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Pricing Mechanism as a Tool for Water Policy using a Linear Programming Model.

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Abstract: Water shortage is a serious problem in most countries in the Middle East. In Jordan, Irrigation water consumes about 70 percent of the available fresh water resources. Unlike, many other more fortunate countries such as Malaysia, water is real and critical natural resource in Jordan. This paper discusses the impacts of pricing policies on the irrigation water demand in the Jordan Valley. It suggests what solutions are optimal that can maximize the total net income of farmers subject to several other resources constraints. The study used a linear programming model to derive farmers' demand for irrigation water. Optimal cropping pattern in the Jordan Valley was also generated from the model. Water demand elasticity was also estimated in the study area. The results shows the effectiveness of the use of pricing mechanism as a policy tool in dealing with water in irrigated agriculture under the current water management institution in the Jordan valley. The results also show that the optimal planted area in the Jordan Valley is about 211 thousand dunum representing about 69 percent of the total available area in the Jordan Valley. This optimal cropping pattern would generate 37.97 Million Jordanian Dinar (JD) at the prevailing water price of 0.025 JD/CM. A reduction in the total net income occurs when the prices of water were increased. It was found that the water demand for agriculture reacts to increasing water prices in a quite inelastic manner over a long period. The results demonstrate that pricing policies are effective as doubling of irrigation water from the prevailing water price of 0.025 JD/CM to 0.05 did have any impact on the cropping pattern, the planted area or the net income. At the prevailing water price of 0.025 JD/CM, the profitability of one dunum is 180.1 JD, and of one cubic meter is 0.177 JD.

Key words: Linear Programming, Econometric Model, Demand Functions, Pricing Policies,

INTRODUCTION

Jordan is about 89 320 square kilometers in area, located between the latitudes of 29.0 and 33.5 degrees north, and the longitudes of 35.0 to 39.5 degrees east. It lies within the semi-arid climatic zone and has a typical Mediterranean short, rainy winter and a long, dry summer. Annual precipitation varies with location and topography, but ranges from 50 mm in the desert to 600 mm in the northwest highlands. Jordan is one of the most water scarce countries in the world. Jordan, a small Arab country with population of about 5.1 million in year 2002 in the Middle East, is one country that has very limited water supply for competing uses in agriculture and human consumption. In fact, Jordan is also poor of other natural resources such as oil.

The climate is generally arid, with more than 90 percent of Jordan's total area receiving less than 200 millimeters rainfall per year and more than 70 percent of the country receiving less than 100 millimeters of precipitation on a year. Only around 2 percent of the land area, located in the north-western highlands has an annual precipitation exceeding 300 millimeters, though the northern highlands may receive as much as 600 millimeters. About 5.5 percent of Jordan's area is considered dry land with annual rainfall ranging from 200 to 300 millimeters, as shown in Table 1, (Haddad, 1991). The pattern of rainfall is characterized by an uneven distribution over the various regions, and strong fluctuation from year to year in terms of quantity and timing.

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Table 1: Agro - Climatological Zones in Jordan

Zone	Average Rainfall Mm	Area Thousand Hectare	Percent
Arid Desert	< 100	6925	77.53
Desert	100 - 200	1130	12.65
Marginal	200 - 300	389	4.36
Semi - arid	300 - 400	169	1.89
Semi - humid	400 - 500	125	1.40
Humid	> 500	94	1.05
The Jordan Valley	100 - 350	100	1.12

Source: Haddad, N. (1991)

Jordan's population has been growing at a very high annual rate of 3.6 percent doubling the Jordanian population in 22 years. About 25 percent of the total population and one third of the poor live in rural areas (CBJ, 2004). Jordanian authorities stated that 21.3 percent of the Jordanian households were below the absolute poverty line of an annual per capita income of 140 JD in 1995. The rate of poverty in rural areas is higher by almost 30 percent compared to about 20 percent of Jordanians living under the poverty line in urban areas. In 2002, the average annual income per capita was 1,888 US$ (CBJ, 2004).

Rapid increases in population have placed unprecedented demands on water resources. In the mid-long term, with a growing population and an increasing water demand, Jordan will not be able to satisfy its increasing water demands from renewable water resources. The increase of population in Jordan is one of the most affecting factors in the increasing demand on drinking water, which increases at high rates annually.

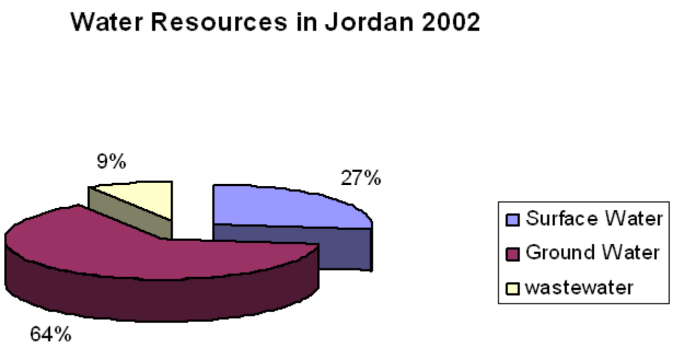
Jordan's population has been augmented by three population influxes: (1) Arab - Israeli war of 1948 (then 450,000 Palestinian refugees); (2) Arab - Israeli war of 1967 (then 400,000 displaced Palestinians); and (3) the returnees during the 1990 Gulf Crisis (then 300,000). Not surprisingly, the sudden waves of refugees and displaced persons provided no time for organized population settlement planning, and they all settled in or nearby these urban areas.

Agriculture and Water Conditions in Jordan:

The contribution of the Jordanian agriculture to the country's GDP at current prices was 2.2 percent in 2002 (CBJ and DOS, 2002). In spite of the agricultural sector's low contribution to the GDP, agriculture still represents - in its economic and social dimensions - one of the fundamental sectors of the national economy. It is the base for integrated rural development, a source for income and employment for rural people and a generator of activities in up-stream and down-stream sectors, like the processing and services sectors. Furthermore, it plays a central role in enhancing the food security, and improving the trade balance and foreign currency earnings.

Jordan is facing a future of very limited water resources - among the lowest in the world on a per capita basis. Available water resources per capita are falling as a result of population growth. They are projected to decline from more than 170 m^3 / capita / year (all uses) at present to only 91 m^3 / capita / year by 2025, putting Jordan in the category of having an absolute water shortage (World Bank, 1997). Current water use already exceeds the renewable water supply. The annual water deficit has been satisfied by the unsustainable practice of overdrawing highland aquifers resulting in lowered water tables and declining water quality.

