THE HARVARD MIDDLE EAST WATER PROJECT:

OVERVIEW, RESULTS, AND CONCLUSIONS

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1 Note on authorship: The project described in the paper is being carried out by Israelis, Palestinians, Jordanians, and Americans under the auspices of the Institute for Social and Economic Policy in the Middle East of Harvard University's John F. Kennedy School. The present report does not itself include the studies and projections of supply and demand curves for water done by Israeli, Jordanian, and Palestinian teams, but relies on them for its data, much of which can be found in the data appendix.

Professor Fisher has signed the current draft as the individual principally responsible and because others have not yet had an opportunity to comment. He does not expect to be the only project participant signing any version that is to be publicly released, nor the only author of the book that is expected to be ready for the press by mid-1995. Indeed, he hopes and expects that many members of the project team, members from each of the countries involved, will also sign.

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Executive Summary

The project here discussed is a joint effort of Israeli, Jordanian, Palestinian, and American experts under the general auspices of Harvard University's Institute for Social and Economic Policy in the Middle East.

We have jointly built a model of the water economies of Israel, Jordan, and Palestine.[2] That model is an annual, steady-state model (i.e., a model for an average year), with data for the 1990 and projections for the years 2010, and 2020. It considers water demand by households, industry, and agriculture. The model is disaggregated into districts within each country; water supply costs in each district and transportation costs between districts are taken into account and play a significant role. The model takes account of the fact that water has a social as well as a private value by examining national policies towards water.

We reach the following conclusions:

1. Ownership vs. Usage. The questions of water *ownership*

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2 We do not intend to prejudge the outcome of any future negotiations. The term "Palestine" is to be taken to mean whatever Palestinian entity eventually emerges from such negotiations. A similar disclaimer applies to any other use of terminology. There is no point in permitting substantive studies to be discounted because of the language used.

and of water *usage* are both very important questions, but they are not the same. In particular, the question of water ownership is a property-rights question, with the property rights involved having an economic value. That value is not merely the cost of supplying water; the fact that water is scarce itself makes water valuable.

2. The Value of the Disputed Water. The value of the water in dispute among the parties is not very great, however. Taking 400 million cubic meters (mcm) per year as roughly representative of the amount of water in dispute in each of the Jordan River (Sea of Galilee) and the Mountain Aquifer and 250 mcm per year for the Yarmouk, we find the following results as to the total values involved:

Total Value of Disputed Water: (millions of 1990$/year)

	1990	2010	2020
Sea of Galilee	70	119-163	206-231
Mountain Aquifer	36	89-135	181-207
Yarmouk	7.5	63-90	118-133

These are not negligible numbers. But they are not so high as to form a barrier to a peace agreement. Relative to the economy of the region and its probable growth, they are small indeed, far less than one percent. They are also very small relative to the cost of a single day of war.

3. Water for Human Consumption. There need be no crisis in water for human consumption, indeed, with one exception, we find prices to household close to or even below current prices and consumption per capita in Jordan and, especially, Palestine

particularly since retaliation need not be restricted to water-connected actions. Of course, in the event of a war for other reasons, rationality is unlikely to prevail. In a context of peaceful relations, however, the joint management and development of regional water resources appears very promising and deserving of further study.

PART I

Ownership and Usage of Water: the General Approach

1. Introduction: Principles and Goals of the Project

All parties to the Middle East peace negotiations view water and water rights as matters of vital importance. The issues involve questions of national importance and arouse strong emotions with deep roots.

The Harvard Middle East Water Project has developed an economics-based method of analyzing water issues that may help the parties to perceive the conflict and approaches to its resolution in a new way. In the long run, this economic approach to regional water management can lead to optimal allocation of the region's scarce water resources taking into account the social and political goals of the governmental authorities involved. More immediately, by calculating the economic value of the quantities of water in dispute, we hope to facilitate negotiations over water rights, for, when this is done, the size of the dispute ceases to be formidable and should thus become amenable to resolution.

The approach is based on the following points:

1. Water is a scarce resource. Scarce resources have value. In the case of water, however, that value is not merely the price that water would obtain in a free market. This is because water often has social value that is not merely private value. For example, the allocation of water can form part of national policies towards agriculture that go beyond the promotion of

privately profitable farms. Issues of social stability can also be bound up in the question of how water should be allocated.

2. In particular, the fact that water is necessary for human life is an important element of the value of water. Were water sufficiently scarce, that fact would be reflected in a private or national willingness to pay large sums for small amounts of water. Where water is somewhat more abundant (although still scarce), the value of water will be lower. But, no matter how scarce water is, every person requires and is entitled to at least the minimal amount of water consistent with human life and dignity.

3. Owners of water who use the water themselves do not in fact get the water at no cost. Such owners give up the money that they could make by selling the water to others. Hence such owners (like anyone who uses the water) are really buying the water.

4. The right of ownership, therefore, is a property right entitling the owner to the value of the water. That is true regardless of who uses the water.

5. As a result, the question of property rights -- of who *owns* the water -- and the question of who *uses* the water are analytically separate questions. Both questions are of great importance and both must be answered in any agreement, but one can think about them separately.

Our project seeks to calculate the value of water at different locations in the region. It does so for 1990 conditions the amount of water really in dispute yields makes the value of the disputed water less than $34 million per year currently and less than $210 million per year by 2020. Similar results apply to the other disputes involved.

These results are not so surprising as they may first appear. To take an outer limit, no matter how important water is, it cannot be worth more than the cost of replacing it. Hence the possibility of desalination puts an upper bound on the value of water. In fact, that upper bound is lower than the cost of desalination, even when desalination is economically feasible on the coast.[11] This is a consequence of the following, much more general point.

