Hands-on Exercises Using the Water Allocation System (WAS)

Jordan Domestic Exercises and Comparisons of Cooperation vs. No Cooperation Regionally

Version 3.6

Developed by the

Water Economics Project

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Part 1: Jordan Domestic Exercises

Getting Started: Model Results for 1995

Base Case Results with and without Fixed Price Policies

Start by double-clicking the WAS_IJP icon. You will see an initial screen, as illustrated in Figure 1 below:

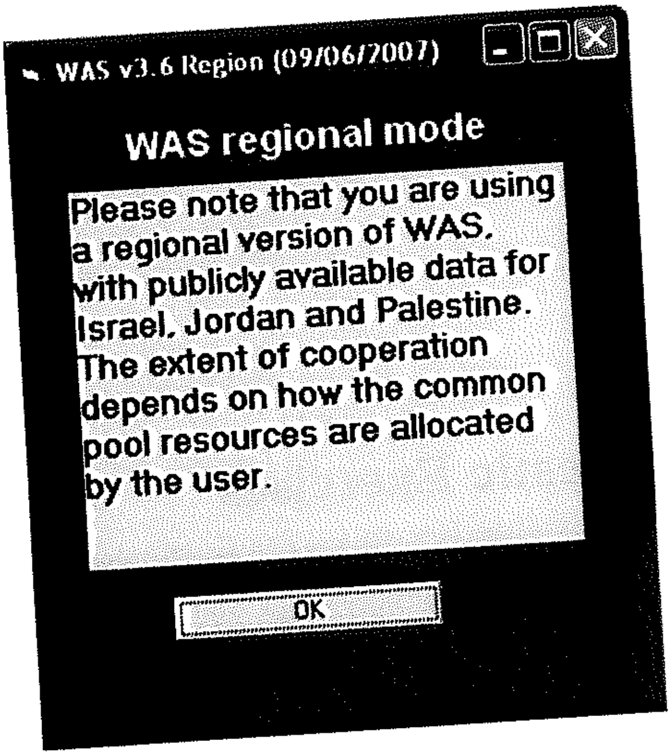


Figure 1

This screen simply indicates that the data are available for the countries of Jordan, Palestine and Israel, and makes no assumptions about cooperation between the countries – that is left to the user to decide.

After clicking the **OK** button, you will see the main WAS screen, as shown below in Figure 2.

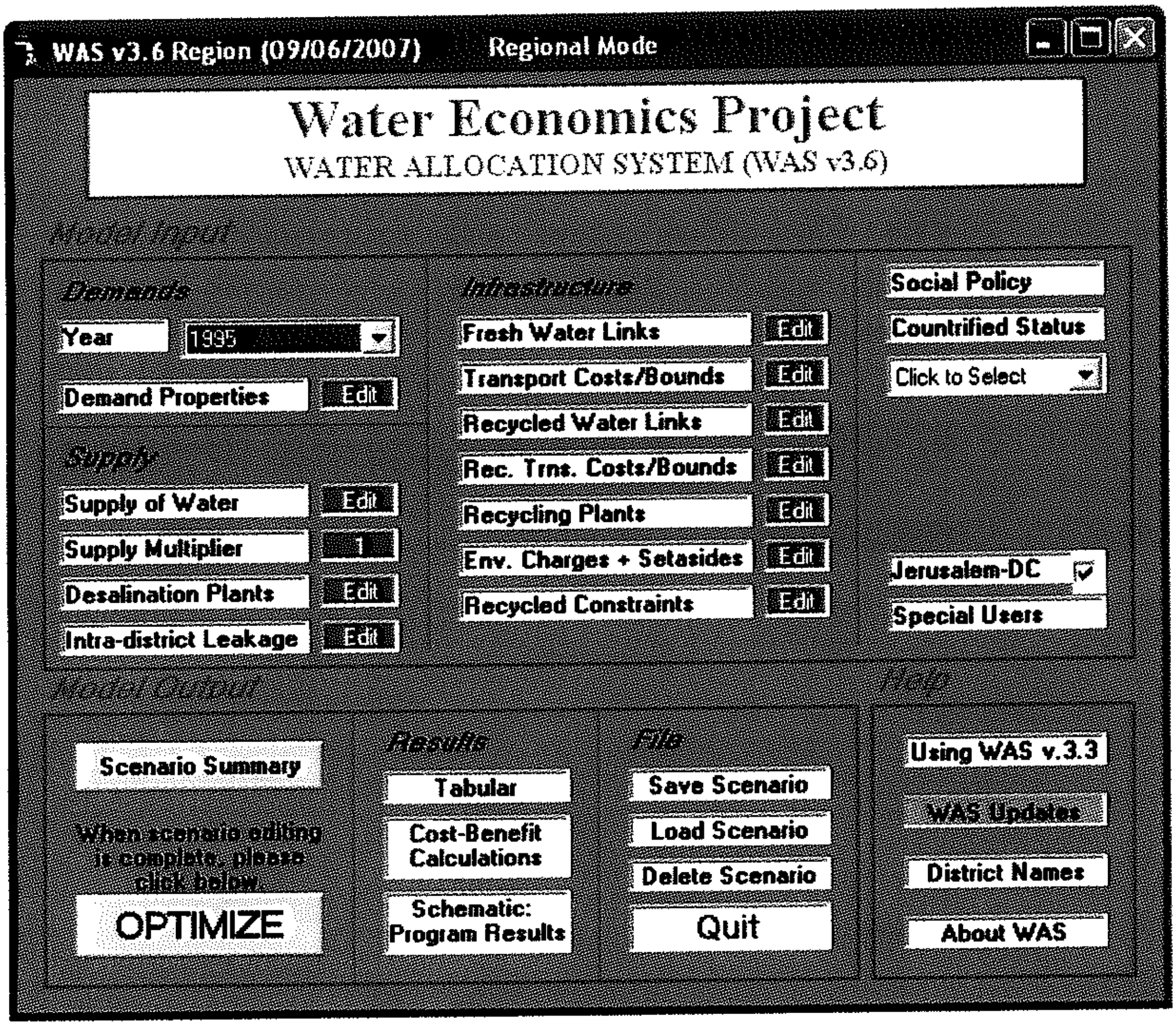


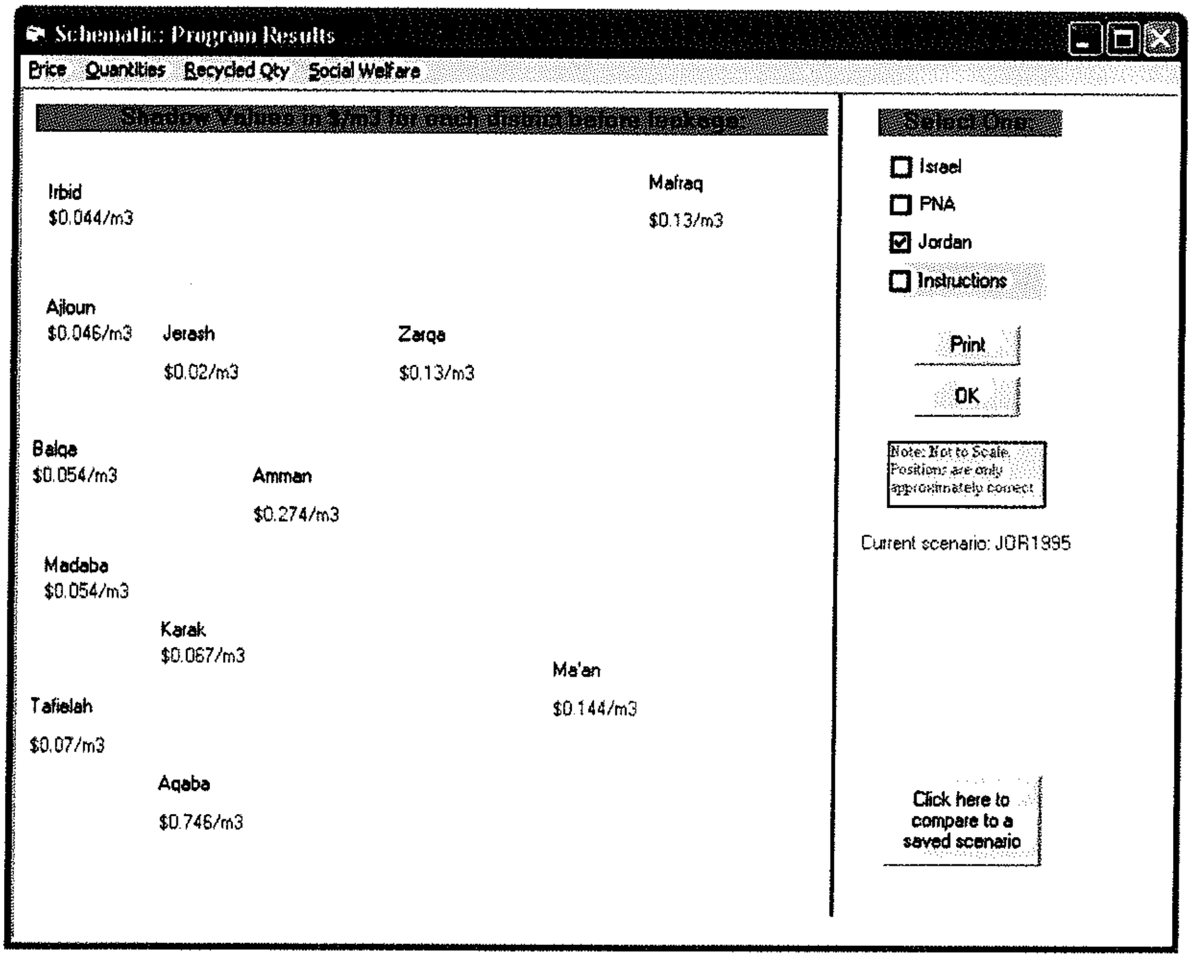
Figure 2 Main Screen

Click on **Load Scenario**, and select the scenario named **JOR1995**. In this scenario, the WAS model was run with the data presented in Annex A, initially with no fixed price policies (FPPs), and constraining withdrawals from supplies to sustainable quantities. A rate of 25 percent leakage is assumed. The shadow values[1] for this case are shown in **Figure 3** below.

[1] Leakage plays an important role in water management in terms of the amount of water that ultimately reaches a consumer. More subtle is the effect leakage can have on decision-making for infrastructure, particularly that of inter-district pipelines. If the shadow values between any two districts differ by more than the marginal cost of conveying water between the districts, it is possible that it would be cost-effective to build the conveyance between those two districts. The decision to construct the pipeline would be positive if the benefits obtained from the conveyed water outweigh the capital cost of construction. However, it is critical that this comparison of shadow values between districts happens with values before accounting for intra-district leakage (that is, value of a cubic meter of water as it enters the district rather than the value for the cubic meter of water that reaches the consumer), as the shadow value of water conveyed to a district is lower, the greater the intra-district leakage. A comparison of shadow values after leakage, which are

Note that the Amman district has a relatively high shadow value of approximately $0.27 versus $0.02 per cubic meter in the neighboring Irbid and Jerash districts. The difference is greater than the cost of conveyance between these districts and Amman (see Table A.7). This indicates a problem stemming from a shortage of conveyance infrastructure[2]. This issue of infrastructure development in Jordan will be explored extensively in the following sections.

Figure 3 – Baseline results for Jordan in 1995 – No Fixed Price Policies



There are two important aspects of the system as described above that are not consistent with how water is currently managed in Jordan – the absence of fixed price policies and the over-

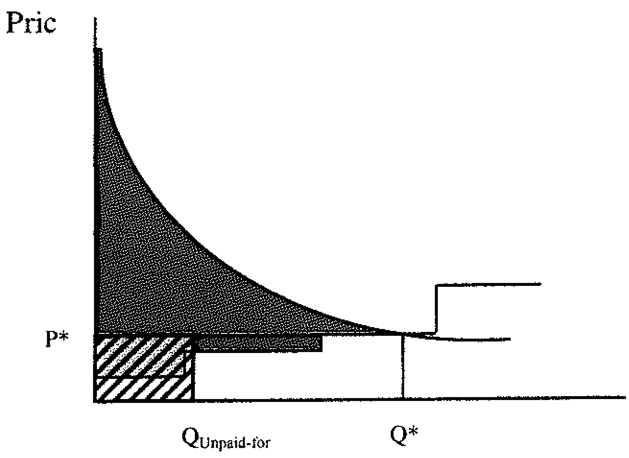
necessarily higher, would therefore be misleading because the actual gain in social welfare is that represented by the before leakage shadow values. Therefore all shadow values shown in this chapter are before accounting for intra-district leakage. Of course, reduction in intra-district leakage is highly desirable, and is considered in scenarios for the future in the following sections.

[2] A similar problem is indicated by the difference in shadow values between Amman and Madaba, but not between Amman and Balqa or Amman and Zarqa.

pumping of aquifers beyond sustainable quantities. We begin with fixed price policies, where there are two items to note.

First, there are existing policies for urban and agricultural sectors as presented in Annex A. The second item is more subtle. Also presented in Annex A is the issue of unaccounted-for-water. An estimated 25 percent of water supplied to the urban sector in 1995 is assumed to have been 'stolen' or unpaid-for. Assuming that the characteristics of this use are identical to those of paying users, these users are effectively facing a fixed price policy of free water for the quantities used. This may be an appropriate policy if these users are extremely poor. This can be handled in WAS by providing this amount of water for free to these users[3] through a 'setaside.' As depicted in Figure 4 below, the diagonally shaded area represents the value of the water that is provided for free or stolen, the costs of which are borne by society. That value is simply the quantity of unpaid-for water ($Q_{Unpaid\text{-}for}$ in the figure) multiplied by the shadow value of the water (P*). Unlike fixed price policies, there is no necessary net loss of social welfare, but rather mostly a *transfer of payments* within society. In effect, the people taking the water get it for free, but it means the rest of society – effectively the water system – is paying for their water. For the case of 1995, the amount of transfer appears to be on the order of US$30 million.

Figure 4 – Accounting for Unpaid-for Water



[3] Note that these quantities can be changed through the interface.

After these free quantities are provided in the model, the price policies described in the previous section are imposed.

When this is done for 1995, however, the results show that the policies involved would not have been feasible without over-pumping of aquifers, which clearly was occurring as shown in Table 1 below. This problem will certainly get worse in the future as demands increase. The infeasibilities are caused by the combination of fixed price policies and the restriction on using water sustainably – a restriction imposed on all future scenarios. Note that they are not caused by the small quantities of water provided for free. Rather, it is the fact that there is not sufficient water available to Jordan to provide the amount of water demanded at very low fixed prices. This is true, even in 1995, as evidenced by the fact that water was not available 7 days a week/24 hours a day even in Amman. Even with the fixed price policies limited to the quantities of water consumed in 1995, the provision of that quantity of water is not possible without exceeding the annual renewable quantities available. Therefore this type of fixed price policy is not further explored.[4]

[4] The water crisis in the projection years is already extremely severe without such policies.

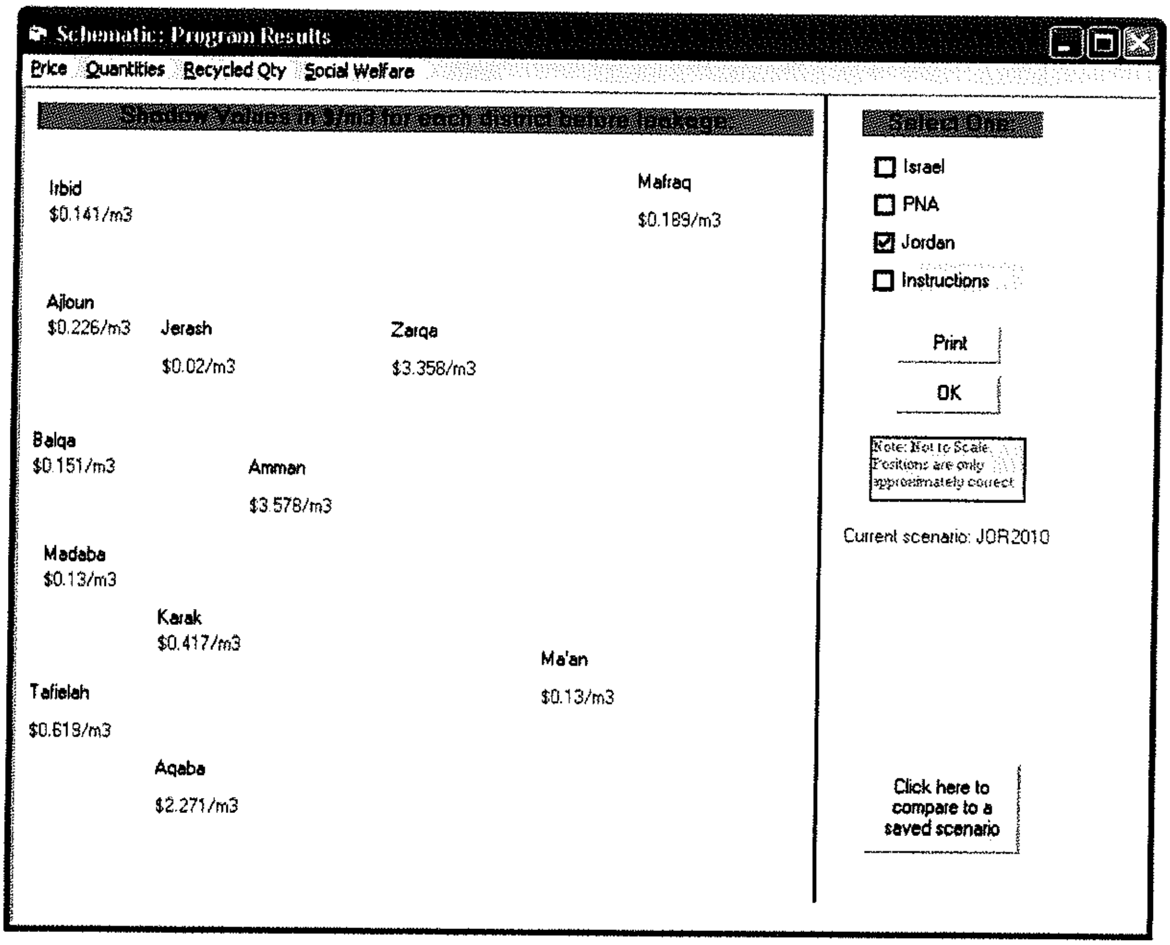
Table 1 Annual Amount of Over-abstraction by Governorate

Groundwater Basin	Annual Renewable Quantity of Water (MCM)	Abstraction in 1998 (MCM)	Balance (MCM)
Yarmouk	40	39	1
Amman-Zarqa	87	150	–63
Azraq	30	52	–22
Jordan Valley	21	36	–15
Rift Side Wadis	15	31	–16
Dead Sea	50	82	–32
Wadi Araba North	4	4	0
Wadi Araba South	6	1	5
Jafr	7	20	–13
Southern Desert	<1	<1	0
Sirhan	5	<1	5
Hammad	8	1	7
Total	274	418	–144

Baseline Results for 2010 and 2020

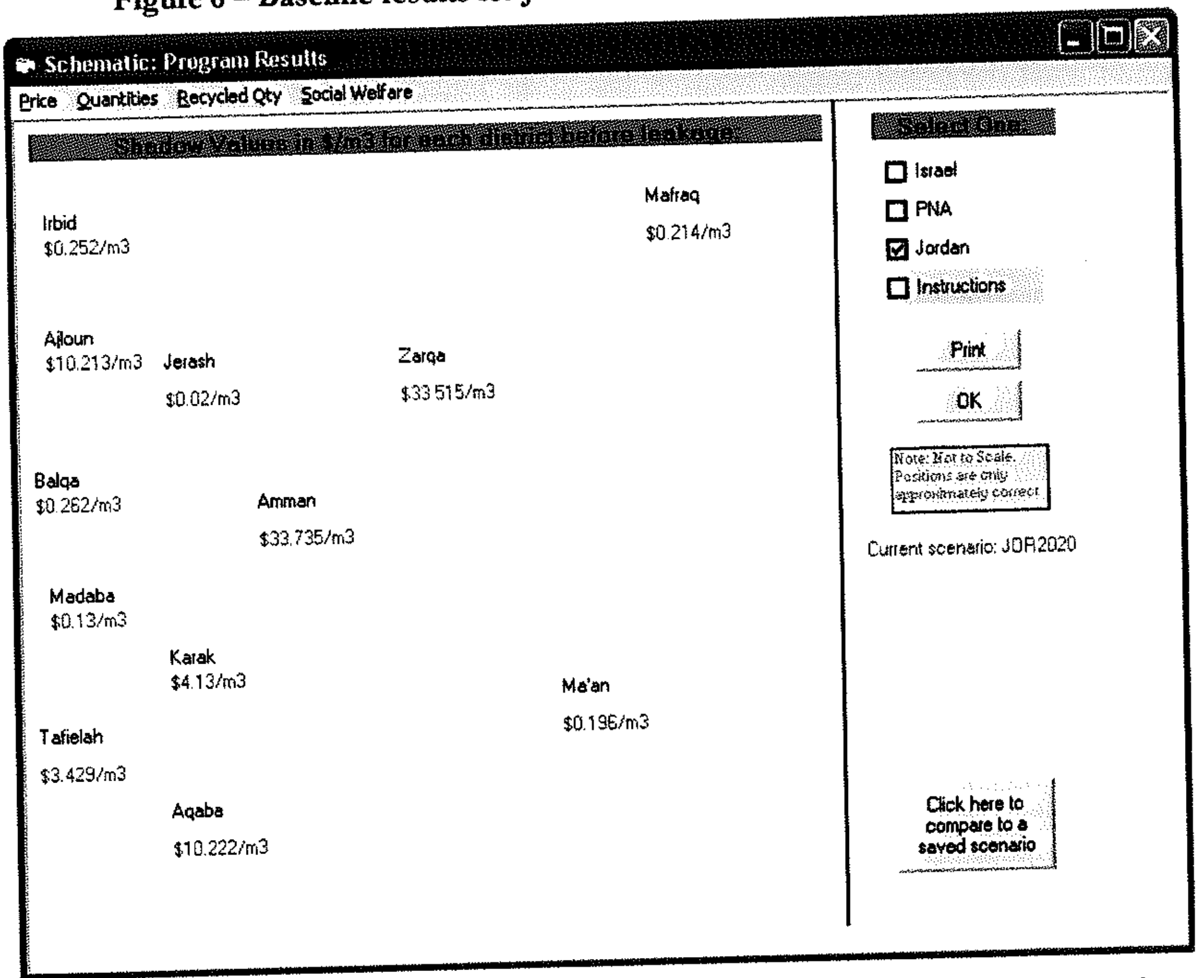
The data presented in Annex B were entered into WAS for 2010 and 2020. Click on **Load Scenario**, and select the scenario named **JOR2010**. In this scenario, as well as the scenario for 2020 (JOR2020), it is assumed that no fixed price policies in place and no changes in infrastructure after 1995. To see results, click on **Schematic Program Results**, and then put a check mark by **Jordan**. Both scenarios show an increasing problem in several governorates, particularly in Amman and Zarqa, as shown by the high shadow values in Figure 5, and especially Figure 6.

Figure 5 – Baseline results for Jordan in 2010 – No Fixed Price Policies



By 2020, (you can see both sets of shadow values by clicking on **Click Here to Compare to a Saved Scenario**, and select **JOR2020**) this reaches crisis proportions in Amman, Zarqa and Ajloun, with the shadow value in Amman greater than $30/m³.[5] Such shadow values of water are clearly unacceptable, and with neighboring districts at much lower shadow values, suggest a strong need for infrastructure improvements.

Figure 6 – Baseline results for Jordan in 2020 – No Fixed Price Policies



One such improvement is suggested by the fact that, by 2020, the shadow value in Aqaba – more than $10/m³ – greatly exceeds even current estimates of the cost of seawater desalination – about $0.60/m³.

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[5] Correspondingly, the value of the unpaid-for water quantities given in Table 7.4.2 is on the order of $300 million per year in 2010, reaching $3 *billion* per year in 2020, primarily due to the water problem in these districts.

But the main infrastructure problem plainly involves getting water to the capital. As just observed, were no further infrastructure to be built after 1995, the shadow value in Amman would exceed $30/m^3$ by 2020. Yet the shadow value in Balqa, in the Jordan Valley would only be about $0.26/m^3$, even though there was, in 1995, a conveyance pipeline taking water from Balqa to Amman. (Shadow values elsewhere in the Jordan Valley would be lower still.) Plainly, the capacity of that pipeline (45 MCM per year) will not be sufficient by 2020. Hence, either that pipeline must be expanded or other ways found to supply the capital.

Note that this is *not* a problem of water *ownership* but a problem of infrastructure. The shadow value of water ownership remains relatively low in the Jordan Valley despite the enormous shadow value in Amman. Since it is always the case in the optimum solution of the model that, for conveyance from A to B,

(1) $p_B = p_A + t_{AB} + \lambda_{con}$

(where p_B denotes the shadow value at B, p_A, the shadow value at A, t_{AB}^{*}, the operating cost of conveyance per cubic meter between the two points, and λ_{Con} the shadow value of conveyance capacity), the shadow value of the capacity constraint on the Balqa-Amman pipeline must be $33.47 per cubic meter of annual capacity in the run shown in Figure 6[6]. This is the rate at which system-wide benefits would increase per cubic meter of additional conveyance capacity.

There is an illuminating story related to this. In 1994, when the project was in its infancy, one of the authors of project's book, Liquid Assets, (add reference) Dr. Munther Haddadin, being exposed to the proposed methods for the first time, asked the somewhat rhetorical question, "If the two of us were lost in the desert east of Amman, what then would be the value of a bottle of water?" The answer is that the value of water in the desert would be very high indeed, but that the value of water in the Jordan River would not change as a result. In such a case, what is involved is a shortage of infrastructure to convey the water from the river to the desert, not a shortage of ownership of the resources.

[6] See Table A.8 in Annex A.

Alleviating the Coming Crisis: Planning Infrastructure Projects

Planned Infrastructure

Not surprisingly, quite a few years ago, the Jordanian government had planned to expand the pipeline from Balqa to Amman from 45 MCM to 90 MCM per year no later than 2005. In addition, the Zara Ma'in project was planned to start in 2006, bringing 35 MCM/year of desalinated brackish water from the Balqa district at a cost of 47 cents per cubic meter[7].

To add these changes in infrastructure, first load the scenario JOR2020. From the Main Screen, choose **Transport Costs/Bounds**, and select **Jordan** for both **Origin** and **Destination**. Choose the Balqa district and you will see a screen similar to that below in **Figure 7**. Change the **Max Transport from Origin to Destination** from **45** to **90** MCM. Then click on **Finished**.

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[7] Source: Ra ed Daoud, personal communication.

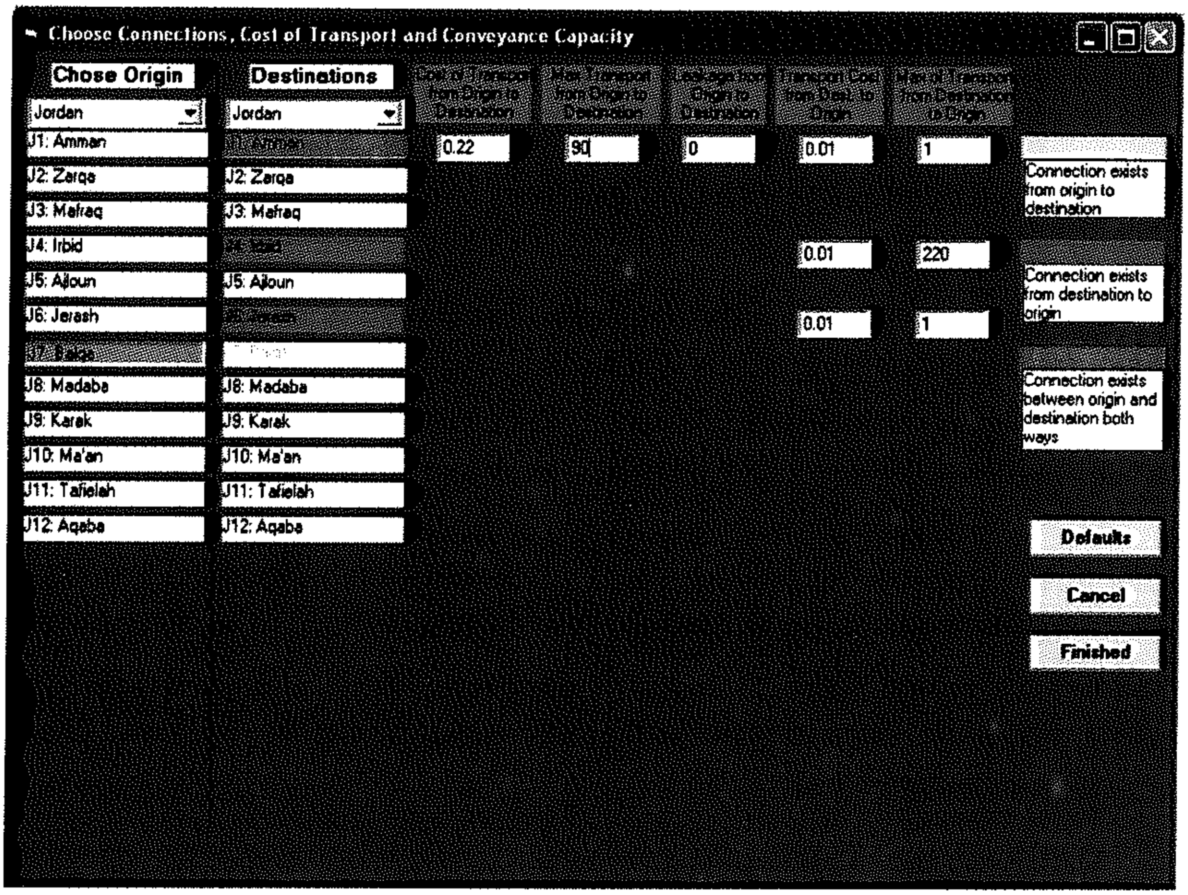


Figure 7

The additional brackish water for Amman can be entered as a new supply. To do this, choose **Supply of Water** from the Main Screen, click on **Edit** by **Supply Step**, and then click on **Jordan**. You should see the same screen as that in Figure 8 below. In Step 2 (**S2**) under **Costs**, change 999 to **0.47,** and under Step 2 under **Quantities**, change 0 to **35** MCM.

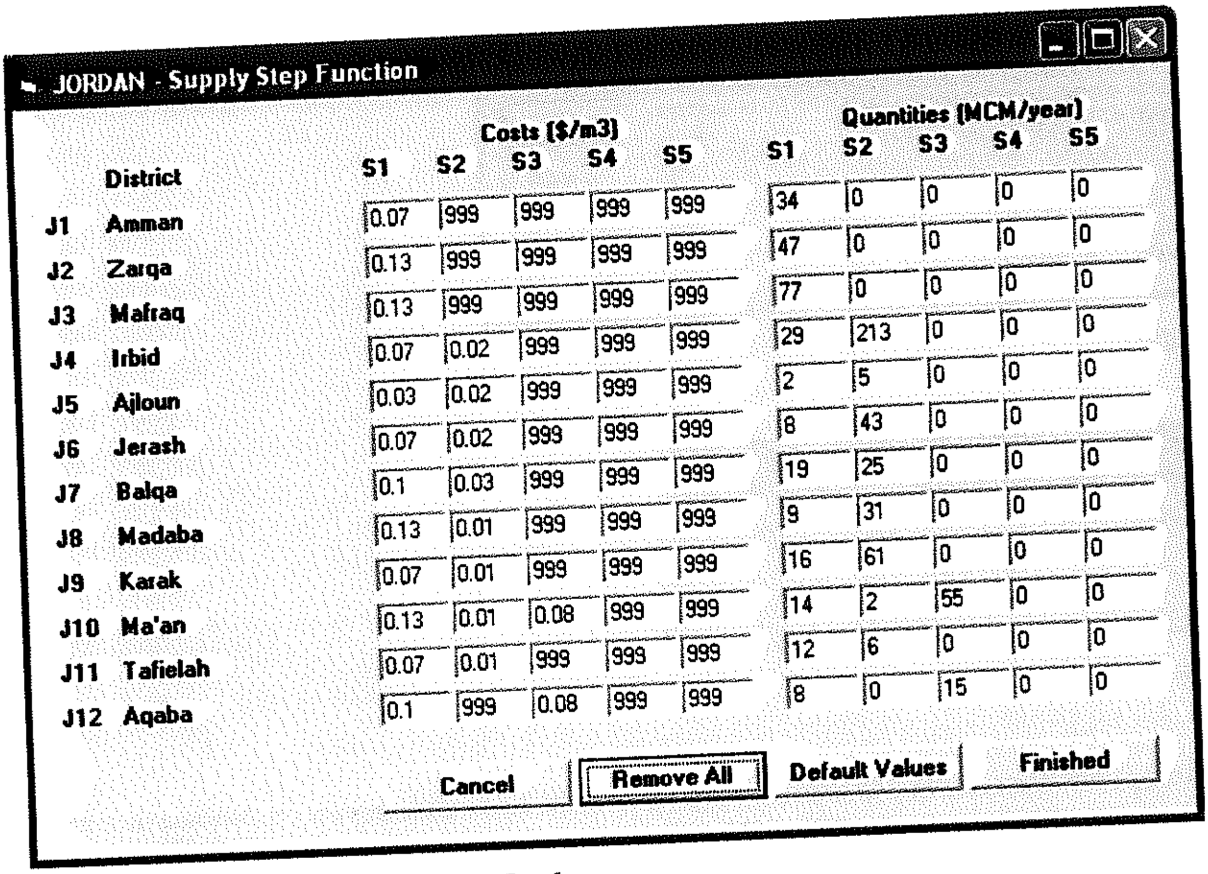


Figure 8: Supply Step Function for Jordan

Click on **Finished**, then click on **Accept**, and finally click on **OK** to reach the Main Screen. Then click on **Optimize**, and give the scenario the name **JOR2020_90mcm**, as shown in **Figure 9**. Once the optimization is complete, click on **OK** to return to the Main Screen as shown in **Figure 10**.

To see results, click on **Schematic Program Results**, and then put a check mark by **Jordan**. For easy comparison, click on **Click Here to Compare to a Saved Scenario**, and select **JOR2020**.

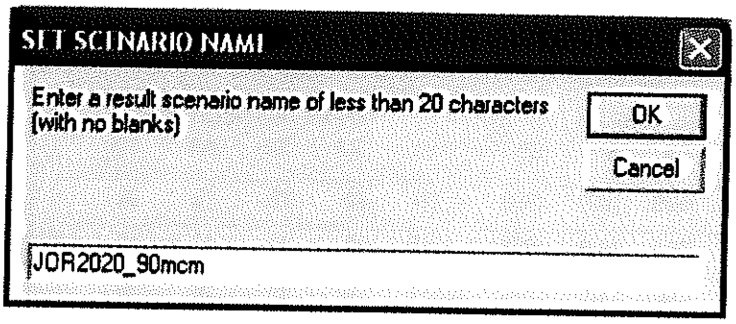


Figure 9

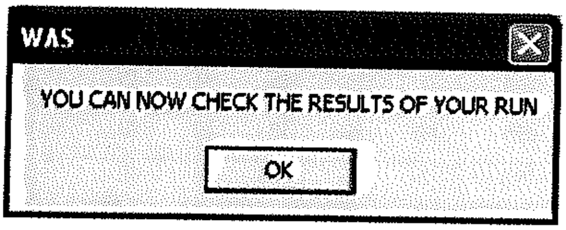


Figure 10

Starting with these changes in infrastructure, we see the immediate impact on Amman in terms of shadow values for 2020 in Figure 11 below. The shadow value in Amman drops from \$33.74 to \$3.34 per cubic meter (Figure 11). Note that shadow values increase along the Jordan Valley where water the water is withdrawn. Irbid sees an increase from \$0.25 to \$0.40, and Balqa from \$0.26 to \$0.41. The scarcity of water in these governorates has increased with the increased competition for water. With an overall gain in social welfare of approximately \$62 million per year in 2010, and reaching more than \$1 billion per year in 2020, this is clearly essential infrastructure.

In all later examples, we assume the capacity of the Balqa-Amman pipeline to have been expanded to 90 MCM/year, and the Zarqa Ma'in Project to have been constructed.

Click on **Save Scenario** on the **Main Screen**, and write a brief description of the run, as illustrated in **Figure 12**.