In 2002, the total quantity of water resources reached about 809.765 MCM distributed on Surface Water; about 215.353 MCM represents 27 percent. Ground Water (renewable & non-renewable); about 522.047 MCM represents 64 percent and Wastewater; about 72.365 MCM represents 9 percent. Figure 1 illustrates the distribution of the quantity of water according to the source.



Source: MWI, Annual Report 2002

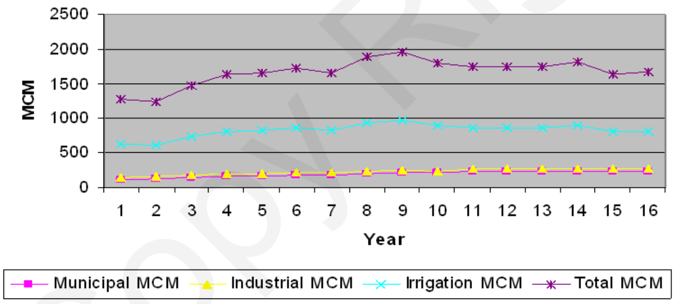
Fig. 1: Water Resources in Jordan 2002

The total water consumption in Jordan increased by more than 28 percent, from 639 MCM in 1985 to 849 MCM in 2000, with an average amount of 807 MCM over the whole time period. However, strong yearly fluctuations can be observed due to high variation in rainfall. For example; Jordan's water budget in 2000, as shown in Table 2 and Figure 2, was approximately 817 MCM or about 16 percent less than the peak year of 1993. In 2000, approximately 534 MCM of water was used for agriculture, 239 MCM was used for municipal purpose, 37 MCM was used for industrial purposes and 7.4 MCM for livestock purposes, or about 65 percent, 29 percent, 5 percent and 1 percent of the budget, respectively.

Table 2: Jordan's Annual Water Budget (1985 - 2000) Utilizations of Water

Year	Municipal		Industrial		Irrigation *		Total
	(MCM)	Percent	(MCM)	Percent	(MCM)	Percent	(MCM)
1985	116.00	18.2	22.00	3.4	496.85	77.8	638.85
1986	134.70	21.8	23.00	3.7	456.24	73.7	618.94
1987	150.40	20.2	23.50	3.2	565.46	76.0	744.36
1988	164.70	20.2	39.22	4.8	607.91	74.4	816.60
1989	169.77	20.4	36.30	4.4	618.35	74.5	830.34
1990	175.57	20.2	36.64	4.2	652.03	75.0	869.49
1991	173.23	20.8	41.83	5.0	613.19	73.6	833.05
1992	206.64	21.7	34.78	3.7	700.47	73.7	950.73
1993	213.54	21.7	33.25	3.4	726.44	73.9	983.58
1994	215.82	23.7	24.45	2.7	655.25	72.1	908.84
1995	239.85	27.3	32.57	3.7	596.33	67.9	878.21
1996	236.36	26.8	35.76	4.1	597.87	67.8	881.77
1997	235.63	26.9	37.24	4.3	591.68	67.6	875.66
1998	236.2	25.5	38.1	4.1	622.7	67.2	926.6
1999	237.3	28.3	38.3	4.6	530.4	63.2	838.9
2000	239.1	28.1	36.7	4.3	541.4	63.7	849.7

* Irrigation's share in water budget included livestock because the low percentage of it.
Source: MWI, Ministry of Water & Irrigation, Annual Reports (1985 - 2002), the 1998 - 2000 Budget. DOS, Department of Statistics, Statistical Year Book (1985-2002)



Source: MWI and DOS, Table 2

Fig. 2: Jordan's Annual Water, Utilization of Water (1985 - 2000)

Future Water Demand, Water Supply and the Deficits:

Table 3 and Figure 3 show that the population of Jordan is expected to increase from approximately 4.4 million in 1996, 5 million in 2000, 6.6 million in 2010, and 8.6 million in 2020. Assuming a modest increase in the per capita water use to 155 liters / day during this period, then the municipal water demand is expected to grow from approximately 239 MCM in 2000, 382 MCM in 2005, 435 MCM in 2010 and 615 MCM in 2020.

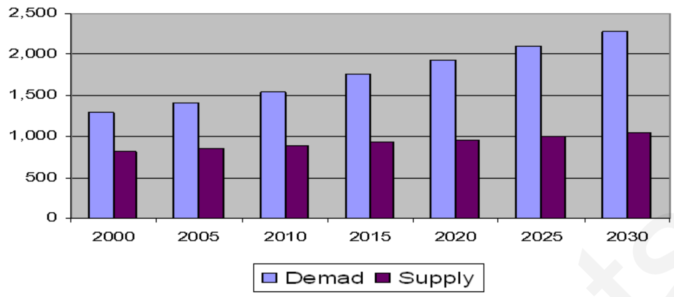
Future industrial water demand depends on future development. Prior to 1989, the industrial water demand was estimated to grow from 37 MCM in 1990 to 80 MCM in 2005. Current projections based on an increasing industrial contribution to overall economic development have industrial water uses increasing from 33 MCM in 1995, to 102 MCM in 2010 and 168 MCM in 2020. This remains a very ambitious development program based on current economic conditions, but is absolutely critical to Jordan's economic stability.

Projected irrigation water demand in Jordan is expected to grow from approximately 596 MCM in 1995 to a stable 949 MCM by the year 2005, 1000 MCM in 2010 and 1153 MCM by the year 2020. The increase is related to the completion of on- going projects (i.e., dams in the south, Wadi Araba, development of the Yarmouk River waters and peace waters) and utilizing treated wastewaters that otherwise would be lost. Table 3, Figure 3, summaries the future water demand, water supply and the deficit.