The value of water is different in different locations. To understand this, consider the following example. Water is (and will remain) quite valuable in Gaza where the population density is high and naturally occurring sweet water sources relatively low. An upper limit to that value (as remarked above) is the cost of desalination at Gaza. But whether or not Gaza is supplied by desalination, the high value of water in that city does not produce an equally high value for the water of the Mountain aquifer. This is because supplying Gaza from the Mountain aquifer involves considerable pumping and transportation costs. The same

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11 In fact, we do not find desalination to be likely efficient outcome until at least 2020 and perhaps not even then.

water which, delivered in Gaza would have a relatively high value, thus has a much lower one *in situ* in the West Bank.

An even more compelling case is that of Amman. In the results presented in Part III, below, we find that, unless expanded transportation facilities are built to take water to Amman, there will be a major fresh water crisis there by 2010. That fact is reflected in the very high scarcity prices we find for Amman (more than $8/m^3 in 2010). Those prices add nothing to the value of the disputed water, however, because the scarcity is not in the water but in the inability to transport it.[12]

Our first conclusion can thus be stated as follows: *Despite the importance of water in use, and despite the consequent importance of the question of who uses the water, the property rights issue -- the question of who owns the water -- should not be nearly so difficult to resolve as is generally supposed. The value of the property rights at issue is small enough that it should prove possible to settle the issue in the context of a general peace agreement. The magnitudes involved are not such as cause war among nations. If the parties will step back from a*

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12 Related to this is the following. In public discussions of our project, it is sometimes pointed out that if we were lost in the desert the value of water would be very great indeed. So it would in the desert. But that fact would not increase the value of water *at the riverside*.

narrow focus on water and consider the matter from the vantage point of the need to reach a workable and lasting settlement, the problem of water ownership should not stand in the way.

In this connection, the peace treaty between Israel and Jordan appears sensibly to settle water issues within a larger context. The 50 million cubic meters per year that Israel is to give Jordan in the short run is important but not earthshaking, for its value is less than $8 million per year.[13]

Note that we do not offer a specific solution for the issue of who owns the water in the sense of offering a specific allocation of the property rights involved. Nor do we claim that the question of who owns the water is unimportant. Indeed, that question must be solved as a prerequisite for any further arrangements. We do claim, however, that clarifying the value of the property rights involved can facilitate reaching a general peace agreement.

The following way of phrasing one of the central propositions above may be helpful here. As already discussed, the value of water in Gaza will be high. That reflects the fact that there is a large population and relatively little water in Gaza. *No matter who owns the water and no matter whether the cost is borne privately or publicly, Palestine will find it expensive to supply*

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13 And the value is unlikely to exceed $30 million per year by 2020.

its Gazan citizens with the water they must have. This is obvious if water has to be purchased from others, but it is also true and true in the same measure if the water is Palestinian. In that case, Gaza will be supplied by giving up the money for which the water could otherwise be sold. The expense will have to be incurred, *but it will be incurred regardless of the solution to the ownership question*.

In this connection, it is important to note the following. It must not be thought that the value or the price of water in any location merely depends on the cost of supplying it there. Such costs are indeed involved, but *scarce* water would have a positive price and a positive value even if there were no cost of extraction, purification, transport, and distribution. Scarce resources have scarcity rents reflecting the fact that there are competing demands for them.

No matter how the question of who *owns* the water is resolved, however, the question of who *uses* the water will remain a very important one. Here the model we have constructed should be useful in a different way, as we now outline.[14]

The model investigates that allocation of water that would be optimal for the peoples of the region, given social as well as

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[14] It must be remembered that this opening section is but a general summary. A full explanation of how the model works and how results are obtained is given in later sections.

private goals. A consequence of that investigation (as with any efficiency problem) is the natural appearance of prices associated with water in different locations. Those prices can serve as guides to rational water management either by individual entities or jointly.

One way to think about our model is to envisage a water authority jointly operated by (at least) Jordan, Israel, and Palestine. (This can happen only after ownership rights are established.) At the very least, some such joint arrangement will be necessary to monitor compliance with any eventual water agreement. We believe, however, that there would be considerable benefits to be gained from rational joint management of the water resources of the region. Such joint management would involve the transfer of water from one country to another at prices reflecting the full social value of water as determined by each side.

It is crucial to realize that such prices need not be those that would prevail in a private market for water. The deep social importance of water makes the question of who uses the water one that does not simply have a private answer. Rather, the answer depends on the values of the political entities involved. That is why we seek to construct demand curves that include national goals as revealed in national water policies. The prices at which water would be traded reflect those goals.

In this regard, it is important to recognize that when a political entity determines for itself how much water it demands at a particular price -- including the demand coming from considerations of national policy -- then that entity should be willing to sell additional water to a neighbor at that price or any higher one. If it does so, it can use the money obtained for greater social benefit than (*according to its own policies*) would be obtained from the water itself. In effect, the selling country has already said what additional water is worth to it. At that price, it must be indifferent between using and selling such additional water. If it wishes not to sell, then it has placed too low a value on the water, and the price should be adjusted upwards.

Our project does not suppose a world in which poorer countries necessarily sell their water to richer ones. Nor does it ignore the fact that all humans must receive at least that minimal amount of water required for a decent life.

Our model can be used as a guide in setting the prices involved in cooperative arrangements. Further, the model can forecast now what those prices might be in the future. Perhaps most important for future developments, it can serve as a guide to the wisdom of various proposed projects such as new canals, plants, or water import programs. To take imports as an example, since the model generates the equilibrium price of water at each location, it tells us the maximum price that the participating entities should be willing to pay for imports from outside (from the Litani or from Turkey, for example).

Of course, water management along the lines described above is not a simple matter. The water system of the area is complex, making precise modeling difficult. Further, policy makers faced with the demand-curve implications of their national policies may decide that national goals are not correctly reflected and may wish to change those policies. There will probably be a good deal of refinement and interaction between policy makers and technocrats, and that is all to the good.

