom of Jordan, Ministry of Water & Irrigation, Jordan Valley Authority, Amman, Jordan.

Thomas, J.-S. and B. Durham (2003): "Integrated Water Resource Management: looking at the whole picture." Science Direct -Desalination 156(1-3): P. 21 - 28.

Treaty (1994): Treaty of Peace Between The Hashemite Kingdom of Jordan and The State of Israel. http://www.kinghussein.gov.jo/peacetreaty.html.

TWWF (2003a): Summary Forum Statement. The Third World Water Forum. Kyoto, Shiga and Osaka, Japan http://www.world.water-forum3.com/en/statement.html.

TWWF (2003b): Ministerial Declaration - Message from the Lake Biwa and Yodo River Basin The Third World Water Forum. Kyoto, Shiga and Osaka, Japan, http://www.world.water-forum3.com/jp/mc/md_final.pdf. .

UN (2008): The Millennium Development Goals Report 2008. Inter-Agency and Expert Group on MDG Indicators led by the Department of Economic and Social Affairs of the United Nations Secretariat. NEW YORK, United Nation: P.56.

UNCED (1992): UN Conference on Environment and Development (Earth Summit): Agenda 21. Rio de Janeiro, Brazil, United Nations Conference on Environment and Development, web :http://www.un.org/esa/sustdev/documents/docs_unced.htm. 2009.

UNDP (2000): Progress made in providing safe water supply and sanitation for all during the 1990s , Report of the Secretary-General Economic and Social Council, Commission on Sustainable Development Eighth session. www.un.org/waterforlifedecade/factsheet.html, United Nations: P. 21.

UNEP (1999): Chapter Two: The State of the Environment Global Environment Outlook 2000. R. Clarke. Nairobi, Kenya Earthscan Publications for and on behalf of the United Nations Environment Programme (UNEP): P.398.

UNEP (2002): World Summit On Sustainable Development (WSSD). the United Nations Environment Programme (UNEP), JOHANNESBURG, http://www.unep.org/wssd/.

UNICEF (2003): Chapter 3: Signing Progress: Indicators Mark the Way. THE UN WORLD WATER DEVELOPMENT REPORT Water for People, Water for Life United Nations Economic Commission for Europe: P.32.

Venkatachalam, L. (2004): "The contingent valuation method: a review." Environmental Impact Assessment Review 24(1): 89-124.

Venot, J.-P., F. Molle, and Y.Hassan (2007): Irrigated Agriculture, Water Pricing and Water Savings in the Lower Jordan River Basin (in Jordan). Comprehensive Assessment of Water Management in Agriculture Research Report 18. Colombo, Sri Lanka, International Water Management Institute (IWMI): P.66.

Watermark Numerical Computing (2004): PEST: Model-Independent Parameter Estimation: User Manual. U.S.A, “S.S. Papadopulos and Associates” (http://sspa.com/pest).

Watson, R., M. Zinyowera, and R. Moss (1997): IPCC SPECIAL REPORT THE REGIONAL IMPACTS OF CLIMATE CHANGE: AN ASSESSMENT OF VULNERABILITY (Summary for Policymakers), Intergovernmental Panel on Climate Change (IPCC)

Weiss, S. M. and C. A. Kulikowski (1991): Computer Systems That Learn: Classification and Prediction Methods from Statistics, Neural Nets, Machine Learning and Expert Systems (Machine Learning Series) SanMateo, Morgan Kaufmann.

Westcot, D. W. (1997): Quality control of wastewater for irrigated crop production. (Water reports - 10). Rome, Food And Agriculture Organization Of The United Nations.

WMO (1992): The Dublin Statement On Water And Sustainable Development. The Dublin International Conference on water and Environment, Economic value of water, women, poverty, resolving conflicts, natural disasters, awareness, The World Meteorological Organization (WMO). http://www.wmo.ch/pages/prog/hwrp/documents/english/icwedece.html.

World Bank (1993): Water Resources Management Policy paper. Washington, D. C., International Bank for Reconstruction and Development / The World Bank P.140.

World Bank (2000): "Water Resource Management." Retrieved January, 2009 http://go.worldbank.org/T86WD35KQ0.

World Bank (2009): Jordan at Glance (2001 -2008)/ database- statistic. Amman, Jordan, World Bank.

World Water Council (2000): Second World Water Forum. Ministerial Conference on Water Security in the 21st Century. The Hague, The Netherland, www.idhc.org/esp/documents/Agua.

World Bank (July, 2006): Water, Food Security & Agricultural Policy in the Middle East & North Africa.: P. 56.

Yates, D., J. Sieber, D. Purkey and A. Huber-Lee (2005): "WEAP21 – A Demand-, Priority-, and Preference-Driven Water Planning Model /Part 1: Model Characteristics." International Water Resources Association - Water International Volume 30(Number 4): P. 487–500.

Zeitoun, M. (2005): Hydro-hegemony theory – a framework for analysis of water-related conflicts. First International Workshop on Hydro-hegemony, King’s College, London.