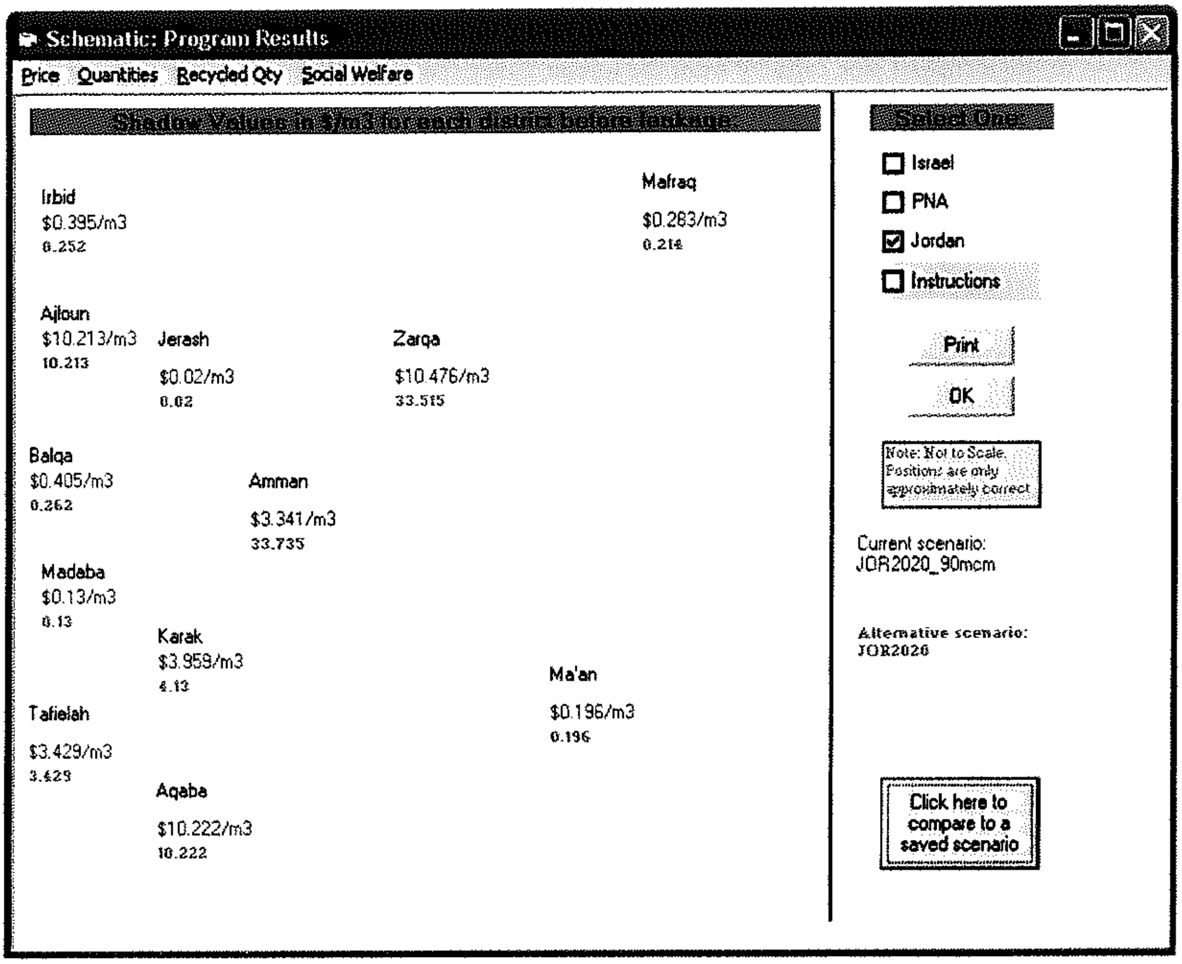


Figure 11 – Results for Jordan in 2020 with (blue) and without (red) Expanded Pipeline from Balqa to Amman increased from 45 MCM/year to 90 MCM/year and Zarqa Ma'in Project Completed

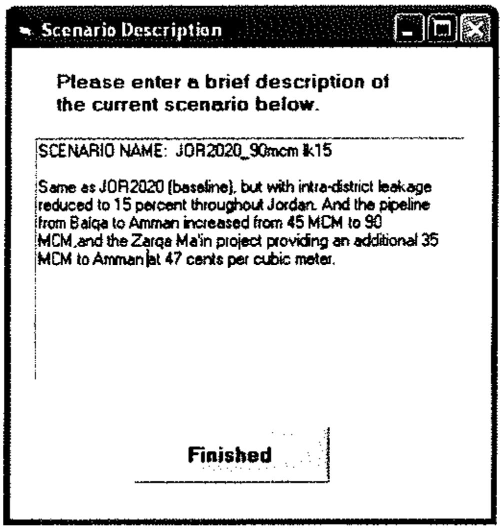


Figure 12: Scenario Description

Reducing Leakage

In addition to the increased pipe capacity from the Jordan Valley (Balqa) to Amman, another approach to alleviate this crisis would be to reduce intra-district leakage. The government of Jordan already has plans to bring leakage down to levels of 15 percent by 2010, with no further improvement expected by 2020.

In order to introduce this planned improvement, click on **Intra-district Leakage** on the **Main Screen**, click on **All Jord. Districts**, and change the leakage from **0.25** to **0.15** , as illustrated in **Figure 13** below.

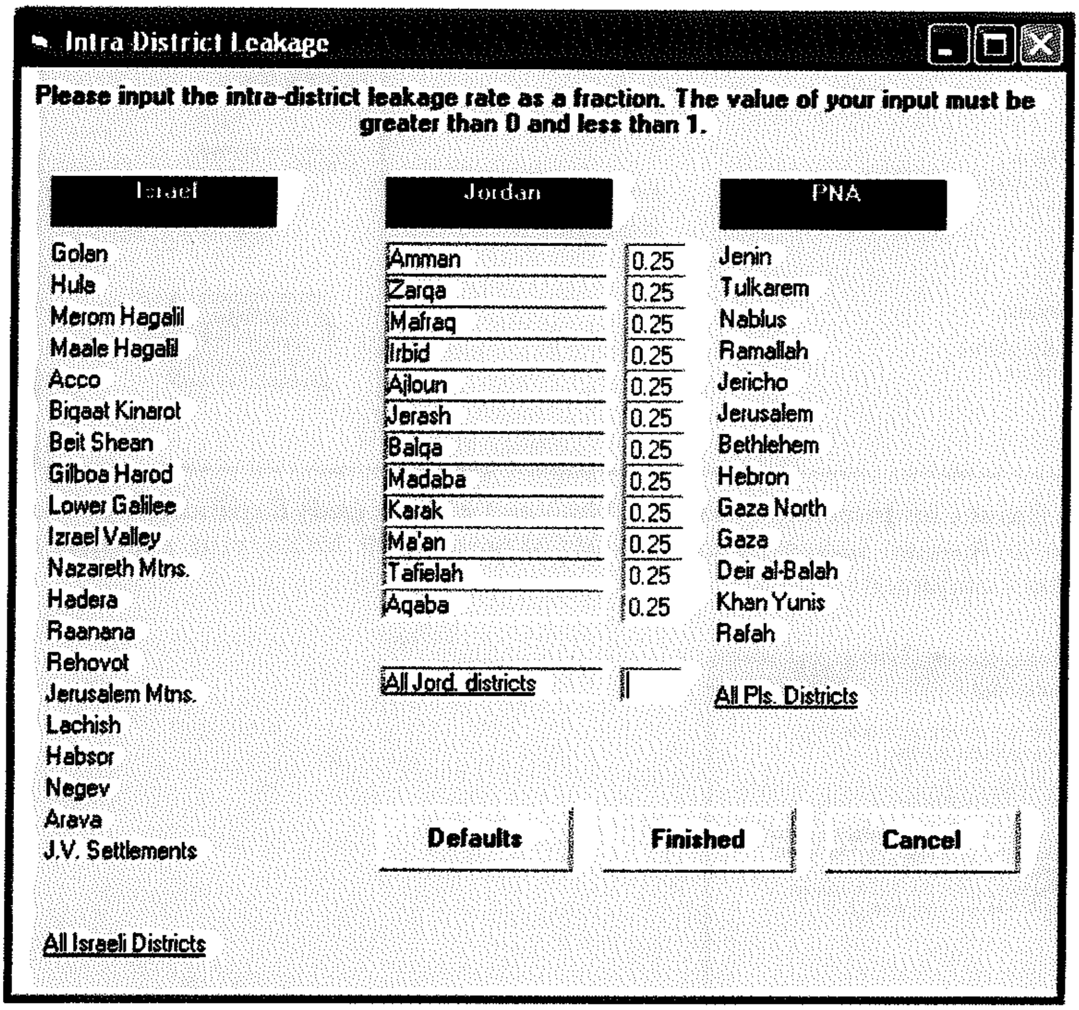
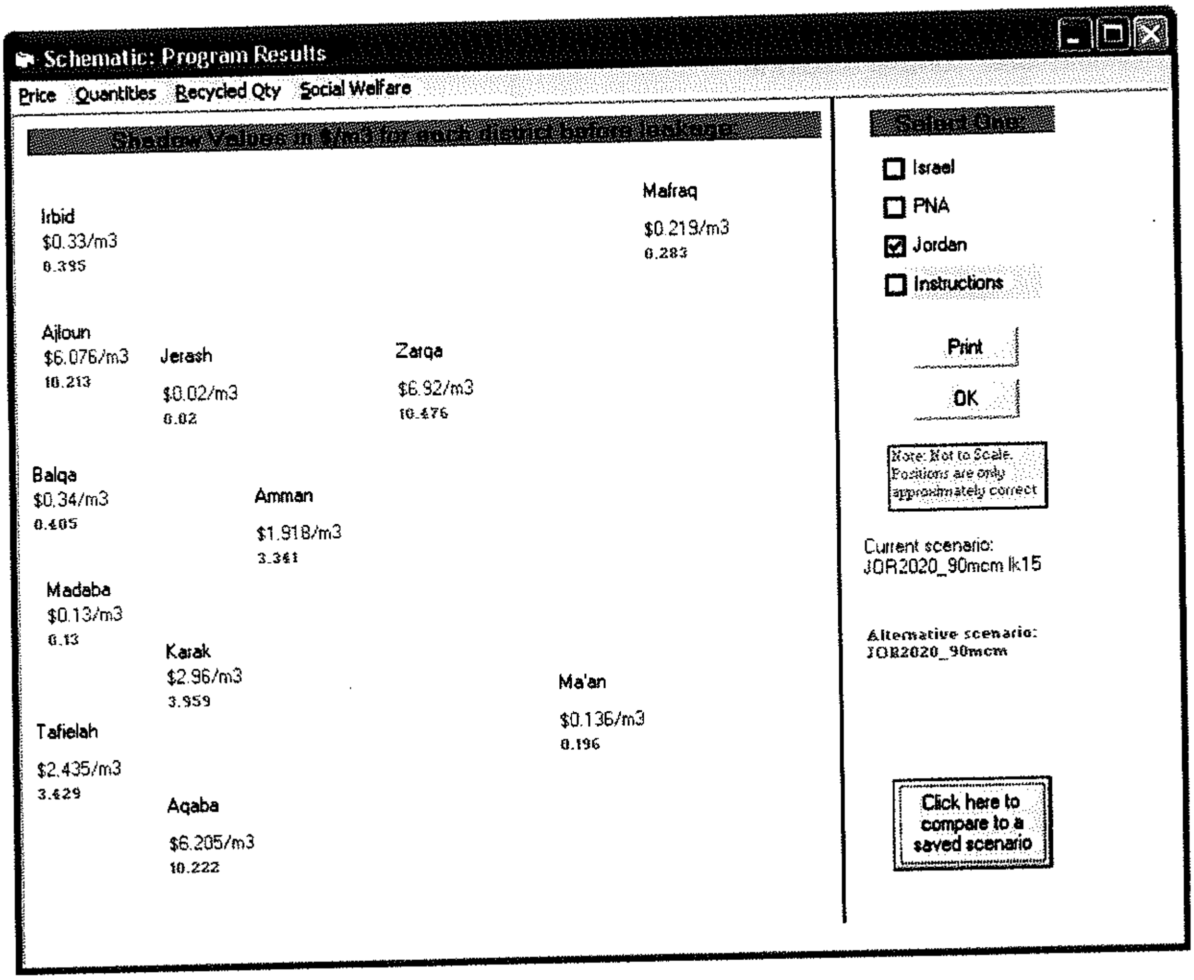


Figure 13: Intra-district Leakage

Click **Finished,** then click on **Optimize** on the **Main Screen,** and give the scenario the name **JOR2020_90mcm_lk15**. Once the optimization is complete, click on **OK** to return to the Main Screen.

To see results, click on **Schematic Program Results**, and then put a check mark by **Jordan**. For easy comparison, click on **Click Here to Compare to a Saved Scenario**, and select **JOR2020_90mcm.** While this reduction in leakage clearly lowers shadow values in the crisis governorates, the values are still quite high in half the governorates, particularly for Zarqa, Aqaba and Ajloun, in 2020, as shown in Figure 14.

Figure 14 – Results for Jordan in 2020 with (blue) and without (red) Intra-district Leakage Reduced to 15%



The shadow values in several governorates adjacent to those in crisis are much lower – Irbid, Balqa, Jerash, and Madaba. This suggests the possibility of inter-district conveyance between these low shadow value districts and high shadow value districts. There are social limitations to these transfers, however, in that agriculture in these governorates is of great social importance – from the perspective of employment, as well as aesthetic and cultural values associated with agriculture.

Click on **OK** to get back to the **Main Screen**, and then click on **Save Scenario**, and write a brief description of the run, as illustrated in **Figure 15**.

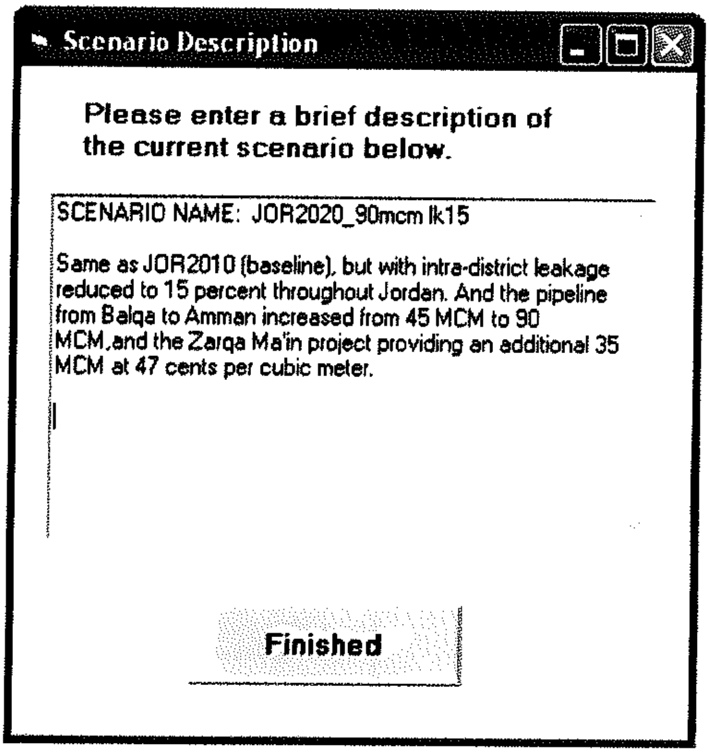


Figure 15: Scenario Description

To understand the possible benefits from this infrastructure improvement, click on **Finished** to get back to the **Main Screen**, and then click on **Cost-Benefit Calculations**. Click on the **Click to Select Scenario without Infrastructure**, and select **JOR2020_90mcm**. Then click on **Click to Select Scenario with Infrastructure**, and select **JOR2020_90mcm_lk15**. Enter **5 percent** as the discount rate, and the life of the project as **20 years.** Enter any non-negative number for capital costs, and the annual and total benefits appear as illustrated in **Figure 16.**

The gain in social welfare from this reduction in leakage in 2020 is on the order of $190 million per year, which, assuming these benefits to be constant (although they clearly will increase over time with increasing demands), the net present value is on the order of $2 billion, suggesting that this could be a critical investment for Jordan over time.

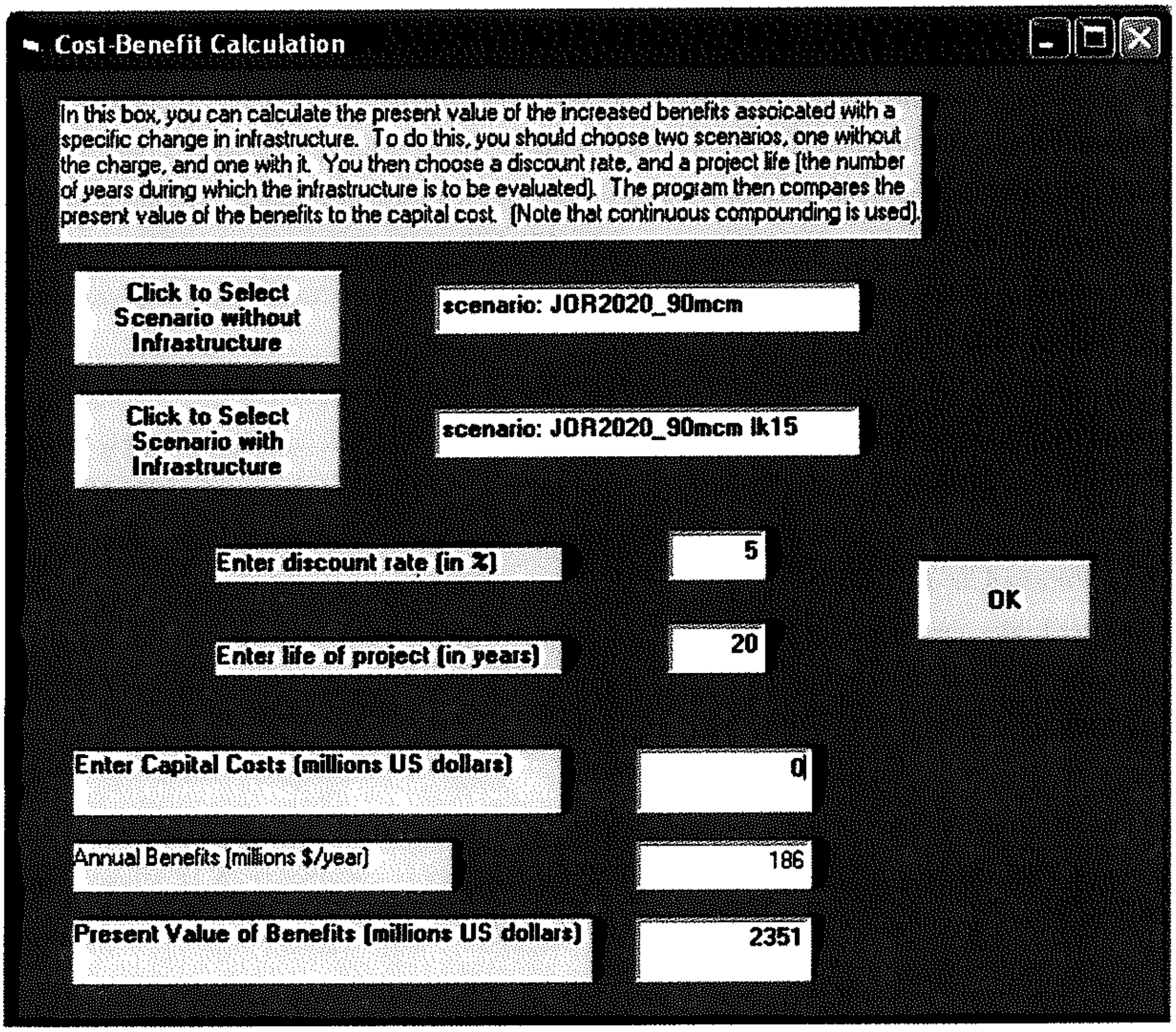


Figure 16: Cost Benefit Calculation

Disi Pipeline

The Jordanian government had also planned to use water from the Disi fossil aquifer to address the problem of persistent water shortages. As described earlier, pumping from this aquifer at a rate of 125 MCM/year is possible for a period of 50 years. A total of 70 MCM was being used from this system, but not transported to Amman. The additional supply of 55 MCM/year can be added to the system in a new scenario, as well as a pipeline to Amman (initially of unlimited capacity to let WAS determine the optimal sizing). Conveyance costs are estimated at $1 per cubic meter[8].

To set up this scenario, choose **Supply of Water** from the Main Screen, click on **Edit** by **Supply Step**, and then click on **Jordan**. In Step 3 (**S3**) of **Ma'an** District under **Quantities**, change **55** to **125** MCM.

Click on **Finished**, then click on **Accept**, and finally click on **OK** to reach the **Main Screen**. Click on **Freshwater Links**, then select **Jordan** and the **Ma'an** District (**J10**). Finally, click on **Amman**, and the district name will show up in **yellow**, indicating a pipeline exists from Ma'an to Amman, as illustrated in **Figure 17** below.

When you click on **Finished**, a box will appear asking for the operation and maintenance costs of the new conveyance, the capacity and leakage. Enter **$1** as the cost, **999** as the capacity (WAS will give the optimal capacity), and **0** for the leakage, as shown in **Figure 18**.

Then click on **Optimize**, and give the name **JOR2020_90mcm_lk15_disi** for the scenario. Once the optimization is complete, click on **OK** to return to the Main Screen. Before looking at results, click on **Save Scenario**, and write a brief description of the run, as illustrated in **Figure 19**. After adding the description, click on **Finished** and **OK** to return to the **Main Screen**.

[8] There is a possibility that the aquifer extends much closer to Amman, only 80 km in distance, which would considerably reduce the transport cost. This possibility is still under exploration (personal communication, Munther Haddadin.)

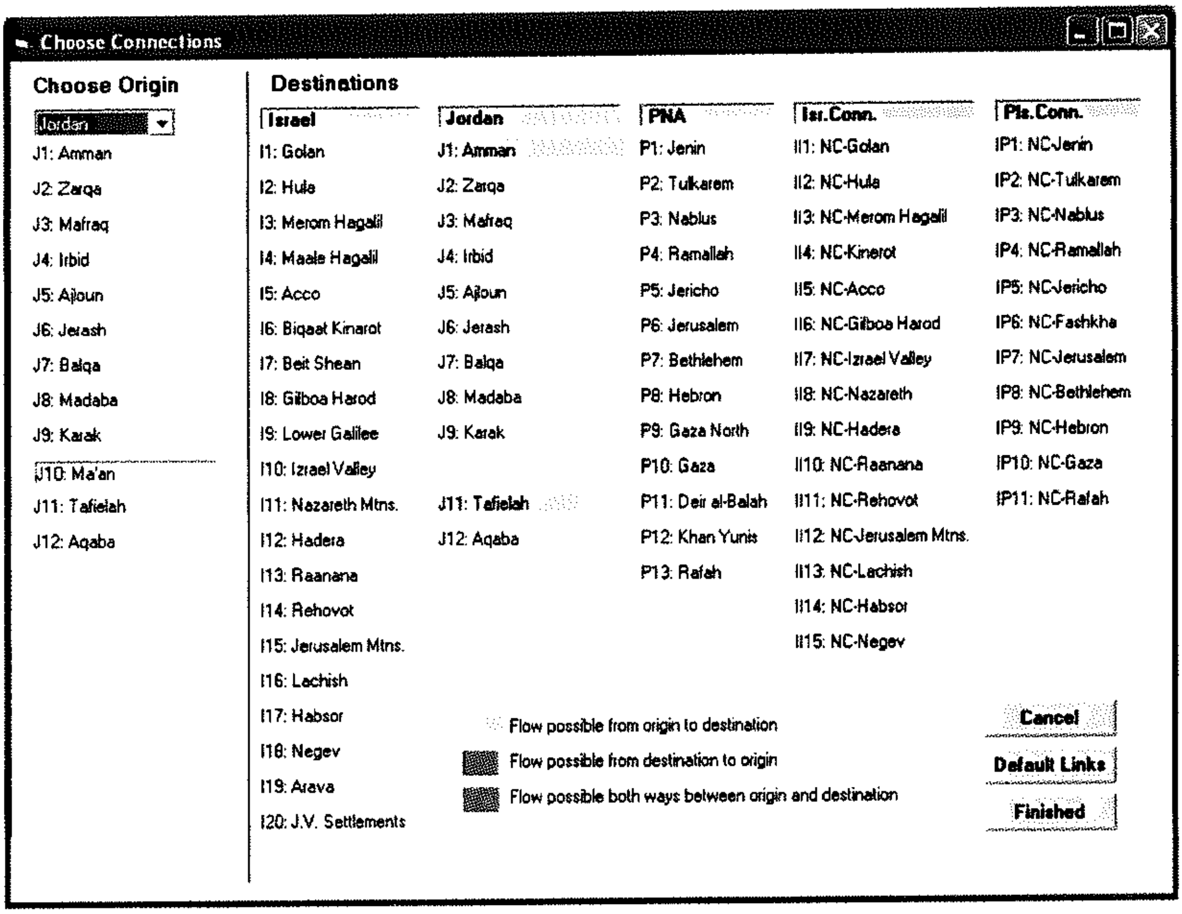


Figure 17: Freshwater Connections

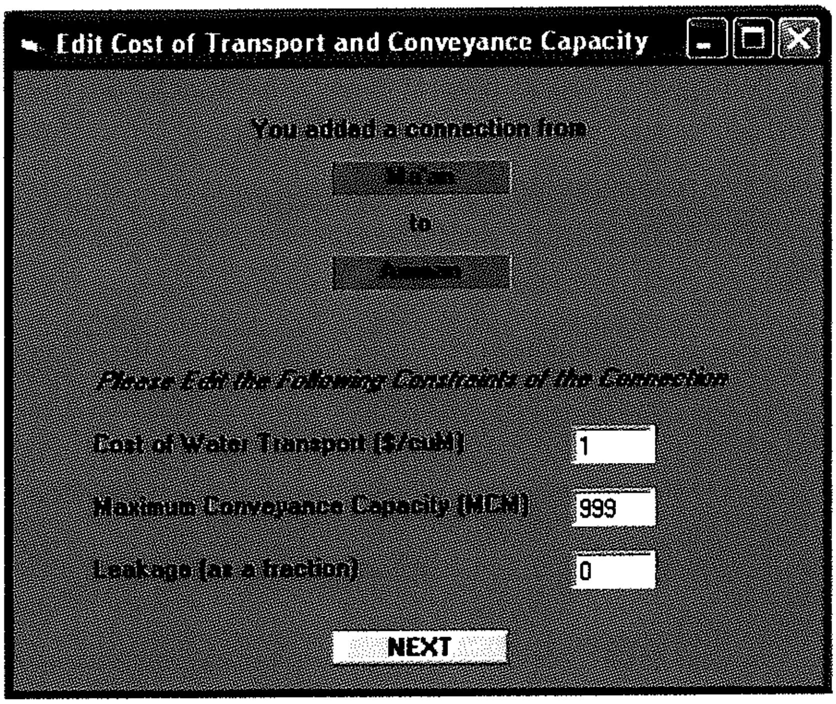


Figure 18: Cost of Transport and Connections

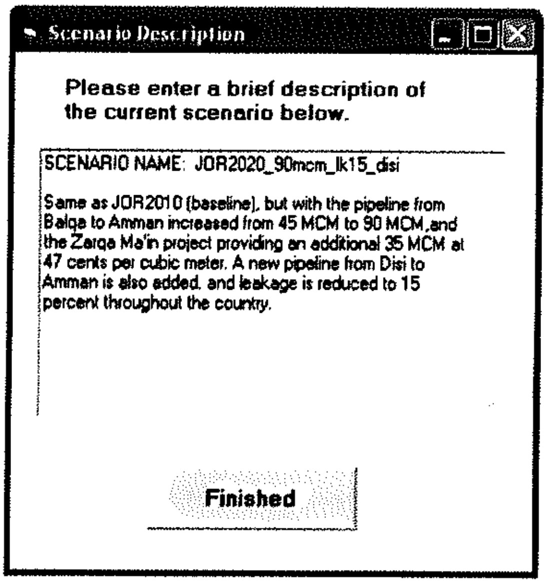


Figure 19: Scenario Description

To see results, click on **Schematic Program Results**, and then put a check mark by **Jordan**. For easy comparison, click on **Click Here to Compare to a Saved Scenario**, and select **JOR2020_90mcm_lk15.**

The results for 2020 are shown in Figure 20, below, relative to the results with leakage reduced to 15 percent alone. and further alleviates the high shadow value in Amman from $1.92 to $1.08 per cubic meter. The volume of water that would efficiently flow through the new pipeline, according to our results, is almost 40 MCM/year in 2020 with no leakage reduction and 20 MCM/year with the additional 10 percent reduction.

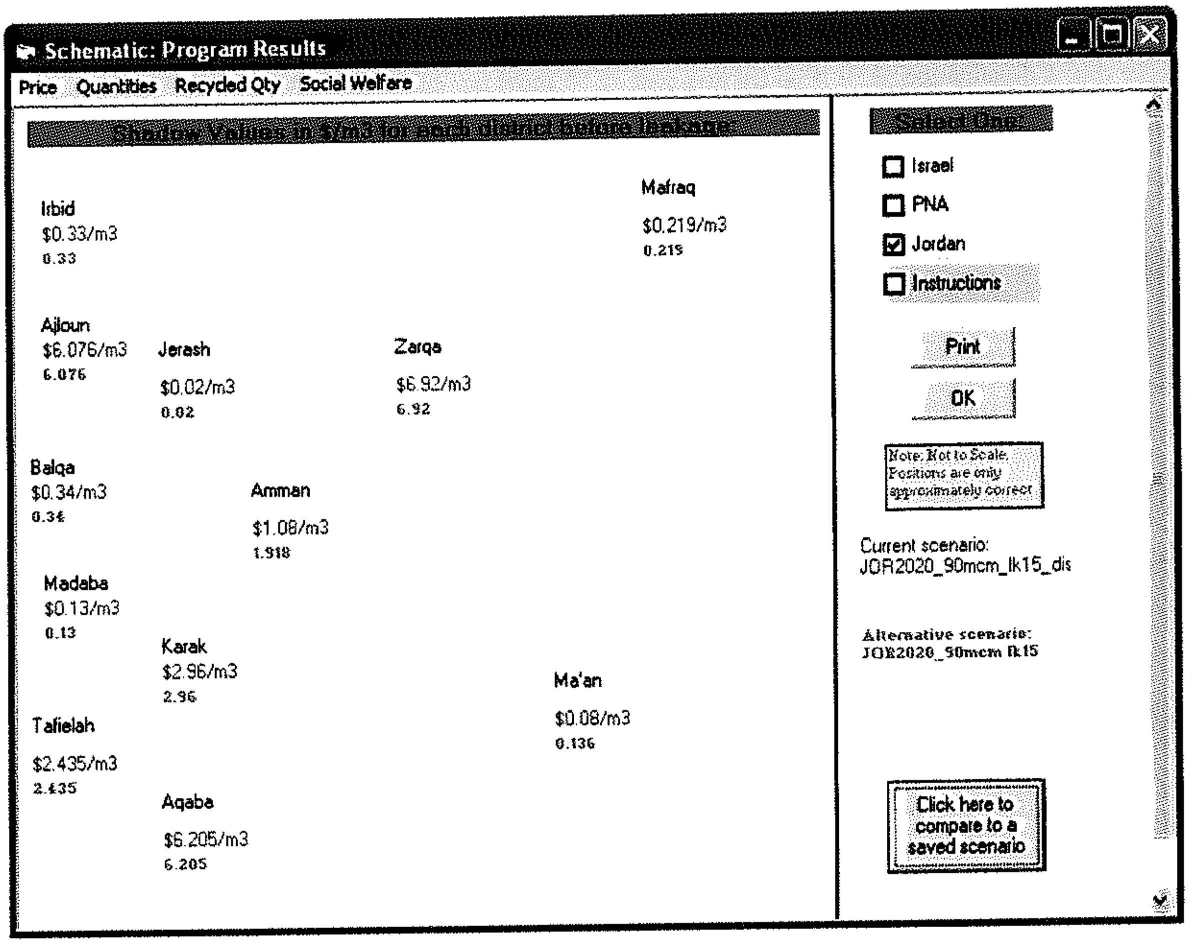


Figure 20: Comparison of Results for Jordan in 2020 with Leakage Reduction and with (blue) and without (red) Disi Pipeline to Amman

The combination of reduced leakage and the Disi pipeline, relative to reduced leakage alone gives an increase in social welfare in 2020 of $8 million per year (assuming a discount rate of 5 percent and a 20 year project life), and the net present value is on the order of $100 million (which should be compared to the capital costs of the pipeline), as illustrated in **Figure 21.** Of course, this assumes no increase in population after 2020, so the actual net benefits are presumably higher[9]. Reducing leakage to 15 percent will have immediate impact on Jordan's social welfare, largely because the reduction in leakage essentially results in a net gain of 10 percent more water (as the baseline leakage is 25 percent) throughout the country, where the Disi pipeline addresses one district's needs only.

However, shadow values in a number of other districts – Zarqa, Karak, Ajloun, Tafeilah and Aqaba – remain quite high. The shadow value in Aqaba in particular, at $6.21 per cubic meter, remains much

[9] Note, however, that it also assumes that no other relevant infrastructure will be built. See the discussion of the proposed Red Sea-Dead Sea Canal, below for possible implications of this type of consideration.

higher than the existing cost of desalination, suggesting desalination as a solution for that district. To explore this, a desalination plant is added at a cost of 60 cents per cubic meter, with unlimited capacity (WAS will show the optimal capacity).

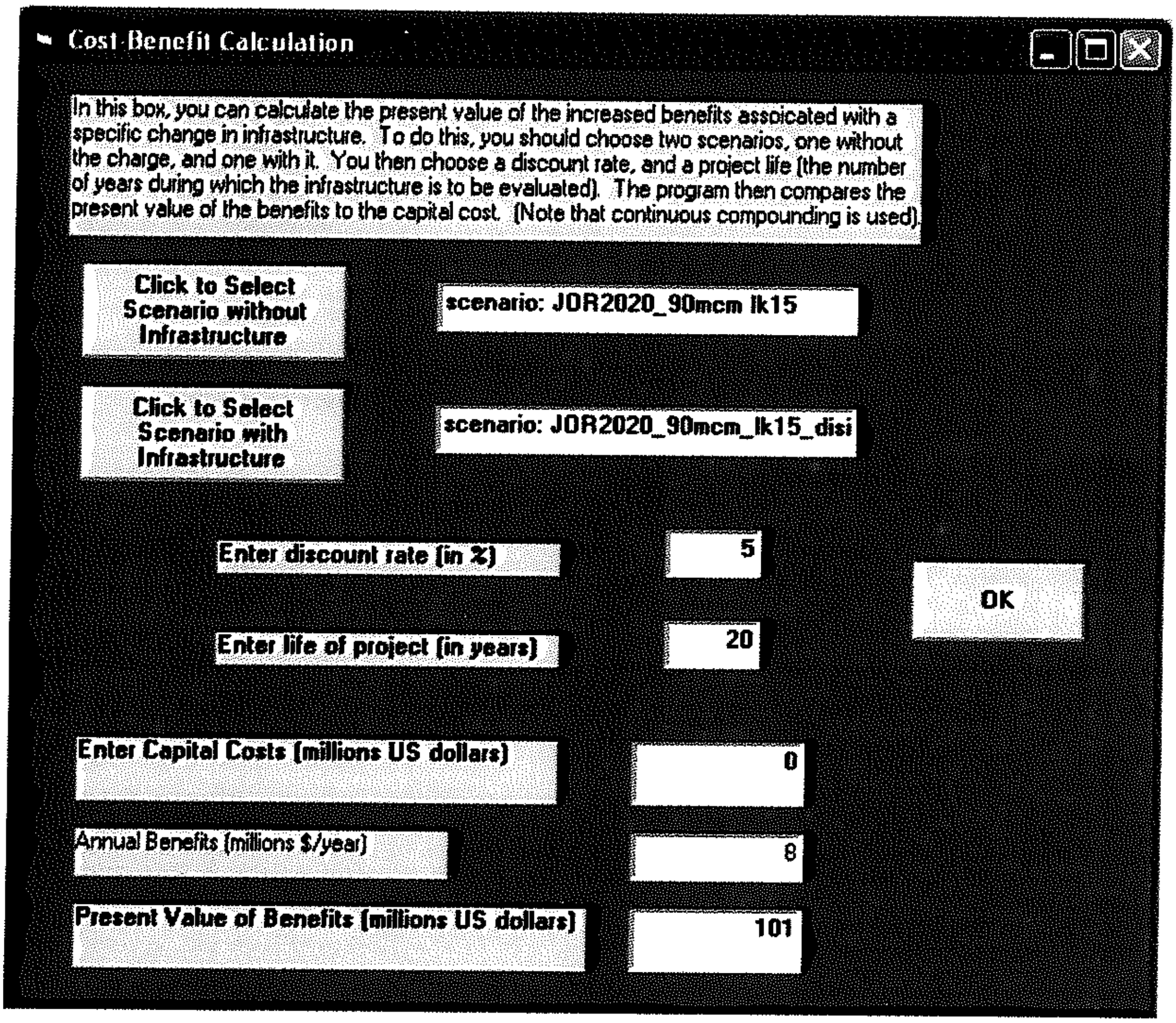
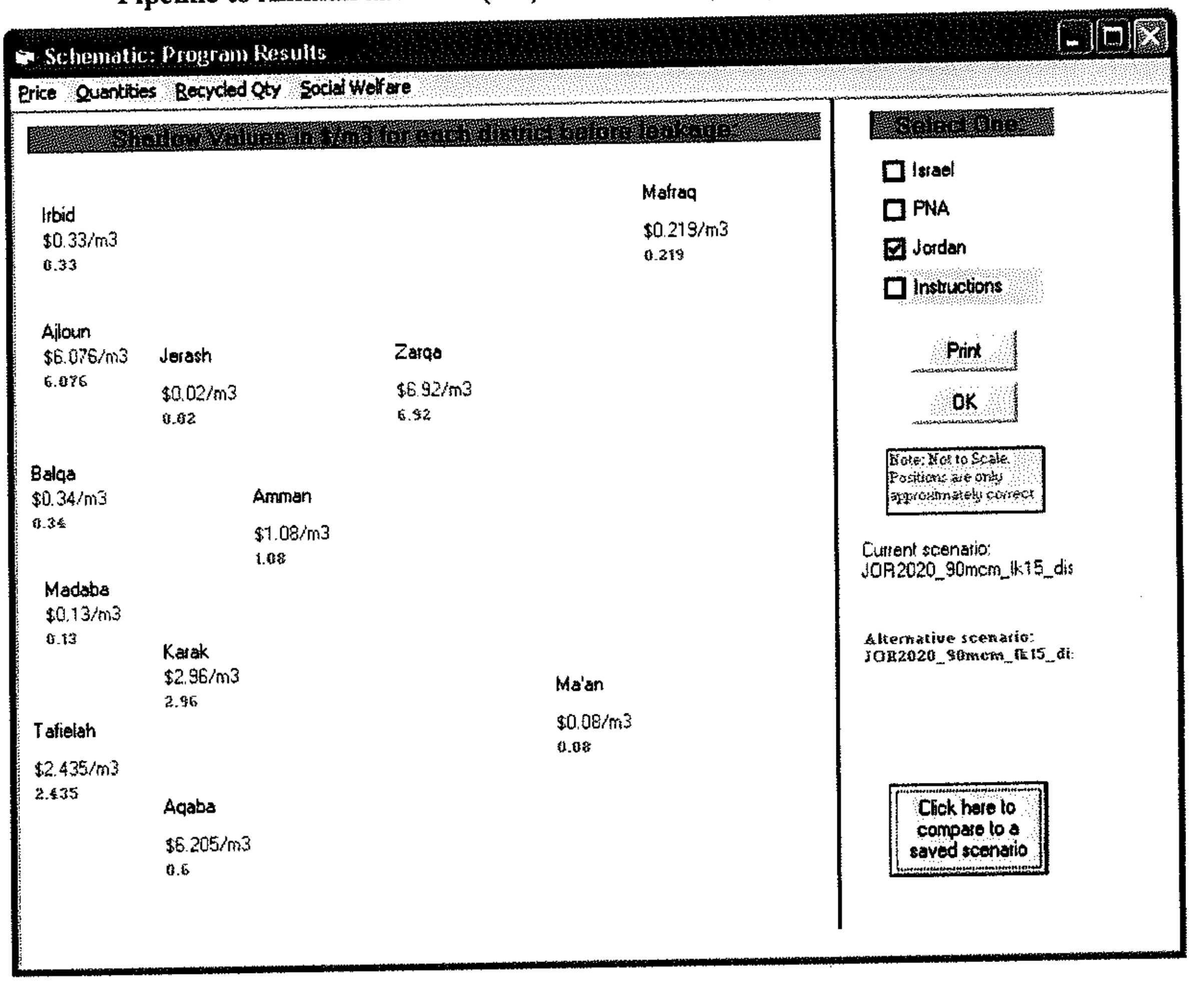


Figure 21: Cost-Benefit Calculation

Figure 22 – Comparison of Results for Jordan in 2020 with Leakage Reduction and Disi Pipeline to Amman and with (red) and without (blue) Desalination in Aqaba



The results, shown in Figure 22 above, show a desalination plant is built, with a capacity of 18 MCM. The net annual benefits are some $30 million.