It is also likely that there will be continuing interplay among the policy makers of the different entities. The issues involved in who uses the water do not go away because one has provided a systematic framework with which to deal with them. In particular, the national policies of one of the entities will affect the water prices and uses of another. A subsidy to agriculture in Jordan, for example, will generally lead to higher water prices in Israel and Palestine, and similar effects run the other way. This may seem to require continuing negotiations over what policies are to be regionally permitted.

Our model appears helpful in two ways in this regard. First, it permits a systematic investigation of the effects of the policies of any one entity on water prices, uses, and benefits in the others. This permits the focusing of the negotiations involved.

The second point is somewhat surprising. For reasons discussed in Part III, our results strongly suggest that effects of this sort are not very large. Further, a principal effect of subsidies appears to be a change in the balance of trade in water as the subsidizing entity imports more or exports less water from the others. (Which of the two alternatives applies depends on how the property-rights dispute is resolved.) This effect appears to dominate the others, making subsidies by one entity possibly beneficial to the others so far as water is concerned.[15]

Of course, this result depends -- as do our others -- on being able to think of water as something that has a price, considering the monetary equivalent of water. That, we know, is an unfamiliar way of thinking about water. To those who believe that water is beyond price, however, we pose the following questions:

Why does Jordan not desalinate water at Aqaba and pump it to Amman? Why, no matter how much or how little of the disputed water it receives, is it unlikely to make sense for Palestine to plan to desalinate water at Gaza and pump it to the cities of the West Bank? Why does Israel not desalinate water at Haifa and Tel Aviv? Why don't all the entities of the region plan on importing water from anyone who will sell it, no matter where located?

The answer in each case is the same. These actions are not or will not be taken because they would be too expensive. But then the value of the water at the places receiving it cannot be greater than the expense that producing at or transporting water to such places would entail. Note that this is so even if

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15 Note, however, that we have not explored effects on competition and trade in agricultural outputs.

(indeed, partly *because*) those places can be more cheaply supplied in other ways. If water were beyond price, this would not matter.

The fact that scarcity prices are inevitably associated with efficient allocation of scarce resources are among the central propositions of economic analysis. Water is not an exception.

2. The Analytic Separation of Issues and the Use of the Model: An Example

A specific example will probably be helpful here in understanding what our model can and cannot do. Moreover, that same example will highlight the separation of issues discussed above. This is important because it is very easy to lose sight of that separation.

Not surprisingly, the Palestinian and Israeli reports for this project differ in several respects. The most important one so far as water is concerned has to do with the water of the Mountain Aquifer. In particular, the Israeli report implies essentially the same pumping pattern as at present, while the Palestinian report has about 470 MCM more per year pumped in Palestinian districts and (by implication) about 470 MCM per year less pumped in Israel.

To focus ideas, we shall examine the various statements that may be implicit in the Palestinian Report. (An absolutely symmetric version would apply to Israel.) In placing the 470 MCM of water in dispute as to be pumped in Palestinian districts, one can be making any or all of the following statements, all of which may be correct:

(a) The water in question belongs to Palestine as of right.

(b) The most efficient places to pump the water are in the Palestinian districts indicated.

(c) It will be Palestinian policy to pump the water in those districts.

Here, statement (a) is a claim as to property rights; statement (b) is a proposition about economics and hydrology; and statement (c) is a declaration of national policy. It is important to understand that not only are these different statements, they are analytically independent.

To see this, consider first the relationship between statement (a), the property-rights claim, and statement (b), the proposition about efficiency. As discussed in detail above, such statements are independent. The location of the most efficient places to pump the water does not depend on who owns it. One should think of the owner of water who uses it himself as first selling the water to the system and then buying it back. This is because such an owner incurs an opportunity cost -- the cost of giving up the money that could have been made had the water been sold to others.

In more specific detail, it could be the case that Palestine owns the water but that the most efficient pumping locations are in Israel. In that case, Palestine would be paid for the water so pumped. (Recall that the model only permits water to be sold after national policies are incorporated in the demand curves.)

Note that this would involve using the pumping pattern of the Israeli Report with payments to Palestine. The matter is symmetric. Using the pumping pattern of the Palestinian Report does not itself imply that Palestine owns the disputed water.[16]

Statements (b) and (c) are also analytically independent. Regardless of whether or not it is more efficient to pump the water elsewhere, it could be Palestinian policy to pump it in Palestine.

Finally (although this is a bit harder to see), statements (a) and (c) are also analytically independent. Even if it did not own the water, Palestine might wish, as a matter of policy, to pump it in Palestine, paying the system at an appropriate price. (Israel might or might not be willing to agree to this.)

Now, by pointing out that these three statements are analytically independent, we do not mean to suggest that they are not important -- far from it. We merely hope to promote clear thinking about them and an understanding of what this project can contribute.

Begin with statement (a), the property-rights claim. Here, the model can value the rights involved. It can do so under a variety of scenarios and national policies. By doing so, we hope

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16 Of course, the authors of the two reports mean to assert their respective property-rights claims. The statements in the text do not contradict this.

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PART II

Model Description and Related Topics

1. What the Model Maximizes: Efficiency and Prices

We now turn to a general description of the model and its operation.[18] The model takes as given the costs of water production and transportation and the benefits of water use, including the social benefits as revealed by national policies. It then allocates water flows to locations and uses so as to maximizes the total net benefits of the water in the region. (In so doing, the model takes account of recycling plants and of the possibility of desalination plants, as described below.)