Table 3: Projected Water Supply, Water Demand and Deficit (MCM)

Year	Water Demand					Water Supply				
	Popu-lation	Muni-cipal	Indu-stry	Irrig-ation	De-mand	Muni-cipal	Indu-stry	Irrig-ation	Supply	Deficit
2005	5,789	382.0	80	949	1,411	266	47	541	854	557
2010	6,630	435.0	102	1,001	1,538	290	53	545	888	650
2015	7,575	520.0	134	1,098	1,752	314	61	548	924	828
2020	8,633	615.0	168	1,153	1,936	341	70	551	962	974
2025	9,815	711.8	185	1,205	2,102	368	81	554	1,003	1,099
2030	11,12	821.6	203	1,251	2,276	396	93	557	1,047	1,229

Source: Calculated by Researcher, The Simple Linear Regression Equation (Trend) is used for Calculating the Future Projected of Demand, Supply and Deficit. Depends on the Annual Reports of MWI, (1980 - 2002). Y: (Municipal or Industrial or Irrigation), X: Time (Years)



Source: MWI, Annual Reports, (1981 - 2002), Table 3

Fig. 3: Projected Water Supply, Water Demand and Deficit

Land Resources:

The total area of Jordan is about 89.2 million dunums as mentioned before, and this area can be divided into seven climatic zones. In general, can be classified as a 'low rainfall region', since over 86 percent of its area is a desert region which has no economic importance, except for some short-term sporadic grazing at certain times of the year.

The level of precipitation decreases from West to East and from North to South and, out of a total cultivable area of about 5000 thousand dunums or 5.7 percent of the total land area, 4900 thousand dunums or 93 percent depend entirely on rainfall to sustain any crops, and only about 739 thousand dunums or 14 percent are irrigated (Haddad, 1991).

The average cultivated area in the 1990 - 1999 period of about 2.385 thousand dunums, representing 3 percent of the total Jordanian area and less than 1 dunum per capita. However, the cultivated area varies strongly due to changes of rainfall. In 2002 the total cultivated area reached to 2.606 thousand dunums compared to 2.354 thousand dunums in the year 2000 with an increase of 9.6 percent. The irrigated area formed 29 percent of the total cultivated area, as shown in Table 4. About 5.5 percent of Jordan's area is considered dry land with annual rainfall ranging from 200 to 300 millimeters. The pattern of rainfall is characterized by an uneven distribution over the various regions and strong fluctuation from year to year. However, rainfall distribution determines the vegetation and cropping pattern in the rainfed areas.

The irrigated area of Jordan is located in the Jordan Valley and the Southern Dead Sea. It is considered the most important region in Jordan to produce vegetable production, as well as banana cultivation. This region has a tropical climate and a high availability of water irrigation which lies between 200 and 350 meters below sea level. The total irrigated area was 253 thousand dunums in 1983. The irrigated area constantly increased to reach almost 538 thousand dunums in 1990, 739 thousand dunums in 1997 and 749.4 thousand in 2002, as shown in Table 4. Thus, more than 14 percent of the total arable land and about one fourth of the average cultivated area is now under irrigation.

Table 4: Irrigated and Non - Irrigated Areas under Fruit Trees, Field Crops and Vegetables in 1983, 1997 and 2002 in Jordan (Dunums)

Years	1983	1997	Growth Rate *	2002
Fruit Trees				
Irrigated Area	82,068	330,068	9.9	356,100
Non - Irrigated Area	343,156	501,369	2.7	526,900
Total Area	425,224	831,437	4.8	883,000
Percentage of Irrigated Area	19.3	39.7	5.2	40.3

Table 4: Continue

Field Crops				
Irrigated Area	28,654	131,679	10.9	74,3
Non - Irrigated Area	1,657,126	1,476,391	-0.8	1,305.9
Total Area	1,685,780	1,608,070	-0.3	1,380.200
Percentage of Irrigated Area	1.7	8.2	11.2	5.4
Vegetables				
Irrigated Area	142,591	277,691	4.8	318,900
Non - Irrigated Area	69,171	25,133	-7.2	23,700
Total Area	211,763	302,824	2.6	342,700
Percentage of Irrigated Area	67.3	91.7	2.2	93
Total Cultivated Areas				
Irrigated Area	253,313	739,437	7.7	749,300
Non - Irrigated Area	2,069,453	2,002,894	-0.2	1,856.600
Total Area	2,322,767	2,742,331	1.2	2,605.900
Percentage of Irrigated Area	10.9	27.0	6.5	28.8

***** G.R: {[S = P (1+i) ^{t}], where, S: value of 1997, P: value of 1983, i: G.R, t: time from 1983 to 1997, (No. of years)}
Source: DOS, Agricultural Census, 1983 and 1997. DOS, Annual Agricultural Statistics, 2002

***Problem Statement*:**

In the Jordan Valley (Area of Study), irrigation water is very cheap and is priced below the cost. It is subsidized to support agricultural production. But recent budget constraints and increasing water scarcity and demand have led Jordan to reduce such subsidies to make irrigation schemes responsible and viable. The current cropping patterns in the study area (JV) contribute to the consumption of large amounts of water at a time when the region seeks greater water savings. There is a need to economize the use of irrigation water to avoid the foreseeable conflicts between users.

The Study Area (Jordan Valley):

The Jordan Valley, study area represents the most important source of the vegetable crops in Jordan, where the production of vegetable crops reached about 50 percent in this region. The Jordan Valley is a 105 km long and 4 - 16 km wide depression, with an elevation from 200 m below sea level in the North down to 400 m below sea level at its southern end at the Dead Sea (JVA, 1997).

The average annual temperature is 24 C°, with a mean maximum temperature of 36 C° in summer and a mean minimum temperature of 14 C° in winter. Rainfall occurs from November until mid-April, and decreases from 377 mm per year in the North to 87 mm per year in the South. The average relative humidity is 65 percent in winter and 45 percent in summer (DOM, 1999).

In 2002, the cropping pattern in the Jordan Valley showed that the vegetables were the dominant crop of which about 53.4 percent of the total cultivated area. The ratio of cultivated area of fruit trees and field crops reached about 34.3 percent and 12.3 percent of the total cultivated area, respectively, as shown in Table 5.

Table 5: The Cropping Pattern in Jordan and the Jordan Valley 2000 and 2002

Region	Cropping Pattern 2000		Cropping Pattern 2002	
Jordan	Area (Du)	%	Area (Du)	%
Fruit Trees	869400	36.9	883000	33.9
Field Crops	1155800	49.1	1380200	52.9
Vegetables	328800	14.0	342700	13.2
Total 2354000	100.0	2605900	100.0	
The Jordan Valley				
Fruit Trees	111611.5	34.3	116800	38.2
Field Crops	40039.6	12.3	33700	11.0
Vegetables	173601.2	53.4	155600	50.8
Total	325252.3	100.0	306100	100.0

Source: DOS, Department of Statistics, Agricultural Statistical Bulletin, 2000 and 2002.