Red Sea – Dead Sea Infrastructure

There is a long-standing proposal to construct a canal with capacity of 850 MCM/yr from the Red Sea to the Dead Sea (the "Red-Dead Canal"). The difference in elevation would be used to generate electricity, which could in turn be used to desalinate the salt water from the Red Sea, and (after pumping) provide much needed fresh water to northern Jordan. In addition to the benefits of provision of additional fresh water, the level of the Dead Sea could be stabilized. This would be environmentally beneficial and could enhance tourism and therefore the economy in the region.

It is worth examining whether this development makes sense from the perspective of water needs in Jordan, with a particular focus on Amman, as that is the district with the highest concentration of population, and in 2020, with the increased capacity of water from the Jordan Valley to Amman, a new pipeline from Disi to Amman and leakage reduced to 15 percent, the shadow value in Amman remains at a relatively high $1.08 per cubic meter.

Assuming the Red-Dead project would deliver fresh water to Madaba, the water could then be transferred to Amman at $0.22 per cubic meter.[10] As long as the marginal costs of the desalination did not exceed the difference of $1.08 and $0.22, or $0.86, the project would likely be beneficial from the standpoint of social welfare. If, in fact, the desalination costs are in line with current costs (estimated at $0.60 per cubic meter inclusive of capital costs), which in fact are likely to be lower as one of the major components of the cost of desalination is energy, and the energy for the desalination would come from the hydropower generated from the canal, shadow values in Amman could drop to below $0.80 per cubic meter.

Note, however, that this result assumes that the Red-Dead Canal is to be undertaken for reasons other than solely the production of desalinated water. If so, then the capital costs of the canal itself should not be attributed (or wholly attributed) to the desalination part of the project.

Since the per cubic meter costs of desalination includes the capital costs of the desalination plant, another way to state the conclusion as to costs and benefits is the following: if the canal is built, desal plants more than pays for itself, generating benefits beyond its own costs. Those benefits can be regarded in contributions to cap costs of the conveyance line [11]used for the desal water, and the capital costs of the canal itself.

[10] See Table 7.2.7 above.
[11] If, in the solution, water is conveyed to Amman, then the operating costs of the conveyance line will be covered.

Exercise Problem: What is the contribution the plant would make towards the capital costs[12], assuming there is and is not a pipeline from Disi to Amman? How does that change with differing interest rates, life times, and demands? Review the Disi Pipeline results, if the Red Sea- Dead Sea pipeline is built.

This does *not* mean, however, that building the line from the Disi aquifer would not be valuable if the Red-Dead Canal is to be constructed – quite the contrary. The transfer from Disi may well be needed between 2010 and 2020 while the more complex and time-consuming Red-Dead project can be approved and constructed.

[12] Refer to the user manual for further discussion on capital costs

ANNEX A: Background Information and Base Year Data

1. Background

Jordan is considered a highly water-stressed country, with only 191 m^3/year per capita fresh water resources available. To get a sense of how water-stressed Jordan is, it is widely accepted that a value of per capita fresh water resources under 1700 m^3/year is considered *stressed*, under 1000 m^3/year *scarce* and under 500 m^3/year *absolute scarcity* – a category including only 12 countries around the globe[13]. Rainfall distribution over the country shows that 90% of the country receives less than 200 mm/year and 70% less than 100mm/year. The country may be divided into three physiographic units: the Jordan Rift Valley, the Jordan Highland and Plateau and the extremely arid South and East Jordan Deserts. Significant precipitation, ranging from 200 - 500 mm/year, only occurs in the mountains at the eastern side of the Jordan Valley. On average, some 90% of the precipitation is lost to evapotranspiration.

The long term average availability[14] of fresh surface water resources in Jordan is approximately 500 MCM/year. More than half of this quantity occurs in scattered wadis with very irregular discharges. Groundwater is a major water resource in Jordan and the only water resource in many regions of the kingdom. The estimated safe yield of renewable groundwater resources in Jordan is 275 MCM/year. However, many wells are over-abstracted; in 2000 the total abstraction from non-fossil groundwater resources was estimated near 525 MCM. An important fossil aquifer (i.e. the last major recharge to this aquifer occurred 10,000 years ago) is located in the Disi area in the south of Jordan. The Water Authority of Jordan (WAJ) estimates the potential capacity of this aquifer at some 125 MCM/year for a period of 50 years. This assumes Saudi abstraction is limited to current uses, and their wells remain at least 50km away from the Jordan borders. The water bearing stratum is a sandstone layer that extends under most of the country's territories, and fresh fossil water has been detected in that layer some 80 kilometers south of Amman. More is yet to be done in exploration of that layer elsewhere before the extent of fresh fossil water availability in the country is determined.

[13] Global Environmental Outlook 3, 2002. United Nations Environment Program, Earthscan, London
[14] Note that the long-term average availability of water can change, both from changes in infrastructure to store additional water, as well as climate change.

The main water using activities in Jordan are agricultural, domestic and industrial. While irrigated agriculture contributes to less than 5% of Jordan's national product, it uses about 70% of the water (and somewhat less in drought years). About 50% of the irrigated agriculture is situated in the Jordan Valley. Highland agriculture is either rain-fed or supported by groundwater extraction. As the quality of the water in the lower Jordan River is poor, the main source of water is the Yarmouk River and the Upper Jordan (Lake Tiberias). Each of these sources supplies the Jordan Valley with water through the King Abdullah Canal. The lower Jordan has been a significant source since July 5, 1995 through the Peace Treaty between Jordan and Israel. Sometimes referred to as *peace water*, the initial agreed-upon quantity was 55 mcm of which 35 mcm are to be replaced with desalinated water[15]. Additionally, groundwater base flow, mainly upwelling in Wadi Shaq el Barid east of Mukheiba, contributes to the flow of the King Abdullah Canal (18 MCM/year) and further modest quantities of groundwater (20 MCM/year) support irrigated lands not served by the King Abdullah Canal.

More than 85 percent of the population of Jordan lives in the cities of Amman, Zarqa, Irbid, Mafraq, Jerash and Ajloun that are located in the Jordan Highland and Plateau at elevations between 700 and 1000 meters above sea level – well above the sources of water in the Valley. More than 50 percent of Jordan's population is concentrated in the greater urban area of Amman and Zarqa with limited local sources of water, domestic and industrial water supply to the capital is a major concern in water resources management. In particular in summer periods the supply of sufficient water of acceptable quality to Amman is problematic. About 50% of the total production of water for municipal uses in Amman is unaccounted for – an amount typical for this sector throughout Jordan. This quantity includes leakage, illegal use, un-metered deliveries, metering and human errors. Several projects are being implemented to improve the situation, but regular shortfalls in meeting demands still persist.

[15] While there was one case where Israel threatened to reduce this amount under drought conditions, to date, these quantities have always been provided. In 1995 only 30 mcm were transferred from the upper Jordan to the King Abdallah Canal. The remainder (25 mcm) started to flow in May 1997.

2. The Data for 1995[16]

a. Districts

Jordan has 12 governorates that are used as the basis for districts in the model, as illustrated in Figure A.1.

b. Water Consumption Data and Water Demand Curves

The procedure used to estimate the demand curves for the three sectors is to estimate a point on the demand curve and assume a price elasticity coefficient. The point on the demand curve is represented by a combination of a price and a quantity of water. For each of the sectors this point was estimated based on data for the actual consumption in 1995[17] and the price paid by the consumers of the water in that year.

It is critical to make the distinction between several terms here – water supplied, demand, consumption and unaccounted-for-water (UFW). *Supply* is the amount of water that is provided, for example, the amount of water leaving a water treatment plant. As noted above, *demand* is the quantity of water desired by a sector at a given price. *Consumption* is the actual amount of water that reaches a given sector. Consumption can differ from demand, primarily when supply is limited or unable to meet demands at the price charged, and therefore the amount consumed is less than the amount demanded at the going price. *Unaccounted-for-water* can be due to a variety of reasons, but for the purposes of this book is treated as one of two categories: water that is lost due to physical leakage, or water that is consumed (effectively stolen) from the system and not paid for. For example, the UAF for the municipal sector is on the order of 50-60 percent for the municipal sector, and it is assumed that half of this is due to physical losses (i.e. leakage), and half due to unpaid-for water.

[16] It is important to stress that all the data and projections presented can be easily changed by the user from the interface of the WAS computer program.
[17] In fact these data vary from 1996 for the domestic sector, and 1998 for the industrial and agricultural sectors, as 1995 data were not readily available. This is assumed adequate for comparison with 1995 data for Israel and Palestine.

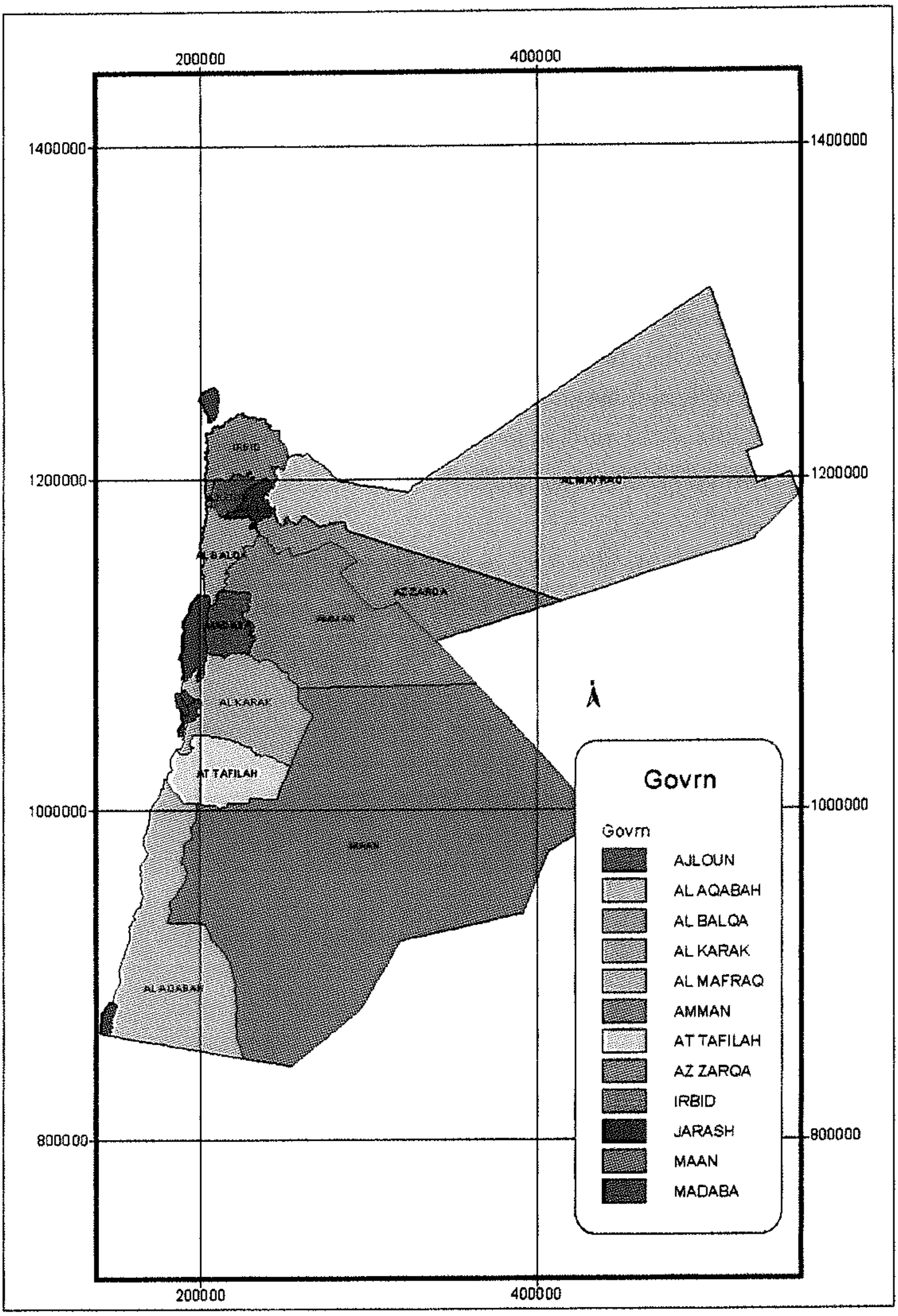


Figure A.1 Map of Jordanian Governorates

The estimated water supplied, consumed and demanded for the urban, industrial and agricultural sectors in 1995 are based on data obtained from the Water Authority of Jordan. The demands for 1995 are represented in Table A.1, A.2, and A.3 below, for the urban, industrial and agricultural sectors, respectively. The most complex case is for that of the urban sector, which has a combination of unaccounted-for-water due to leakage and unpaid for water. In all districts it is assumed that 25 percent of supply is lost due to leakage, and 25 percent is not paid for (shown in Table A.1 below). In estimating the demand, it is assumed that the demand curve of those not paying for the water is identical to those paying for the water. This could be problematic if the consumers not paying for water were the very poor who, due to low incomes are not likely to have the same demand curves as do more wealthy consumers. This does not appear to be the case, however, and we assume that the consumers of unpaid-for water to have the same demand curve on average as do those who pay. (The failure of this assumption would be likely to affect the elasticity of the demand curve but not its position, and results are not sensitive to reasonable changes in elasticity[18].)

There is a further problem in the data. While we have data on consumption, this is not equivalent to demand, which is known to be constrained due to limited supplies (similar to the situation described in the Palestinian chapter). For illustrative purposes only, for 1995 the consumption data are used in place of demand at the prices paid in 1995.

Table A.1 – 1995 Urban Water Supply and Consumption Data

Governorate	Municipal Water Supply (mcm)	Population	Consumption (mcm)	Liters per capita per day consumed	Unpaid-for quantities (mcm)
Amman	89.62	1,696,300	67.22	109	22.41
Zarqa	31.58	687,000	23.69	94	7.90
Mafraq	17.10	191,900	12.83	183	4.28
Irbid	31.97	802,200	23.98	82	7.99
Ajloun	3.48	101,400	2.61	71	0.87
Jerash	3.85	132,500	2.89	60	0.96
Balqa	19.17	301,300	14.38	131	4.79
Madaba	12.89	110,700	9.67	239	3.22
Karak	8.48	182,200	6.36	96	2.12
Ma'an	6.76	85,300	5.07	163	1.69
Tafielah	2.04	67,500	1.53	62	0.51
Aqaba	15.37	85,700	11.53	369	3.84
Total	242.32	4,444,000	181.73	112	60.59

[18] The effects of changes in elasticity can be readily explored through the WAS interface.

The industrial sector primarily uses groundwater. The amount of pumping is restricted to the amounts shown in Table A.2 below. As with the household sector, for illustrative purposes, we take these amounts as equal to demand at the price paid by industry of about $1.40 per cubic meter. The fact that such demand must exceed actual consumption only makes our results below stronger.

Table A.2 – 1995 Industrial Water Consumption Data

Governorate	Water Consumption (MCM)
Amman	0.86
Zarqa	6.14
Mafraq	0.25
Irbid	1.04
Ajloun	0.00
Jerash	0.00
Balqa	0.45
Madaba	0.17
Karak	11.72
Ma'an	7.22
Tafielah	5.29
Aqaba	5.81
Total	38.95

Agricultural data, including irrigated area and water consumption are presented in Table A.3. There is no reported unaccounted for water in this sector. As with the urban and industrial sectors, the quantities consumed are constrained, and therefore the consumption data are not representative of demand. However, for illustrative purposes for 1995, we again begin by using these data.

Table A.3 – 1995 Agricultural Irrigated Area and Water Consumption Data

Governorate	Irrigated Area (1000 ha)	Water Consumption (MCM)
Amman	6.8	37
Zarqa	10.6	60
Mafraq	16.9	55
Irbid	11.2	92
Ajloun	1.2	6
Jerash	2.6	12
Balqa	12.4	124
Madaba	0.8	7
Karak	8.2	60
Ma'an	10.6	53
Tafielah	1.8	5
Aqaba	1.9	18
Total	85.0	675

The average price paid by domestic water users is US$0.38 (with adjustments in four of the governorates: US$ 0.58 per cubic meter in the Amman district, US$0.35 in Zarqa, US$1.18 in Aqaba and US$0.34 in Irbid). Industrial users primarily use groundwater, paying approximately US$1.40 per cubic meter. In 1995 agricultural users paid US$0.0114[19]. To obtain the complete demand curve in the relevant range, we assume constant elasticities: -0.2 for the urban sector, -0.33 for industry and -0.5 for agriculture, as are generally appropriate for these sectors from the literature.

c. Supply Data

Supply data are based on data from the Jordan Ministry of Water and Irrigation on the availability of groundwater and surface water. Twelve groundwater basins are distinguished in Jordan, as illustrated in Figure A.2. Table A.4 gives the annual renewable quantities of water for these basins for each governorate. In addition to the renewable quantities of water, fossil water from the Disi aquifer was also in 1995 used in the Ma'an and Aqaba districts, at a rate of 55 MCM/year and 15 MCM/year, respectively.

[19] FAO report gives a rate of US$0.0114/m3 for 1995.

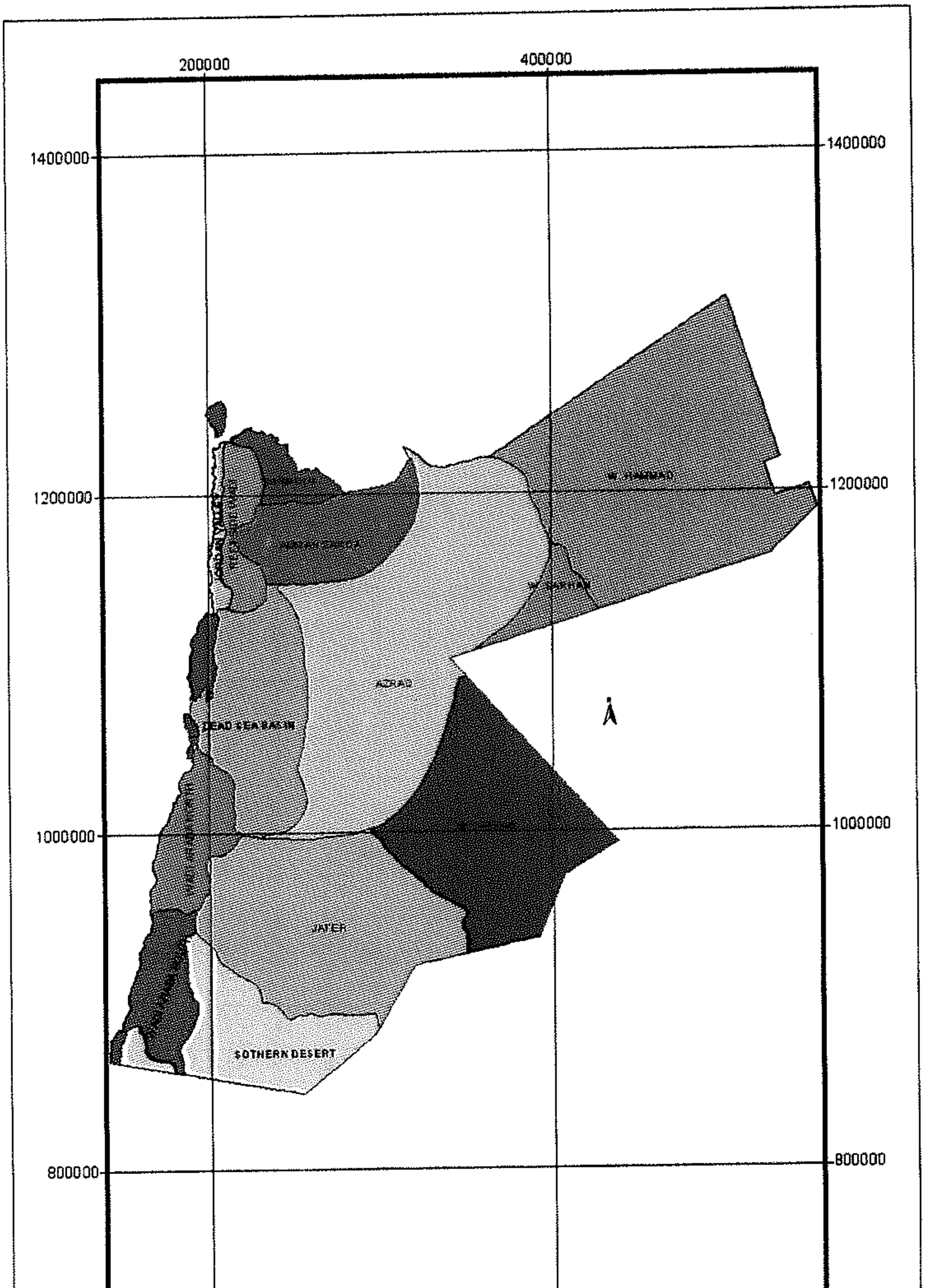


Figure A.2 Map of Jordanian Groundwater Basins

Table A.4 Renewable Groundwater Resources by Governorate (MCM)

Governorate	Yarmouk	Amman-Zarqa	Azraq	Jordan Valley	Rift Side Wadis	Dead Sea	Wadi Araba North	Wadi Araba South	Jafer	Southern Deserts	Sirhan	Hammad	Total
	Groundwater Basin												
Amman		12 (14%)	6[a]		2 (13%)	14 (24%)							*34*
Zarqa		17 (19%)	24[b]		6 (41%)								*47*
Mafraq	20 (50%)	48 (55%)									1 (8%)	8 (100%)	*77*
Irbid	18 (45%)			8 (38%)	3 (19%)								*29*
Ajloun					2 (13%)								*2*
Jerash	2 (5%)	6 (7%)											*8*
Balqa		4 (5%)		13 (61%)	2 (14%)								*19*
Madaba						9 (15%)							*9*
Karak						16 (35%)							*16*
Ma'an						3 (6%)	1 (14%)		6 (100%)	<1 (57%)	4 (92%)		*14*
Tafielah						11 (20%)	1 (35%)						*12*
Aqaba							2 (47%)	6 (100%)		<1 (43%)			*8*
Total	40	87	30	21	15	53	4	6	6	<1	5	8	*275*

Note: Bracketted figures show the ratio of the area of the groundwater basins in the governorates. The potential of the renewable groundwater is divided into governorate based on the distribion rate of the groundwater basin areas in the governorates.

a : Distribution area of A7/ B2 aquifer in the Azraq Basin is limited to the southern part of the Amman Governorate.

b : As the renewable groundwater in the central to northern part of the Azraq Basin is mainly abstructed in Zerqa governorate (Al Azraq) and abstruction amount has exceeded the its safe yield (24MCM/ a), all of the safe yield is given to Zarqa governorate.

Table A.5 gives the data on Jordan's surface water resources. Mean annual discharges are presented for the various rivers and Wadis in the 12 districts. Note that flood flows are not now captured. The flow from the Yarmouk River is shown at 246 MCM, as was true in 1995, however, after the construction of dams in Syria the Yarmouk flows have decreased. This is addressed in the future scenarios Table A.6 presents the fresh water supply step functions for the districts as they are used in the WAS schematization. Supply step 1 represents the groundwater in a district; supply step 2 represents surface water. The cost estimates of the various supply steps were derived from the Ministry of Water and Irrigation Water Sector Investment Program (1997- 2011).

Table A.5 Historical Average Annual Surface Water Flow by Governorate

Governorate	River or Wadis	Base Flow (MCM/a)	Flood Flow (MCM/a)	Total Flow (MCM/a)
Amman	None	0.00	0.00	0.00
Zarqa	Wadi Butum	0.00	0.92	0.92
Mafraq	Local Wadis	0.00	30.92	30.92
Irbid	Yarmouk River	246.00[20]	109.00	353.00
	Local Wadis	32.38	10.89	43.27
	Jordan River	30.00[21]	2.73	32.73
	Total	308.38	122.62	429.00
Ajloun	Wadi Rajib	4.99	1.12	6.11
Jerash	Wadi Zarqa	43.00	25.30	68.30
Balqa	Local Wadis	25.18	7.92	33.10
Madaba	Wadi Mujib and Wala	31.38	33.62	65.00
Karak	Local Wadis	61.32	12.12	73.44
Ma'an	Local Wadis	1.64	17.07	18.71
Tafielah	Local Wadis	5.51	1.80	7.31
Aqaba	Local Wadis	0.00	2.10	2.10
	Total	481.40	255.51	734.91

In addition to the production cost of the water, environmental charges have been assumed for the treatment of the effluents produced by households and industry. For urban and industrial water supply an environmental charge of US$0.30 per cubic meter is assumed as in previous chapters. As regards recycled water for agriculture, recycling plants existed in all districts in 1995, with capacities as shown in Table A.7.

[20] Note, while Jordan has ownership of 246 mcm per year, only 126 mcm per year is available due to limitations of infrastructure – namely storage facilities to impound floods and a diversion structure to divert the Yarmouk flow to the King Abdallah Canal.

[21] The 30 mcm pertains to the amount that flows from to the upper Jordan as a result of the Peace Treaty.

Table A.6 1995 Supply:

Annual Renewable Quantities with Fossil Aquifer Use in Step 3

District		Step 1		Step 2		Step 3	
		Quantity (MCM / y)	Cost ($ / m³)	Quantity (MCM / y)	Cost ($ / m³)	Quantity (MCM / y)	Cost ($ / m³)
J1	Amman	34	0.07	0	-	-	-
J2	Zarqa	47	0.13	0	-	-	-
J3	Mafraq	77	0.13	0	-	-	-
J4	Irbid	29	0.07	188	0.02	-	-
J5	Ajulun	2	0.03	5	0.02	-	-
J6	Jerash	8	0.07	43	0.02	-	-
J7	Balqa	19	0.10	25	0.03	-	-
J8	Madaba	9	0.13	31	0.01	-	-
J9	Karak	16	0.07	61	0.01	-	-
J10	Ma'an	14	0.13	2	0.01	55	0.08
J11	Tafielah	12	0.07	6	0.01	-	-
J12	Aqaba	8	0.10	0	-	15	0.08
	Total	275		361			

As in previous chapters, the cost of recycled water for agriculture[22] has been assumed to be 10¢/m³ above the environmental charge, except that in Amman City we assume a lower cost of 5¢/ m³ due to economies of scale. Furthermore, we assume that no more then 66% can be recovered from the urban and industrial use of fresh water for use in recycling (as an average feasible figure).

[22] Recycled water is also used in industry, but was, in quantities, sufficiently small to be ignored.

Table A.7 – Annual Capacity of Treatment Plants in 1995

Governorate	Recycling Capacity (MCM)
Amman	26
Zarqa	23
Mafraq	1
Irbid	12
Ajloun	2
Jerash	1
Balqa	5
Madaba	1
Karak	1
Ma'an	1
Tafielah	1
Aqaba	2
Total	76

d. The Existing Conveyance System

Jordan has an inter-governorate conveyance system, which primarily focuses on bringing fresh water to the densely populated area of Amman. The following table (A.8) presents the inter-district conveyance systems[23]-for each link with the conveyance capacity and costs (in US ¢ per m^3). These are the operating costs and do not include capital costs.

[23] In addition to the inter-district system, Jordan has several conveyance links systems that transport water within a district.

Table A.8 - Fresh water links in 1995 with capacities and costs

To / From	Amman	Zarqa	Mafraq	Irbid	Ajloun	Jerash	Balqa	Madaba	Karak	Ma'an	Tafielah	Aqaba
Amman							1mcm 1¢	4mcm 5¢	1mcm 5¢			
Zarqa	20mcm 22¢		1mcm 5¢			1mcm 5¢						
Mafraq		20mcm 5¢		5mcm 5¢		1 mcm 5¢						
Irbid					1mcm 6¢	1mcm 6¢	220mcm 1¢					
Ajloun												
Jerash							1mcm 1¢					
Balqa	45mcm 22¢											
Madaba	15mcm 22¢											
Karak												
Ma'an											1 mcm 2¢	
Tafielah												
Aqaba												

A substantial part of the wastewater from Amman and Zarqa districts is recycled and used for irrigation in the Jordan Valley. The total capacity of the recycling link between Amman/Zarqa and the Jordan Valley (Balqa governorate) is estimated at 65 MCM/year. As the water is transported by gravity, O&M costs are low, at US$0.01 / m3.

ANNEX B: Projections for 2010 and 2020

1. <u>Water Demand Curves</u>

Demand projections have been jointly developed by the Ministry of Water Irrigation (MWI) and the World Bank (WB) in Jordan for the years 2010 and 2020. One of the scenarios is based on unrestricted demands (rather than on expected water availability), and that is the scenario used in this chapter. Population and demand projections for domestic use are presented in Table B.1. This demand is assumed to be at the same real prices paid in 1995 in each governorate.

Table B.1 – 2010 and 2020 Population and Domestic Demand Projections

Governorate	2010 Population	2010 Demand (mcm)	2020 Population	2020 Demand (mcm)
Amman	2,670,748	116.28	3,517,571	191.21
Zarqa	1,058,505	45.21	1,394,129	75.73
Mafraq	285,471	18.60	375,986	20.60
Irbid	1,257,320	48.99	1,655,982	90.02
Ajloun	171,870	6.55	226,365	12.30
Jerash	207,359	7.79	273,107	14.85
Balqa	466,429	22.81	614,321	33.40
Madaba	168,077	11.14	221,370	12.10
Karak	284,266	12.55	374,400	20.37
Ma'an	135,826	7.45	178,892	9.74
Tafielah	112,336	4.16	147,955	8.04
Aqaba	151,792	10.97	199,922	10.96
Total	6,970,000	312.49	9,180,000	499.30
Growth Rate/Yr	3.1%		2.7%	

One further issue with this sector is unpaid-for water. The quantity of water unpaid-for in 1995 was presented in Table 7.2.1. This quantity is assumed to grow as the population grows, yielding the quantities presented in Table 7.2.2 by governorate. These quantities will be treated as discussed in the previous section, as a form of fixed price policy that provides these quantities of water for free.

Table B.2 – 2010 and 2020 Unpaid-for Water Projections

Governorate	Unpaid for 2010	Unpaid for 2020
Amman	35.28	46.46
Zarqa	12.16	16.02
Mafraq	6.36	8.38
Irbid	12.53	16.50
Ajloun	1.47	1.94
Jerash	1.51	1.98
Balqa	7.42	9.77
Madaba	4.89	6.44
Karak	3.31	4.36
Ma'an	2.69	3.54
Tafielah	0.85	1.12
Aqaba	6.81	8.96
Total	95.27	125.48

While tourism was a relatively small sector in 1995, it is expected to grow in the coming decades, especially along the east coast of the Dead Sea. Estimates of increased water demand for the tourism sector are presented in Table B.3 below. Although there is significant growth in tourism, it still represents a relatively small portion of the urban demand – on the order of 5 percent. Most of the water use is characteristic of other urban demands, including basic domestic uses and landscaping. We therefore combine the tourism sector with the urban sector demands in WAS. It is possible, however, that the elasticity of demand for hotels is different than that of households, and probably less elastic. Elasticities can be adjusted through the WAS interface to explore the sensitivity to changes. Just as an example, in this case it could be assumed that hotels are completely inelastic versus households with an assumed elasticity of -0.2. Using a weighted average of the two, 95 percent times -0.2 and 5 percent times zero would give an adjusted elasticity of -0.19 – a difference not worth exploring further.

Table B.3 – 2010 and 2020 Tourism Demand Projections

Governorate	2010	2020
Amman	1.79	3.98
Zarqa	0.02	0.06
Mafraq	0.01	0.01
Irbid	0.04	0.09
Ajloun	0.00	0.01
Jerash	0.00	0.01
Balqa	7.29	7.29
Madaba	6.56	6.60
Karak	0.02	0.05
Ma'an	0.23	0.51
Tafielah	0.00	0.01
Aqaba	1.21	2.69
Total	17.18	21.28

Industrial water demand projections are based on the existing trend in the growth rate of industry, and an assumption that growth in water use will grow in parallel. These projections are shown by governorate in Table B.4, with the assumption that these are the demands at the same real price paid for water in 1995.

Table B.4 – 2010 and 2020 Industrial Demand Projections

Governorate	2010	2020
Amman	1.54	2.41
Zarqa	24.70	30.67
Mafraq	0.40	0.63
Irbid	9.22	10.43
Ajloun	0.00	0.00
Jerash	0.00	0.00
Balqa	0.80	1.26
Madaba	0.31	0.48
Karak	33.14	70.99
Ma'an	12.56	19.69
Tafielah	9.10	14.27
Aqaba	9.81	17.83
Total	101.57	168.66

The Jordanian Ministry of Water and Irrigation has developed projections for irrigation water demands for 2010 and 2020 based on several factors, including:

- Irrigation patterns in 1995
- Cropping patterns
- Distribution of irrigation methods
- Types of distribution systems
- Salinity of irrigation water
- Climatic conditions

The resulting total irrigated areas and water demands for each governorate are presented in Table B.5 below. As in the case of urban and industrial demands, these are the quantities assumed to be demanded at the same real prices paid per unit of water in 1995.

Table B.5 – 2010 and 2020 Annual Agricultural Demand Projections

Year / Gov.	2010		2020	
	Irrigated Area 1000Ha	Water Demand MCM	Irrigated Area 1000Ha	Water Demand MCM
Amman	6.8	55	6.8	54
Zarqa	10.6	97	10.6	93
Mafraq	16.9	122	16.9	120
Irbid	17.9	170	17.9	158
Ajulun	1.2	9	1.2	8
Jerash	2.6	23	2.6	20
Balqa	25.8	336	25.8	329
Madaba	0.8	4	0.8	4
Karak	9.4	63	9.4	60
Ma'an	10.6	85	10.6	83
Tafielah	1.8	18	1.8	16
Aqaba	2.3	20	2.3	20
Total	106.5	1,002	106.5	963

Part 2: Exercises for Comparing Cooperation vs. No Cooperation

WAS-GUIDED COOPERATION IN WATER: THE GRAND COALITION AND SUB-COALITIONS[24]

WITH COOPERATION EXERCISES
FOR THE
WAS AMMAN SYMPOSIUM (in blue)

Franklin M. Fisher[25] and Annette Huber-Lee[26]

Abstract

This paper builds on the earlier development of WAS – a method of dealing with water issues that focuses on water values rather than water quantities and takes into account public values that are not simply private ones (see Fisher *et al.*, 2005). WAS can be used for infrastructure or policy planning, but it can also assist in the resolution of water disputes. Indeed, WAS-guided cooperation in water can turn what appears to be a zero-sum gain into a win-win situation. It is shown that if WAS sets the rules for cooperation, then, when all claimants use those rules, the coalition of all of them together is stable. Results for possible coalitions of Israel, Jordan, and Palestine are given for varying assumptions as to water ownership. The gains from cooperation are compared and analyzed. WAS-guided cooperation is seen to make the value of ownership shifts relatively trivial.

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[24] Please note that these exercises are largely based on a paper submitted for publication in Environment and Development Economics and therefore should not be cited or further distributed.
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Introduction[27]

Starting in 1993, the Water Economics Project (WEP) in which we participated (with Fisher as Chair) developed economics-based methods for optimal water management, especially for resolving water disputes. Those methods are described most fully in the Project's book, (Fisher, *et al.*, 2005), and are summarized below.[28] There it is shown that an agreement to trade in water-permits (permits to use each other's water in specified amounts) sold at the shadow values generated by the WAS (Water Allocation System) model is never inferior and usually superior to the standard agreement as to a fixed division of water quantities among countries.

Of course, the realization that water can (and should) be treated as an economic commodity – with special properties – is not new. It goes back at least as far as the Harvard Water Program of the 1950s and 1960s (see Eckstein, 1958 and Maass *et al.,* 1962; see also Hirshleifer, DeHaven, and Milliman, 1960). That realization has led to a large literature on water markets, to policy recommendations for water markets, particularly by the World Bank, and, in some cases, to the adoption of such recommendations (see for example Saliba and Bush, 1987).