It is important to realize that the result of this optimization procedure can be described in several equivalent ways. First, technically speaking, the model allocates water to maximize the sum of producer and buyer surplus. (This is explained below.) Second, the allocation of water and the associated water (shadow) prices given in the model solution is such that, at those prices, noone would either wish to buy or to sell more water than he is allocated. In other words, the equilibrium prices as computed by the model fully reflect both the

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18 A more technical discussion will be given in an accompanying paper.

private and social values of using the water at the various locations. Anyone using water values each unit of that water at least as highly as the price at which it could be sold; anyone who does not purchase additional units of water values those additional units at less than the price at which those units could be bought. Equivalently, the prices and water allocations are those that a free, competitive market would reach *if the demand curves in that market were those that reflect national policies*.

Because these equivalencies are important to an understanding of the model, we discuss them further. We do so using the example of a single district with a single kind of private demand and water supplied only within the district (and not recycled).

The demand curve for any user -- and hence the demand curve for all users together -- shows how much water will be purchased at any price. Considered differently, the same curve (properly now called the "inverse demand curve") shows how much users would be willing to pay for each unit of water. That curve shows the value that users place on different amounts of water. Assuming that the inverse demand curve is downward sloping, users will be willing to pay more for the first units of water than they will pay for additional units.

Suppose that users are able to buy water at price P_c (Figure 1). They receive a "consumer surplus" from so doing. That is, they need only pay P_c for all units of water, whereas they would have been willing to pay higher amounts (given by the inverse demand curve) for some of those units. The shaded triangle-like area in Figure 1 measures the amount of consumer surplus so received. This is the full amount that users would have been willing to pay for water less the amount that they actually have to pay.

Now, it is obviously desirable to produce quantities and charge prices for water that generate large consumer surpluses (unless doing so conflicts with explicit national policies). The catch is that such production does not come without cost. It is easy to see, however, that any unit of water that can be provided to users at a cost lower than those users are willing to pay should be so provided.

This situation is represented in Figure 2. Here we have added the lower, step-like curve, representing the cost of supplying water in different amounts.[19] Plainly, the efficient quantity of water to provide is Q_c, corresponding to C, the point where the cost and demand curves cross.

In Figure 2, the shaded area represents both consumer and producer surplus. The latter is the amount received by producers above and beyond what would be required to induce production (i.e., their net profit). In the figure, this is the lower part of the shaded area (assuming water is priced at P_c). In general,

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19 The fact that the curve is step-like reflects the cost functions used in the model but is not required for the discussion in the text.

no matter what pricing arrangements are used, the entire shaded area represents the net benefits from water production and consumption. It measures (in monetary terms) the total benefits received by consumers less the social cost of providing those benefits.

Notice that the solution to the problem of how much water to produce can be represented in more than one way.[20] The first way is to say that production should be chosen to maximize the shaded area in the diagram -- the total net benefits of providing the water. This is the way the WAS algorithm (the algorithm used in our model) works. It represents the solution to a pure efficiency problem and can be stated without any reference to markets or prices.

A very important fact, however, is that efficiency problems have prices implicit in them even if they are not stated in terms of markets and prices. The second way to describe the solution to the problem shown is to observe that were water (in this example) bought and sold in a competitive market, then the cost curve would be the supply curve of water. The intersection of the two curves would then be the equilibrium outcome of the free market. Note that P_c, the vertical coordinate of that intersection turns out to

20 This corresponds to what is perhaps the deepest and most important result of microeconomic analysis, the equivalence between efficiency and equilibrium of competitive markets.

be the price which would, if charged to users and received by producers, lead the participants to act so as to generate the efficient solution (the production of quantity Q_c).

We now introduce the social value of water as revealed through national policies. To do this, it will be convenient as an expository device to think of the government as purchasing water from producers and reselling it to users. (This does not mean that we are recommending that this happen in practice; that may or may not be a good idea.) The national policy involved can then be represented by considering how the government behaves.

An example will make this clear. Suppose that the government decides to subsidize water by a fixed amount. Consider Figure 3. Here the solid sloping line starting at A represents the original private demand curve (not the same one as in Figures 1 and 2). The amount of the subsidy is the distance B-A. With water prices subsidized by this amount, users pay (B-A) less for each unit of water than they would have had to do without the subsidy. This means that, at each quantity, the amount they are willing to pay producers is greater than before by (B-A). Hence their inverse demand curve is shifted up by that amount and becomes the dotted line starting at B.

This dotted line is the demand curve that producers face. In effect, we can think of the government as buying the water according to that dotted line and then reselling it to users for (B-A) less than was paid for it to producers. The national policy has shifted the demand curve from the solid line starting at A to the dotted one. More generally, any national policy toward users that directly changes the price that they pay can be represented in terms of the effect it has on the demand curve as seen by producers.

Now consider consumer surplus once again. The amount that the *government* is just willing to pay for any unit of water is greater by (B-A) than the amount that users are willing to pay for it. Hence, if consumer surplus from buying a particular amount, Q, were some quantity, CS, total "buyer surplus" would equal CS + Q(B-A). The additional surplus reflects the social benefit of the water. More important, *the new demand curve and the buyer's surplus it generates measure the total benefits -- private and social -- from having the water*. This is because it measures the amounts that the whole society, acting through its government, is prepared to pay for the water.

Once one has realized this, however, it is evident how to proceed. Go back to Figures 1 and 2 and assume that the demand curve is not now merely the private demand curve but incorporates national policies. Then the solution to the efficiency problem remains one of maximizing the shaded area in Figure 2 -- maximizing the total net benefits of the water. This now means the benefits, *including the social benefits as embodied in national policies*, less the cost of providing those benefits. In fact, this is what the WAS algorithm does in our model.