Objectives:

This study seeks; therefore, to enhance the value of the information available to irrigation planners by incorporating the data into mathematical model for optimizing temporal water allocation and use**.** However, the study will examine the impact of rising water prices on the optimal allocation of water and use of land area.

Literature Review:

Water scarcity and its impacts on agricultural production and food security are growing concerns worldwide. Among various policies in dealing with the intensifying water stress, pricing mechanism has been given a high priority (Bjornlund and McKay, 1998; Dosi and Easter, 2000; Forch, 2000; Berbel and Gomez-Limon, 2000; Ahmad, 2000; Cosgrove and Rijsberman, 2000). Implementing pricing mechanism, efficiency of water use and sustainable management of water resources have been high on the agenda of policy makers at all levels (Feng, 1999; Wei, 2001; Yang et al 2003; Gutman 2001; Johanssona et al 2002; Grimble 1999; Abu-Madi et al 2003; Abu-Sharar and Battikhi 2003; Dridi 2005; Voora 2005; Schoengold and Ziberman 2005; Lautze et al 2005 and Farzaneh et al 2002).

Particularly there is a focus on approaches and mathematical models for assessing and improving the performance of water use in agriculture in terms of increasing the water use efficiency (Amir and Fisher 1999, 2000; Haouari and Azaiez 2001; Al-Weshah 2000; Doplar et al 2002 and Al-Assaf 2003) used a linear programming model for optimal allocations of water under water deficits in Jordan Valley and other regions as well as determining a profit maximizing combination of activities (crops) that is feasible with respect to a set of constraints such as water and land.

Data and Methodology:

Both of primary and secondary data are used in the study. The necessary primary data was compiled, classified and tabulated from the raw data collected by DOS, to serve the objectives of study. The information on the availability of the different water qualities, the prices paid for the water, the amount of land allocated to each activity by season, crop productivity, total revenue and WRCs (water related contribution) are gathered from different sources in Jordan. These sources are primarily the Department of Statistics (DOS), Ministry of Water and Irrigation (MWI), Ministry of Agriculture (MOA), Agricultural Market Organization (AMO), Central Market (CM), The Jordan Valley Authority (JVA). The secondary data are from the bulletins, the statistical reports and the publications of DOS, MOA, MWI, AMO, CM and JVA, as well as the studies related to the World Bank and the different International Organizations like FAO, United Nations, WHO.

The study uses the cropping pattern at the year 2002 based on the available data of the Department of Statistics (DOS) because the data reflects the impact of the irrigation water policies in the Jordan Valley adopted after year 2000. In addition, year 2002 was considered the nearest data point for defining the needs of the required agricultural commodities, taking into consideration the increase in future population and consequent increase in demand of agricultural commodities for future years.

Model Specification:

The model in this study was developed from the (Agricultural Sub-Model, (AGSM)) by Amir and Fisher (1999), which were designed specially for Middle East region. The modified model is a linear optimizing model for water used in agriculture. The model use data on available land, water requirements per unit land area for different crops, and net revenues per unit of land area generated by the growing of those crops in different locations. These net revenues did not include payments for water, which were handled separately. The model takes prices and quantity allocations for water and generates that cropping pattern which maximizes agricultural income. By varying water prices, the demand function for water can generally be constructed.

Model Objective Function:

The model is formulated at the Jordan Valley. Its objective function is the net agricultural income, which is maximized by selecting the optimal mix of water-consuming activities (vegetables, fruit trees and field crops). In this procedure, the decision variables are the land areas of the activities. Each activity is characterized by its water requirements per dunum [(according to the type of water, soil classes, production technology (i.e. open field, plastic) and irrigation technology (i.e. drip, surface, sprinklers) in each district of the Jordan Valley)] and the gross margin per dunum that has not included the cost of water. However, each activity can, in principle, use one or more types of water and the quality of water depends on the sources. Irrigation water is distributed on monthly basis. There are two production seasons: autumn and spring.

The model has been formulated to support up to 12 different water prices due to season-quality water types. After achieving the optimal allocation of water among water consuming activities a near optimal solution will be conducted in order to generate alternative solutions that could be raised by decision makers.

The objective function that is maximized in the modified model (Eq.1) is the total net income of agriculture in the Jordan Valley. Net income is considered in two parts. The first is referred to WRC. WRC_j, the water-related contribution of activity j, is defined as the gross margin generated by activity j, per unit area less all direct expenses (machinery, labor, materials, fertilizers… etc) associated with doing so, except for direct payments for water. It measures the maximal ability of the activity to pay for water. The second component of net income consists of direct payments for water and its value is subtracted from its corresponding WRC. It is important to mention that such payments have not been included water-related expenses because these expenses are involved in the price charged by the government for the different water qualities to cover the operational and maintenance costs of the conveyance and distribution irrigation system.

Model Constraints:

The model has two main constraints: water and land. The quantity of irrigation water is allocated according to season, location and quality for each activity.

Water Constraints:

For determining the net water requirements of activities planted in the Jordan Valley, the model took into consideration the fact that the efficiency of the irrigation system is about 72 percent as estimated by (MWI, 1999) and that rainfall is about 80 percent effective. Consequently, 80 percent of precipitated rainfall during winter season contributes to water crop requirements. The evaporation and leakage rates are included in the irrigation efficiency. The water requirements for a given activity increases as we go from north to south due to an increase in temperatures. Water requirement is for 12 months (October-September) for a given activity. In addition, the formulation of the water supply and the storage-transfer constraints have been included in the modified model. This is done by specifying that current inflows can be used either for current irrigation or can be stored for later season (Eq. 2).

Land Constraints:

Land areas can be specified according to the districts, crops and water qualities (Eq. 3). This way, it is ensured that each crop will enter the solution in order to produce sufficient quantities to meet domestic demand and export activities. Thus, the retail prices of crops in general will be stable for the coming season. The area is divided into two districts, Northern Shounah and "Dair-Alla & Southern Shounah". The model will optimize the allocated areas within the districts and the entire region.

The model developed also included technological level in production and irrigation methods by defining the quality of water used in the irrigation from the different sources and for the cultivated areas of each crop in year 2002.