But, for reasons discussed below, actual water markets will often, indeed generally, *not* lead to efficient or optimal results. There are several reasons for this, but perhaps the most important is because, in allocating water, there are social benefits and costs that are not simply private benefits and costs. While some of these "externalities" are recognized in the literature (environmental issues, for example), others are not. In particular, the fact that subsidization of water for a particular use (usually agriculture) implies a policy decision that there are social benefits from such use above and beyond those realized by the direct users themselves is typically ignored. But private markets will fail to handle this, and, where such views are held by policymakers, such failure will properly make them unwilling to institute actual market mechanisms.[29]

The analysis here discussed overcomes such difficulties by the use of WAS, an explicit optimizing model that allows the policymaker to impose his or her own views as to water values or, equivalently, to impose certain water policies and also to take other externalities into account. This is a form of systems analysis.

The application of systems analysis to water management is also not new (see for example Rogers and Fiering, 1986 and the papers cited in footnote 6). But Rogers and Fiering state (1986, p. 150):

> Systems analysis is particularly promising when scarce resources must be used effectively. Resource allocation problems are worldwide and affect the developed

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[27] We are indebted to Ariel Dinar for raising the questions that prompted this paper and urging us to write it.

[28] Fisher, et al., 2005. See also our expository article, Fisher and Huber-Lee, 2006.

[29] A referee points out that subsidization of water for agriculture may simply reflect the political power of farmers. That makes no difference here. If the government has decided that such political power is to have its way, then that has become a social goal. We do not take a position on whether such goals are in some way inappropriate, a principal contribution of our work being that the use of our model permits the decision-maker to impose his or her own values, however derived.

> and the developing countries that today must make efficient use of their resources. At any given time some factor such as skilled manpower, energy, transport, material or capital is in short supply and that scarcity impedes progress. Under these conditions, governments and their planners, but particularly those in less developed countries (LDCs), are constantly faced with the need to make the best use of those resources that will be needed at further stages of progress, and with the future need to balance current needs against investment for the future. This is the domain of systems analysis.

However, they also point out (p. 150S) that:

> [M]any, if not most, conventional uses of mathematical programming to solve water resource problems pursue optimality indiscriminately. ... Unfortunately, the stated ... goals and measures of merit do not fully reflect the true concerns of the decision makers, and experience shows that mathematical programming, while often used in some vague way by planners, is rarely used to make the critical decisions associated with project planning.

As discussed above, the WAS tool attempts to solve this problem by permitting the user of WAS to impose his or her own values.

In addition, there are other differences between the present work and its predecessors. First, much previous work concerns the cost-benefit analysis of particular projects, whereas the present work provides a tool for the overall management of water and water projects taking into account countrywide (or regionwide) effects while using a model that is geographically quite disaggregated.

Second, perhaps the most familiar use of such models is that of minimizing cost in connection with fixed demand quantities.[30] The WAS model described below goes beyond that in more than one respect:

- WAS takes account of demand considerations and the benefits to be derived from water use rather than fixing water quantities to be delivered.
- WAS permits the user to impose social values that differ from private ones and to impose policies that the optimization must respect.
- Beyond mere optimization, WAS can be used in conflict resolution, an area highly important in water issues, as it can be used to value disputed water, thus effectively monetizing and de-emotionalizing the dispute. Moreover, for international disputes, the water systems of each party can be analyzed separately, testing options of links to other parties, or of analyzing the combined territory of two or more parties as one. This provides estimates of the benefits of cooperation, which can then be weighed against the political issues involved in such cooperation.

While the methods developed are applicable to water disputes around the globe, Fisher *et al.*, 2005 applied them to Israel, Jordan, and Palestine, which have a long history of water

[30] For examples that go beyond mere cost minimization, see Brown and McGuire, 1967; Dandy, McBean, and Hutchinson, 1984; and McCarl, 1999. The model that appears most similar to WAS is the CALVIN model, an optimizing water model for California developed at the University of California, Davis (see for example Newlin *et al*,. 2002; Jenkins, Lund, and Howitt, 2003; and Jenkins *et al.*, 2004).

disputes, and examined the gains to such cooperation compared to the much lower values of fairly large changes in ownership of the water in dispute. Most of the discussion concerned two-way cooperation between Israel and Palestine[31] and Israel and Jordan.[32] Cooperation among all three countries was considered, giving results on particular aspects of the water flows that would occur, but the analysis did not exhibit fully the gains from three-way cooperation (although the case in which the third country joins a cooperative agreement already in place between the other two was also discussed).

This paper considers the benefits of different coalitions, especially trilateral cooperation, and presents a number of results thereon. Before this is done, however, a related question is considered:

Suppose that there are *n* countries. Is the "grand coalition" – that is, WAS-guided cooperation among all countries involved – stable? In game-theoretic terms, is the grand coalition in the core or can there exist a subset of countries that, by cooperating among themselves, can all do better than they can in the grand coalition and therefore block the latter?

It is shown that the answer to this question is in the negative[33] – an important fact with an easy demonstration, once one understands how WAS-guided cooperation works. Since this is also essential for an understanding of the results for the three countries discussed below, that mechanism is first summarized.

Water Ownership and the Value of Water

There are two basic questions involved in thinking about water agreements. These are:

- the question of water ownership and
- the question of water usage.

One must be careful to distinguish these questions.

All water users are effectively buyers irrespective of whether they own the water themselves or purchase water from another. An entity that owns its water resources and uses them itself incurs an opportunity cost equal to the amount of money it could otherwise have earned through selling the water. An owner will thus use a given amount of its water if and only if it values that use at least as much as the money to be gained from selling. The decision of such an owner does not differ from that of an entity that does not own its water and must consider buying needed quantities of water: the non-owner will decide to buy if and only if it values the water at least as much as the money involved in the purchase. *Ownership only determines who receives the money (or the equivalent compensation) that the water represents.*

[31] We use the term "Palestine" and refer to Palestine as a "country" both for convenience and out of respect for our Palestinian colleagues.

[32] Two-way cooperation between Palestine and Jordan was not investigated. This is considered in subsection 9.3 below.

[33] Note that this result does not imply that every country in the grand coalition does better than it would in some partial coalition. See below, Section 9d.

Water ownership is thus a property right entitling the owner to the economic value of the water. Hence a dispute over water ownership can be translated into a dispute over the right to monetary compensation for the water involved, taking into account social and environmental values.

The property rights issue of water ownership and the essential issue of water usage are analytically independent. For example, resolving the question of where water should be efficiently pumped does not depend on who owns the water. While both ownership and usage issues must be properly addressed in an agreement, they can and should be analyzed separately.[34]

The fact that water ownership is a matter of money can be brought home in a different way. It is common for countries to regard water as essential to their security because water is essential for agriculture and countries wish to be self-sufficient in their food supply. This may or may not be a sensible goal, but the possibility of desalination implies the following:

Every country with a seacoast can have as much water as it wants if it chooses to spend the money to do so. Hence, so far as water is concerned, every country with a seacoast can be self-sufficient in its food supply if it is willing to incur the costs of acquiring the necessary water. Disputes over water among such countries are merely disputes over costs, not over life and death.

Note that, in valuing water, one must consider the following:

1. Unless water is very abundant, the value of water does not simply consist of the costs of extraction, treatment, and conveyance. In general, water value also includes a *scarcity rent*, reflecting the opportunity cost of its use – the value of using or selling it elsewhere.
2. When we speak of "the value of water", we are speaking of the value of molecules of H_2O.[35] That is not the only value of importance, however. There may be religious or historical values placed on particular water sources. Further, water in certain uses (agriculture, for example), may be considered as more valuable to society than is reflected in the private valuations of the users. And water in sources thought to be secure may be considered more valuable than water in less secure sources. In the WAS model, we permit the user to take such things into account by constraining the model to reflect such considerations. In that sense, our analysis is not confined to narrowly-defined economic considerations.

[34] This is an application of the well-known Coase Theorem of economics. See Coase, 1960.

[35] In the WAS model discussed below, that value is not simply the economic value narrowly considered. It incorporates the particular values imposed by the user of the model. These can include environmental and social considerations.

Why Actual Water Markets Will Not Work[36]

In the case of many scarce resources, free markets can be used to secure efficient allocations. This does not always work, however; the important propositions about the efficiency of markets require the following conditions:

1. The markets involved must be competitive consisting only of very many, very small buyers and sellers, so that individual participants cannot affect prices.
2. All social benefits and costs associated with the resource must coincide with private benefits and costs, respectively, so that they will be taken into account in the profit-and-loss calculus of market participants.

Neither of these conditions is generally satisfied when it comes to water (in the Middle East or elsewhere). First, water markets will not generally be competitive with many small sellers and buyers. Second (and perhaps more important), because water in certain uses – for example, agricultural or environmental uses – is often considered to have social value in addition to the private value placed on it by its users. The common use of subsidies for agricultural water, for example, implies that the subsidizing government believes that water used by agriculture is more valuable than the farmers, themselves, consider it to be.[37]

This does not mean, however, that economic analysis has no role to play in water management or the design of water agreements. One can build a model of the water economy of a country or region that explicitly optimizes the benefits to be obtained from water, taking into account the issues mentioned above.[38] Its solution, in effect, provides an answer in which the optimal nature of competitive markets is restored and serves as a tool to guide policy makers.[39]

Such a tool does not itself make water policy. Rather it enables the user to express his or her priorities and then shows how to implement them while maximizing the net benefits to be obtained from the available water. While such a model can be used to examine the costs and benefits of different policies, it is not a substitute for, but an aid to the policy maker.

It would be a mistake to suppose that such a tool only takes economic considerations (narrowly conceived) into account. The tool leaves room for the user to express social values and policies through the provision of low (or high) prices for water in

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[36] Although the region we have specifically studied (Israel, Jordan, and Palestine) is clearly one in which actual water markets involving private sellers and buyers are unlikely to work, the principles here discussed are applicable around the globe and to regions where such markets may be thought possible and desirable. Hence we include this section.

[37] See footnote 5, above. Of course, externality issues such as water quality or return flows can also prevent actual markets from acting optimally.

[38] The pioneering version of such a model (although one that does not explicitly perform maximization of net benefits) is that of Eckstein *et al*,. (1994).

[39] There is a large literature and much discussion about *actual* free water markets, but it is crucial to understand that what is proposed here is *not* such a market. We do recommend below a system of water trading among (in this case) countries, but even such trading is not at freely bargained prices but rather at prices and quantities prescribed by joint operation of an optimizing model. Hence, we do not discuss the water market literature explicitly.

certain uses, the reservation of water for certain purposes, and the assessment of penalties for environmental damage. These are, in fact, the ways that social values are usually expressed in the real world.

The Was Tool

As already indicated, the tool is called WAS for "water allocation system" (see the Appendix for a detailed mathematical description). As here discussed, it is a single-year, annual model, although the conditions of the year can be varied and different situations evaluated.[40] The objective function maximizes net water benefits for a given region, subject to constraints. These include:

- The capacity of various pieces of infrastructure (e.g. water treatment plants, desalination plants, and conveyance lines or canals)
- The constraints represented by social policies due to environmental or other factors, including constraints restricting the water taken from any natural source to be no greater than the annual renewable flow available from that source (although that maximum can be adjusted according to climatic conditions)
- The price policies (such as subsidization of water for agriculture) that are prescribed by the model user
- Most important of all, the constraint that the quantity of water consumed in a particular location cannot exceed the quantity produced there plus the quantity imported into less the quantity exported from that location.

The country or region to be studied is divided into districts. Within each district, demand curves for water are defined for household, industrial, and agricultural use of water. Extraction from each water source is limited to the annual renewable amount. Allowance is made for treatment and reuse of wastewater and for inter-district conveyance. This procedure is followed using actual data for a recent year and projections for future years.[41]

Environmental issues are handled in several ways. Water extraction is restricted to annual renewable amounts; an effluent charge can be imposed; the use of treated wastewater can be restricted; and water can be set aside for environmental (or other) purposes. Other environmental restrictions can also be introduced.

The WAS tool permits experimentation with different assumptions as to future infrastructure. For example, the user can install wastewater treatment plants, expand or install conveyance systems, and create seawater desalination plants.

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[40] A multiyear version has now largely been developed.

[41] Note that the data requirements just described are not small. Further, the building of a WAS model is not a trivial enterprise. It requires more than just the software, needing also intelligent modeling of the water economies involved.

Finally, the user specifies policies toward water. Such policies can include specifying particular price structures for particular users such as agriculture; reserving water for certain uses; and imposing ecological or environmental restrictions.

Given the choices made by the user, the model allocates the available water so as to maximize total net benefits from water. These are defined as the total amount that consumers are willing to pay for the amount of water provided less the cost of providing it.[42, 43]

Shadow Values and Scarcity Rents

It is an important theorem that, under very general conditions, when an objective function is maximized under constraints, the solution also generates a set of nonnegative numbers, usually called "shadow prices", but here called "shadow values" to emphasize that these are not necessarily the prices to be charged to water users. Such shadow values (which are the Lagrange multipliers corresponding to the various constraints) have the property that they show the amount by which the value of the objective function would increase if the corresponding constraints were to be relaxed a little.

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

The central shadow values in the WAS model, however, are those of water itself. The shadow value of water at a given location corresponds to the constraint that the quantity of water consumed in that location cannot exceed the quantity produced there plus the quantity imported less the quantity exported. That shadow value is thus the amount by which the benefits to water users (in the system as a whole) would increase were there an additional cubic meter per year available free *at that location*. It is also the price that the buyers at that location who value additional water the most would just be willing to pay to obtain an additional cubic meter per year, given the net-benefit maximizing water flows of the model solution.[44]

Experience shows that the following points about shadow values cannot be overemphasized:

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[42] The total amount that consumers are willing to pay for an amount of water, Q*, is measured by the area up to Q* under their aggregate demand curve for water. Note that "willingness to pay" includes ability to pay. The provision of water to consumers that are very poor is taken to be a matter for government policy embodied in the pricing decisions made by the user of WAS.

[43] Despite the complexity of the WAS model and the very large number of constraints involved, it converges very rapidly (i.e. less than a minute for the entire Israel, Jordan and Palestine region on a laptop). It uses the GAMS software as its principal maximizing engine.

[44] If the user of the model – for example the government of a country – would value additional water in a particular location more than would private buyers, then the shadow value reflects that valuation.

- Shadow values are not necessarily the prices that water consumers are charged. That would be true in a purely private, free market system. But in the WAS model, as in reality, the prices charged to some or all consumers can (and often will) be a matter of social or national policy. When such policy-driven prices are charged, the shadow values of water will reflect the net benefits of additional water given the policies adopted.

- Related to this is the fact that shadow values are *outputs* of the model solution, not inputs specified a priori. They depend on the policies and values put in by the user of the model.

It is important to note that the shadow value of water in a given location does not generally equal the direct cost of providing it there. Consider a limited water source whose pumping costs are zero. If demand for water from that source is sufficiently high, the shadow value of that water will not be zero; benefits to water users would be increased if the capacity of the source were greater. Equivalently, buyers will be willing to pay a nonzero price for water in short supply, even though its direct costs are zero.

A proper view of costs accommodates this phenomenon. When demand at the source exceeds capacity, it is not costless to provide a particular user with an additional unit of water. That water can only be provided by depriving some other user of the benefits of the water; that loss of benefits represents an opportunity cost. In other words, scarce resources have positive values and positive prices even if their direct cost of production is zero. Such a positive value — the shadow value of the water *in situ* — is called a "scarcity rent".

Where direct costs are zero, the shadow value of the resource involved consists entirely of scarcity rent. More generally, the scarcity rent of water at a particular location equals the shadow value at that location less the direct marginal cost of providing the water there.[45] Just as in a competitive market, a positive scarcity rent is a signal that more water from that source would be beneficial were it available.

Water shadow values and, accordingly, water scarcity rents depend upon the infrastructure assumed to be in place.

When water is efficiently allocated, as in the solution of the WAS model, the following relationships must hold. Equivalently, if they do not hold, then water is not being efficiently allocated. (All values are per unit of water.)

- The shadow value of water used in any location equals the direct marginal cost plus the scarcity rent. For water *in situ*, the shadow value is the scarcity rent.

- Water will be produced at a given location only if the shadow value of water at that location exceeds the marginal cost of production. Equivalently, water will only be produced from sources whose scarcity rents are nonnegative.

- If water can be transported from location *a* to location *b*, then the shadow value of water at *b* can never exceed the shadow value at *a* by more than the cost of such transportation. Water will actually be transported from *a* to *b* only if the shadow

[45] If this calculation gives a negative figure, then the scarcity rent is zero, and water is not scarce at the given location.

value at b exactly equals the shadow value at a plus the transportation cost. Equivalently, if water is transported from a to b, then the scarcity rent of that water will be the same in both locations.

This situation is illustrated in Figure 23, where water in a lake (L) is conveyed to locations a, b, and c. It is assumed that the only direct costs are conveyance costs. The marginal conveyance cost from the lake to a is denoted $t_{l,a}$; similarly, the marginal conveyance cost from a to b is denoted t_{ab}; and that from b to c is denoted t_{bc}. The shadow values at the four locations are denoted P_L, P_a, P_b, and P_c, respectively.

To see that the equations in Figure 23 must hold, begin by assuming that $P_a > P_L + t_{l,a}$ and that there is extra conveyance capacity from L to a at the optimal solution. Then transferring one more cubic meter of water from L to a would have the following effects. First, since there would be one cubic meter less at L, net benefits would decline by P_L, the shadow value of water at L. (That is what shadow values measure.) Second, since conveyance costs of $t_{l,a}$ would be incurred, there would be a further decline in net benefits of that amount. Finally, however, an additional cubic meter at a would produce an increase in net benefits of P_a, the shadow value of water at a. Since, by assumption, $P_a > P_L + t_{l,a}$, the proposed transfer would increase net benefits; hence, we cannot be at an optimum.

Similarly, assume that $P_a < P_L + t_{l,a}$. Then too much water has been transferred from L to a, and transferring one less cubic meter would increase net benefits. Hence, again, we cannot be at an optimum.

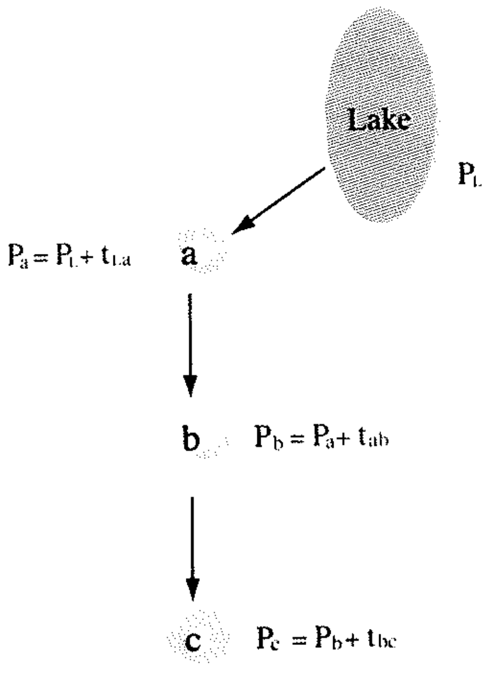


Figure 23. Efficient water allocation and water values

It follows that, at an optimum, $P_a = P_L + t_{La}$, and a similar demonstration holds for conveyance between any two points.

Now, the first part of the demonstration just given requires the assumption that conveyance capacity is adequate to carry an additional cubic meter of water from L to a. Even were this not true, however, it would remain true that, in a generalized sense, $P_a = P_L + t_{La}$ at an optimum. Suppose that, with the conveyance system operating at capacity, it would increase net benefits if an additional cubic meter of water could be transferred from L to a. In this case, the capacity of the conveyance system would itself have a positive shadow value measuring the additional benefit that would occur if that capacity were increased by one cubic meter. If one includes that shadow value in t_{La} (adding it to the operating costs), then the relation, $P_a = P_L + t_{La}$ is restored.

Note that shadow values play a guiding role in the same way that actual market prices do in competitive markets. An activity that is profitable at the margin when evaluated at shadow values is one that should be increased. An activity that loses money at the margin when so evaluated is one that should be decreased. In the solution to the net-benefit maximizing problem, any activity that is used has such shadow marginal profits zero, and, indeed, shadow profits are maximized in the solution.

That shadow values generalize the role of market prices can also be seen from the fact that, where there are only private values involved, at each location, the shadow value of water is the price at which buyers of water would be just willing to buy and sellers of water just willing to sell an additional unit of water.

Of course, where social values do not coincide with private ones, this need not hold. In particular, the shadow value of water at a given location is the price at which the *user* of the model would just be willing to buy or sell an additional unit of water there. That payment is calculated in terms of net benefits *measured according to the user's own standards and values.*

This immediately implies how the water in question should be valued. *Water* in situ *should be valued at its scarcity rent.* That value is the price at which additional water is valued at any location at which it is used, less the direct costs involved in conveying it there.

Note that the propositions about profitable and unprofitable activities involve water being so valued. Those propositions take full account of the fact that using or processing water in one activity can reduce the amount of water available for other activities. The shadow values accompanying the maximizing solution include such opportunity costs, taking into account systemwide effects. (This is particularly important in using WAS for cost-benefit analysis.)

One should not be confused by the use of marginal valuation in all this (the value of an additional unit of water). The fact that people would be willing to pay much larger amounts for the amount of water necessary for human life is important. It is taken into account in the optimizing model by assigning correspondingly large benefits to the first relatively small quantities of water allocated. But the fact that the benefits derived from the first units are greater than the marginal value does not distinguish water from any other economic good. It merely reflects the fact that water would be (even) more valuable if it were scarcer.

It is the scarcity of water and not merely its importance for existence that gives it its value. Where water is not scarce, it is not valuable.

Cost-Benefit Analysis of Infrastructure and the Treatment of Capital Costs

Before proceeding, it is useful to understand how WAS can be used in the cost-benefit analysis of proposed infrastructure projects and how it handles capital costs (which can be quite substantial).

Consider the discussion of the lake and the conveyance line (Figure 23). Suppose that there were no existing conveyance line to carry water from the lake to city *a*. Suppose further that, if the WAS model were run without such a conveyance line, the resulting shadow values would be such that $P_a < P_L + t_{La}$, where t_{La} is the per-cubic-meter conveyance *operating* cost that would be incurred were such a conveyance line in place. Such a result would show that the conveyance line in question should not be built, because it would not be used even if it were. On the other hand, if the inequality were reversed, so that $P_a > P_L + t_{La}$, then that conveyance line might well be worth building – but whether it should be built would depend on the capital costs involved.

There are two ways of incorporating capital costs into the analysis of WAS results. One option is to impute an appropriate charge for capital costs to each cubic meter of water processed by the proposed facility.

The second option is more direct. One runs the WAS model with and without the proposed infrastructure.[46] This generates an estimate of the annual increase in benefits that would result from having such infrastructure in place. Given the estimated life of the projected infrastructure, one can repeat the exercise for the expected conditions of the various years of that life. Then, choosing a discount rate, one calculates the present value of such benefits and compares that with the capital costs.

In MYWAS, the multiyear version of WAS mentioned in footnote 16 above, the treatment of capital costs is more straightforward. One treats them as cash outlays incurred at various times when the project in question is begun or expanded. MYWAS then takes them directly into account in the calculation of the present value of total net benefits being maximized.

Conflict Resolution: Negotiations and the Gains from Trade in Water Permits

By using the WAS model to value water in dispute, water disputes can be monetized, and this may be of some assistance in resolving them. Consider bilateral negotiations between two countries, A and B. Each of the two countries can use its WAS tool to investigate the consequences to it (and, if data permit, to the other) of each proposed water allocation. This should help in deciding on what terms to settle, possibly trading off water

[46] A similar method can be used to analyze different proposed water policies.

for other, non-water concessions. Indeed, if, at a particular proposed allocation, A would value additional water more highly than B, then both countries could benefit by having A get more water and B getting other things which it values more. (Note that this does not mean that the richer country gets more water. That only happens if it is to the poorer country's benefit to agree.)[47]

Exercise 1: How do I use Common Pools to Explore Cooperation vs. No Cooperation over the Jordan River?

1. Load NoCoop2010_80120P_92i8j
2. Click Edit on the Supply of Water, then Common Pool as illustrated below in Figure 24.

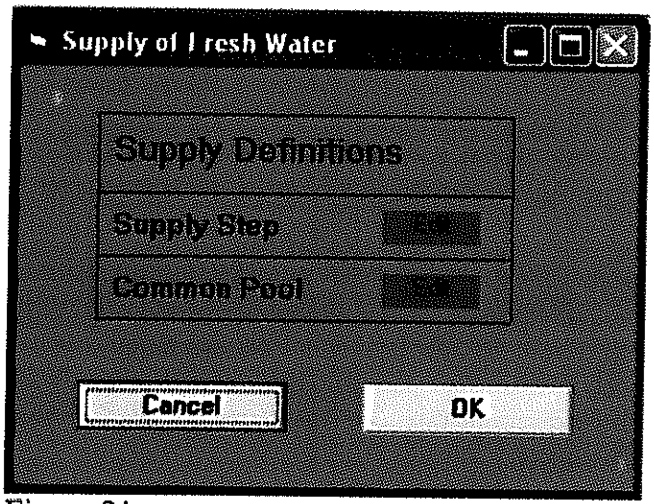


Figure 24

3. Click on Click to Select and Select Israel, as shown in Figure 25.
4. Note this illustrates Common Pool Constraint 1, which is the common pool within Israel for the Jordan River.
5. To explore cooperation, we will need to add Jordan's access to the Jordan River to this Common Pool Constraint. To do so, click on the word Israel and select Jordan. You will see no check marks for this Common Pool because this is a no cooperation run. Jordan's access to the Jordan River is in Irbid, step 3 (you can see this in the Supply Step table in the amount of 55 MCM). Click that box, and change the total quantity from 662 to 717.

6. Now we want to explore questions of ownership. The current split is approximately 92%

[47] If trading off ownership rights considered sovereign is unacceptable, the parties can agree to trade short-term permits to use each others' water.

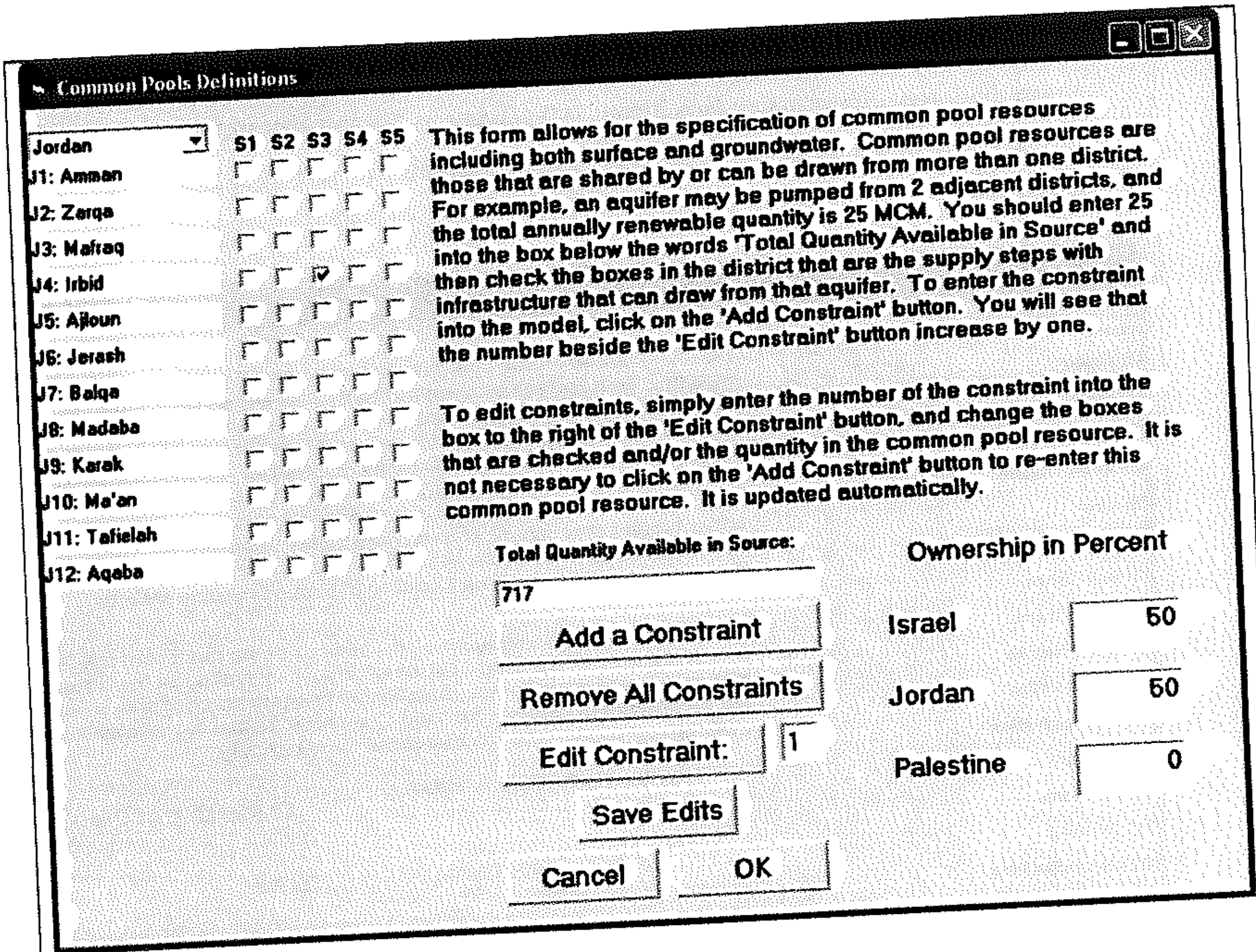


Figure 26

8. Now we need to make the appropriate adjustments in the supply steps.
9. Click on Supply Step and choose Jordan. Change the third supply step of Irbid to 717, as illustrated in Figure 27. Click Finished.

Israel and 8% Jordan. Just for the sake of exploration, let's change that to 50-50. To do so, on the lower right, change Israel from 100 percent to 50, and Jordan from 0 to 50.

7. Click Save Edits, then OK. Your screen should match that of Figure 26.

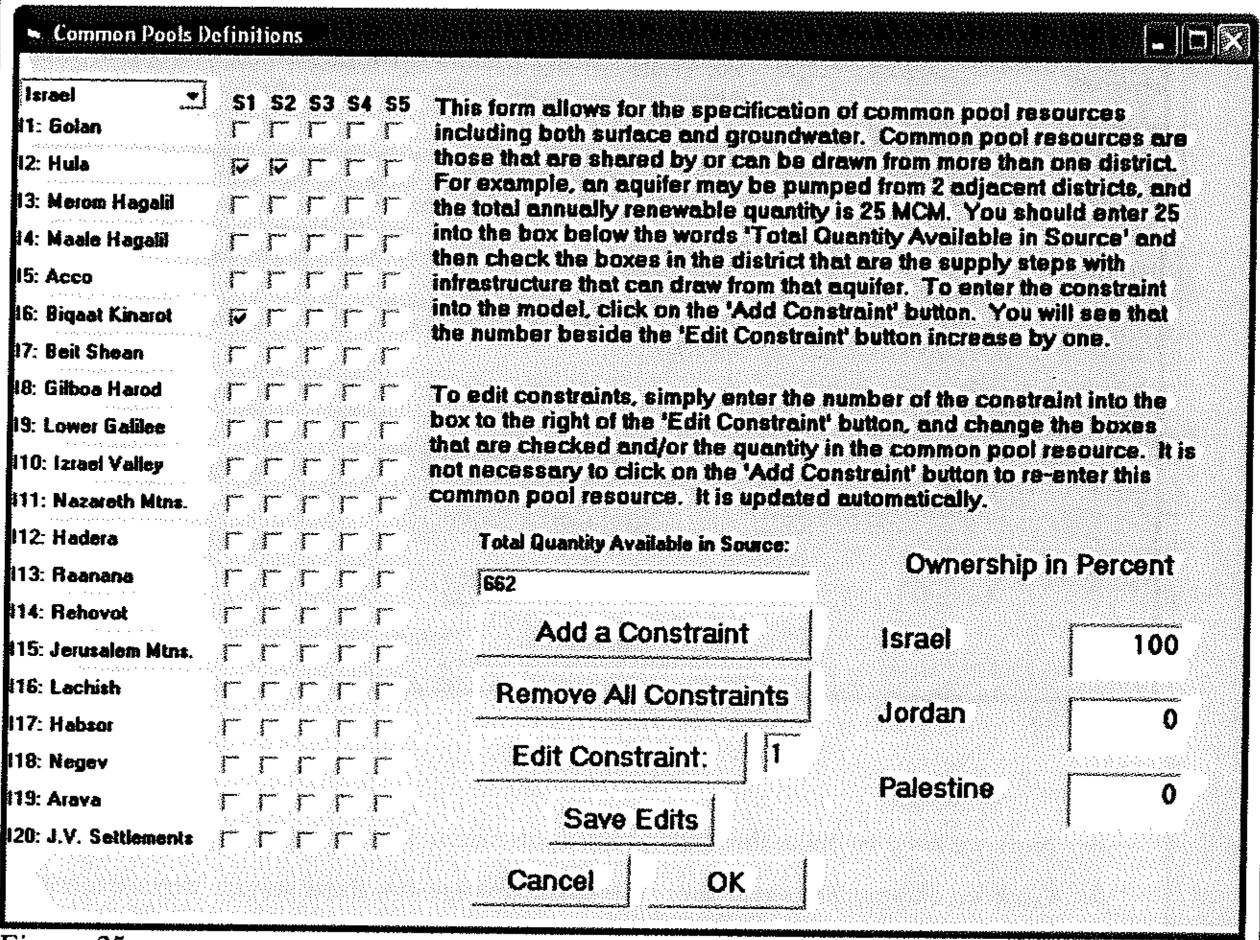


Figure 25

JORDAN - Supply Step Function

	District	Costs ($/m3) S1	S2	S3	S4	S5	Quantities (MCM/year) S1	S2	S3	S4	S5
J1	Amman	0.07	0.47	999	999	999	34	35	0	0	0
J2	Zarqa	0.13	999	999	999	999	47	0	0	0	0
J3	Mafraq	0.13	999	999	999	999	77	0	0	0	0
J4	Irbid	0.07	0.02	0.06	999	999	29	158	717	0	0
J5	Ajloun	0.03	0.02	999	999	999	2	5	0	0	0
J6	Jerash	0.07	0.02	999	999	999	8	43	0	0	0
J7	Balqa	0.1	0.03	999	999	999	19	25	0	0	0
J8	Madaba	0.13	0.01	999	999	999	9	31	0	0	0
J9	Karak	0.07	0.01	999	999	999	16	61	0	0	0
J10	Ma'an	0.13	0.01	0.08	999	999	14	2	125	0	0
J11	Tafielah	0.07	0.01	999	999	999	12	6	0	0	0
J12	Aqaba	0.1	0.08	999	999	999	8	15	0	0	0

Cancel | Remove All | Default Values | Finished

Figure 27

10. Choose Israel, and change the first step of Biqaat Kinerot from 662 to 717. Click Finished, Accept and then OK.
11. Optimize
12. Name the run IJCoop2010_80120P_50i50j
13. Save and describe.
14. Go to the tabular results and go forward one page to Overall Results
15. Scroll down the page until you see International Payments, illustrated in Figure 28 below. You will see that Israel is paying $8.2 million dollars a year for the use of the Jordan River owned by Jordan.