Notice that the equivalence between the solution to the efficiency problem and the free-market intersection of supply and demand curves has now become the equivalence described at the beginning of this discussion. First, the model allocates water to maximize the sum of producer and buyer surplus. Second, the allocation of water and the associated water (shadow) prices given in the model solution is such that, at those prices, noone would either wish to buy or to sell more water than he is allocated. In other words, water values -- including social values -- are fully reflected in the prices. Anyone using water puts a value on each unit of that water that is greater than the price; anyone who does not purchase additional water values additional units of water at less than the price. Equivalently, the prices and water allocations are those that a free, competitive market would reach *if the demand curves in that market were those that reflect national policies*.

2. The Model Itself: An Overview

We now turn to a description of the setting in which the maximization of the sum of buyer and producer surplus takes place, to a closer description of the model itself. We shall describe the general framework of the model. Specific assumptions correspond to specific runs of the model and will be taken up in Part III. The model offers a flexible device for examining the consequences of changing or challenging those assumptions, and users are invited to do this.

Each of the three entities is divided into districts with transportation costs within districts assumed negligible.

(Jerusalem and the Golan are treated separately and are not assigned to any entity.[21])

The present version of the model is an annual, steady-state version. That is, the estimate of the available water supply from each source has been taken to be the replenishable amount of that source, and demand has been taken to be annual demand.

This does not mean that we take no account of changes, however. The model is used for population and demand conditions for 1990, 2010, and 2020, conditions for the latter years being forecast. In particular, we study the effects of different population projections for Palestine (low, middle, and high[22]) and

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21 The reason for this separate treatment is that our project cannot possibly decide the eventual political fate of these districts. It should be noted that the Jerusalem district includes not merely the city proper but also the surrounding area claimed by Israel to be part of Jerusalem. We intend no statement on that claim either. From the point of view of the project, the people in the district must receive water. That is true no matter what the governmental arrangements, and this is all that matters here.

22 The Palestinian country report provides these three projections which are reflected in the data appendix. The results reported in Part III, however, only use the middle and high growth

also the effects of different assumptions about what facilities are in place in future years.

The fact that the model is an annual, steady-state one does limit what is studied at this stage, however. Thus, no attention has been paid to intra-year variations in supply or demand nor has any account been taken of the effects of one year's actions on later years. Further, we have not taken the stochastic nature of rainfall into account, although we have done runs representing unusually dry and unusually wet years. We plan to expand our analysis to deal with intertemporal and stochastic phenomena at a later stage, but believe the current results to be of substantial interest on their own.[23]

The model allocates water to locations and uses (and finds the associated prices) so as to maximize the total net surplus derived from water as measured using national policy demand curves. It takes as given the costs of supply, transport, recycling, and desalination. It also takes as given the private demand curves for each district and the national policies specified for the run.

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scenarios.

23 The model currently only permits one quality of fresh water (and also recycled water). This too can be altered with future research.

The general constraint under which the model optimizes is that, for each district, water consumed must equal water produced plus water imported from other districts less water exported to other districts. Such a constraint applies both to fresh and to recycled water (about which more below).

The demand and supply estimates are taken from the country reports.[24] Many of the interesting runs for future years, however,

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24 Demand curves are assumed to have constant elasticities (-.2 for households, -.33 for industry, and -.5 for agriculture). They are then calibrated so that, at 1990 prices, they yield the quantities demanded given in the country reports for each year.

In a number of cases there was more than one price charged. We approximated the necessary prices as follows: $.90/m^3 for households in all countries, and $.144/m^3 for industry except in Jordan, where we used the cost of pumping groundwater (because industry uses private wells). For agriculture, we used $).173/m^3 except in Jordan. In Jordan, we used $.90/m^3 for all districts except the Jordan Valley. In the latter district, we used $.009/m^3 (approximately 6 *fils/m*^{3}) and adjusted the quantity demanded to take account of the fact that not all water that would be demanded at that price was actually so available. (The data appendix gives more details.) Note that because elasticities are low results are not sensitive to the choice of prices used for calibration..

modify the existing situation so as to be able to ask what would happen if various things were done. This is done for recycling, for transportation, and for desalination. (Again, the model offers a flexible opportunity to change assumptions; one must not believe that the only results possible are those reported below.)

There are three topics that require some discussion. These are: the treatment of the hydrology of the Mountain Aquifer; the treatment of recycling; and the treatment of capital costs.

3. The Hydrology of the Mountain Aquifer

An additional important constraint that needs to be taken into account is the physical one provided by the hydrology of the Mountain Aquifer. As already discussed (and as is not surprising), both the Palestinian and the Israeli reports list the water of the aquifer as capable of being pumped in their districts. The amount of water so double-counted is approximately 470 million cubic meters per year.

Obviously, the same water cannot be pumped in two places at the same time (or in a steady state). A full treatment of what is involved here appears to require a hydrological analysis in which the costs of pumping at any location is given as a function of the rates of pumping at all locations. Our model could then optimize taking such interdependence into account.

The construction of such a model is underway and will be incorporated when ready. We can, however, make some progress in the right direction without waiting for a full model.

We do this simply by imposing the constraint that the same water cannot be pumped in two places. We have assigned Palestinian and Israeli districts into sets with the total Mountain Aquifer water pumped in each set fixed.[25] The model chooses optimal pumping patterns subject to this constraint.[26]

4. Effluent Charges and Recycling Profits

As already indicated, the model permits the use of recycled water. It does so by permitting the user to specify for each type of consumer the maximum percentage of the water used that can be collected for recycling. Naturally, this requires determining where recycling plants exist or are to be located.

In the model runs reported below, it is assumed that recycled

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25 The sets are: 1. Jenin, Hadera, and Afula; 2. Tulkarem, Nablus, and Netanya; 3. Ramallah, Bethlehem, and Ramla; and 4. Hebron, Lachish, and Negev. As described below, the tables presenting the results give not only the water pumped from the Mountain Aquifer in each district but also the maximum amount permitted to be pumped there (taken from the country reports).