Mathematical Notation of the Model:

The objective function of the model can be written as:

$$\text{Max } Z = \sum_j \sum_m \sum_k \sum_t \sum_z X_{jmktz} * \left[WRC_{jmktz} - \sum_i \sum_m (P_{im} W_{im}) - \sum_i \sum_m G_{im} W^{+}_{(i-1)m} \right] \quad (1)$$

Where:

Z represents the maximum achieved total net agricultural income; X_{jmktz} is the total land area of activity $_j$ using water type$_m$, in site$_k$, using technology$_t$, in season$_z$. WRC$_{jmktz}$ is the water related contribution or Gross Margin per Dunum of activity$_j$ using water type$_m$, in site$_k$, using technology$_t$, in season$_z$. P_{im} is the price of water per cubic meter in month$_i$ (October to September) using water type$_m$ and W_{im} is the allocated amount of water in month$_i$, using water type$_m$. G_{im} is the per-cubic meter cost of storing water of type *m* in order to transfer it from month$_{i-1}$ to month$_i$. $W^{+}_{(i-1)\,m}$ is the quantity of water of type$_m$ that already stored from the previous month$_{i-1}$.

This objective function is subjected to the following constraints:

The main constraints are:

Water constraint

$$\sum_j \sum_m \sum_k \sum_t \sum_z a_{ijmkt}\, x_{jmkt} + \sum_i \sum_m \left(-W^{o}_{im} - W^{+}_{i-1,m} + W^{-}_{i+1,m} \right) \leq 0 \quad (2)$$

Land constraint

$$\sum_{j}\sum_{m}\sum_{k}\sum_{t}\sum_{z} X_{jmktz} \leq A_{mktn} \qquad (3)$$

Where:
a_{ijmktz} is the water requirement per dunum of activity$_j$ for water type$_m$ in month$_i$, in site$_k$, using technology$_t$. W^{0}_{im} is the total supply of water of type$_m$ in month$_i$, excluding storage; $W^{-}_{i+1,\,m}$ is the transfer of water of type$_m$ to the month after$_{i\ (i+1)}$. A_{mktn} is the total allocated area for all crops using water type$_m$, in site$_k$, using technology$_t$ for crop category$_n$, where the crop categories are vegetables, fruit trees and field crops.

The modified model identified the cropping pattern at each level of water prices in The Jordan Valley, consumption, distribution, excess and shortages of water and the transfer possibilities of water between months or seasons. The modified model is solved by the software: XA/EXCEL system.

Variables:

The most important crops of vegetables have been chosen which they form more than 85 percent of the total cultivated vegetables area in the study region. The vegetable crops are: Tomatoes, cucumbers, eggplants, potatoes, squash, cauliflower, hot peppers, sweet peppers, string beans, onion (green), broad beans, cabbages and Jew's mallow. The vegetables have reached 70 crops in JV. There are 27 fruit trees in JV. The most important crops of fruit trees include mandarins, oranges, pummelors, clementines and lemons from the citruses, in addition to other fruit trees which include olives, bananas, palms or dates, apples, guava, plums, peaches, pomegranate and grapes. The field crops have reached 8 crops in JV. The most important crops of field crops include wheat, barley, clover trifoil and maize.

The total arable area in the Jordan Valley for the various crops is about 255 thousand dunum in the year 2002. The arable areas for each crop are fixed to be equal or less than the cropping pattern in 2002. This is based on the reports of the Department of Statistics in 2002. The quantity of water which is available to be used in the Jordan Valley for irrigation is about 214 MCM, supplied by the Jordan Valley Authority.

Water Prices:

The policy of using different levels of water prices in the Jordan Valley is one of the methods used by the decision makers to reduce the consumption of water. Many decision makers think that the agricultural sector consumes large amounts of water to produce low income crops which cause waste in this very important source in Jordan. Thus, different water prices levels are used in the model to study the effect of this pricing policy on the constraints: planted area, cropping pattern, the total net income of agricultural sector in the area of study with each suggested price level. The analysis starts with water price at below the prevailing price 0.025 JD/CM from 0.01 JD/CM and stop at 2.5 JD/CM.

The water prices in the Jordan Valley are actually range between 0.008 - 0.035 JD/CM in the consumption segments of the market. The prevailing water price is about 0.025 JD/CM. The objective function that is maximized in the model is the total annual net income of agriculture in the Jordan Valley.

RESULTS AND DISCUSSION

Results of mathematical model outputs reached to the optimal cropping pattern that achieved the highest revenue at all different water price levels including the prevailing water price level 0.025 JD/CM in the Jordan Valley.

The quantity of water, 214.2 MCM, is the main factor in the determination of the arable areas. The optimal planted area in the Jordan Valley is about 211 thousand dunum and the total available area is about 306 thousand dunum. The difference is attributed to the water requirements of the crops. The limited quantity of water covers only about 82 percent of the total area according to the estimation of the model, as shown in Table 6. This percentage almost corresponds to the data that was used in the study. However, the ratio of actual planted area in the agricultural unit is about 70 percent for vegetables, and about 80 percent for fruit trees (DOS, 2002).

The figures mentioned above, show that the farmers in the Jordan Valley were able to obtain results which correspond between the actual planted area of their units and the available water amounts. The data that has been used in the study is representative, and the calculated gross margins from this data for the various crops give a good estimation of the actual gross margins for the farmers in the Jordan Valley.

Table 6: The Optimal Allocation of Planted Area in JV according to the different Prices of Water

Water Prices JD/CM	Optimal Planted Area 000/DU Jordan Valley
0.01	211
0.0125	211
0.015	211
0.025	211
0.05	211
0.075	194
0.10	190
0.125	159
0.15	147
0.175	115
0.20	104
0.22	83
0.30	82
0.40	57
0.50	33
0.60	25
0.70	25
0.80	10
0.90	5
1.00	3.2
1.10	2.7
1.20	2.2
1.50	1.55
2.00	1.3
2.50	1.3

Source: LP Model of the Study

Optimal Allocation of Planted Area in the Jordan Valley:

Table 6 illustrate that the optimal planted area in the Jordan Valley of about 211 thousand dunum, remained unchanged after the reduction of water prices from the prevailing price of 0.025 JD/CM. This is due to the limit of water which is available to 214.2 MCM. This amount is sufficient to plant this area and there is no possibility to increase the planted area by using the same limited amount of water and the same technology level. This shows the necessity for using more developed technology levels, to increase the efficient use of water. The area also remained unchanged until water price reach to 0.05 JD/CM. After that, the area started to decrease until it reached 194 thousand dunum at water price of 0.075 JD/CM. It continued to decrease with the increasing of water prices until the planted area reached 83 thousand dunum at water price of 0.22 JD/CM. The price 0.22 JD/CM represents the cost of irrigation water in the Jordan Valley according to the World Bank, 2001.