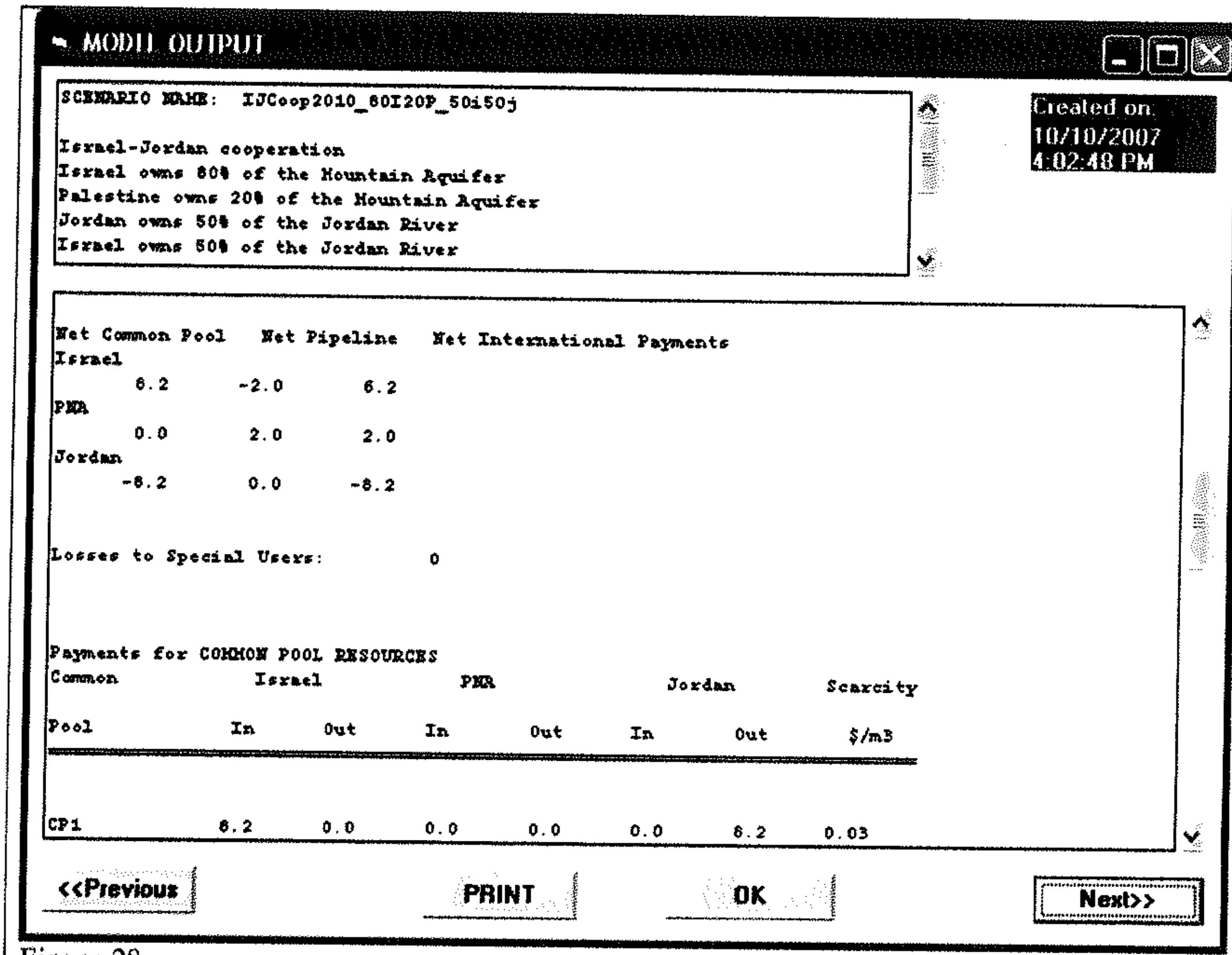
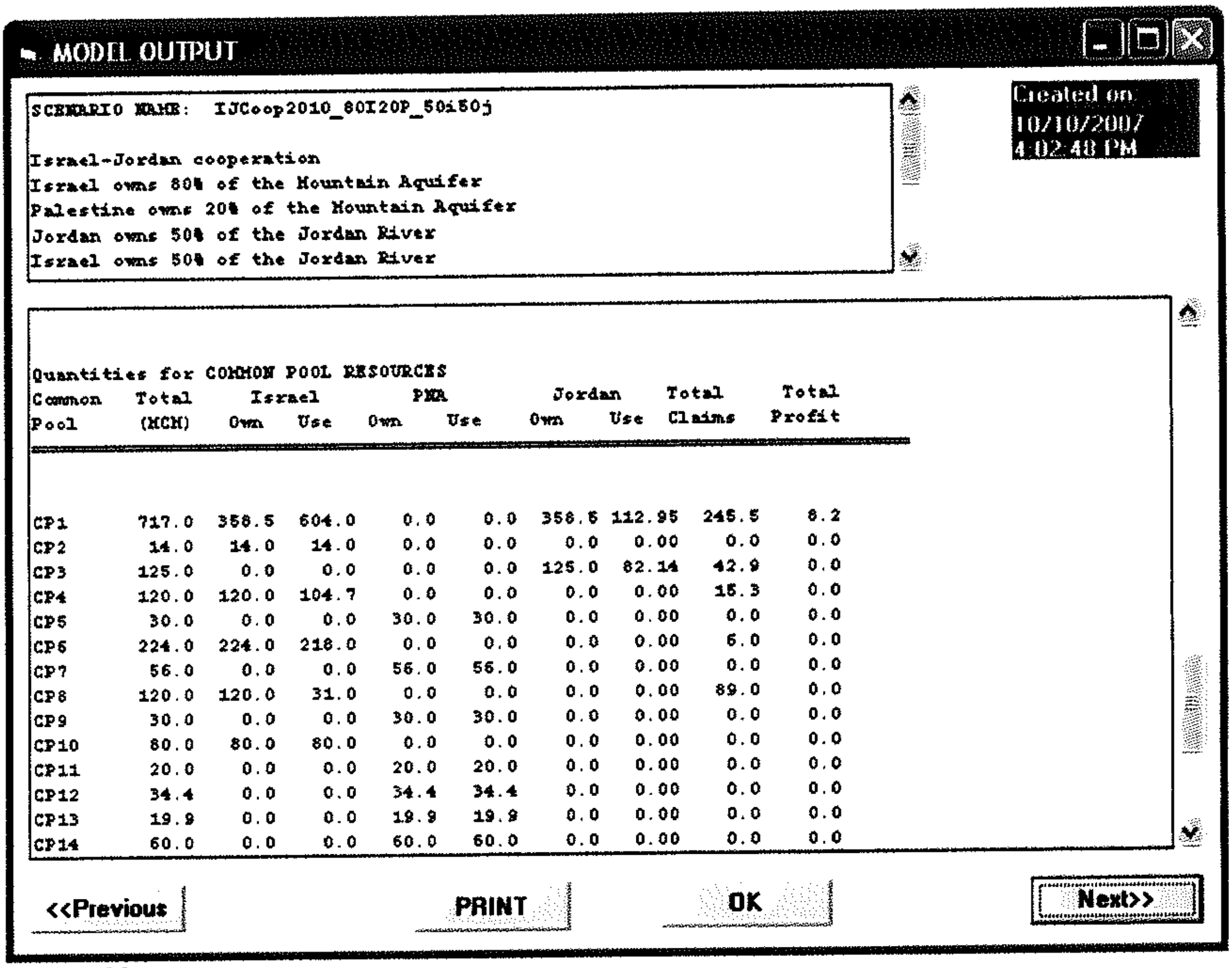


Figure 28

16. To learn the scarcity rent for this Common Pool, you can see at the bottom of Figure 6 that the amount is $0.03.

17. If you scroll down further, you will find Quantities for Common Pool Resources, and the ownership and quantities for Common Pool 1, as illustrated in Figure 29 below.



Quantities for COMMON POOL RESOURCES

Common Pool	Total (MCM)	Israel Own	Israel Use	PNA Own	PNA Use	Jordan Own	Jordan Use	Total Claims	Total Profit
CP1	717.0	358.5	604.0	0.0	0.0	358.5	112.95	245.5	8.2
CP2	14.0	14.0	14.0	0.0	0.0	0.0	0.00	0.0	0.0
CP3	125.0	0.0	0.0	0.0	0.0	125.0	82.14	42.9	0.0
CP4	120.0	120.0	104.7	0.0	0.0	0.0	0.00	15.3	0.0
CP5	30.0	0.0	0.0	30.0	30.0	0.0	0.00	0.0	0.0
CP6	224.0	224.0	218.0	0.0	0.0	0.0	0.00	6.0	0.0
CP7	56.0	0.0	0.0	56.0	56.0	0.0	0.00	0.0	0.0
CP8	120.0	120.0	31.0	0.0	0.0	0.0	0.00	89.0	0.0
CP9	30.0	0.0	0.0	30.0	30.0	0.0	0.00	0.0	0.0
CP10	80.0	80.0	80.0	0.0	0.0	0.0	0.00	0.0	0.0
CP11	20.0	0.0	0.0	20.0	20.0	0.0	0.00	0.0	0.0
CP12	34.4	0.0	0.0	34.4	34.4	0.0	0.00	0.0	0.0
CP13	19.9	0.0	0.0	19.9	19.9	0.0	0.00	0.0	0.0
CP14	60.0	0.0	0.0	60.0	60.0	0.0	0.00	0.0	0.0

Figure 29

18. As you can see, Israel is indeed using more than it's share of the Jordan River.

19. Discuss

Of course, the positions of the parties will be expressed in terms of ownership rights and international law, often using different principles to justify their respective claims. The use of the methods here described in no way limits such positions. Indeed, the point is not that the model can be used to help decide how allocations of property rights should be made. Rather the point is that water can be traded off for non-water concessions, with the trade-offs measured by WAS.

In addition to monetizing water disputes, WAS can facilitate water negotiations by permitting each party, using its own WAS model, to evaluate the effects on it of different proposed water arrangements. As we now exemplify, this can show that the trade-offs just discussed need not be large.

Water on the Golan Heights (see Figure 30) is sometimes said to be a major problem in negotiations between Israel and Syria, because the Banias River that flows from the mountains of the Golan is one of the three principal sources of the Jordan River.[48] By running the Israeli WAS model with different amounts of water, we have evaluated this question.

[48] The others are the Hasbani which rises in Southern Lebanon and the Dan which rises in pre-1967 Israel.

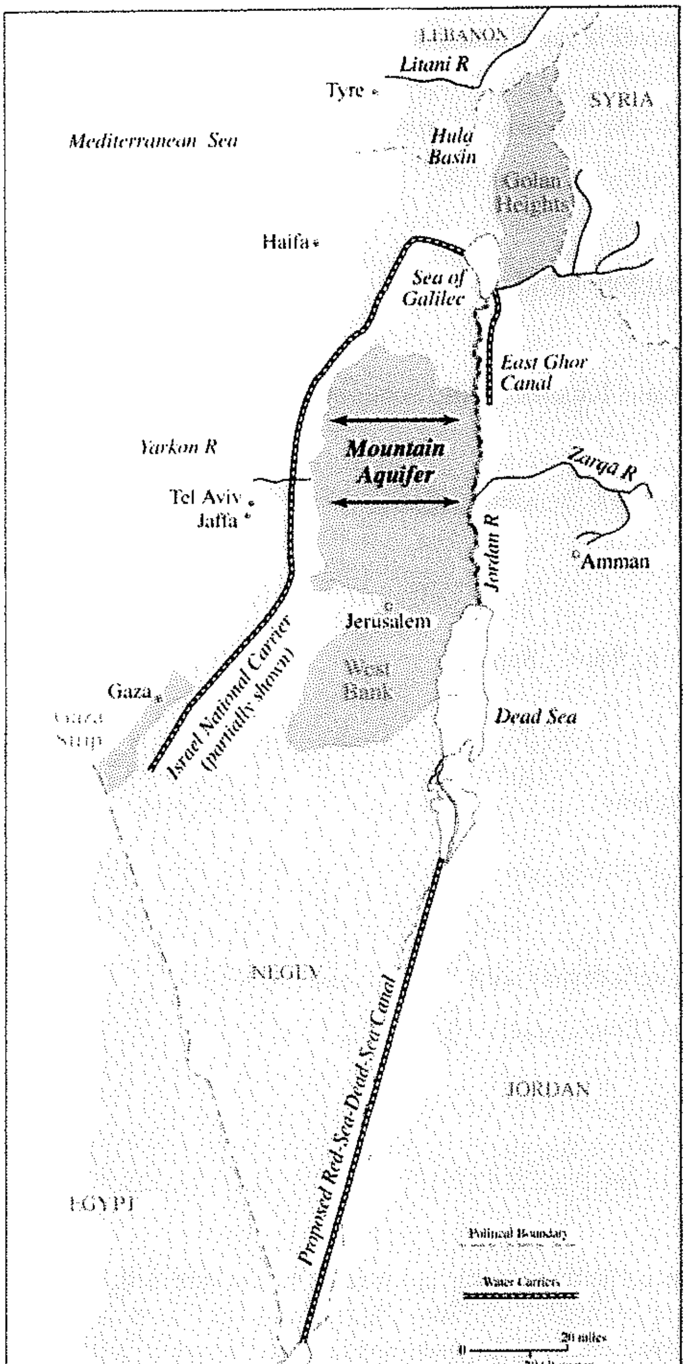


Figure 30. Partial Regional Map with Water Systems[49,50]

[49] The map in Figure 2 shows the name of the large lake on the Jordan River as "Sea of Galilee". That lake is called "the Kinneret" by Israel and "Lake Tiberias" by Jordan and Palestine. The map is adapted from Wolf (1994, p. 27).

[50] It will be noticed that we have not marked the map with the names "Israel" and "Palestine". That is because we do not wish to prejudge the ultimate borders that may be agreed upon.

Exercise 2: What is the impact on Israel if the Banias River were not available?

1. Load NoCoop2010_80I20P_92I_8J
2. Reduce Common Pool #1 by the amount of the Banias – 125 mcm (i.e. 625-125=537), and click save edits before clicking OK.
3. Optimize
4. Name the run NoCoop2010_80I20P_9218J_noB
5. Save and describe.
6. Compare shadow values at Biqaat Kinerot in the schematics with the first run you loaded.
7. Compare the two runs using the Cost Benefit Analysis
8. Reduce supply by 30%
9. Optimize
10. Name run NoCoop2010_80I20P_9218J_.3dnob
11. Save and describe
12. Return supply to normal (1.0)
13. Optimize
14. Name run NoCoop2010_80I20P_9218J_.3d
15. Save and describe
16. Compare shadow values in the schematics with the first run you loaded.
17. Compare the two runs using the Cost Benefit Analysis
18. Discuss

In 2010, the loss of an amount of water roughly equivalent to the entire flow of the Banias springs (125 million cubic meters annually) would be worth no more than $5 million per year to Israel in a year of normal water supply and less than $40 million per year in the event of a reduction of thirty percent in naturally occurring water sources. These results take into account Israeli fixed-price policies towards agriculture.

Note that it is *not* suggested that giving up so large an amount of water is an appropriate negotiating outcome, but water is not an issue that should hold up a peace agreement. These are trivial sums compared to the Israeli GDP (gross domestic product) of approximately $ 100 billion per year or to the cost of fighter planes.

Similarly, a few years ago, Lebanon announced plans to pump water from the Hasbani River – another source of the Jordan. Israel called this a *casus belli* and international efforts to resolve the dispute were undertaken. But whatever one thinks about Lebanon's right to take such an action, it should be understood that our results for the Banias apply equally well to the Hasbani. The effects on Israel would be fairly trivial.[51]

Water is not worth war!

Monetization of water disputes, however, is neither the only nor, perhaps, the most powerful way in which the use of WAS can promote agreement. Indeed, WAS can assist in guiding water cooperation in such a way that all parties gain.

The simple allocation of water quantities after which each party then uses what it "owns" is not an optimal design for a water agreement. Suppose that property rights issues have been resolved. Since the question of water ownership and the question of water usage are analytically independent, it will generally not be the case that it is optimal for each party simply to use its own water.

Instead, consider a system of trade in water permits – short term licenses to use each other's water. The purchase and sale of such permits would be in quantities and at prices (shadow values) given by an agreed-on version of the WAS model run jointly for the two (or more) countries together. (The fact that such trades would take place at WAS-produced prices would prevent monopolistic exploitation.). There would be mutual advantages from such a system, and the economic gains would be a natural source of funding for water-related infrastructure.

Both parties would gain from such a voluntary trade. The seller would receive money it values more than the water given up (else, it would not agree); the buyer would receive water it values more than the money paid (else, it would not pay it). While one party might gain more than the other, such a trade would not be a zero-sum game but a win-win opportunity.

We illustrate such gains for Israel, Jordan, and Palestine below. First, however, we consider the stability of the grand coalition.

The Stability of the Grand Coalition

Consider a group of n countries all in the same river basin, aquifer or otherwise connected water. Let G denote the grand coalition – where, by "coalition" is meant a WAS-guided cooperation arrangement as described above. It will be shown that G is stable – that is, that there exists no nonempty proper subset, S, of the countries such that a coalition of the members of S, using their own water resources, can lead to all such members being better off than they would be in G. (Of course, this applies to single-member subsets where a single country optimizes the use of its own water.)

Proposition: The grand coalition is stable.

Proof: The proof begins with:

[51] Of course, the question naturally arises as to what the effects on Syria and Lebanon, respectively would be in these two situations. Without a WAS model for those two countries, we cannot answer that question. Both countries would surely profit from such a model.

Lemma: The proposition is true for $n = 2$.

Proof of lemma: Let the two countries be denoted by X and Y respectively. Suppose that the joint WAS solution calls for a transfer of water from some district of X to some district of Y. (For simplicity of notation, assume that each country has only one district.) Then it must be the case that, without such transfer, $P_X < P_Y + t^*_{XY}$, where P_X denotes the (pre-transfer) shadow value of water at X, P_Y denotes the (pre-transfer) shadow value of water at Y, and t^*_{XY} denotes the per-cubic-meter conveyance cost – this time including the appropriate capital charge.[52] Then, after the transfer from X to Y, the shadow value at X will be higher than P_X, and the shadow value at Y will be lower than P_Y, the respective pre-transfer shadow values. But then both X and Y must have total benefits higher than they would be without the transfer – X because it has received money that it values more than the water given up, and Y because it has received water that it values more than the money it has paid.[53]

Proof of proposition: Now, consider any nonempty proper subset, S, whose members form a coalition. Let T be the set of all countries that are not in S. Consider a coalition formed by the members of T. Then the water resources of the members of S are being used optimally as though S were a single country, and similarly for T. But the grand coalition, G, is nothing but a coalition formed by S and T. This is a bilateral agreement. Hence, by the lemma, both S and T must be at least as well off as they were alone. It follows that it cannot be true that the members of S (or the members of T) can all be better off than they would be in G. *QED*

Some comments need adding. First, note that the user-specified water valuations of each of the countries are respected in any WAS-guided arrangement in which they participate.

Second, because the use of WAS shadow values, given those valuations, essentially restores the properties of a competitive market, the result just given is not surprising. It essentially mirrors the well-known result that the competitive equilibrium is always in the core of the economy.

Third, as already remarked in footnote 9, and exemplified below, the result does not imply that every country does better in the grand coalition than it would in other coalitions. For example, in the case of Israel, Jordan, and Palestine, for plausible (but not inevitable) distributions of water ownership, Israel is a net seller and the other two countries are net buyers of water under WAS-guided arrangements.[54] It is therefore not surprising that Israel does better in the grand coalition than in bilateral ones, while the other two countries do (slightly) better in bilateral coalitions with Israel than in the grand coalition. Note, however, that, as should be expected from the proposition under discussion, if side-payments are

[52] The simplest case is to assume that the conditions of the year being studied will continue for the life of the project. More realistic cases only complicate the discussion without changing the nature of the proof.

[53] Note that this is true regardless of how the transfer costs, t^*_{XY}, are allocated. Y ultimately pays those costs – either directly to X or by building and operating the conveyance system itself – but the surplus benefits generated are large enough to cover such payments and still leave Y better off than it would have been without the transfer.

[54] This does not mean that sales go in only one direction. It is typically found that the direction of sales differs at different locations.

allowed, then all three countries can be made better off when a third one joins an existing bilateral coalition.[55]

Finally, we comment below on why the use of the WAS mechanism rather than some direct bargaining mechanism is to be preferred,

The Gains from Was-Guided Cooperation: Israel, Jordan, and Palestine

We now present results for Israel, Jordan, and Palestine, illustrating the gains from cooperation – and especially those from participation in the grand coalition. We concentrate on predictions for 2010. Predictions for 2020 are generally qualitatively similar, and we comment on them only when that seems instructive.[56]

We concentrate on two sources of water that are the subjects of conflicting claims. These are the Jordan River and the so-called Mountain Aquifer (see Figure 30). Both of these are (very roughly) of equal size, each yielding about 650 million cubic meters a year. The Jordan River is claimed by all three countries, while the Mountain Aquifer is claimed only by Israel and Palestine. Since the gains from cooperation are a function of the water ownership assumptions made, we obtain results for selected varying assumptions about such ownership. *It must be emphasized that such assumptions are not meant as a political statement. They are illustrative only.*

For the Jordan River, we examine ownership cases as follows:

A. Israel 92%, Jordan 8%; Palestine 0. (This is approximately the existing situation.)

B. Israel 66%; Jordan 17%; Palestine 17%.

C. Israel 33.3%; Jordan 33.3; Palestine 33.3%.

For the Mountain Aquifer, we examine ownership cases varying from Israel 80%-Palestine 20% (close to the existing situation) to Israel 20%-Palestine 80% by shifts of 20% at a time.[57]

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[55] See Fisher *et al.* 2005, pp. 216–17.

[56] At this time, it is appropriate for us to correct a minor error in Fisher, et al. (2005) pointed out to us by Yoav Kislev, whom we thank (not desiring to shoot the messenger). In that work, all prices are meant to be at the city gate, so to speak. But, when dealing with Israeli fixed-price policies for households and industry, we mistakenly set the fixed price for urban and industry at the prices charged at the user tap. We also calibrated the household and industry demand curves using those too-high prices. Correction of this slip has almost no effect on our important qualitative statements (indeed, it strengthens the finding that desalination is not yet an efficient technology except in times of extreme drought), but it does affect numerical results. We have corrected the mistake in the results discussed below.

[57] The Mountain Aquifer in fact consists of several sub-aquifers. We have made no attempt to divide ownership except in the arbitrary manner described in the text.

Exercise 3: How to allocate the Jordan River among the three parties? (Case A to Case B)

1. Load NoCoop2010_80120P_92i8j
2. Go to Supply of Water and Supply Steps
3. Select Jordan, and change Irbid (J4), Step 3 to 121.89 and click Finished
4. Select Palestine, and change Jenin (P1), Step 4 to 121.89
5. Select Israel, and change Biqaat Kinerot (I6), Step 1 to 473.22 and click Finished and Accept
6. Select Common Pool
7. Change CP1 to 473.22, and click OK, and OK
8. Optimize
9. Name the run NoCoop2010_80120P_67i17jp
10. Save and describe run
11. Compare shadow values in the schematics with the first run you loaded.
12. Discuss

We first present results on two-way cooperation. These differ from those in Fisher et al. (2005) primarily because of the expanded set of ownership assumptions.[58] We assume that, both for Israel and for Jordan, the fixed-price policies of the late 1990's are in place. For both countries, this means subsidies for agriculture and, for Israel, higher fixed prices for the other sectors. The Palestinian water price in each district is assumed to equal the corresponding shadow value.

a. Israel-Palestine Bilateral Cooperation

We begin with bilateral Israeli-Palestinian cooperation. Figure 31 shows the gains from such cooperation in 2010 as a function of the different ownership assumptions. (Note that cooperation here is not merely cooperation on the Mountain Aquifer but full cooperation in water including new water infrastructure.) Effectively, this and the similar figures that follow represent slices of multi-dimensional diagrams. (In the figures starting with Figure 31, Israel is represented by blue, Jordan by yellow, and Palestine by red.)

[58] In Fisher et al. (2005), we examined the gains from cooperation for each of the two water sources separately while assuming that Israel had most or all of the other source.

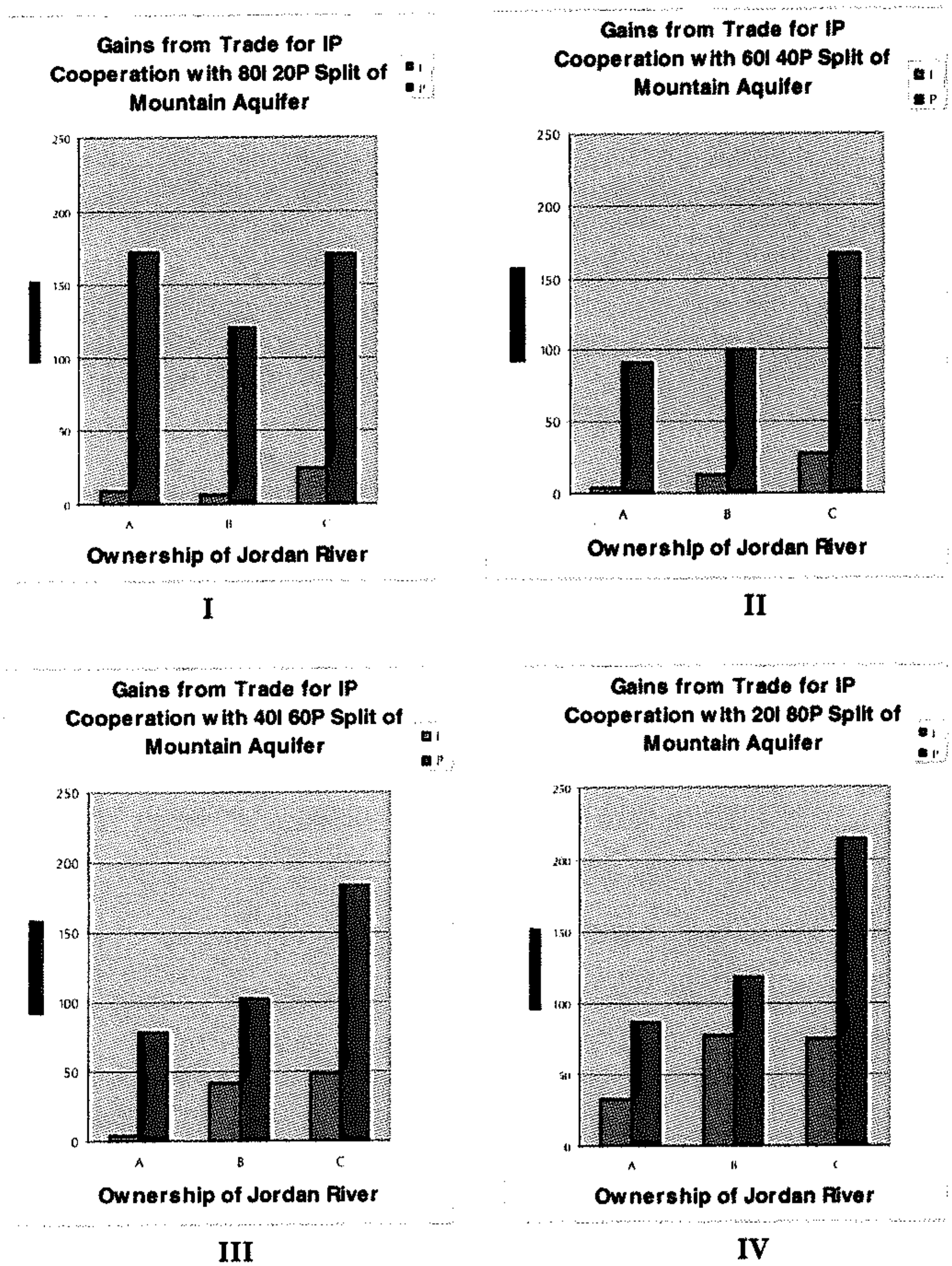

Figure 31: Gains from Bilateral Cooperation between Israel and Palestine in 2010

Look first at Figure 31(I) – the case of an 80-20 Israel-Palestinian division of the Mountain Aquifer. As we should expect, in Case A of Jordan River ownership, where Israel has most of the river and Palestine has none, it is Palestine that benefits most from cooperation – far more than relatively water-rich Israel. Further, the same is true for the other cases of Jordan River ownership. But an interesting phenomenon appears. As expected, Palestine gains more from cooperation in Case A in which it owns no Jordan River water than it does in Case B, in which it has 17% of the river. When we move to Case C, however, where Palestine has 34% of the river, the gains to Palestine once again increase being very nearly as high ($171 million dollars per year) as in Case A ($172 million dollars per year), even though Palestine has considerably more water in case C than in Case A.

The reason for this is not hard to find. Palestine has considerably more water in Case C than in Case A, but Israel has considerably less. Both buyer and seller gain from WAS-guided cooperation, and, in Case C, Palestine gains by selling water to Israel, despite its low share of the Mountain Aquifer. Correspondingly, Israel, whose gains as a seller decrease slightly from Case A to Case B has increased gains as a buyer in Case C.

This phenomenon becomes even more pronounced in the other panels of Figure 31, in which Palestine has increased shares of the Mountain Aquifer. In each of those panels, Palestinian's gain *from cooperation* increases as it owns more and more Jordan River water; that is because it gains as a *seller*. Correspondingly, Israel gains as a buyer.

b. Israel-Jordan Bilateral Cooperation

Figure 32 shows the gains from bilateral cooperation between Israel and Jordan for 2010. Here the gains are generally lower than in the Israel-Palestine case. The interesting phenomenon is as follows.

Exercise 4: What are the gains in 2010 from bilateral cooperation between Israel and Jordan?

1. Load NoCoop2010_80120P_92i8j
2. Go to Tabular Results, the second page on Overall Results
3. Write down the numbers for Total Surplus for each party.
4. Load IJCoop2010_80120P_92i8j
5. Go to Tabular Results, the second page on Overall Results
6. Write down the numbers for Total Surplus for each party.
7. Compare and discuss

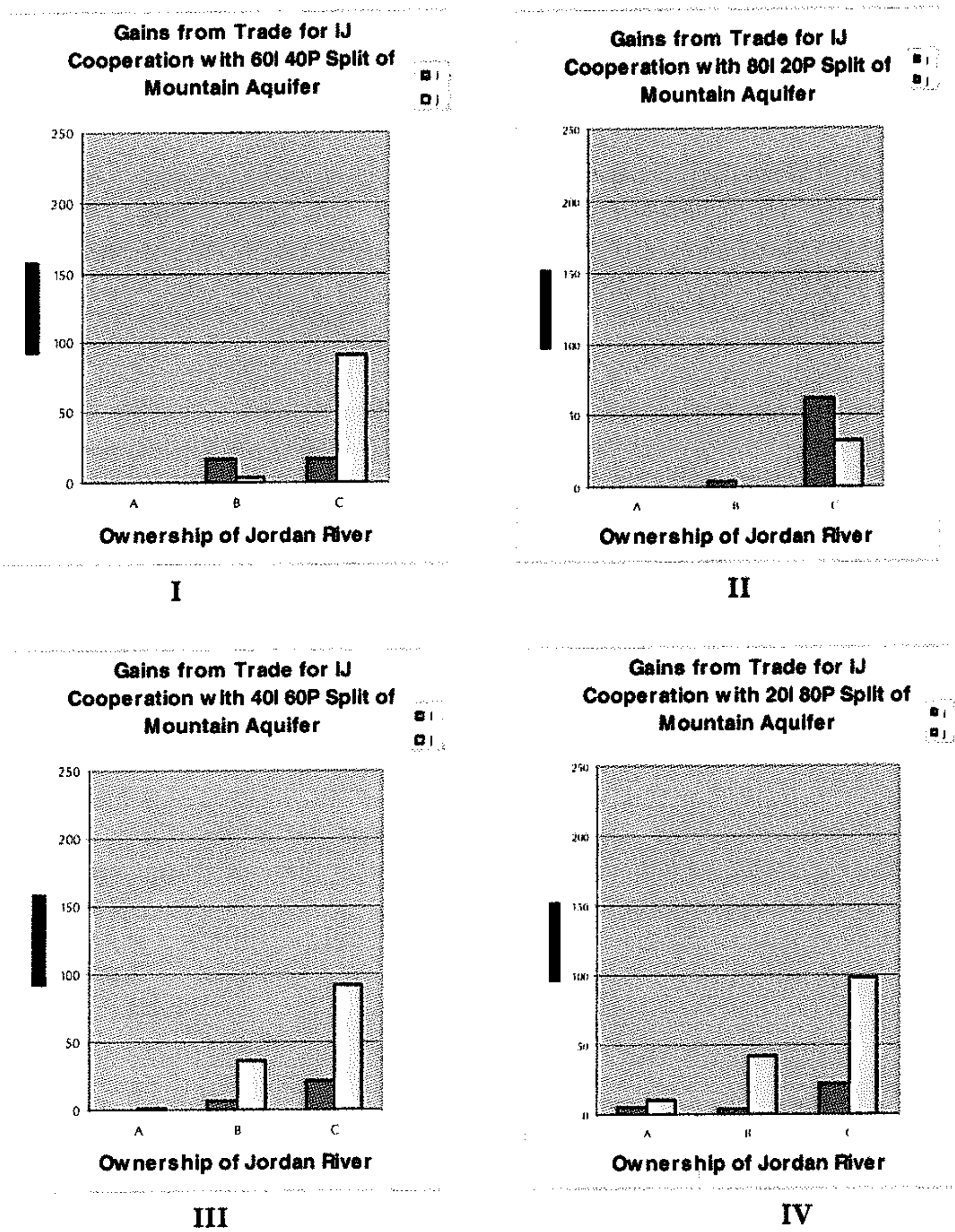

Figure 32: Gains from Bilateral Cooperation between Israel and Jordan in 2010

Where Israel has the lion's share of the Mountain Aquifer (Figure 32(I) and Figure 32(II)) and also 92% of the Jordan River (Case A), there are no gains from cooperation at all. Neither Israel nor Jordan gains from trading Jordan River water – despite Jordan's small share thereof. When we stay with the same shares of the Mountain Aquifer and move to

Case B for the Jordan River, small gains do appear[59] and the gains are quite a bit larger in Case C. In Figure 32(III) and Figure 32(IV), where Israel has 40% and 20% of the Mountain Aquifer, respectively, there are larger gains for Jordan, the increase being most noticeable in Case B (although the gains remain largest in Case C).

What is going on here is that, as Jordan owns more and more of the river, it pays both parties for Jordan to transfer water *to* Israel by *selling* water permits. This is even true when Israel owns 92% and Jordan only 8% of the river[60], but is more pronounced in Cases B and C as Israel's share of the river goes down and Jordan's goes up. This reflects the finding in Fisher, et al. (2005) that Jordan has a major problem of conveyance infrastructure in using Jordan River water.

It is also interesting to note that Israel's gains from such purchases in Case C are greatest when it owns 92% of the Mountain Aquifer (Figure 32(I)) and hence presumably needs the Jordan River water less than it does when it has less Mountain Aquifer water. The explanation is that Figure 32(I) shows a case in which Israel has sufficient water to make the shadow value of the Jordan River water lower than in the other cases. Hence the price that Israel pays for such water is also lower, and this benefits Israel (while correspondingly reducing Jordan's gains as a seller).

By 2020, a somewhat different picture emerges (Figure 33). By that year, Jordan's water situation worsens. As a result, when it owns only 8% of the river and Israel owns 92% (Case A), Jordan always *buys* water permits from Israel, gaining from so doing. When Jordan and Israel each own 33% of the river (Case C), Jordan always *sells* water permits to Israel, again gaining from so doing. In the middle case of Jordanian ownership of 17% and Israeli ownership of 66% (Case B), very little trade in water permits takes place. This pattern is qualitatively independent of the ownership of the Mountain Aquifer, although the quantitative amount of the gains is not.

[59] In the 80-20 split of the Mountain Aquifer, the gain to Jordan in Case B rounds off to zero.
[60] In the 40-60 split of the Mountain Aquifer, Jordan gains $1 million a year – too small to show up in Figure 2 (III).

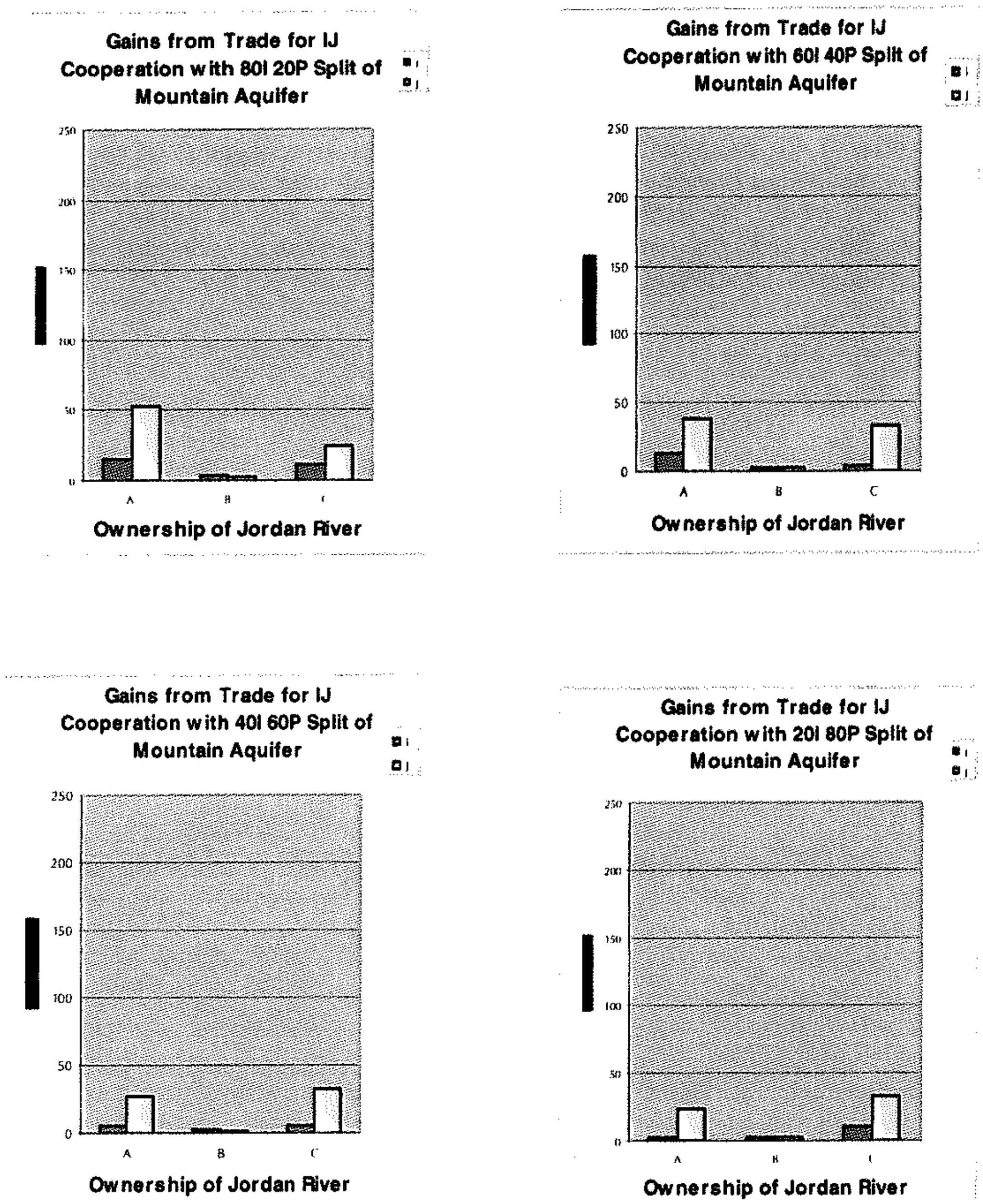

Figure 32: Gains from Bilateral Cooperation between Israel and Jordan in 2020

c. Jordan-Palestine Bilateral Cooperation

The case of bilateral cooperation between Jordan and Palestine can be handled quickly and does not require diagrams for 2010. Here the only possible beneficial trades are those that involve Jordan River water – and both countries have relatively little water to trade. As a result, for 2010, the only case in which gains from cooperation are not totally negligible is that where Palestine owns only 20% of the Mountain Aquifer and none of the Jordan River (Case A). There, even though Jordan only owns 8% of the river, it gains $10 million per year by selling a permit to Palestine to use river water, and Palestine has a net gain of $12 million per year from buying it.