26 The model also permits the imposition of the pumping patterns given in the Israeli or Palestinian report (labeled "Low Aquifer Pumping" and "High Aquifer Pumping", respectively), but the runs discussed below do not do this.

water comes only from households and industry and is used only by agriculture.[27] Recycled water is assumed usable either in the district of origin or in districts to which it can be transported. In general, this means transportation from Tel Aviv to Lachish and the Negev and transportation from Amman to the Jordan Valley. We also perform runs for future years in which recycling plants are assumed to be located near major West Bank cities and transported to the Jericho district and in which such a plant is located in Gaza and can send water to the Negev.

In assessing whether recycled water is worth producing, the model takes into account the fact that the water involved would in any case have to be treated to a level permitting environmentally safe disposal. We impose effluent charges of $.30 per cubic meter on household and industrial consumption. Recycling costs are taken as an additional $.10 above this.[28]

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27 No attempt has been made as yet to segregate types of agriculture into those that can readily use recycled water and those that can not. This can certainly be done if the appropriate information on demands and cropping patterns can be collected.

28 As with all parameters, these can be changed by the user. The figures mentioned are those supplied for Israel. Jordanian figures are not yet broken down into such effluent and recycling components. For at least some of the Jordanian waste water

One should note, however, that there can be costs of water usage even where the water is not retreated. This is because untreated waste water can have environmental consequences. Thus, in the runs reported, we have imposed the same effluent charge of $.30 per cubic meter in every district whether or not the district has a water treatment plant.

It is important to understand that the imposition of effluent charges and the possible profitability of recycled water influences the prices paid by water consumers in the model. Indeed, those phenomena lead to a difference between the shadow price of fresh water -- implicitly, at least, the price received by water producers[29] -- and the prices paid by water consumers.

For the moment, assume that water is not recycled and consider only effluent charges. The shadow price of the fresh water in a given district reflects the additional net benefit that would be obtained if another cubic meter of that water were

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plants, the sum of the two Israeli costs seems pretty close to the total operating costs. Model users can easily experiment with other figures.

29 Where water is locally produced, this price can be thought of as the price received by local producers. Where water is transported into the district in question, the price includes transportation costs.

available on the surface in that district. But that net benefit consists of the price consumers (or the government) would be willing to pay for the water *less* the cost represented by the effluent charge. Hence the price paid by consumers will exceed the shadow price of the fresh water by the amount of the effluent charge.

Another way of saying this is that efficiency requires that those uses leading to effluent costs should be discouraged by being charged those costs.[30]

Now consider the profits from recycling. Here consumption of fresh water by households, say, results in a net benefit that is in addition to that reflected by the price the households are willing to pay, the benefit reflected by the fact that recycled water is profitable. As a result, efficiency requires that household (or industry) prices be reduced by the profit per cubic meter consumed involved in recycling.[31]

Another way to say this is that, if recycled water is

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30 It may perfectly well be government policy not to do this in practice. In such a case the prices paid by consumers will be set by national policy. The model can handle this case, but it is only confusing to discuss it here.

31 Because not all consumed water is captured for recycling, this is not the same as the profit per cubic meter recycled.

profitable, one wants to encourage its production and this means encouraging fresh water consumption by those consumers whose waste water goes to recycling plants.

Obviously, if effluent charges are large relative to recycling profits per cubic meter consumed, the net effect will still be to make the prices paid by consumers greater than the shadow price of fresh water. But the presence of recycling profits will reduce the size of the effect.

The fact that recycling profits lead to a reduction in the price paid by consumers has an interesting corollary. Placing a profitable recycling plant in operation lowers the price paid by the consumers whose water is recycled, but it actually *raises* the shadow price of the fresh water in the district -- the price received by producers. As we shall now see, that means the price seen by producers of fresh water goes up[32] but the price as seen by users of fresh water that can be recycled goes down.

To see how this happens, consider the following simplified example. Assume that there is only one district and only one type of consumer. Thus, with recycling, that consumer type both supplies and uses recycled water. Assume that the recycling profits per unit of fresh water used are a fixed amount.

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32 As discussed in a moment, this does not take into account the fact that the recycled water will compete with the fresh water in agriculture.

Consider Figure 3 once again. Let the inverse demand curve be the solid line starting at A. Let the fixed amount of profits per consumed unit be represented by (B-A). Then the presence of such profits makes it efficient to reduce the price to consumers by (B-A). Like a governmental subsidy, this shifts the demand curve to the dotted line starting at B. Since the supply curve is upward sloping (the cost of producing additional units of fresh water rises as more is produced), the equilibrium price of fresh water *as seen by producers* (the shadow price) rises from G to F. So long as the demand curve is downward sloping and the supply curve is upward sloping, it must turn out (see the diagram) that (F-G) is less than (B-A). So consumers experience a net decrease in price and producers have a net increase. Effectively, the profits from recycling are shared, and both sides gain.

Another way to think about this is to observe that the presence of a profitable recycling plant makes fresh water more valuable in terms of the benefits it brings. This means that its use should be encouraged. But the increased shadow price that reflects the increased value will *discourage* consumption if consumers have to pay it. As the diagram above shows, the solution is a sharing of the increased benefits with consumers experiencing a net price *decrease* which encourages greater consumption.

Of course, there is another effect on fesh water prices, however. The fact that recycled water provides a substitute for fresh in some uses reduces the demand for fresh water, and this lowers the fresh water price. Which of the two effects dominates is an empirical matter.

5. The Treatment of Capital Costs

As is evident, many of the runs of the model involve experimenting with new projects involving capital as well as operating costs. This is true not only of recycling plants but also of pipelines and desalination plants, for example. The question thus naturally arises as to how (or whether) to take capital costs themselves into account.