Table 6 and Figure 4 clarify the effects of pricing policy on the optimal planted area of the study area according to the different levels of water prices used in the study. Furthermore, they illustrate the relation between various water prices and the derived demand of optimal planted area in the Jordan Valley. The estimation of demand function and the derived demand curve for optimal planted area in the Jordan Valley are obtained from the output of the model as discussed below. However, the relation between the derived demand for planted area and the suggested water prices is also clarified next:

Estimation of Demand Function for Optimal Planted Area in the Jordan Valley:

Derived Demand Function for Optimal Planted Area in the Jordan Valley within Water Prices Levels (0.025 – 1.5 JD/CM)

Function	T-value	R^2	F	Price - Elasticity Mid-point (0.51 JD/CM)	Price - Elasticity Actual Price (0.025 JD/CM)
A = 159.81 – 151.73 P	(-7.4)*	75	54.2*	- 0.93	- 0.02

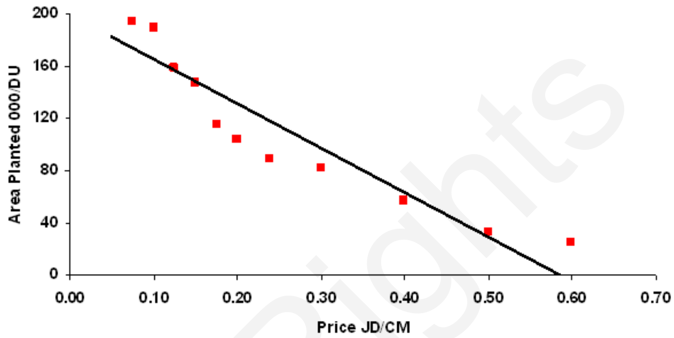
A: Optimal Area in JV, P: Price of Water.
* Significant at ά = 0.05

The linear function above shows the effect of increasing water prices from 0.025 JD/CM to 1.5 JD/CM on the optimal planted area in the Jordan Valley. The derived demand function is graphically presented in Fig. 4 creating the optimal demand curve for planted area in the Jordan Valley.

A linear approximation to the curve fits quit well; the corresponding regression coefficient is presented in the function above. The own - price elasticity of planted area, which is derived from the linear equation, is about - 0.02 at the prevailing water price of 0.025 JD/CM. This is a very low elasticity, but that is very largely a consequence of the very low actual price at which it is evaluated. This means that, an increase of one percent in the price of water will reduce the planted area by about 0.02 percent, so that derived demand is inelastic. One of the advantages of the linear function is the possibility to calculate price elasticity for each price level individually, so it can be determined the quantity demanded and the type of price elasticity for the optimal planted area at each price level. At the midpoint of the range of water prices studied (0.51 JD/CM), the own - price elasticity of optimal planted area is about - 0.93. This means that, starting at that price, an increase of one percent in the price of water will decrease the planted area demanded by about 0.93 percent, so that derived demand is slightly inelastic.

From the function, it can be determined the price level at which the absolute value of elasticity will be equal or greater than one. The water price level at which the price elasticity of planted area demand is unitary elastic is about 0.55 JD/CM. Above this price, optimal planted area demand is price elastic and at lower prices, optimal planted area demand is price inelastic.

Figure 4 shows the derived demand curve of the optimal planted area in the Jordan Valley according to wide range of suggested water prices. The best fitting demand curve for optimal planted area is the linear.



Source: LP Model, Table 6

Fig. 4: Derived Demand Curve for Optimal Planted Area in JV

Total Net Income:

Total net income from the optimum planted area (211 thousand dunum) is about 41.2 million JD at the water price of 0.01 JD/CM and about 37.97 million JD at the prevailing water price of 0.025 JD/CM. When the price of water rises from 0.025 JD/CM to 0.22 JD/CM, a reduction in the total net income occurs (from 37.97 to 10 million JD), which translates to 27.97 million JD. This is due to the fact that field crops leave the optimal solution, as they are no longer competitive with other crops.

On the other hand, the optimal water demand is reduced by 179 MCM (from 214.2 to 35.2 MCM), and this means that, saving one cubic meter of water will reduce the total net income by about 0.16 JD in the Jordan Valley. The cost of water is increased by 2.64 Million JD (from 5.36 to 8 Million JD). In Addition, the optimal planted area is reduced by 128 thousand dunum (from 211 to 83 thousand dunum), the results of varying the water prices and their effect on net income, optimal planted area, optimal water demand and cost of water are presented in Table 7.

The pricing policy and its effect on the net income must be taken into consideration when it is applied by the decision makers where the objective is to reduce the demand of irrigation water.

Table 7: Net Income, Optimal Allocation of Area, Optimal Allocation of Water and Cost of Water in JV

Water Prices JD/CM	0.01	0.0125	0.015	0.025	0.05	0.075	0.10	0.15	0.22
Income									
Total Net Income (Deducted Cost of Water) Million JD	41.2	40.7	40.1	37.97	32.6	27.7	23.1	15.1	10
Total Net Income (without Deducted Cost of Water) Million JD	43.3	43.3	43.3	43.3	43.3	41.7	41.3	36.6	17.6
Area									
Optimal Allocation of Area in JV (000/DU)	211	211	211	211	211	194	190	147	83
Water									
Optimal Allocation of Water* (MCM)	214.2	214.2	214.2	214.2	214.2	186.4	181.6	143	35.2
Optimal Allocation of Water in JV (MCM)	214.2	214.2	214.2	214.2	214.2	186.4	181.6	143	35.2
Cost of Water in JV (Million JD)	2.1	2.68	3.2	5.36	10.7	14	18.2	21.4	8

Source: LP Model of the Study

***** The quantity of irrigation water, estimated 214.2 MCM according to JVA

Optimal Cropping Pattern in the Jordan Valley:

The optimal cropping pattern for all studied crops in JV is obtained and determined by the model. The optimal cropping pattern in JV comprises 57 crops out of 105 crops, 42 crops of vegetables, 11 of fruit trees, 4 of field crops.