Exercise 5: What are the gains in 2020 from bilateral cooperation between Israel and Jordan?

1. Load NoCoop2020_80I20P_92i8j
2. Go to Tabular Results, the second page on Overall Results
3. Write down the numbers for Total Surplus for each party.
4. Load IJCoop2020_80I20P_92i8j
5. Go to Tabular Results, the second page on Overall Results
6. Write down the numbers for Total Surplus for each party.
7. Compare and discuss

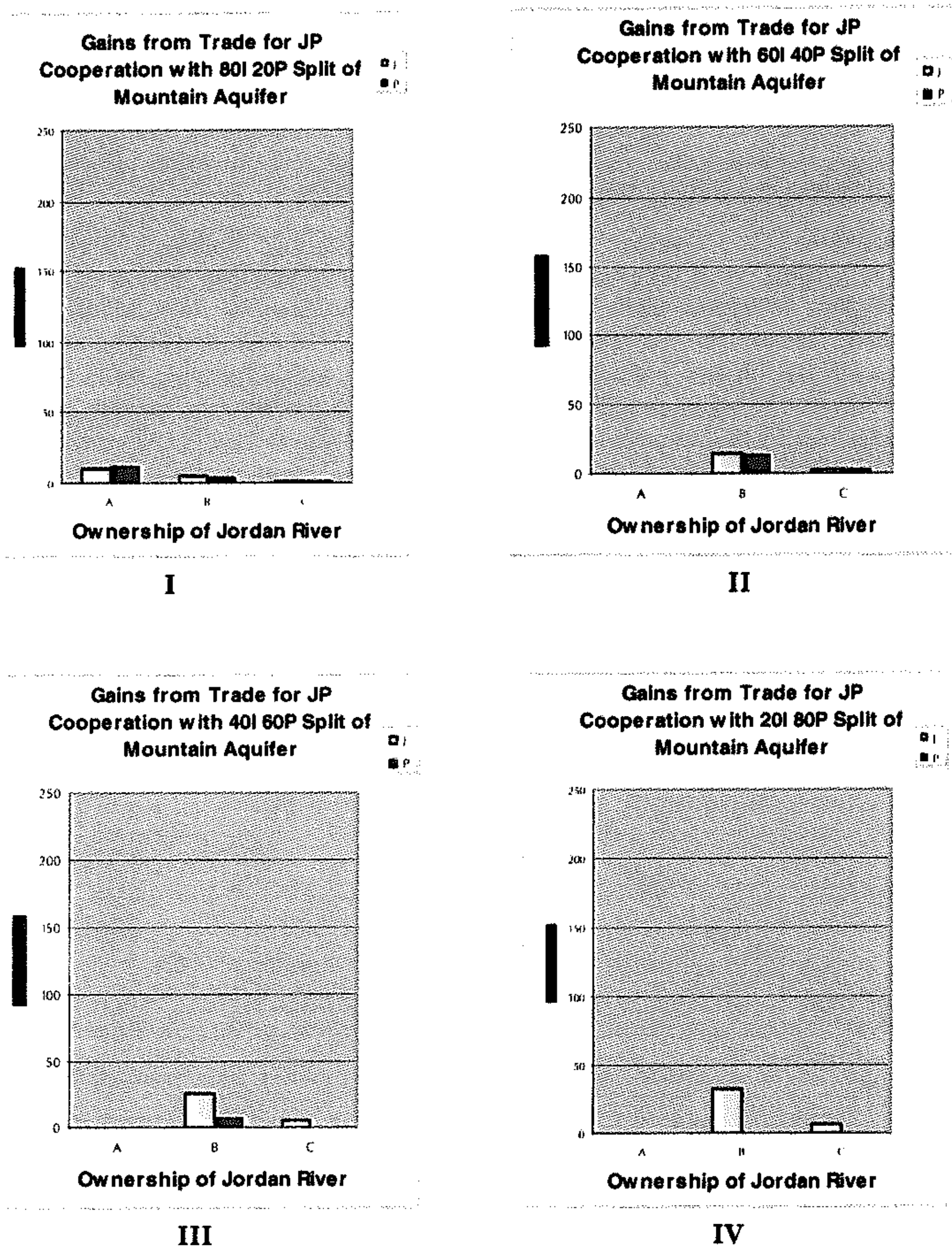

Figure 33: Gains from Bilateral Cooperation between Jordan and Palestine in 2020

By 2020, however, the situation becomes more interesting and is shown in Figure 33. Here there are gains in all of the panels. Consider Figure 33(I). As in 2010, when Palestine owns only 20% of the Mountain Aquifer, and none of the Jordan (Case A), the two parties gain by Jordan selling Jordan River water to Palestine. As Palestine's share of the Jordan River rises (Cases B and C), those gains decrease and almost disappear, but, unlike the result for 2010, there are still some visible gains in Case B. This is surely due to the predicted increase of the Palestinian population between 2010 and 2020.

Moreover, when Palestine owns 40% or more of the Mountain Aquifer (Figures 33(II)-33(IV)), gains from cooperation no longer occur when Palestine owns no Jordan River water, but do appear when it does. Here, Palestine gains by *selling* additional Jordan River water to Jordan (which it can afford to do because of the additional Mountain Aquifer water it owns). By the case pictured in Figure33(IV), in which Palestine owns 80% of the Mountain Aquifer, it owns enough water that it sells to Jordan very cheaply, so that the pictured gains are all Jordanian (and are quite substantial in Case B).[61] (Note that this does not occur in the parallel ownership situation under trilateral cooperation.)

d. Trilateral Cooperation (Grand Coalition)

Figures 35 and 36 give the results for trilateral cooperation for 2010 and 2020, respectively.

[61] In fact, Case C with Palestine owning 80% of the Mountain Aquifer is quite extreme. Without cooperation, Palestine has so much water that it does not use all the Jordan River water that it owns. Jordan, on the other hand, would benefit moderately from additional river water. Under cooperation, the model transfers water from Palestine to Jordan (in the form of water permits), and, while Jordan benefits from that transfer, at its end, neither Jordan nor Palestine would benefit from additional river water. The shadow value of such water is zero in both countries, and the model assumes that the transfer takes place at a zero price. In practice, of course, were such an extreme situation to arise, the needed transfer would presumably take place at a very low price.

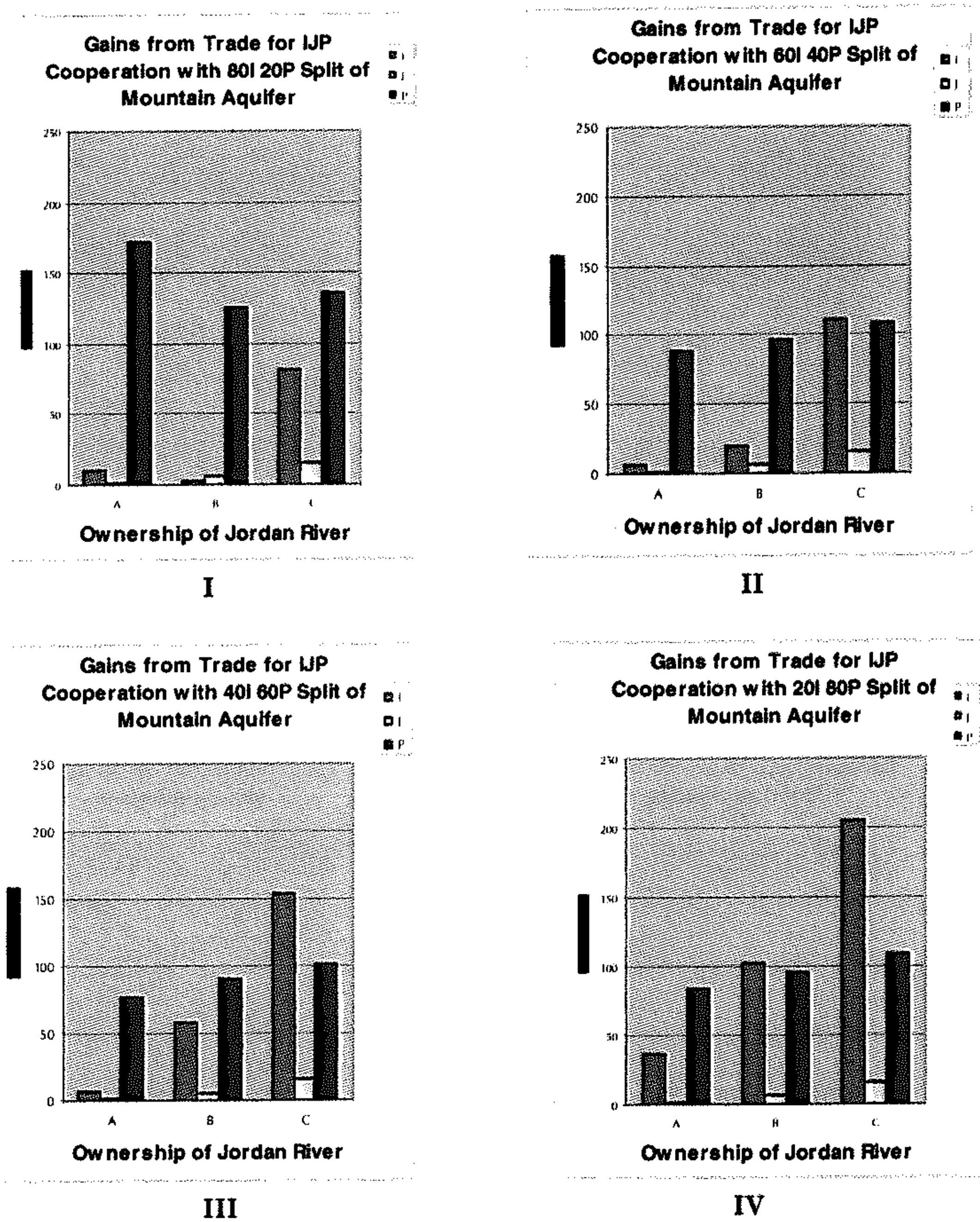

Figure 35. Gains from Trade for Trilateral Cooperation (Grand Coalition) in 2010

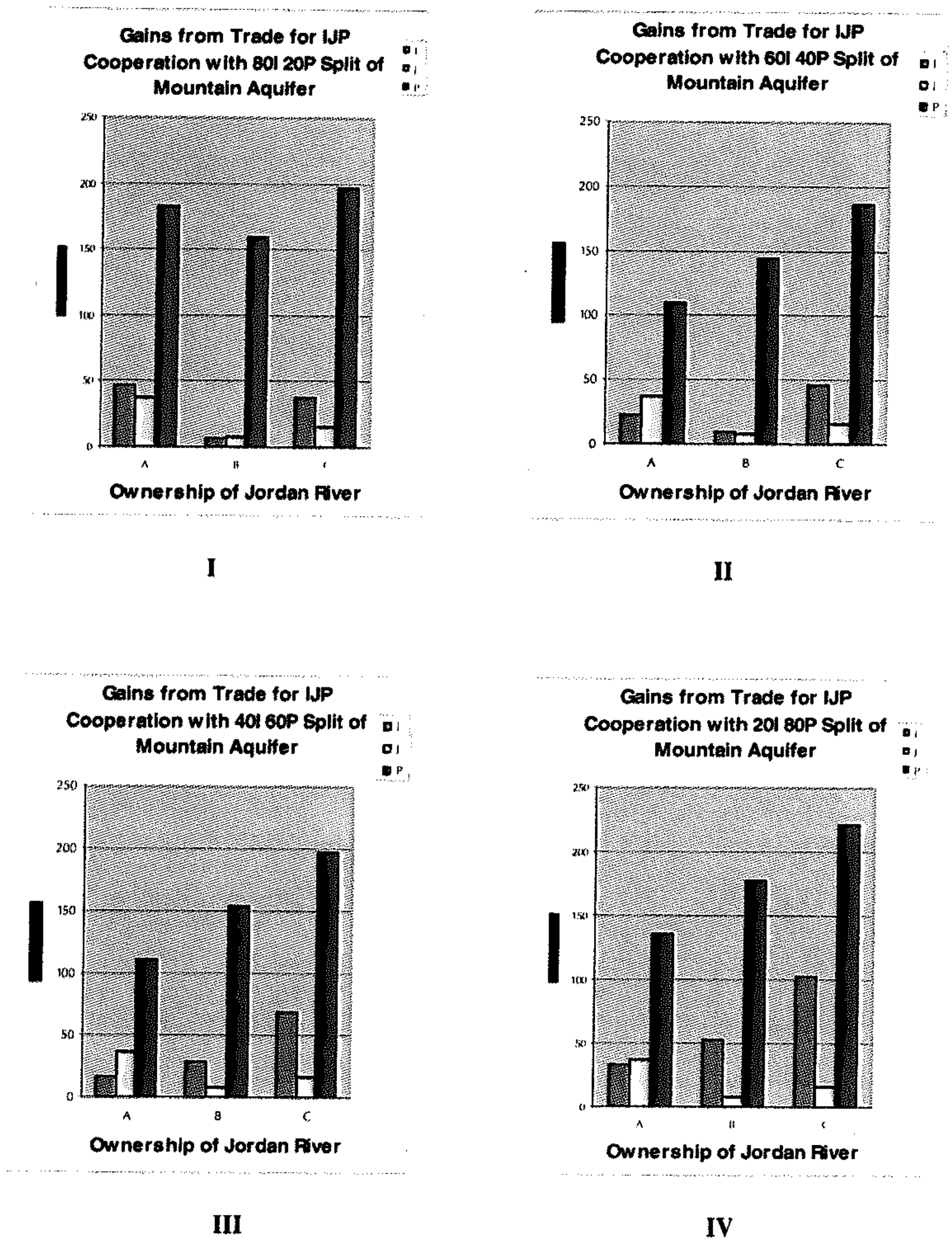

Figure 36. Gains from Trilateral Cooperation (Grand Coalition) in 2020

Here what stands out is that, in general, the smallest gains are Jordanian. Not surprisingly, generally the less water Israel owns, the more it has to gain from cooperation. On the other hand, Jordan gains more from cooperation the **more** water it owns – selling permits to Israel.

Like Jordan, Palestine presents a mixed picture. It also tends to benefit more from cooperation the larger is its share of the Jordan, selling permits to use river water to Israel. On the other hand (Figure 35(I)), when Palestine owns relatively little Mountain Aquifer water, it also benefits as a buyer.

In 2020 (Figure 36), the main thing to notice is that the gains to all parties – Israel, Jordan and Palestine – from cooperation are larger than they are in 2010.

TABLE 2. GAINS FOR ALL COALITIONS, 2010 (millions of 1995 dollars)[62]

J.R. / **M.A.**		**I 92% J 8% P 0%**			**I 66% J 17% P17%**			**I 33.3% P 33.3% J 33.3%**		
		I	J	P	I	J	P	I	J	P
I 80%	IJP	**10**	**1**	**172**	**3**	**6**	**126**	**82**	**16**	136
	IJ	**0**	**0**	**--**	**4**	**0**	**--**	**62**	**32**	--
P 20%	IP	**9**	**--**	**172**	**6**	**--**	**121**	**24**	**--**	171
	PJ	**--**	**10**	**12**	**--**	**0**	**1**	**--**	**0**	0
I 60%	IJP	**6**	**1**	**89**	**20**	**6**	**97**	**111**	**16**	109
	IJ	**0**	**0**	**--**	**17**	**4**	**--**	**17**	**91**	--
P 40%	IP	**4**	**--**	**91**	**13**	**--**	**101**	**28**	**--**	167
	PJ	**--**	**1**	**1**	**--**	**1**	**1**	**--**	**0**	1
I 40%	IJP	**7**	**1**	**77**	**58**	**6**	**90**	**154**	**16**	102
	IJ	**0**	**1**	**--**	**7**	**37**	**--**	**21**	**92**	--
P 60%	IP	**4**	**--**	**79**	**42**	**--**	**103**	**48**	**--**	184
	PJ	**--**	**0**	**0**	**--**	**1**	**1**	**--**	**0**	0
I 20%	IJP	**37**	**1**	**84**	**102**	**6**	**96**	**205**	**16**	109
	IJ	**5**	**10**	**0**	**4**	**42**	**0**	**22**	**99**	0
P 80%	IP	**33**	**--**	**87**	**77**	**--**	**119**	**75**	**--**	215
	PJ	--	0	0	--	2	0	--	0	0

[62] The occasional appearance of gains of 0 for one party and positive gains for another in cases of bilateral cooperation is due to rounding error.

TABLE 2. GAINS FOR ALL COALITIONS, 2020 (millions of 1995 dollars)[63]

J.R. / M.A.		I 92% J 8% P 0%			I 66% J 17% P17%			I 33.3% P 33.3% J 33.3%		
		I	J	P	I	J	P	I	J	P
I 80%	IJP	47	37	187	7	8	159	38	16	197
	IJ	15	53	--	4	3	--	12	25	--
P 20%	IP	28	--	197	5	--	159	24	--	206
	PJ	--	11	12	--	5	4	--	1	1
I 60%	IJP	22	37	110	9	8	144	46	16	187
	IJ	13	48	--	2	2	--	4	33	--
P 40%	IP	11	--	117	12	--	140	23	--	204
	PJ	--	0	0	--	14	13	--	2	3
I 40%	IJP	16	37	111	28	8	154	69	16	197
	IJ	5	27	--	3	1	--	5	33	--
P 60%	IP	11	--	110	34	--	145	38	--	222
	PJ	--	0	0	--	26	7	--	6	0
I 20%	IJP	33	37	135	52	8	178	103	16	221
	IJ	3	24	--	3	2	--	10	33	--
P 80%	IP	35	--	127	62	--	165	64	--	254
	PJ	--	0	0	--	33	0	--	6	0

[63] The occasional appearance of gains of 0 for one party and positive gains for another in cases of bilateral cooperation is due to rounding error.

Exercise 6: How do you compare the gains from trilateral versus bilateral cooperation?

1. Go to Table 2 to explore
2. Discuss

For 2010 and 2020, respectively, Tables 2 and 3 show numerically the gains for each party from trilateral cooperation and for each case of bilateral cooperation.[64] The following points appear:

- As shown in the Proposition proved above, there is no bilateral coalition in which the two members both do better than they do in the corresponding grand coalition.
- On the other hand, as already remarked, it is not generally true that *both* members of a bilateral coalition do better in the grand coalition. However, the total increase in gains to the two members achieved in the grand coalition are always positive.

This reflects the fact that, where there are two countries in the grand coalition that are net buyers and one that is a net seller of water permits, it can easily happen that each of the net buyers would be better off without the presence of the other in the coalition competing to buy. The single net seller, however, is always better off in such circumstances and so much better off that (if the bilateral coalition is already operating), the seller could profitably pay its existing partner to permit the new entry. A similar phenomenon can arise when there is a single net buyer and two net sellers.

- It should be recalled that Israel is not always a seller in the cases portrayed. Nor is it invariably the case that the country owning the least water has the most to gain from cooperation. Sellers benefit also.

Exercise 7: How do you measure gains via 10 percent ownership shifts?

1. Go to Excel Spreadsheet
2. Discus

[64] The numbers in Tables 1 and 2 are not the total benefits achieved but rather the gains achieved by each form of cooperation. For technical reasons, the level of total benefits as measured using the particular form of the demand curves that appear in WAS does not have a natural origin, and only changes in benefits are meaningful. (See Fisher, *et al 2005.*, p. 26, n. 1.)

The most important general conclusion from all these cases should be clear. WAS-guided cooperation in water would benefit all parties – Israel and Palestine the most. As we shall now see, the gains from such cooperation generally exceed those that would be obtained from moderately large ownership shifts. This is particularly true under cooperation.

We measure the gains from ownership shifts as follows. Holding constant the distribution of ownership in one of the two water sources being studied, we look at the change in benefits that accrue to each of the parties as a result of moving from one of the ownership cases examined above to the next. (For example, in the case of the Mountain Aquifer, we hold ownership in the Jordan River constant and examine the gains – or losses – to Israel and Palestine from an ownership shift of the aquifer from 80% Israel-20% Palestine to 60% Israel-40% Palestine and from there to 40% Israel-60% Palestine, and so on, repeating the exercise for each case of ownership of the Jordan River.) We then normalize the results by expressing them as the gain from a 10% ownership shift.

The gains from such shifts under trilateral cooperation are constant for each of the two resources. The reason for this is that, under cooperation, the optimal water flows in the WAS solution are independent of the ownership assumptions[65]. Hence, the only gains from changes in ownership are the changes in the money that ownership represents. But all water permit trades take place at the shadow values for the optimal solution. These are the scarcity rents of the water resources involved and also do not depend on ownership. Hence the value of a 10% shift in the ownership of a given resource is independent of the initial ownership assumptions.[66]

Under trilateral cooperation, the gains from such shifts in 2010 would be only about $5 million per year for a shift in ownership of 10% of the Mountain Aquifer and about $7.5 million per year for 10% of the Jordan River. In 2020, where the gains from cooperation are also larger, the corresponding gains from 10% ownership shifts would be about $15 million per year for the Mountain Aquifer and $25 million per year for the Jordan River.

It should come as no surprise, however, that the value of ownership shifts would be considerably different (and usually higher) when there is no cooperation. Moreover, in that case, the value would be substantially different for different parties (reflecting the fact that there are gains to be had from trading in water permits) and also widely different for different ownership circumstances.

For 2010, the value of a 10% shift in Mountain Aquifer ownership ranges from $3 million per year to $34 million per year. The low figure occurs for Palestine when it already owns 33.3% of the Jordan River and moves from 60% to 80% ownership of the Mountain Aquifer. The high figure also comes for Palestine when it owns none of the Jordan River and moves from 20% to 40% ownership of the Mountain Aquifer. With a more equal division of

[65] Note, however, that this is not true for bilateral cooperation, since water ownership by the excluded party affects the amount of water which is available for bilateral cooperation.
[66] In the case of the Jordan River, there is a single scarcity rent. In the case of the Mountain Aquifer, however, scarcity rents can vary with geography as there is more than one pool from which to draw. However, our shifts in Mountain Aquifer ownership always transfer the same percentage of each pool, hence the average scarcity rent of what is being transferred remains constant.

both water sources, the value of a 10% shift in Mountain Aquifer ownership ranges from $8 million per year to $24 million per year. For 2020, the corresponding figures are similar, but a bit higher.

For the Jordan River, there are more extreme cases. For 2010, without cooperation, the value of a 10% ownership shift in Jordan River ownership ranges from $0 per year to $38 million per year. Again the low point occurs for Palestine when it owns at least 60% of the Mountain Aquifer,[67] but the higher values occur for Israel. Most of the values for Jordan and Palestine are below $2 million per year, the principal exception being a value of $34 million per year starting from an ownership level of no Jordan River water and 20% of the Mountain Aquifer.

For 2020, however, the picture changes. Here the lowest value of a 10% shift in Jordan River ownership is still $0 per year (occurring for Palestine when it owns 60% or more of the Mountain Aquifer), but the highest value is now $58 million per year and occurs when Jordan goes from 8% to 17% ownership of the river.

Note, then, that one value of WAS-guided cooperation is that it reduces the value of ownership shifts, making them easier to negotiate.

Note that it is *not* the case (see Tables 2 and 3 and Figure 35 and 36) that the gains from cooperation are high only when the party receiving those gains has little water and the value of ownership shifts are high to it. That phenomenon naturally tends to occur when the big gainer is a *buyer* of water permits. But large gains also occur when the party receiving those gains has a large amount of water and the value of ownership shifts are low to it. In such cases, the big gainer is a *seller* of water permits. A good example of this can be seen in Tables 2 and 3, where the largest Palestinian gains from trilateral cooperation occur both in the upper left-hand corner where Palestine has very little water and in the lower right-hand corner where it has a good deal. Indeed, in Table 3, the Palestinian gains in the lower left-hand corner are greater than those in the upper left-hand corner.

Moving onward, the gains from WAS-guided cooperation would be greater in other ways than are shown above. In particular, as populations and other factors change, a quantity agreement that is adequate when signed can easily become out of date and a source of new tension. WAS-guided cooperation provides a flexible means of readjusting water usage in a way that all parties benefit.[68]

In addition, our results show clearly that Israel and Palestine would both benefit from the creation of a sewage treatment plant in Gaza, with the treated effluent sold to Israel for use in agriculture in the Negev. This means that Israel has a positive economic incentive to assist in the construction of such a plant. That would be a confidence-building measure that does not impinge on the core values of either party.

[67] Except when Palestine moves from 0 to 17% of Jordan River water and owns 60% of the Mountain Aquifer. In that case, the value to it of the ownership shift (averaged over the 17% increase) is $3 million per year for 10%.

[68] Note that this applies even if the initial ownership allocation just happens to be that of the WAS optimizing solution -- an unlikely event.

Possible Objections

Of course, there are possible objections to such a plan, however. Some of those are without merit, but others need to be more carefully considered. We begin with the less meritorious ones.

a. Forced Sales

Throughout the history of the Water Economics Project, some have raised the objection that "You are going to force us to sell our water." or "Why should we give water to our neighbors?"[69] This is simply a misunderstanding of what is being proposed.

In the first place, with a finite number of countries involved and no outside trades, it is literally impossible for all of them to be net sellers. But put that aside. The more important point is that WAS-guided permit sales are *never* "forced". The selling country sells only when it is to its advantage to do so. Both parties gain.

b. "The Richest Country Will Buy all the Water"

A related objection is that the richest country will end up buying all the water or that the disparity in the economies involved makes water-permit trading either somehow impossible or, at least, unfair.

The primary reason that this is not valid is as before. The poorer countries only sell when it benefits them. If they do that, then they gain from the sale. Naturally, as they sell more and more water, the remaining water becomes more valuable to them, and, sooner or later, they will stop selling.

The other reason is the mirror image of this. The rich country may have a lot of money, but why should it want to buy all the water in sight. Water is valuable when it is scarce and needed for essential uses (drinking, for example). But it becomes less valuable as its scarcity decreases and additional water is used for less important uses (washing cars several times a week, for example). Just as the price at which poor countries gain from sales goes higher and higher the more is sold, so the price at which the rich country gains from purchases goes lower and lower the more that is bought. Once these two prices pass each other, nothing further is to be gained from the transactions and the sales stop.

We now turn to more cogent objections.

c. Other Bargaining Methods: Why WAS?

One referee of this paper, observing (correctly) that the optimal water allocations are independent of the water-ownership assumptions, asks why the WAS division of gains in moving to those allocations are not completely arbitrary. He or she points out that various

[69] Indeed, that objection has repeatedly been publicly voiced by an Israeli water expert who should certainly know better.

bargaining models would lead to different results and asks "Why does the division of gains from trade [cooperation] presented here have relevance?"

This is a good question and one that has more than a single answer.

1. Bargaining over water ownership and water rights is a difficult process. Different principles of international law point to different answers. The outcome of most bargaining methods depends on the ownership positions from which the parties start. But that leaves those positions as very important elements of the process. As shown above, while WAS-guided trade in water permits does not resolve the ownership question, it greatly reduces the gains to be had from ownership shifts. Under those circumstances, bargaining about ownership becomes bargaining over relatively small sums of money. This can be a way out of the impasse.
2. One virtue of the WAS-guided process is that it automatically adapts water allocations to changing circumstances, doing so in a way that all parties benefit. Other bargaining methods do not do this, making it likely that bargaining will have to tale place repeatedly over time.
3. Other bargaining methods permit parties to employ deception as to their needs and positions. We show below that such activities are unlikely to pay off in WAS-guided cooperation.
4. The parties must be induced to play the game. WAS-guided cooperation has the merit that each party can see the win-win nature of the trades. This is particularly so if each one is already using its own WAS model and has studied the shadow values that emerge from it, using them to value additional water in different locations.

d. Other Questions

A different referee asks a number of questions (rather than objections). Some of them are answered with the present version. Others suggest subjects for further work.

1. Q. Can WAS be adjusted to take account of variations in flow rates and water volumes?

   A, Yes it can. That facility already exists.

2. Q. Does WAS have anything to say about water quality or about multiple-use or reuse issues?

   A. Reuse issues are already handled in the treatment of the use of treated waste water. Water quality and multiple use issues can be treated, but that remains for future development.

3. Q. Does WAS require or can it use predictions of next year's flow?

   A. The one-year model here reported does not. But the multiyear version, MYWAS, certainly does and can. Indeed, it can be used to study the effects on optimal policy of climate change and the stochastic nature of rainfall.

4. Q. What kinds of government policies, like low-priced water for agriculture will no longer be available if WAS is implemented.

A. Explicit provision has been made for low-priced water for agriculture (and for other fixed-price policies). In addition, the user can specify that water should be set aside in certain locations for environmental or other purposes. In general, any consistent policy can be allowed after suitable programming.

5. Q. If WAS is going to be used to allocate the water, where do the data come from? Who checks data integrity and completeness, and who checks the input? Once WAS comes up with an allocation, who enforces it, and who monitors the implementation? What kind of lag time is involved between the recognition of a low-flow condition and the implementation of a new allocation?

A. These are all good questions and, except for our comments below on deception, we do not have the answers. We envisage an interregional authority responsible for most of these items with perhaps a Chair form outside the region involved.

e. Deception

What about the possibility that the parties to an arrangement such as that being proposed would deliberately misrepresent their demands for or policies toward water so as to gain an advantage? In this connection, note first that a party that acted in this way would run some risk. If a party that is a buyer were to overstate its demand, it would end up paying prices higher than its true value of the water obtained. Similarly, if a party that is a seller were to understate its demand, then it would end up selling water at prices below its true value.

This does not end the matter, however. Since water demand is likely to be inelastic at reasonable prices, a party that is a seller might gain by overstating its demand. In such a case, the selling party would retain some water that it values less than the price, but it might succeed in earning sufficiently greater revenue from the water it does sell to leave it better off. In effect, such a seller would be exercising market power by withholding water from the market and exploiting the fact that it faces a declining (and inelastic) demand curve. (An analogous statement holds for a buying party understating its demand.)[70] The fact that trade leads to gains shows that there is a surplus to be split among the parties; behavior of the sort described could affect the way in which that surplus is divided.

How important this phenomenon is likely to be may depend in part on the overall atmosphere in which trading in water permits takes place. But such misrepresentation is not likely to be easy or long repeated. We are talking here about misrepresentation either of objective demand data or of policies to be applied. (Misrepresentation of costs can also matter.) These are issues of checkable facts, rather than projections of events long in the future, and parties should be able to agree on how to check them. That includes checking actual water consumption and checking whether announced water policies are actually carried out.

Two more observations are worth making. First, even if such misrepresentations are successful, there will still be a surplus to be divided and both sides will gain relative to a fixed quantity agreement.

Second, altering debates about water rights to discussions of facts and data would itself be a gain in settling water issues.

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[70] Note that the supply curve facing such a party is effectively the demand curve of the seller and is hence also inelastic.

f. Security Considerations: Hostages to Fortune

The major objection to trade in water permits among previously hostile neighbors, however, is likely to be one of security. When an agreement is reached among long-term adversaries, is it wise to rely for water on a promise of trade? What if the water were to be cut off?

There are several points to be made here. First, the geographic situation does not change with an agreement to trade in water permits. Thus, if an upstream riparian could cut off a downstream neighbor's water in the presence of an agreement, it could equally well do so in its absence.

A system of trade in water permits, however, makes this less likely to happen, because it is a system in which continued cooperation is in the interest of all parties. When joint infrastructure has been constructed and gains from water-permit trade are large, withdrawal from the trade scheme will hurt the withdrawing party.

There is, however, one aspect of reliance on an agreement to trade in water permits that does raise an issue. Where such an agreement leads either to the construction of infrastructure that would become useless if trade were cut off or to the failure to construct infrastructure that would be needed in such an eventuality, reliance on trade may involve some risk. In effect, in such cases, one or another of the parties may be giving hostages to fortune.

Are such cases likely in the Israel-Palestine case for either bilateral or trilateral cooperation?[71] We begin with the case of Israel. If there were to be an agreement with Palestine along the lines we have suggested, it would make sense for Israel to invest in trade-facilitating infrastructure. Were trade to cease, that investment would largely be lost. This does not seem a major problem, however.

The reverse problem — failure to build infrastructure that would become vital in the absence of trade in water permits — does not seem at all serious for Israel. Israel now has a well-developed infrastructure. There does not appear to be any project that would be both unnecessary in the case of an agreement on water-permit trade and vital if such trade were suddenly to cease.

Palestine, by contrast, may have more exposure in the form of hostages to fortune. Without water-permit trade, and with an unfavorable agreement on West-Bank water property rights, the Palestine would soon be forced to build desalination plants in Gaza. In the presence of trade, such plants would be unnecessary for a long time to come. Hence, if an Israel-Palestine agreement takes the form of water-permit trade and cooperation, the Palestinians will have to consider whether they should build such desalination plants in any case. If they do, they will lose a good deal of the economic benefits from trade. If they do not, then there may be a problem should trade cease.

What that choice should be depends on how likely it is that Israel would abrogate such an agreement and on the situation that one believes would then arise. For example, in such an event, presumably the Palestinians would feel justified in extensively pumping the Mountain Aquifer, even if that were not the regionally efficient or agreed-on thing to do.

[71] It does not seem likely that Jordan would have a major problem.

Surprisingly, however, we have found[72] that, in the absence of cooperation, the Palestinian need for desalination would stem not directly from the need to use desalinated water in Gaza itself but from the need to (inefficiently) supply the Southern West Bank from the Gazan desalination plants by piping it uphill to the area of Hebron (see Figure 30). Hence, the apparent crisis caused by an Israeli abrogation of a cooperative water treaty could be overcome by Palestinian pumping of Mountain Aquifer water beyond the amounts permitted by the water treaty, doing so until the needed desalination facilities can be built.[73]

Conclusion

We believe that WAS and its extensions are powerful tools for domestic planning of water infrastructure and policy. Beyond that, we have argued that WAS-guided cooperation can provide a resolution of international water disputes, turning them from apparent zero-sum games to win-win situations for the benefit of all.

But, of course, such cooperation requires a generally peaceful atmosphere and a willingness to cooperate. We have said that water is not worth war, but -- apart from the misconception that it is – it can be used as a tool with which to weaken or harm one's adversaries. In the case of Israel, Jordan, and Palestine, the required atmosphere and willingness does not yet exist. We await the day when it will. Perhaps the removal of water as a major issue will help to bring that day closer.

[72] Fisher, *et al.*, 2005, pp. 146-7.

[73] Alternatively, the Palestinians might seek alternative sources of supply from Egypt or others — sources that might be efficient even in the presence of trade.

Appendix. The Mathematics of the Was Model

The WAS model is written in the generalized algebraic modeling system (GAMS) language. As the objective function is not linear, the MINOS nonlinear operating system is used to solve the WAS model. The model is presented below in the standard form for optimization, namely, the objective function followed by the constraints. In mathematical terms,[74] the model is as follows[75]:

$$Max \quad Z = \sum_i \sum_d \left(\frac{B_{id} \times (QD_{id} + QFRY_{id})^{ALPHA_{id}+1}}{ALPHA_{id}+1} \right) - \sum_i \sum_s (QS_{is} \times CS_{is})$$

$$- \sum_i \sum_j (QTR_{ij} \times CTR_{ij}) - \sum_i \sum_j (QRY_{ij} \times CR_{ij})$$

$$- \sum_i \sum_j (QTRY_{ij} \times CTRY_{ij}) - \sum_i \sum_j [CE_{id} \times (QD_{id} + QFRY_{id})]$$

Subject to:

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

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

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

$$(QD_{id} + QFRY_{id}) \geq \left(\frac{PMAX}{B_{id}} \right)^{1/ALPHA_{id}} \quad \forall i,d$$

With the following bounds:

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

[74] The notation used is restricted to this appendix.

[75] Note that the first term of the objective function is the integral of the *inverse* demand function:

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

$$P_{id} = B_{id} \times \left(QD_{id} + QFRY_{id}\right)^{ALPHA_{id}}$$

All variables non-negative.