To fix ideas, we consider the case of a pipeline as an example, but, of course, the principles are not so restricted. We assume that the capital costs in question do not vary with use in the short run. In other words, costs that vary with the flow through the pipeline are considered operating costs in this memo even if they include maintenance. Of course, capital costs will vary with use in the long run in the sense that the size of the pipeline may depend on the amount of long term demand.

First consider the case in which a pipeline has been constructed and the capital costs already expended. Suppose, to begin with, that if only marginal operating costs are charged for in the price of the water, the pipeline will not be used to capacity. In this case, it is inefficient to charge for the capital costs in the price of the water. The proper charge for the water is merely marginal operating costs per cubic meter.[33] Any higher charge will reduce water consumption at the margin, even though marginal users are willing to pay marginal costs so that they can be made better off without anyone being made worse off and net benefits increased.

An analogous case is the example of a bridge with the property that, once the bridge is built, it costs nothing to use and its capacity is not reached by the traffic over it. Once such a bridge is in existence, it is not efficient to charge a toll for its use, since such a toll will reduce the usage of a then costless facility..

On the other hand, bridges yet to be built and pipelines yet to be constructed or replaced must have their capital costs met from somewhere. The question is where and how this should occur and how we should proceed in the model.[34]

Consider a pipeline that does not now exist but which may be

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[33] These costs should include opportunity costs -- what the water is worth in its next best use. The model does this. There is no point in discussing this issue here.

[34] The basic analysis involved here stems from an article by Harold Hotelling, "The General Welfare in Relation to Problems of Taxation and of Railway and Utility Rates," *Econometrica* 6 (1938), pp. 242-69.

constructed in the future. Suppose that, once it is constructed, the demand for its use at a price equal to marginal operating costs does not reach its capacity. In such circumstances, the pipeline, once constructed, fits the case already considered. Hence it cannot be optimal to plan to recover the capital costs of such a pipeline in the price of the water.

The catch here lies in the assumption that the pipeline will not be used to capacity at a price of marginal operating costs. Suppose that this is not the case, so that the capacity of the pipeline will be a constraint on its use. In that case, optimal pricing requires charging a water price equal to marginal operating costs *plus the shadow price of the pipeline-capacity constraint*.

How does this relate to capital costs? It can be shown that optimal capacity *planning* involves building pipeline capacity to exactly the point where the present discounted value of such capacity shadow prices equals the marginal capital cost of the pipeline.[35]

Hence, capital costs of facilities should be charged for in water prices; they appear in the shadow prices on facility

35 Here the optimization problem involved is that of maximizing the present discounted value of all future buyer and producer surpluses. This is not done explicitly in the current version of our model which deals with one year at a time.

capacities. This has several consequences for our analysis.

First, note that it is not optimal to make capital charges per cubic meter the same at different moments of time. Aside for the necessity to allow for discounting, the shadow price of the capacity constraint for a given facility is most unlikely to be the same in different years. The strongest example of this is that of a facility that is designed for a large throughput expected to be encountered some years in the future but is put in place some years before demand is expected to reach capacity. (This can easily occur if it is efficient to build a large facility once rather than building a middle-sized one early and then later enlarging it.) In such a case, the capacity shadow price will be zero in the early years. All capital costs will be assigned to users in the later years for which the large capacity was designed.

Note that, in terms of our model, we do not have to worry about how to allocate capital costs to different years. All we need is the capacity of the project involved. With that capacity imposed as a constraint on the model, the optimization procedure itself will generate the shadow price of that constraint and will include it in the price of the water.

To take a specific example, with current facilities, the pipeline that brings water to Amman from the Jordan Valley district of Jordan is used to capacity. That capacity has a positive shadow price, and the results in Part III show that that price will be enormously higher in the future if capacity is not expanded. As we shall see in the results, that fact is a principal reason that the high shadow price of water in Amman fails to be fully reflected in the shadow price of water in the Valley.

As we shall see in the model results below, this situation makes the expansion of the pipeline involved a prime target for investigation as a capital project. Such expansion should be undertaken if the present discounted value of such shadow prices exceeds the marginal capital cost of pipeline expansion. The optimal size for expansion is reached when that present value just equals marginal capital cost.

There is another way of using the model to see if a projected facility should be built. That alternative way has the (possible) advantage of not requiring estimation of marginal capital costs. It also avoids certain technical problems with the previous analysis which can arise if facilities are subject to large economies of scale in construction.

We can proceed as follows. Define the facility and its size. Run the model both with and without the proposed facility. The facility is worth constructing if and only if the increase in the sum of buyer and producer surplus[36] caused by the facility

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36 As always, buyer surplus involves the area under the national policy demand curves. It involves social gains as measured by national policy, not just pure consumer surplus.

discounted at an appropriate interest rate over the life of the facility exceeds the capital costs of construction.[37] (The same principle applies when considering whether or not an existing facility is worth replacing.)

Now, if the facility is not worth constructing on this criterion, then the capital costs should not be expended and need not be raised. If the facility is worth constructing, then the capital costs should be expended. In that case, we know that there exists *some* way of raising the necessary funds and making everyone at least as well off as before.[38]

There are then two possibilities. In the simplest case, the discounted value of the revenue recovered by including shadow prices of the facility-capacity constraints in water charges will cover the capital costs of the facility. Essentially, this is the case already discussed.

If there are sufficiently large increasing returns in

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37 More generally, if the discounted additions to surplus exceed the discounted stream of all capital costs associated with the pipeline.

38 Note, however, that it would take a series of these runs to find the optimal capacity for the facility. One can also adapt the model to find optimal capacities directly, but this is left to a later stage where interyear effects are taken into account.

facility construction, this may not happen, however. In that case, it is suboptimal to cover all the capital charges in the water rates. Rather those rates should continue to include the shadow prices of the capacity constraint, as before, and the shortfall should be made up in a different way. This can be done, for example, with an annual hook-up charge for users of the facility with the charge not affecting the marginal use of water.