The model uses many water prices start from 0.01 JD/CM to of 2.5 JD/CM as mentioned previously. In addition, the model determines the optimal planted area for each crop at different levels of water prices to examine the price elasticity of water for all types of crops and to determine which crop to be continued or discontinued in the optimal cropping pattern.

Any crop which enters or leaves the optimal cropping pattern depends to the two major factors: the first is the gross margin and the second is the water consumption for each activity. Increasing gross margin and decreasing water consumption, allow the crop to stay in the optimal cropping pattern, and the opposite is also correct.

Most of the crops that have been chosen in the optimal cropping pattern are perfectly price elastic according to water, within the water prices range (from 0.01 JD/CM to 0.025 JD/CM). However, from the field crops, maize and barley, and from the fruit trees, mandarins and clementines are the first crops to leave the optimal cropping pattern when water price reaches 0.075 JD/CM. This reduces the total net income in the Jordan Valley from 38 million JD at the prevailing water price of 0.025 JD/CM to 28 million JD at the water price of 0.075 JD/CM. Maize and barley also leave the optimal cropping pattern because of low gross margins. The gross margins per dunum of maize and barley are about 9 JD and 38 JD, respectively. On the other hand, mandarins and clementines leave the optimum cropping pattern because of low gross margins and high water consumption. The gross margins per dunum of mandarins and clementines are about 74 JD and 71 JD, respectively, and the water consumption per dunum is about 1184 CM and 1250, respectively.

As expected, the crops with low gross margin and high water consumption will leave the optimal cropping pattern earlier than others. However, the model is working to maximize the net incomes of farmers in this region. The water price of 0.70 JD/CM is considered a critical price level for most of the activities. The majority of vegetable crops left the optimal cropping pattern at this level of water prices. The water price of 0.70 JD/CM represents the critical level (break - even price) for most vegetable crops.

Optimal Allocation of Irrigation Water in the Jordan Valley:

The effect of pricing policy on the optimal allocation of irrigation water (water demand) is reported and cleared in Tables 7 and 8. It can be seen from these tables that price elasticity of irrigation water in the Jordan Valley is inelastic at water prices levels from 0.01 JD/CM to 0.05 JD/CM. The optimal cropping pattern continues to utilize all available water (214.2 MCM). Quantities of water consumption start to decrease at water price of 0.075 JD/CM, which is about 186.4 MCM. Whenever water prices increase, the water consumption will continue to be decreased. This shows that, water price elasticity is becoming higher when water price is increasing. This is due to low gross margin for crops in consequence of increasing water prices.

The results of systematically changing the water price and the effect of pricing policy on the optimal allocation of irrigation water (water demand) at the area of study are presented in Table 8 and Figure 5. The Table and the Figure show the relation between the different water prices and the demand of irrigation water in JV.

Table 8: The Optimal Allocation of Irrigation Water in JV according to the different Prices of Water

Water Prices JD/CM	Optimal Allocation of Irrigation Water (Consumed Water) MCM
	Jordan Valley
0.01	214.2
0.0125	214.2
0.015	214.2
0.025	214.2
0.05	214.2
0.075	186.4
0.10	181.6
0.125	160.9
0.15	143
0.175	73.6
0.20	67
0.22	35.2
0.30	35
0.40	22.6

Table 8: Continue

0.50	12.2
0.60	8
0.70	8
0.80	2.5
0.90	0.958
1.00	0.442
1.10	0.340
1.20	0.217
1.50	0.053
2.00	0
2.50	0

Source: LP Model of the Study

According to the results of the mathematical model, it has been able to specify the function and the curve of irrigation water demand in JV at different water price levels from 0.01 JD/CM to 0.70 JD/CM. The range of water price levels has been adopted where most of crops are included. This means, the agricultural activities is stopped after water price of 0.70 JD/CM.

Estimation of Demand Functions for Optimal Irrigation Water in the JordanValley:

Demand Function for Optimal Irrigation Water in the Jordan Valley within Water Prices Levels (0.01 – 0.70 JD/CM)

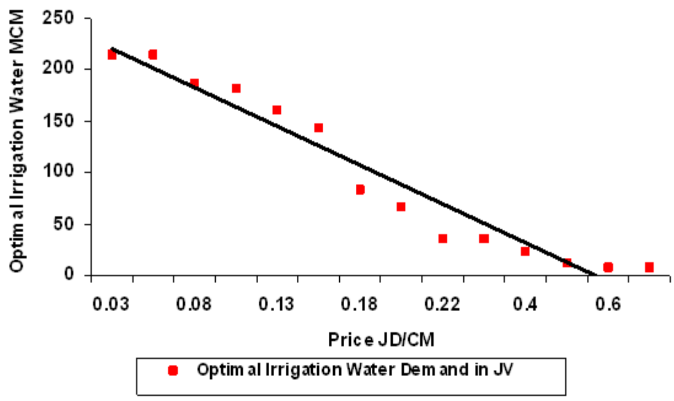
Function	T-value	R^2	F	Price-Elasticity Mid-point (0.215 JD/CM)	Price - Elasticity Actual Price (0.025 JD/CM)
W = 194.55 – 356.19 P	(-7.3)*	78	53.2*	- 0.65	- 0.04

W: Optimal Irrigation Water in JV, P: Price of Water.
* Significant at ά = 0.05

The linear function above shows the effect of increasing water prices from 0.01 JD/CM - 0.70 JD/CM on the optimal irrigation water consumption in the Jordan Valley. The demand function is graphically presented in Fig. 5, creating the optimal demand curve for irrigation water in the Jordan Valley. A linear approximation to the curve fits quit well; the corresponding regression coefficient is presented in the function above. The own - price elasticity of irrigation water, which is derived from the linear equation, is about - 0.04 at the prevailing water price of 0.025 JD/CM. This is a very low elasticity, but that is very largely a consequence of the very low actual price at which it is evaluated. This means that, an increase of one percent in the price of water will reduce the irrigation water by about 0.04 percent, so that demand is inelastic. One of the advantages of the linear function is the possibility to calculate price elasticity for each price level individually, so it can be determined the quantity demanded and the type of price elasticity for the optimal irrigation water at each price level. At the midpoint of the range of water prices studied (0.215 JD/CM), the own - price elasticity of optimal irrigation water is about - 0.65. This means that, starting at that price, an increase of one percent in the price of water will decrease the irrigation water demanded by about 0.65 percent, so that demand is slightly inelastic.