Where:

Indices

i = district (Israel: I1,I3…I15; Jordan: J1…J8; Palestinian Authority: P1…P10; Golan: GOL; Jerusalem: JER)

d = demand type (urban, industrial, or agricultural)

s = supply source or steps (S1…S5)

Parameters

$ALPHA_{id}$	Exponent of inverse demand function for demand d in district i
B_{id}	Coefficient of inverse demand curve for demand d in district i
CE_{id}	Unit environmental cost of water discharged by demand sector d in district i ($\$/m^3$)
CR_{id}	Unit recycling cost of water supplied from demand sector d in district i ($\$/m^3$)
CS_{is}	Unit cost of water supplied from supply step s in district i ($\$/m^3$)
CTR_{id}	Unit cost of water transported by demand sector d in district i ($\$/m^3$)
$CTRY_{id}$	Unit cost of recycled water transported by demand sector d in district i ($\$/m^3$)
$PMAX_{id}$	Maximum price of water from demand sector d in district i
$PRMAX_{id}$	Maximum percent of water from demand sector d that can be recycled in district i
$QSMAX_{is}$	Maximum amount of water from supply step s in district i (MCM)

P_{id} Shadow value of water for demand sector d in district i (computed) in $

Variables

Z Net benefit in from water in million $

QS_{is} Quantity supplied by source s in district i in MCM

QD_{id} Quantity demanded by sector d in district i in MCM

QTR_{ij} Quantity of freshwater transported from district i to j in MCM

$QTRY_{ij}$ Quantity of recycled water transported from district i to j in MCM

QRY_{id} Quantity of water recycled from use d in district i in MCM

$QFRY_{id}$ Quantity of recycled water supplied to use d in district i in MCM

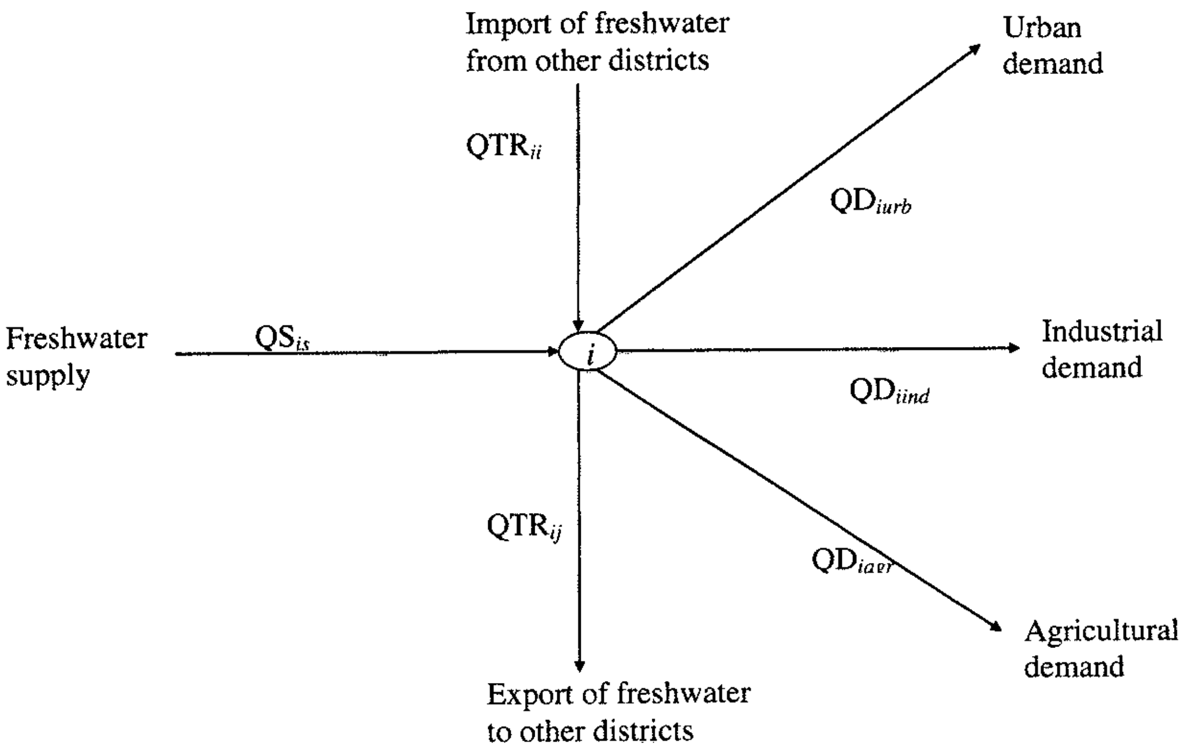
PR_{id} Percentage of water recycled from sector d in district i in MCM

Note: MCM = million cubic meters.

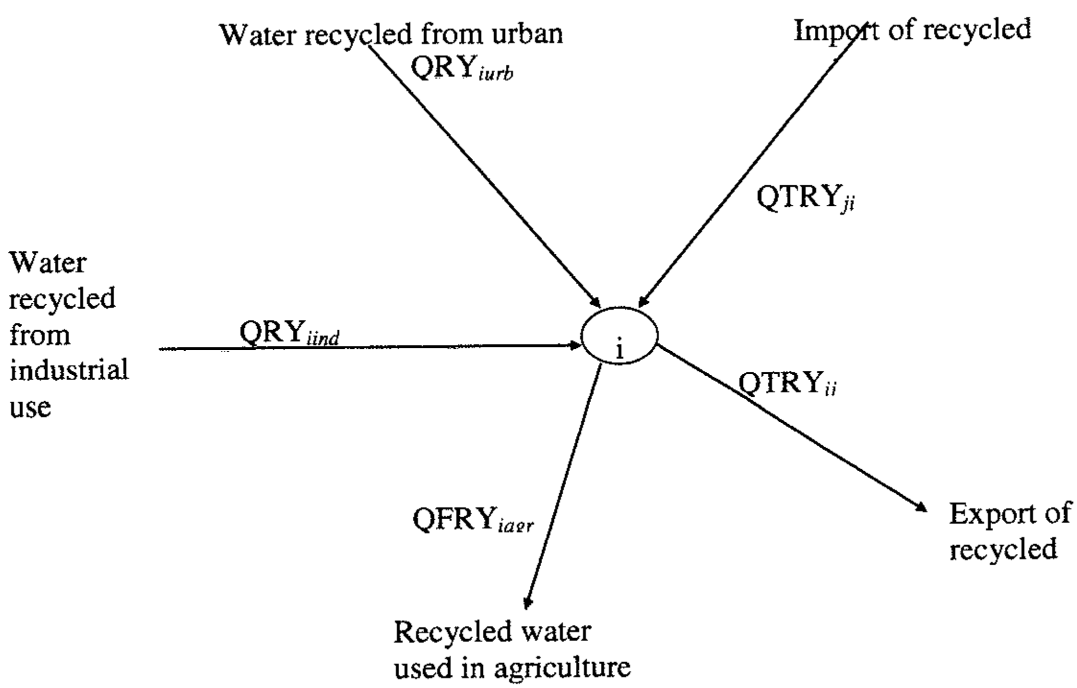
Figures 37A and 37B give an illustration of continuity for freshwater and recycled water, respectively, as given in the first two constraint equations listed above.

Figure 37. Continuity of flows at node *i*

A. Freshwater continuity



B. Recycled water continuity



Example 1

West Bank Infrastructure

Example 1: West Bank Infrastructure

Motivation

The current conveyance infrastructure in the West Bank is limited, with connections running only between Bethlehem and Hebron (there is also a connection between Bethlehem and Jerusalem). As shown in **Figure 1**, the prices in several districts exceed $US 1 in the projection year 2010 while others are below $US 0.50—a clear signal that there may be connections among these districts that would be beneficial. In this example, we evaluate the potential benefits of conveyance systems within the West Bank.

Model Assumptions for Initial Run

The first run begins by selecting the year 2010, and the *Middle1* population growth rate and distribution. No further modifications are made to demand or supply. With respect to infrastructure, the current infrastructure is selected, as well as *PLS Links* Option 1. The selection of these options combined represents the infrastructure in the region as of 1990. The *PNA Countrified* option is selected, with the assumptions of 50 percent ownership of the mountain aquifer, no ownership of the Sea of Galilee or the Yarmouk, no added connections, and no supply of Jerusalem[1]. This run is then optimized and called Example1_1.

Model Results for Example1_1

The freshwater shadow prices from Example1_1 are shown in **Figure 1**, which is taken from the *Schematic Program Results*. The price in Jenin is $3.18 and Nablus is $1.77, while the prices in the adjacent districts, of Tulkarem and Ramallah are just $0.34. Given this price difference of approximately $1 to $3, unless the terrain or the distances between the districts is extraordinary, interdistrict conveyance systems would benefit both the exporting and importing districts.

Model Assumptions for Comparison Run

In order to explore this further, a second run is made, called Example 1_2. The only change made in this run is the selection of Option 2 under *PLS Links*. This option adds the possibility of unlimited conveyances between:

- Jenin to Nablus at a cost of $0.036
- Tulkarem to Nablus at a cost of $0.019
- Nablus to Jenin at a cost of $0.036
- Nablus to Tulkarem at a cost of $0.019
- Nablus to Ramallah at a cost of $0.052
- Ramallah to Nablus at a cost of $0.052

---

[1] Of course, no political implications are intended by these choices, which are made for exemplifying purposes only.

- Ramallah to Jerusalem at a cost of $0.014
- Bethlehem to Jerusalem at a cost of $0.010
- Hebron to Bethlehem at a cost of $0.020
- Jerusalem to Ramallah at a cost of $0.014

Note that these data are likely inaccurate, and may be changed readily through the use of the freshwater links editor, but are sufficiently representative for the purposes of illustrating the use of the software. The model is optimized, and given a scenario name, Example1_2.

Model Results for Example1_2

The results for Example 1_2, as shown in **Figure 2,** show a significant drop in shadow prices for Jenin and Nablus, from $3.18 to $0.57 and $1.77 to $0.53, respectively. As expected, the prices rise in Tulkarem, and Ramallah, but by less than $0.20. These changes indicate that the conveyances between several of these districts are, in fact, optimal to use. Of the ten links potentially available to the system, the following three links are used:

- Nablus to Jenin (42.0 MCM)
- Tulkarem to Nablus (24.2 MCM)
- Ramallah to Nablus (25.9 MCM)

These conveyance links must be further evaluated before doing more detailed analyses. The costs assumed above for the connections only include operation and maintenance costs. Capital costs must be considered before a connection can be considered viable. This analysis is described below in the discussion.

Discussion

At first glance, the added connections in the West Bank appear promising, because of price reductions, in one case substantial, in three districts, and minor increases in prices (~$0.20) in two districts. However, the capital costs for these changes infrastructure must be compared against gains in social welfare. Reviewing the net change in social welfare in the affected districts provides this comparison. **Figure 3** and **Table 1** below, which draws from page 10 in Appendix A and page 10 in Appendix B (both taken from the Social Welfare Results page from the *Tabular Results*), shows a net gain in social welfare of $46 million per year. It is against this amount that the capital costs of the conveyance structures must be compared.

Table 1. Comparison of Social Welfare Results (Million $ per year)

District	Example1_1	Example1_2	Change from 1_1 to 1_2
Jenin	675	709	34
Tulkarem	454	458	4
Nablus	512	516	4
Ramallah	449	453	4
Bethlehem	310	310	0
Hebron	555	555	0
Total			**46**

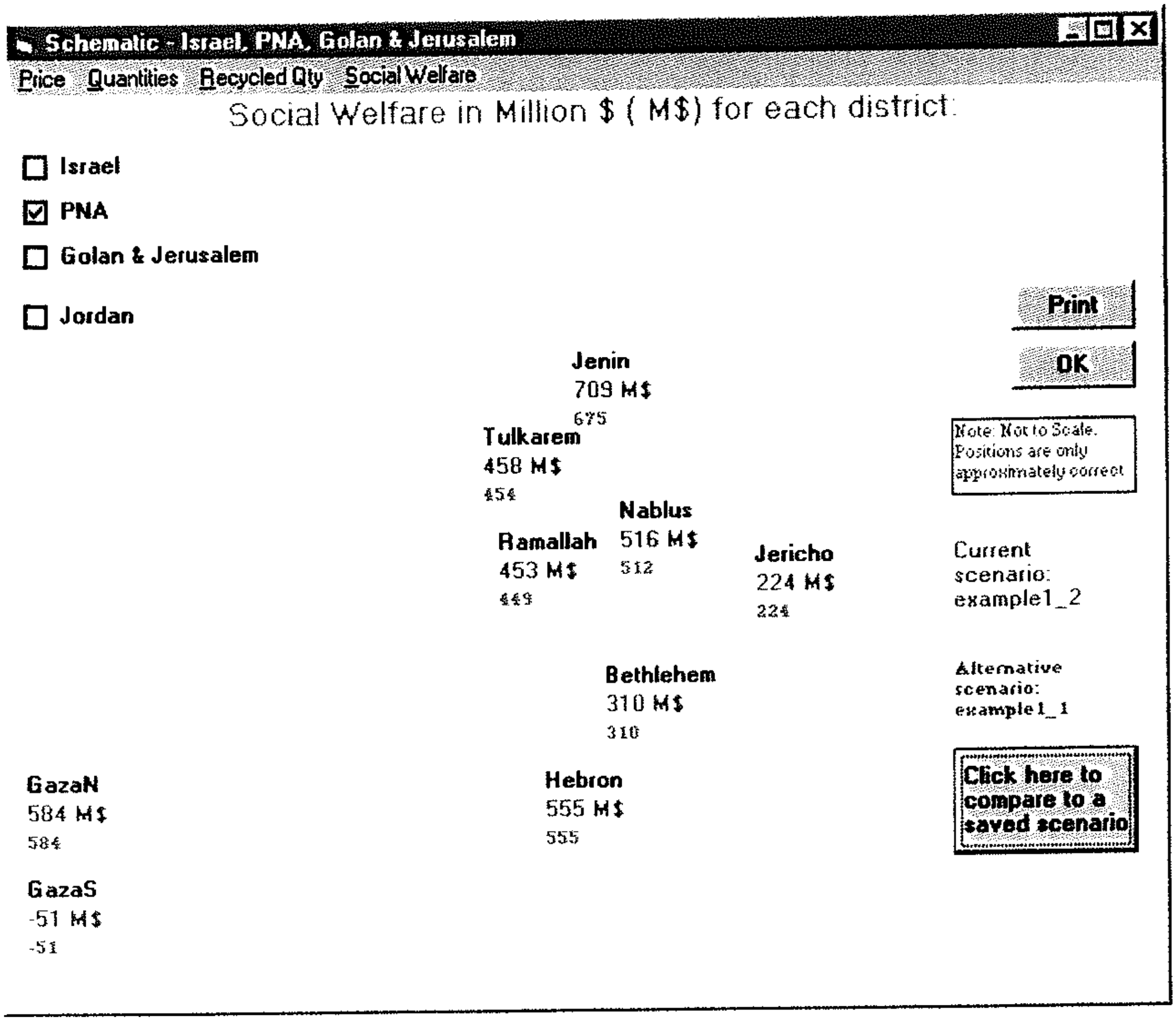


Figure 3: Comparison of Social Welfare

Example 2

Evaluation of Recycling Links In Northern Israel

Example 2: Evaluation of Recycling Links in Northern Israel

Motivation

As population increases, the water demanded in all sectors is likely to increase, even with the implementation of water conservation technologies and programs. One potential source of additional water can be found through recycling. A recycling plant in the north of Israel is currently located in Haifa. However, the only district connected to Haifa for the transport of recycled water is Afula, with a limit on conveyance capacity of 25 MCM/year. The questions we ask here are the value of increasing the capacity of the conveyance systems between Haifa and Afula, and the possibility of exporting recycled water to other districts as well.

Model Assumptions for Baseline Run

The first run begins with selecting the year 2010 and the *Middle1* scenario for population growth rate and distribution. No further modifications are made to demand or supply. With respect to infrastructure, the *Current+* infrastructure is selected. The *Israel Countrified* option is selected, with the assumptions of: 50 percent ownership of the mountain aquifer; 100 percent of the Sea of Galilee and none of the Yarmouk; no added connections; and 100 percent supply of Jerusalem[2]. This run is called Example2_1.

Model Results for Example2_1

The shadow prices for recycled water for Example2_1 are shown in **Figure 4**, which is taken from the *Schematic Program Results.* The price in Haifa is $0.10, while the price in Afula is $0.42. From the *Transport of Recycled Water Table* from the *Tabular Results* (page 12 of Appendix A), the amount transferred from Haifa to Afula is the 25 MCM limit. The transport cost is $0.035, which indicates that the difference in shadow prices in Haifa and Afula is due to the constraint on the pipeline capacity (otherwise the shadow price of recycled water in Afula would simply be the shadow price in Haifa plus the transport cost, or $0.135, not $0.42). We examine the increase in the pipeline capacity in the following example.

Model Assumptions for Comparison Run with Increased Capacity

Example2_1 is modified using the *Recycling/Transport Cost and Bounds* editor. The bound on the capacity from Haifa to Afula is changed from 25 MCM to 999 MCM, to see the results of removing the capacity bound.

Model Results for Example2_2

The change in recycling shadow prices is dramatic, as shown in **Figure 5**. Haifa's recycled water price increases from $0.1 to $0.36, while Afula's price decreases from $0.42 to $0.395. Now that the limit is removed from the pipeline capacity, the difference in shadow prices is

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[2] Of course, no political implications are intended by these choices, which are made for exemplifying purposes only.

exactly the transport cost of $0.035. The shadow prices for recycled water in all districts are either the same or lower, with the exception of Haifa.

In fact, there are also effects on freshwater shadow prices. This happens in Haifa because the increased profits from recycling are credited to urban and industry users encouraging them to consume more freshwater and hence produce more recycled water. With the shadow price of fresh water in Haifa down, the model also readjusts flows so that freshwater shadow prices in districts connected to Haifa are also down (see **Figure 5**).

The net result of all this is an increase in social welfare of $11 million. The estimated capital costs, once annualized, can be compared against this amount to evaluate the viability of this change in infrastructure.

Model Assumptions for Comparison Run with Added Recycling Links

A possible alternative to the increase of pipe capacity from Haifa to Afula is to add recycling connections to districts currently without access to recycled water. The only recycling connections from Haifa that could be beneficial are those to districts with higher prices. In this case, we can see from **Figure 4** that all of the adjacent districts, namely West Galil, Afula, and Hadera are likely to benefit since they have higher prices. Since the comparison is to be made against the increased capacity pipeline to Afula, we explore the two remaining links in Example 2_3, and keep the 25 MCM limit to Afula.

Example2_1 is modified to add recycling links to West Galil and Hadera. This requires the use of the *Recycling Links* option. After adding links, the program asks the user to specify the cost of transport; in this example the cost for both links is assumed to be $0.03. The model is then optimized and the run is called Example2_3.

Model Results for Example2_3

The results for Example 2_3, as shown in **Figure 6**, appear similar to that of Example 2_2. The shadow price of recycled water in Haifa increases from $0.1 to $0.36, and the prices elsewhere drop, somewhat less dramatically than in the previous example. In order to understand what has happened to the transport of recycled water, we look at the results from the *Transport of Recycled Water Table* from the *Tabular Results* (page 12 of Appendix C). The amount of recycled water transferred from Haifa to Afula is *zero*. The amount from Haifa to Hadera is 60 MCM. Effectively the flow has been taken from Afula to Hadera, as shown in **Figure 7**.

The change in social welfare is $13 million.

Discussion

The value of increasing the recycling conveyance system from Haifa to Afula, as given in Example2_2 is comparable to that of adding a new connection from Haifa to Hadera (i.e. 11 and 13 million, respectively). However, this is a complicated comparison, since the new link leads to the existing link not being used. This change in flow reduces buyer surplus in Afula and raises it in Hadera. The effect on net social welfare elsewhere in the system occurs because of slightly more profitable use of recycled water in Example2_3 (such effects do not always show in results rounded to millions of dollars).

Plainly, the choice of adding new links versus expanding the existing one depends on the capital costs. The results, however, clearly indicate that it is *not* efficient to do both projects.

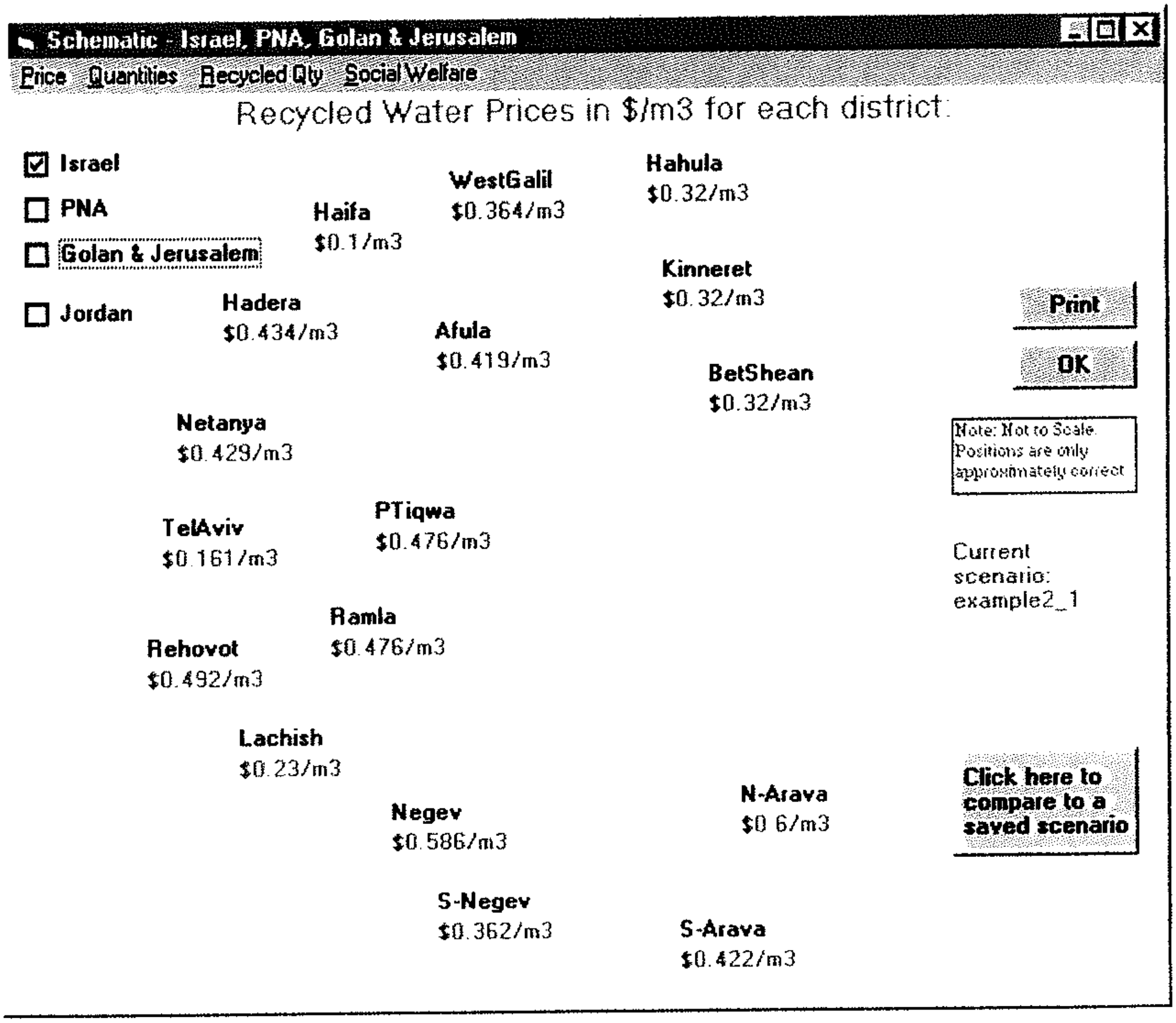

Figure 4: Recycled Prices in Example2_1

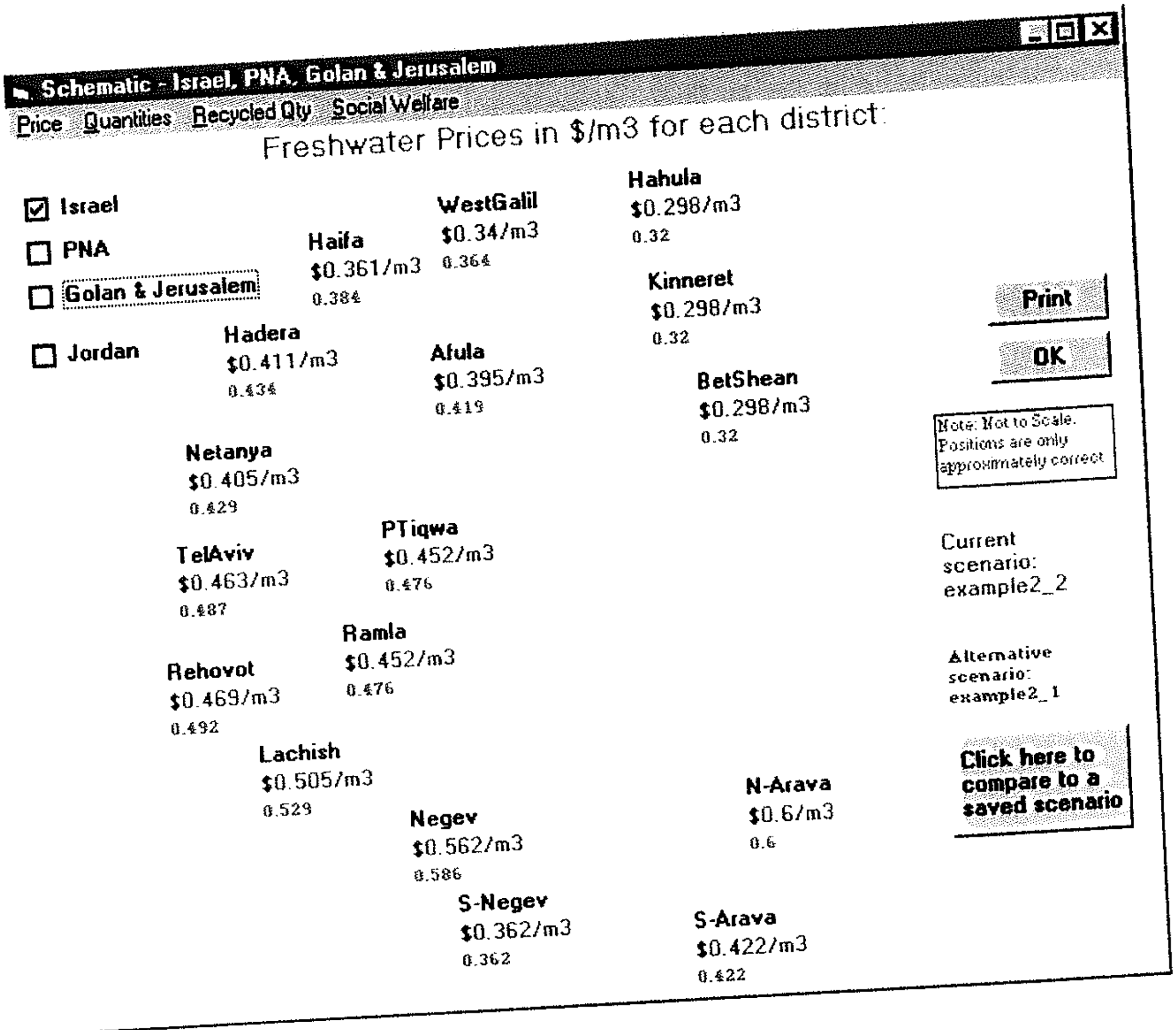

Figure 5: Comparison of Recycled Prices

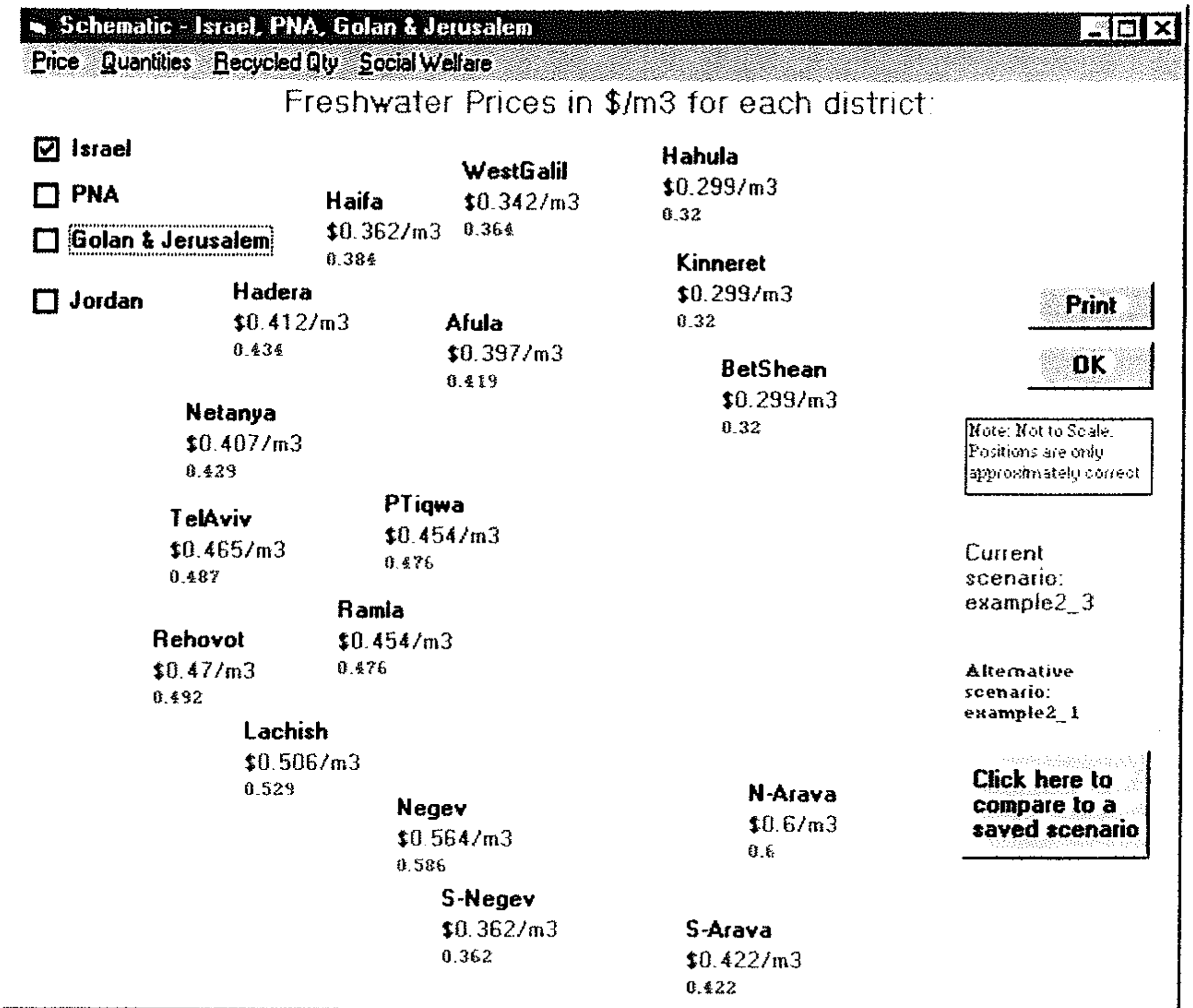

Figure 6: Comparison of Recycled Prices

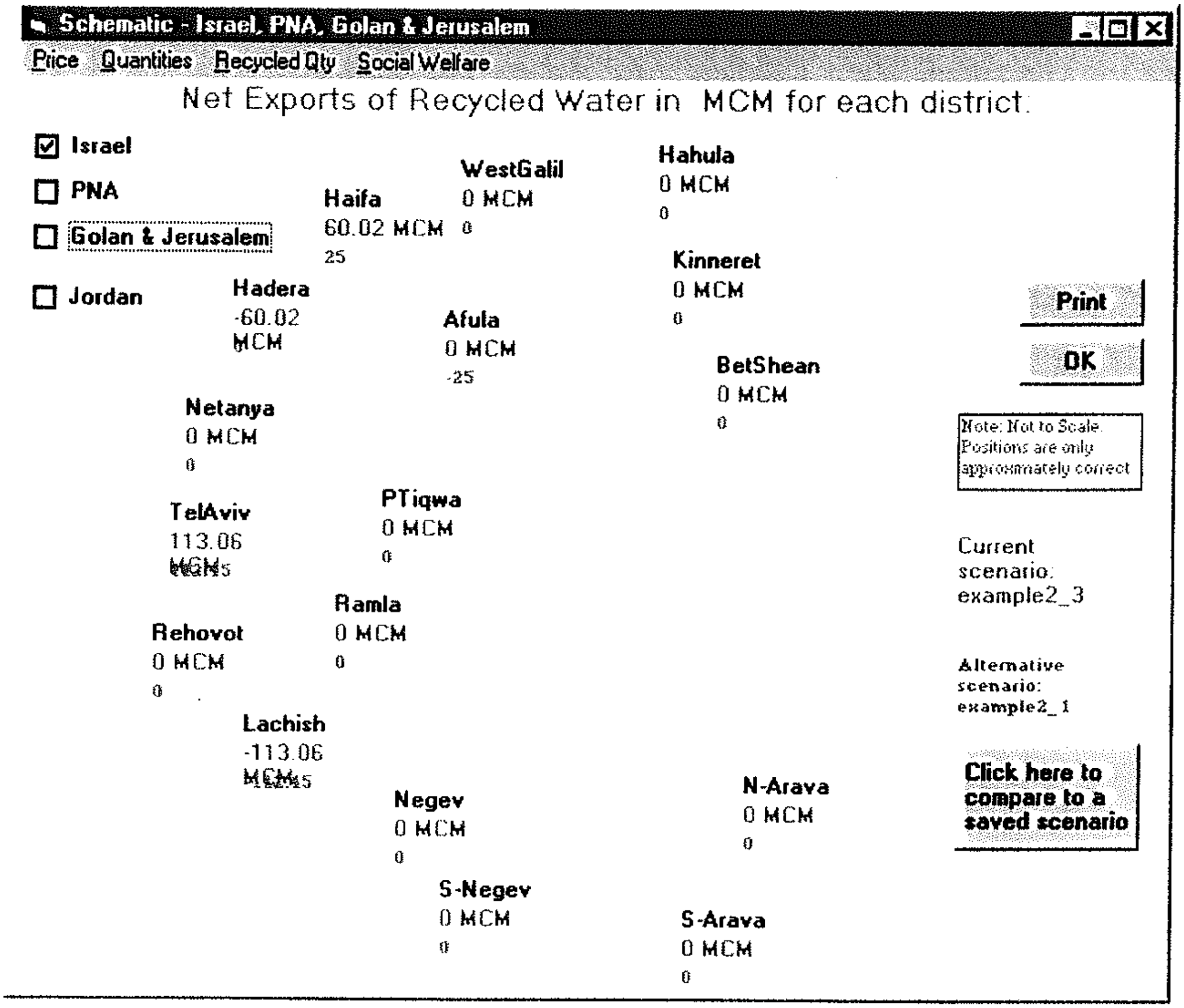

Figure 7: Comparison of Exports of Recycled Quantities

Example 3

Gaza Strip Infrastructure

Example 3: Gaza Strip Infrastructure

Motivation

The Gaza Strip will face severe water shortages in the future if neither the infrastructure nor the supplies available are supplemented. This is immediately evident from a simple run of the system for the year 2010; as shown in Figure 1 the prices are astronomical, and not likely to be observed in reality. It is clear that there is a need for new water sources or modified behaviors. This example first explores the possibility of using recycled water through the installation of recycling plants, as a relatively cheaper source of additional supply, and then looks at desalination as an additional part of the future infrastructure.

Model Assumptions for Baseline Run

The first run begins with selecting the year 2010 and the *Middle1* scenario for population growth rate and distribution. No further modifications are made to demand or supply. With respect to infrastructure, the *Current* infrastructure is selected. The *PNA Countrified* option is selected, with the assumptions of 50 percent ownership of the mountain aquifer, no ownership of the Sea of Galilee or the Yarmouk, no added connections, and no supply of Jerusalem[3]. No further changes are made with the model interface, and this run is then optimized and called Example3_1.

Model Results for Example3_1

The freshwater prices (i.e. the shadow prices) from Example3_1 are shown in **Figure 8**, which is taken from the *Schematic Program Results*. The price in both Gaza North and Gaza South is $57. Clearly these prices are unacceptable and unthinkable. These are purely an indication of a need for serious infrastructure, additional supply, and/or changes in population or consumption. This example explores means of obtaining additional supply through the installation of recycling and desalination plants in the two runs below, and the effects on prices and social welfare in the final discussion section.

Model Assumptions for Comparison Run with Recycling Plants

Example3_1 is modified to add recycling plants in both Gaza North and South. The default assumptions concerning the percentage of water recycled from industrial and urban users, at 66 percent, and the additional cost of recycling above that of standard treatment, at 10 cents per cubic meter, are accepted. The model is then optimized and the run is called Example3_2.

Model Results for Example3_2

The results for Example 3_2, as shown in **Figure 9,** show a significant drop in shadow prices for both districts, from $57 to $43. However, the prices are still ridiculously high. It is clear that

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[3] Of course, no political implications are intended by these choices, which are made for exemplifying purposes only.

recycling alone will not be sufficient to provide adequate supply for the area in the year 2010. A third run is therefore made, looking at the possibility of desalination.

Model Assumptions for Comparison Run with Desalination

Example3_2 is modified to add a desalination plant in Gaza North, and an unlimited connection from Gaza North to Gaza South at a cost of $0.05 per cubic meter. The desalination plant is assumed to be of unlimited capacity, and the cost of the treatment is set at $0.80 per cubic meter. The scenario name given to this run is Example3_3.

Model Results for Example3_3

The shadow prices for Example 3_3, as shown in **Figure 10**, are $0.80 for Gaza North and $0.85 for Gaza South; the price difference is simply the cost of transport between the two districts. The prices are much more reasonable that in the previous examples, however, only further analysis of social welfare will provide insight into the value of doing more detailed analyses. The examination of social welfare in all three examples is given below in the discussion.

Discussion

The reduction in prices is so substantial in these examples that it appears unnecessary to investigate further the need for the infrastructure. However, the capital costs for the recycling plants, and especially for the desalination plant, are sufficiently high to warrant a review of the changes in social welfare. **Table 1** shows a net gain in social welfare of $387 million per year. In addition, the per capita consumption rises from an average of 39 MCM/year to 41 MCM/year.

Table 1. Comparison of Social Welfare Results with Recycling (Million $ per year)

District	Example3_1	Example3_2	Change from 3_1 to 3_2
Gaza North	584	688	104
Gaza South	-51	232	283
Total			**387**

Numbers of this scale are more than sufficient to justify detailed evaluation of recycling. However, the shadow prices still indicate that the recycling plants alone will not provide sufficient water for the estimated demand for the year 2010.

A comparison in social welfare between Example3_2 and 3_3 is given in **Table 2**. The change in social welfare, even *with* two recycling plants is $595 million per year. Clearly, consideration should be given to the construction of a desalination plant in Gaza Strip, assuming the current access to the Israeli National Carrier is limited.