From the function, it can be determined the price level at which the absolute value of elasticity will be equal or greater than one. The water price level at which the price elasticity of irrigation water demand is unitary elastic is about 0.335 JD/CM. Above this price, optimal irrigation water demand is price elastic and at lower prices, optimal irrigation water demand is price inelastic.

Figure.5 shows the demand curve of the optimal irrigation water in the Jordan Valley according to wide range of suggested water prices. The best fitting demand curve for optimal irrigation water is the linear.



Source: LP Model, Table 8

Fig. 5: Demand Curve for Optimal Irrigation Water in JV

Economic Efficiency Indicators:

Table 9 summarizes optimal selected values in the Jordan Valley. In this Table, the results for the JD 0.025 water price (fourth row) are those calculated with prevailing price for 2002. The results of the systematic increase of the water prices for the Jordan Valley are presented in Table 9. The columns of Table 9 are explained by their respective headings. The last column shows the main efficiency indicators (profitability of land and water).

For instance, the seventh row of the table reads as follows: for price (p = 0.10 JD per cubic meter CM), the entire planted area is 190 thousand dunums, the total water demand is 181.6 MCM (million cubic meters) resulting in an average of 956 CM (cubic meters) of water per dunum. Total expenses for water are 18.16 Million JD; and net income is 23.1 Million JD (Water Related Contribution, WRC) is, therefore, 18.16 + 23.1 = 41.3 Million JD). Water expenses are 44 percent of WRC. The profitability of one dunum is 121.6 JD, whereas the profitability of one cubic meter is 0.127 JD.

Table 9: Optimal Selected Values in JV according to the different Prices of Water and Efficiency Indicators

Water Prices JD/CM	Planted Area 000/DU	Water Demand (Consumed Water) MCM	Water per Land CM/DU	Water per s Million JD	Net Income Million JD	Water Expenses/Net Income %	Profitability	
							Land JD/DU	Water JD/CM
0.01	211	214.2	1015	2.143	41.2	5	195.3	0.192
0.0125	211	214.2	1015	2.678	40.7	6.2	193	0.190
0.015	211	214.2	1015	3.214	40.1	7.4	190.1	0.187
0.025	211	214.2	1015	5.356	38	12.4	180.1	0.177
0.05	211	214.2	1015	10.713	32.6	24.7	154.5	0.152
0.075	194	186.4	961	13.978	27.7	33.5	143	0.149
0.10	190	181.6	956	18.161	23.1	44	121.6	0.127
0.125	159	160.8	1011	20.104	18.79	51.7	118.2	0.117
0.15	147	143	973	21.458	15.1	58.7	102.7	0.106
0.175	115	73.6	640	12.880	12.49	50.8	108.6	0.170
0.20	104	67.3	647	13.457	10.68	55.8	102.7	0.159
0.22	83	35.2	424	7.736	10	43.6	120.5	0.284
0.30	82	34.8	424	10.445	7.1	59.5	86.6	0.204
0.40	57	22.6	396	9.047	4.17	68.5	73.2	0.185
0.50	33	12.2	369	6.074	2.54	70.5	77	0.208
0.60	25	7.7	308	4.642	1.68	73.4	67.2	0.218
0.70	25	7.7	308	5.416	0.907	85.7	36.3	0.118
0.80	10	2.5	250	1.978	0.426	82.3	42.6	0.170
0.90	5	0.958	192	0.863	0.237	78.5	47.4	0.247
1.00	3.2	0.442	138	0.442	0.181	71	56.6	0.410
1.10	2.7	0.340	126	0.374	0.144	72.2	53.3	0.424
1.20	2.2	0.217	99	0.261	0.144	64.4	65.5	0.664
1.50	1.55	0.053	34	0.079	0.086	48	55.5	1.623

Source: LP Model of the Study
GM 1: Water Cost is not included in TVC,
GM 2: Water Cost is included in TVC,

Conclusions:

It is expected that the outputs of the modified model in the study could be useful to bridge the gap between the limited water resources and the increased agricultural production in areas that suffer from severe water scarcity in JV through finding the optimal cropping pattern, the optimal allocation of irrigation water and maximization income in JV. The demand of agriculture for water reacts to increasing water prices in a quite inelastic manner over a long interval.

Water pricing, aided by analysis can be an appropriate and efficient means of controlling agricultural water consumption. The model can provide planners with tools to see the impact of pricing policy on the optimal planted area, net income, optimal water demanded, water expenses and profitability of land and water.

The optimal cropping pattern is characterized that the crops of high water consumption and low value gross margin will be left the optimal basis when prices of water increase within suggested range. It is recommended to increase water price from 0.025 JD/CM (prevailing water price) to 0.05 JD/CM, to reduce irrigation water consumption because this price will not affect planted area or agricultural labor or agricultural fertilizers in addition to keep gross margin stable.

LIST OF ABBREVIATIONS AND MEASURES

CBJ	Central Bank of Jordan, Jordan
CM	Cubic Meters
DOM	Department of Meteorology, Jordan
DOS	Department of Statistics, Jordan
Du	Dunum
GDP	Gross Domestic Product
GM	Gross Margin
Ha	Hectare
JD	Jordan Dinar; Jordanian Currency
JV	Jordan Valley, Jordan
JVA	Jordan Valley Authority, Jordan
JRV	Jordan Rift Valley, Jordan
Km	Kilometer
M or m	Meter
m3	Cubic Meters
MCM	Million Cubic Meters
MOA	Ministry of Agriculture, Jordan
M&I	Municipal and Industrial
mm	Millimeter
MOP	Ministry of Planning, Jordan
MWI	Ministry of Water and Irrigation, Jordan
Sq.Km	Square Kilometers
WB	World Bank
MEASURES	
Dunum	0.1 hectare (1,000 square meters)
1 Ha	10000 m^2
1 Fills	0.001 Jordan Dinar
1 Ton	1000 KG
EXCHANGE RATE	
Jordan Dinar JD	1 $ = 0.709 Jordan Dinar for the year 2001/2002

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