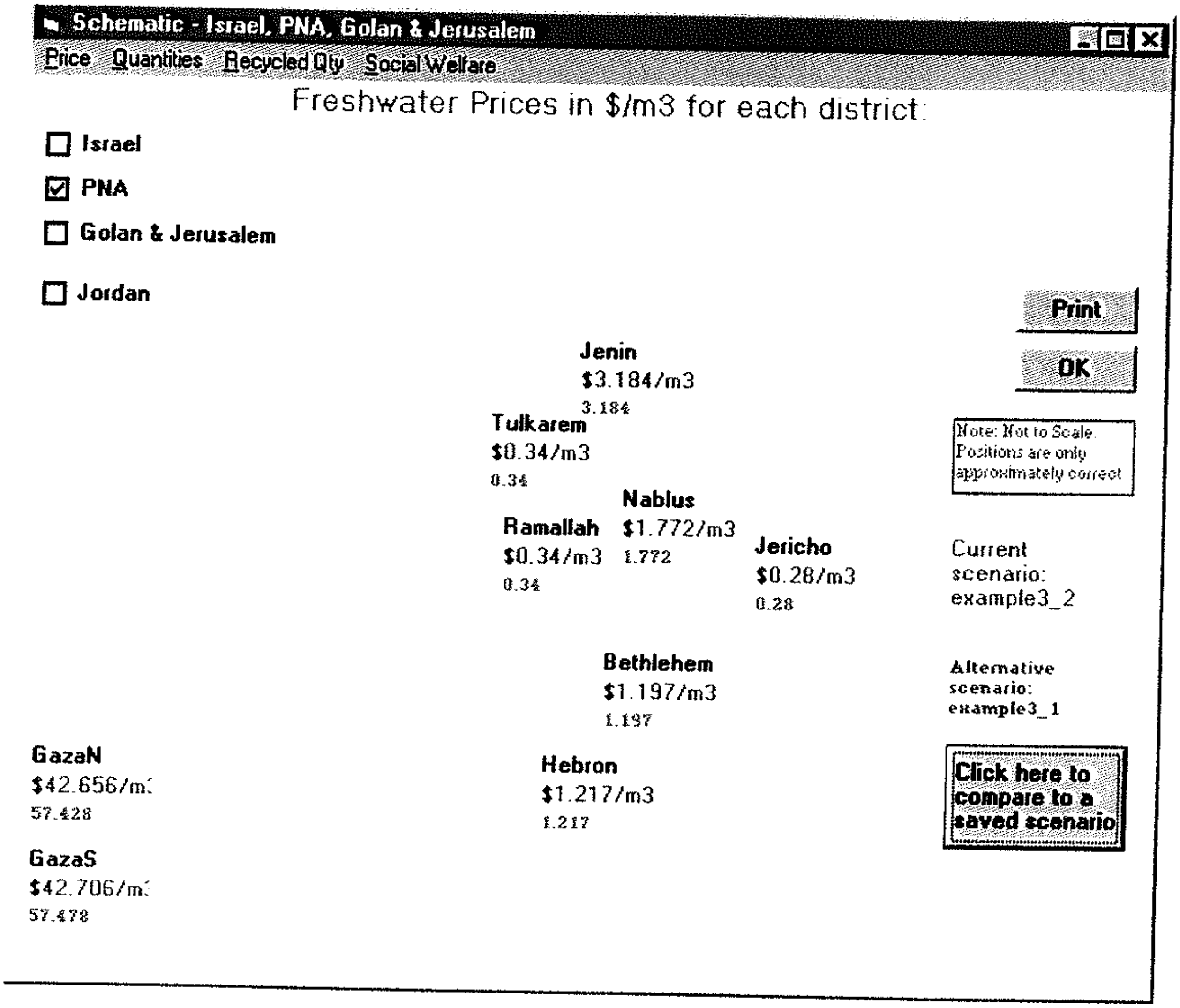

Figure 9: Comparison of Shadow Prices

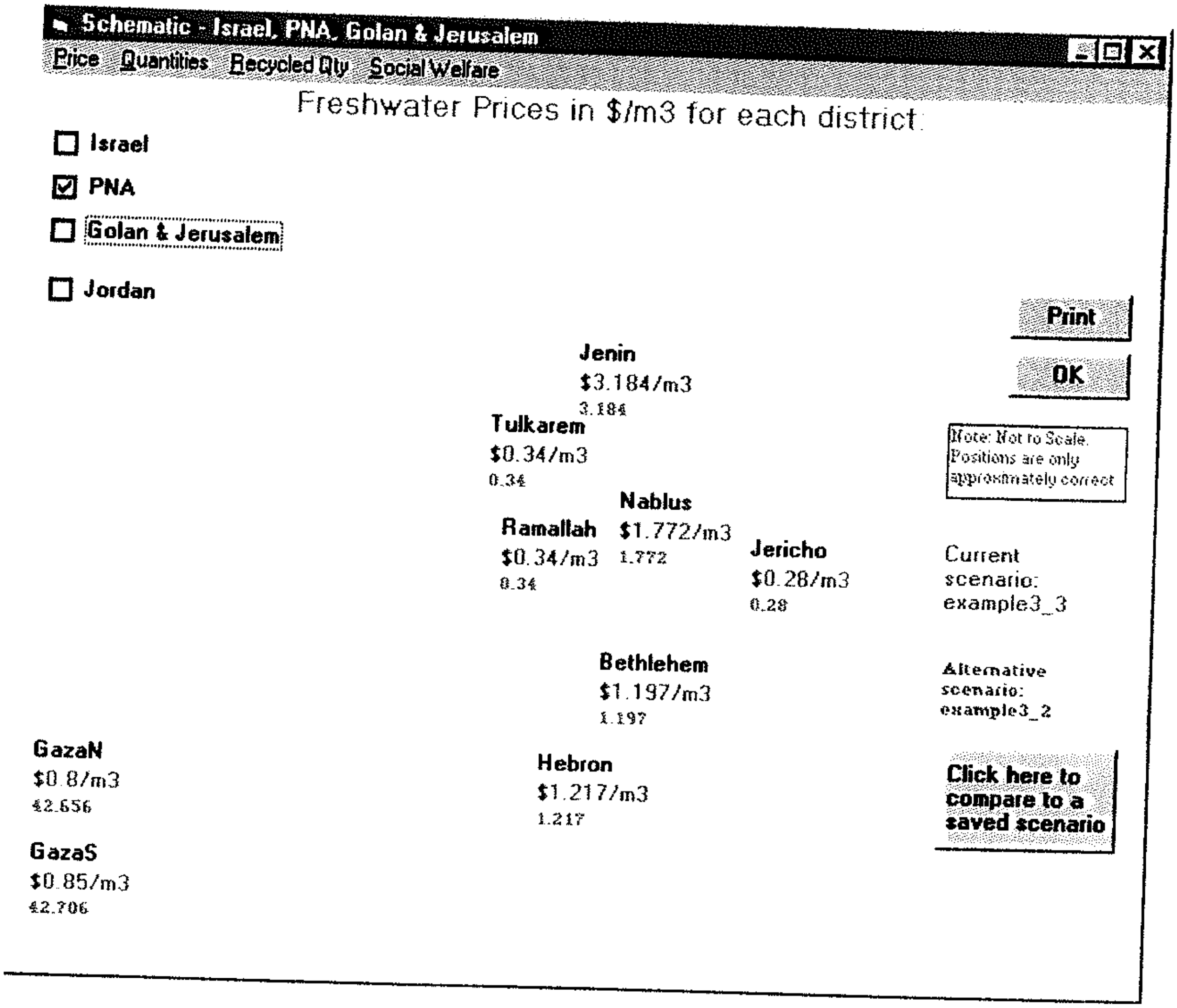

Figure 10: Comparison of Shadow Prices

Example 4

Agricultural National Policy
In Jordan

Example 4: Agricultural National Policy in Jordan

Motivation

National policies for agriculture, both in the form of subsidies, quotas or other pricing structures are common throughout the world, particularly with respect to water. There are many reasons for this, ranging from cultural and religious to political and economic. Regardless of the reason, it is crucial that the formulation of the policy take into account the costs imposed on society. This example compares the changes in social welfare that occur with a national price policy for agriculture in Jordan.

Model Assumptions for Baseline Run

The first run uses the year 2010, and the *Middle1* demand scenario for population growth rate and distribution. No further modifications are made to demand or supply conditions. With respect to infrastructure, *Plausible+* is selected. A desalination plant is added to South Wadi Araba, assuming a cost of $1 per cubic meter. The Jordanian countrified option is selected, with 100 percent of the Yarmouk and none of the Sea of Galilee[4]. This run is called Example4_1.

Model Results for Example4_1

The freshwater prices (i.e. the shadow prices) from Example4_1 are shown in **Figure 11**, which is taken from the *Schematic Program Results*. The freshwater shadow prices range from a low of $0.12 in Hammad to a high of $1.03 in North Wadi Araba. As illustrated in **Figure 12**, agricultural water prices are virtually identical, with the exception of Amman, which has recycled water available at a relatively low cost. However, agricultural water prices on the order of $0.30 to $1 are extraordinarily high for this region, and would undoubtedly result in the elimination of some traditionally grown crops and a restructuring of the industry.

Model Assumptions for Comparison Run

Example4_1 is modified to add a price policy. Under *National Policy*, Jordan is selected, and the first option, called *Fixed Price Policy,* is selected. A simple policy is imposed for one district, the Jordan Valley: for the first 100 MCM of water used, the price is set at $0.01, and all further water use incurs a cost of $0.05. The model is then optimized and the run is called Example4_2.

Model Results for Example 4_2

One of the implications for a price policy that lowers the cost to one user type, is price increases to other user types. This is illustrated in **Figure 13**, where the freshwater prices increase on the order of $0.2 in the Jordan Valley and four linked districts (Northern Highlands, Amman, the Dead Sea and Azraq). **Figure 14** shows the impact on agricultural prices. Where the price in the

[4] Of course, no political implications are intended by these choices, which are made for exemplifying purposes only.

Jordan Valley is $0.05, the adjacent districts are paying an additional $0.2 on top of already relatively high prices.

Discussion

The WAS model allows an evaluation of at least two of the questions likely to arise when looking at the use of national water policies: (1) what are the effects on agricultural water use, and (2) how does the policy impact social welfare. The first question is readily answered by looking at *Schematic Results* and *Agricultural Demand*, as shown in **Figure 15**. Agricultural water use in the Jordan Valley jumps from 53 MCM to 133 MCM—an 80 MCM increase, with relatively minor changes elsewhere.

The change in social welfare is somewhat more subtle. The change in social welfare, taken from *Tabular Results* of both runs, shown in Table 1, is a substantial $35 million/year. However, the cost of the policy to the government is $62 million, as shown on page 9 of Appendix B. Therefore the net impact of the policy is *negative* $27 million/year. Of course, the government may well consider that the benefits from having Jordan Valley agriculture so subsidized outweighs these costs.

Table 1. Comparison of Social Welfare Results (Million $ per year)

District	Example4_1	Example4_2	Change from 4_1 to 4_2
Jordan Valley	454	477	66
N. Highlands	1379	1377	-18
Amman	3301	3298	-30
Dead Sea	651	652	10
Azraq	39	39	7
N. Wadi Araba	541	541	0
S. Wadi Araba	471	471	0
Maan Disi	929	929	0
Hammad	3	3	0
Total			**35**

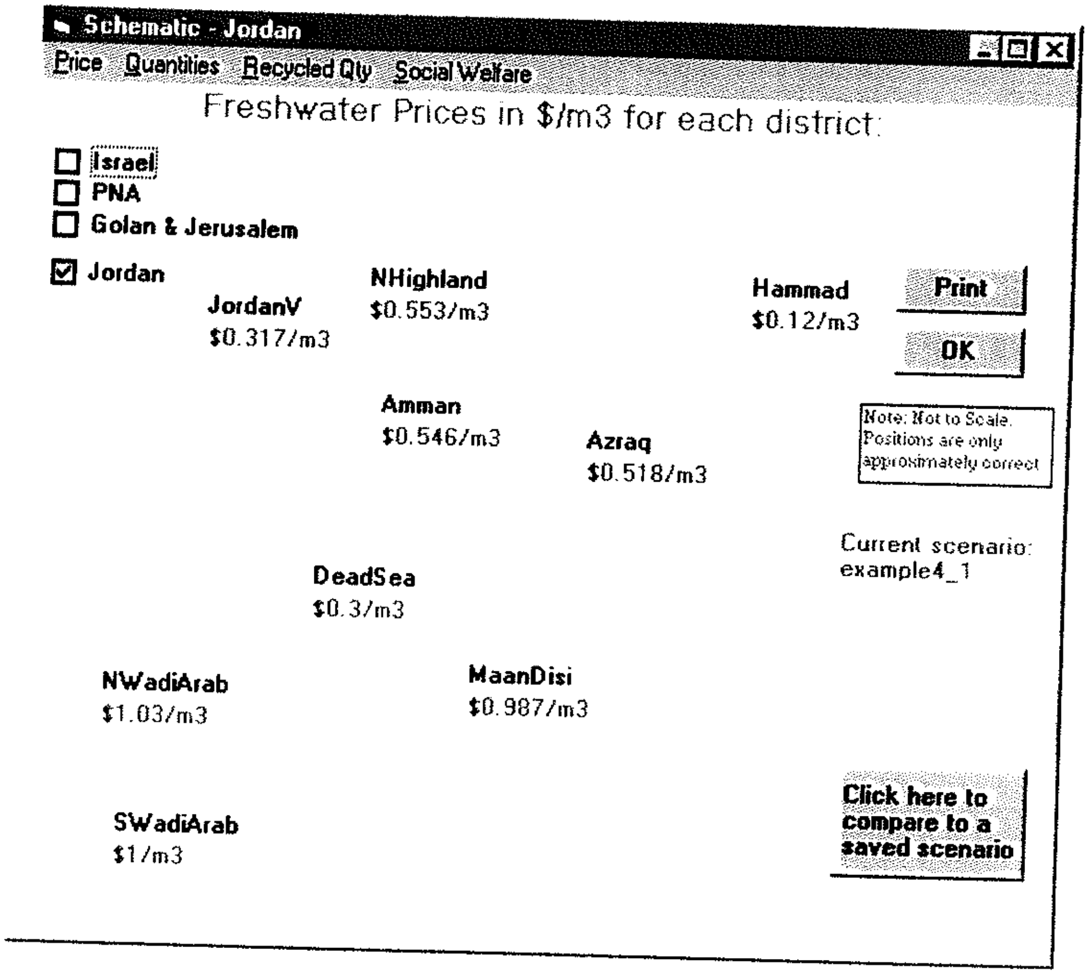

Figure 11: Shadow Prices for Example4_1

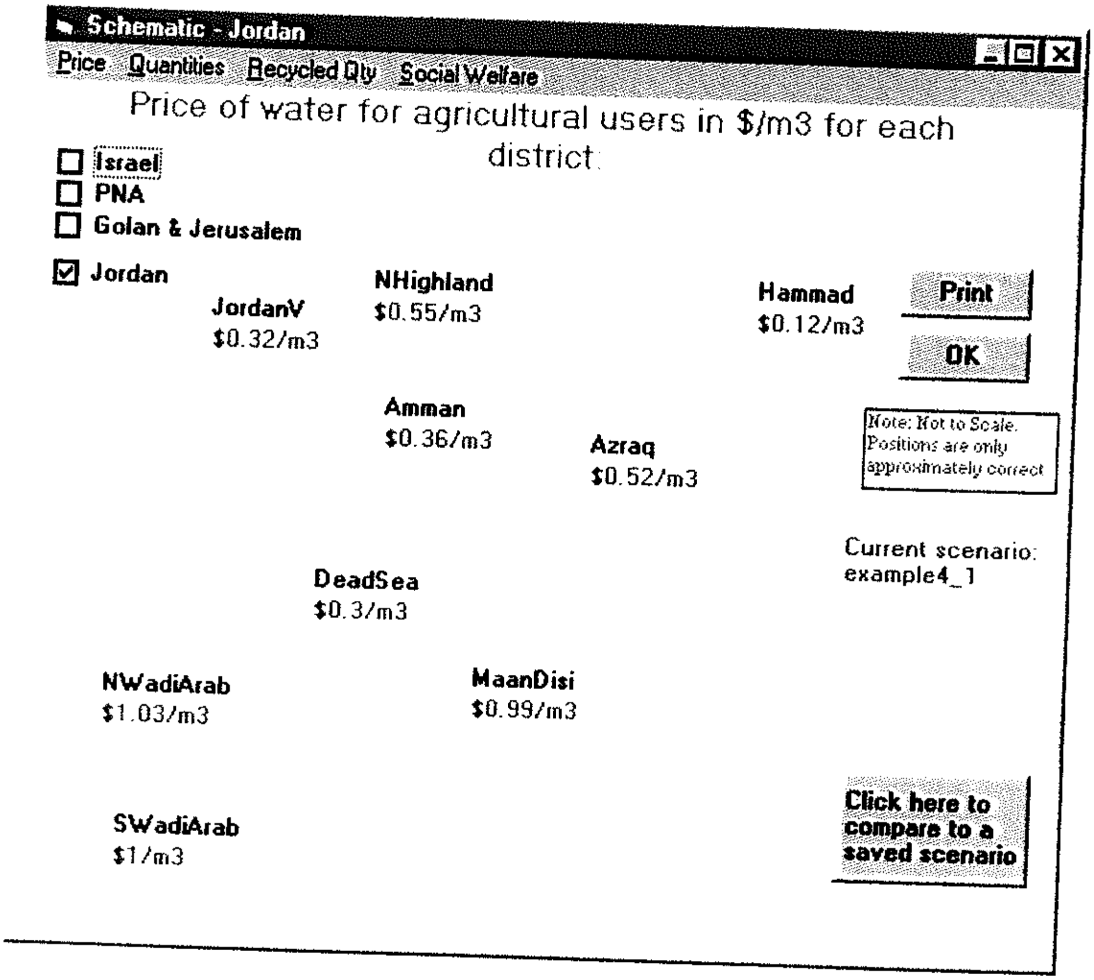

Figure 12: Agricultural Prices for Example4_1

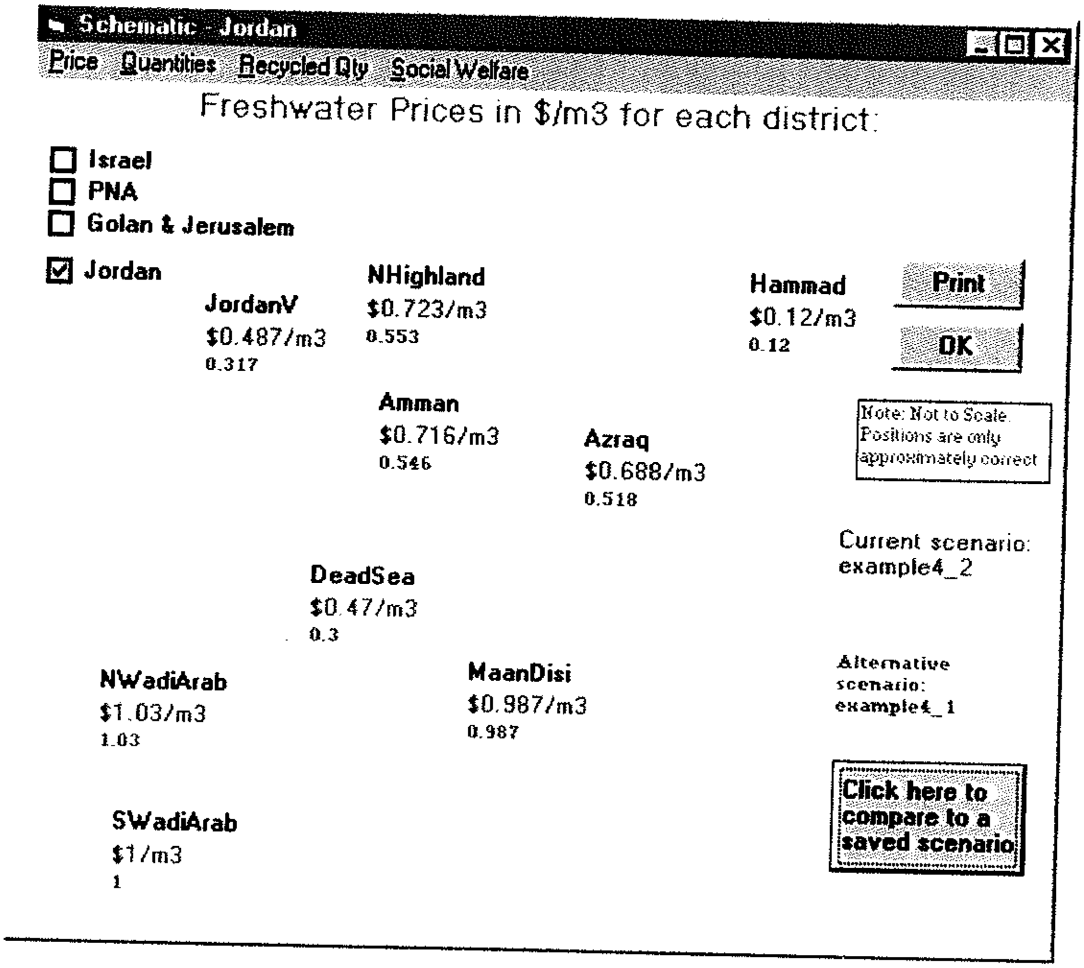

Figure 13: Comparison of Shadow Prices

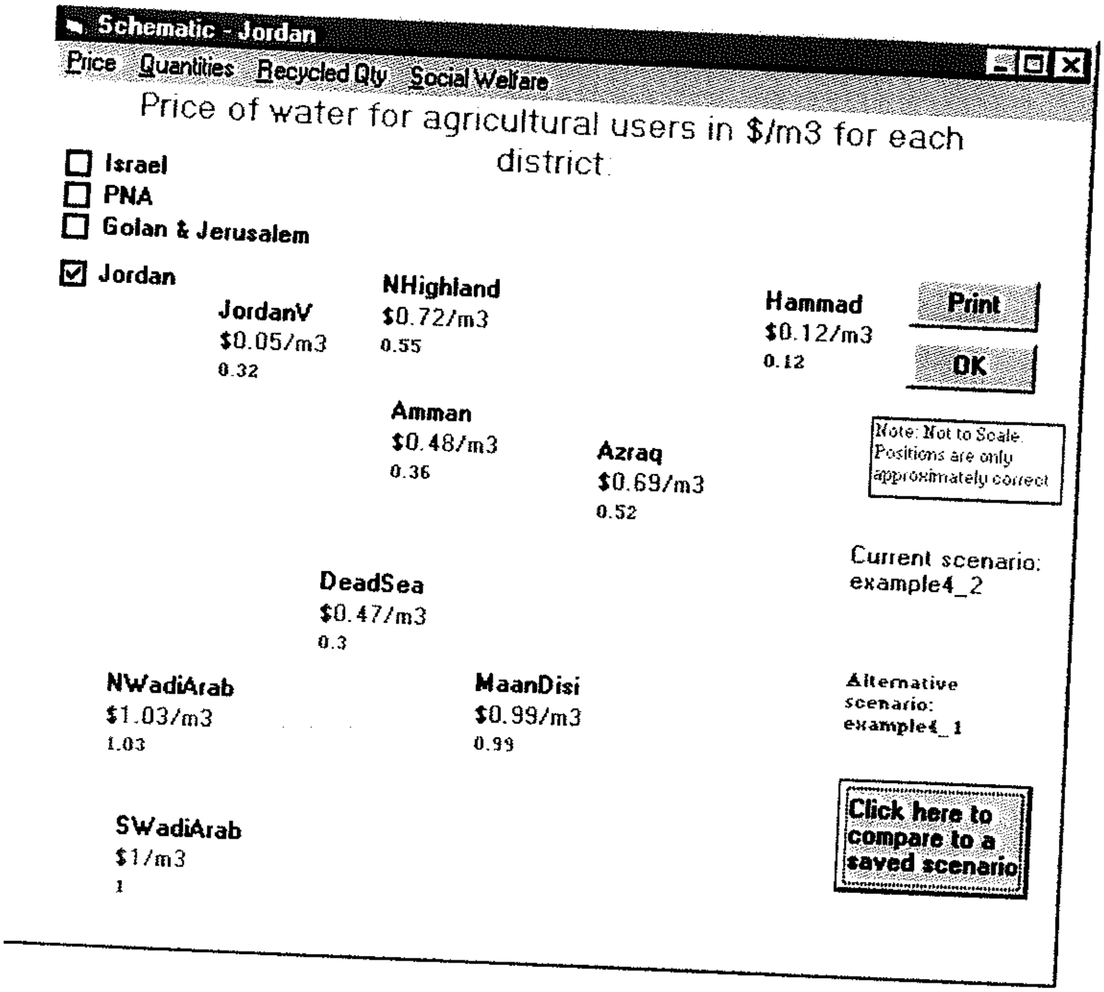

Figure 14: Price of Fresh Water for Agriculture

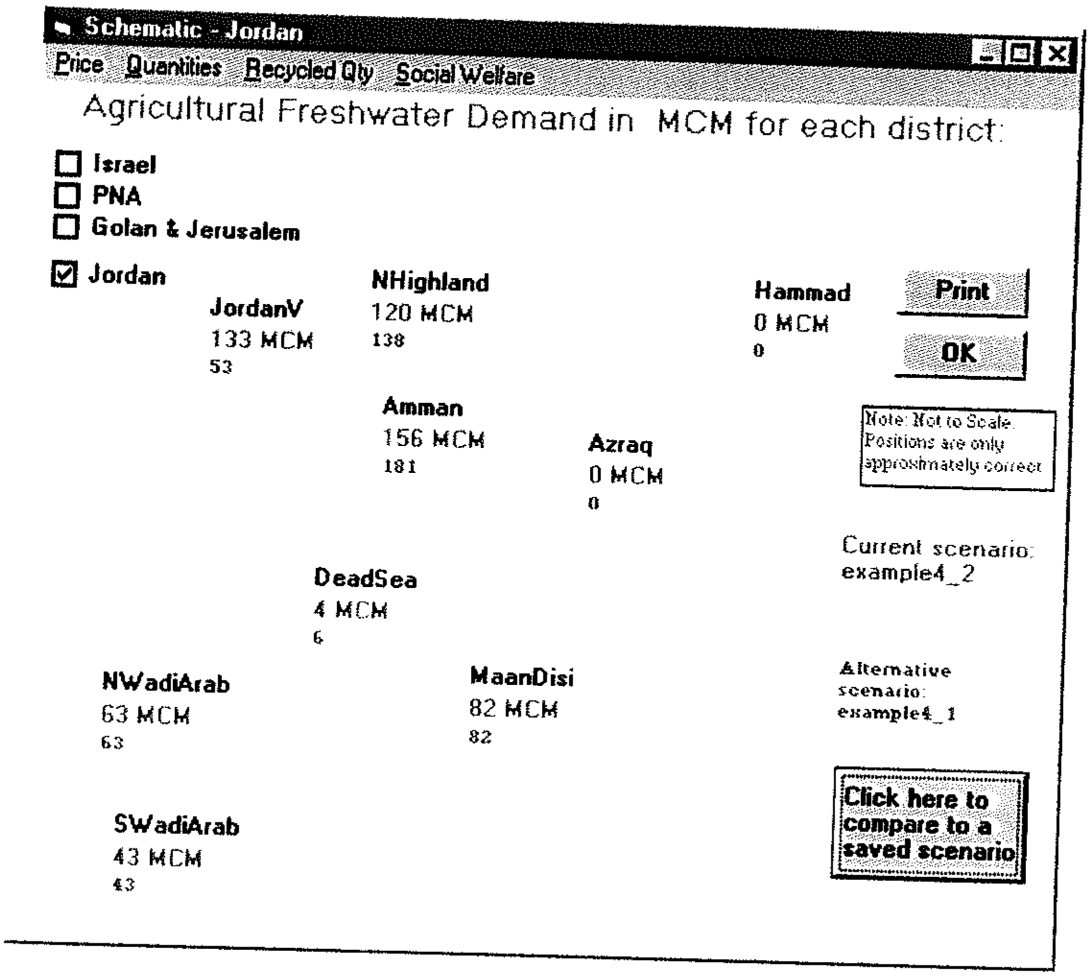

Figure 15: Comparison of Agricultural Water Use

Example 5

Change of Demand Assumptions
For Gaza Strip

Example 5: Change of Demand Assumptions for the Gaza Strip

Motivation

As shown in Example 3, the Gaza Strip will need to build a desalination plant unless the current supplies available are supplemented through other means. Of course these results are only as good as the data and assumptions used to derive the results. One very basic assumption made with the runs in Example 3 was the use of demand curves based on population projections made several years ago. In this example, we change the demand multiplier to evaluate the effect of varying these projections on the decision to build desalination plants in the Gaza Strip.

Model Assumptions for Baseline Run

The first run begins with selecting the year 2010 and the *Middle1* scenario for population growth rate and distribution. No further modifications are made to demand or supply. With respect to infrastructure, the *Current* infrastructure is selected. The *PNA Countrified* option is selected, with the assumptions of: 50 percent ownership of the mountain aquifer; no ownership of the Sea of Galilee or the Yarmouk; no added connections; and no supply of Jerusalem[5]. Recycling plants are added in both Gaza North and South. The default assumptions concerning the percentage of water recycled from industrial and urban users, at 66 percent, and the additional cost of recycling above that of standard treatment, at 10 cents per cubic meter, are accepted. This run is called Example5_1.

Model Results for Example5_1

The freshwater prices (i.e. the shadow prices) from Example5_1 are shown in **Figure 16**, which is taken from the *Schematic Program Results*. The shadow price in both Gaza North and Gaza South is $43. As discussed in Example3_1, these shadow prices are purely an indication of a need for serious infrastructure, additional supply, and/or changes in population or consumption. In Example3_3, this implied desalination as one way to deal with the problem.

Model Assumptions for Comparison Run with Reduced Demand Multiplier

Example5_2 changes the demand multiplier through the *Demand Properties* editor. Under the editor, the *Demand Multiplier* for each of the three demand types (Agriculture, Urban and Industrial) is selected, and the values for Gaza North and Gaza South are changed from 1.0 to 0.5. In the case of urban demand, this amounts to halving the population projection for 2010, and other demands are reduced proportionately.

[5] Of course, no political implications are intended by these choices, which are made for exemplifying purposes only.

Model Results for Example5_2

The results for Example 5_2, as shown in **Figure 17,** show a significant drop in shadow prices for both districts, from $43 to slightly more than $1. If the price of desalination is less than this amount, and the change in social welfare sufficiently high to cover capital costs, desalination would still be the preferred/necessary option for the future water supply for Gaza. On the other hand, if desalination costs were more than this, desalination would not be efficient in 2010.

Discussion

One of the key questions to ask when there is uncertainty about the validity of certain data, parameters or assumptions, is how the change of these affects the outcome or the decisions to be made. In this example, the demand multipliers were reduced by one half. The prices change dramatically with the change in the multipliers, and the strong result as to the desirability of desalination in 2010 changes so that such desirability is no longer totally obvious[6].

[6] Recall again that this assumes no expanded supply of Gaza from Israel.

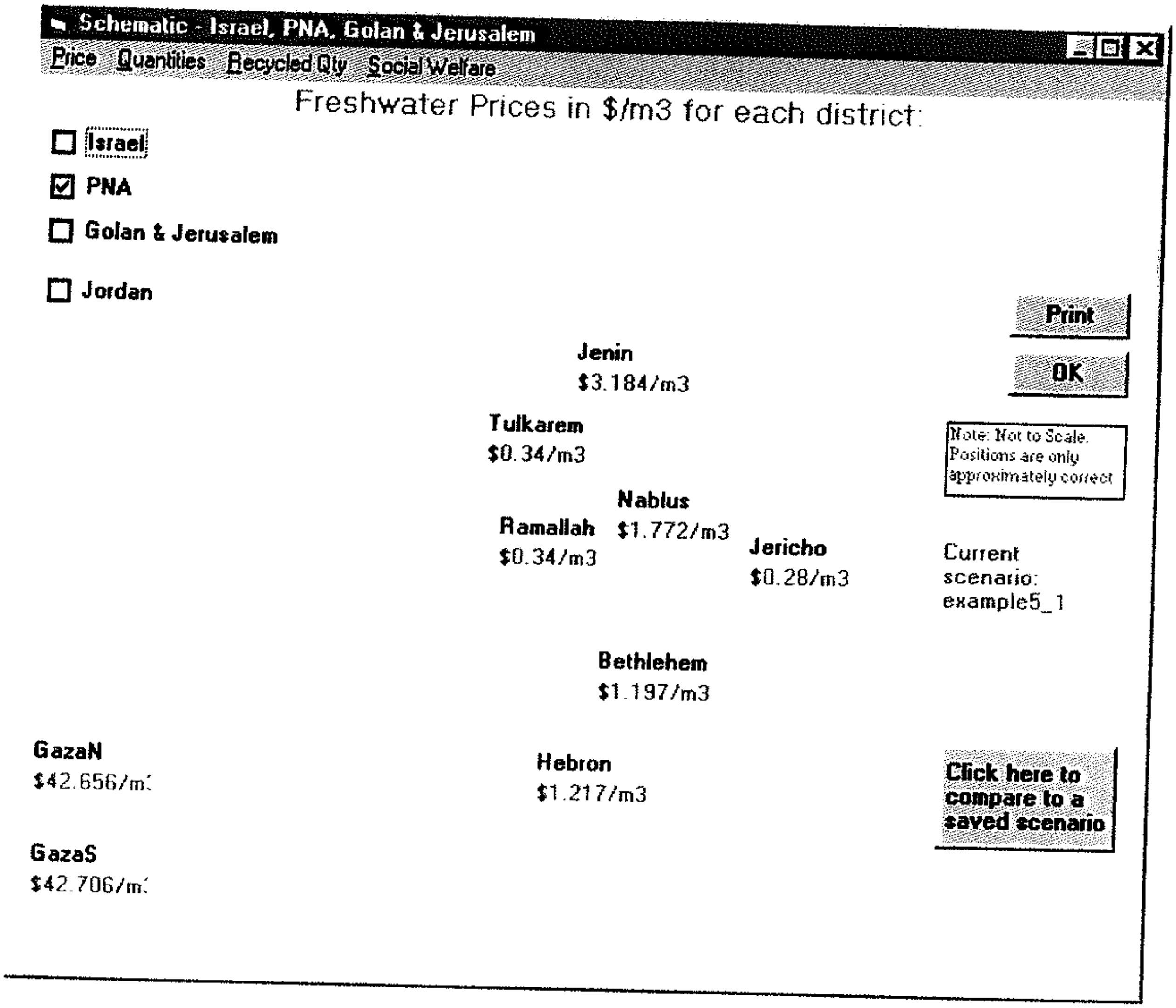

Figure 16: Shadow Prices for Example5_1

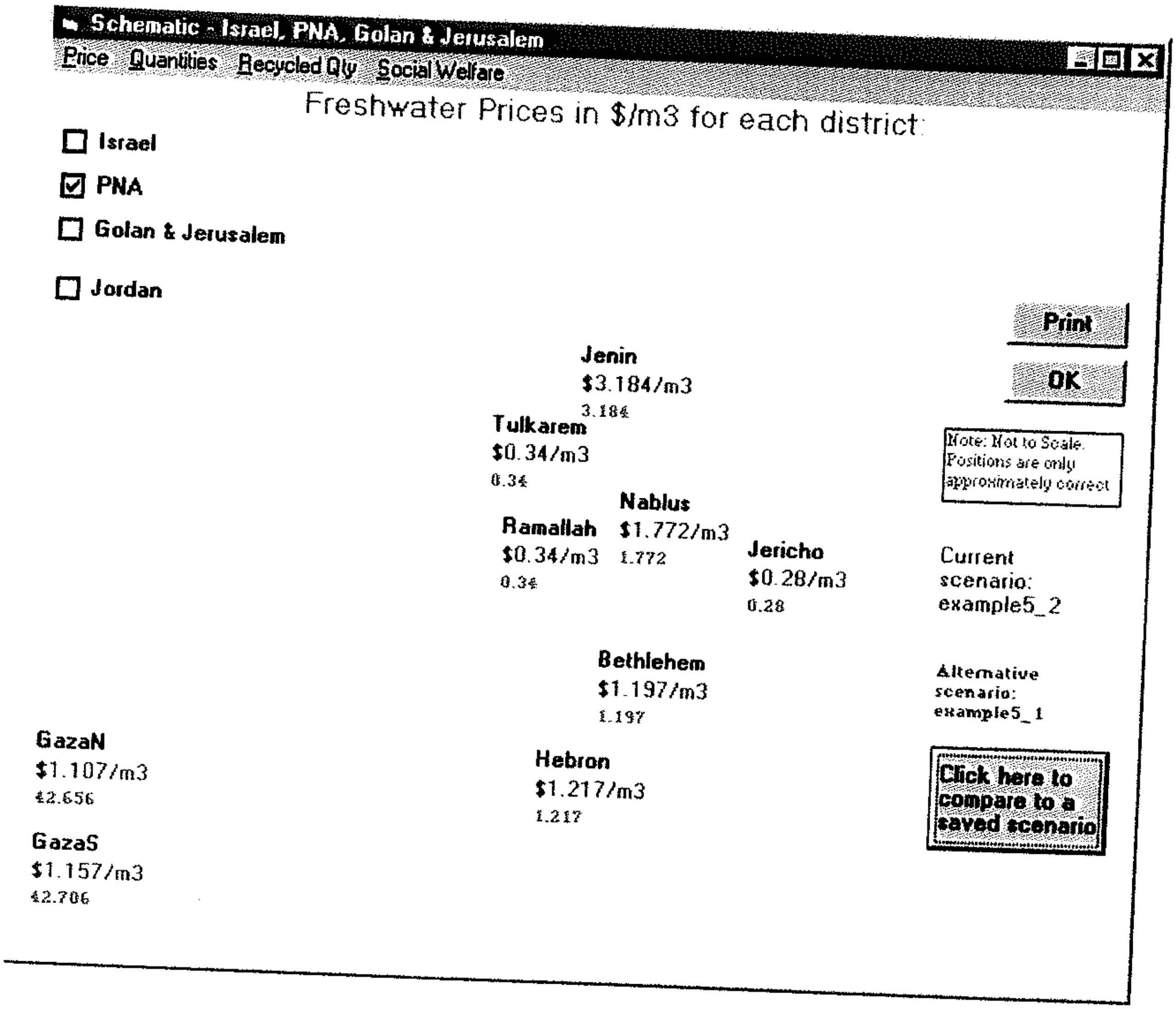

Figure 17: Comparison of Prices