We need not worry further about such problems at this stage, however. We can run the model with (and without) facilities of particular capacities and include the appropriate capacity charge in water prices. Indeed, in the results below, we run the model assuming that capacity constraints are not binding for new projects, so that capacity charges are zero for the years in question. It is evident from the results that some projects merit considerable further investigation, while others seem less promising. Full investigation of promising projects requires more model runs and explicit estimation of the capital costs involved.

PART III

Results and Conclusions

1. Scenarios and Terminology

We are now ready to discuss the principal results obtained. In doing so, understanding will be facilitated if we define some terminology.

The model runs performed vary in several respects. One of these involves the capital facilities assumed to be in place. We vary these in four principal ways and give those ways the following names:

1. Current. In the "current" scenarios, only pipeline and recycling facilities actually now in place are assumed. (Desalination is assumed possible at a cost of \$.80 per m^3, but this does not matter until 2020, as discussed below.)

2. Current+. In the "current+" scenarios, we add the possibility of bringing water from the Sea of Galilee to both the Jordan Valley region of Jordan and the Jericho region of Palestine at a cost of \$.08 per m^3. This cost can be thought of as that of operating a pipeline or of other arrangements for the Jordan riverbed. It should be noted that at a lower cost, the results would be stronger.

3. Plausible-. In the "plausible-" scenarios, we additionally remove the capacity constraints on the pipelines in Jordan that carry water from the Jordan Valley to Amman and permit water to be carried from the Jordan Valley to the Northern Highlands. We also include a pipeline connection between Amman

and the Northern Highlands.

4. Plausible+. Finally, in the "plausible+" scenarios, we add certain recycling plants and pipelines to the facilities of the plausible- scenarios. These recycling plants are in the major cities of the West Bank with pipelines leading to the Jericho district, in the Northern Highlands of Jordan with a pipeline to the Jordan Valley, in Haifa with a pipeline to Afula, in other points in with pipelines leading to the Lachish district, in that district with a pipeline to the Negev, and the Negev, in Gaza with a pipeline leading to the Negev and in Jerusalem with the water used only locally.[39] All recycled water can also be used locally. We also remove all capacity constraints on pipelines.

Unless otherwise stated, all runs reported assume 250 mcm per year of Yarmouk water available for use in the region.[40] Up to 100 mcm per year can be taken by Jordan and brought to the Jordan Valley district (the King Abdullah canal) at a cost of $\$.12/m^3$[41]. The remainder[42] can be used in three ways: by Israel at Bet Shean

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39 A more detailed description is given below.

40 Effectively, this means 250 mcm per year not taken in Syria and not needed to preserve the level of the Dead Sea.

41 All prices and monetary values are in 1990 dollars.

42 In practice, it always proves efficient for Jordan to use the

(cost $\$.05/m^3$), by Palestine in Jericho ($.13/mcm) or by Jordan again in the Jordan Valley ($\$.13/m^3$). Obviously, these latter ways involve taking the water from flow down or parallel to the Jordan riverbed, but this need not literally be the case. Effectively, we simply permit Yarmouk water to be lifted at the costs stated, constraining the total as stated.

Of course, users of the model are encouraged to explore other scenarios.

2 The Value of the Water in Dispute

Our first principal focus, of course, is on the value of the disputed water. We give this in two ways for each of the three major water sources involved (the Jordan, the Yarmouk, and the Mountain Aquifer). The first way is in terms of the price per cubic meter of the water *in situ*. In the case of the Jordan, this is the value at the Sea of Galilee. In the case of the Yarmouk and the Mountain Aquifer, this is the average value in the river at the different extraction sites.[43]

The second way is in terms of total value per year. To fix

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first 100 mcm, taking it as described, but this is not assumed *a priori*.

43 The average is taken weighting by the amounts extracted.

ideas, we multiply the price of water in the Sea of Galilee and in the Mountain Aquifer by 400 m^3 per year and the price of Yarmouk water by 250 m^3 per year. While these are not precisely the quantities in dispute, they are close enough to give an idea of what is involved. Since we give the prices, totals for any other quantities can easily be derived by the reader.

Prices and values are in 1990 dollars.

The results are as follows for the three different years.

1. 1990. Only the current and current+ scenarios were run for this year, since it is already past. There was no difference in results as to disputed water prices between the two scenarios. Prices per cubic meter were as follows:

Table 1a

Value of Disputed Water: 1990 (1990$/$m^3$)

Current and Current+ Scenarios

Sea of Galilee	.176
Mountain Aquifer	.091
Yarmouk	.030

As we shall see, the reason for the low price of Yarmouk water when much of it is available is that the facilities to use that water efficiently are not available in these scenarios.

Transforming these into total values per year as described above, we obtain:

Table 1b

Total Value of Disputed Water: 1990 (millions of 1990$/year)

Current and Current+ Scenarios

Sea of Galilee	70
Mountain Aquifer	36
Yarmouk	7.5

2. 2010. Here the the plausible- and plausible+ scenarios come into play. The middle Palestinian growth scenario is used.

Table 2a

Value of Disputed Water: 2010 (1990$/m^3)

Middle Palestinian Growth Scenario

	Current	Current+	Plausible-	Plausible+
Sea of Galilee	.365	.365	.408	.298
Mountain Aquifer	.292	.292	.338	.222
Yarmouk	.021	.034	.362	.252

Note that the capital facilities available make quite a difference; we comment on this below.

The corresponding total values per year are as follows.

Table 2b

Total Value of Disputed Water: 2010 (millions of 1990$/year)

Middle Palestinian Growth Scenario

	Current	Current+	Plausible-	Plausible+
Sea of Galilee	146	146	163	119
Mountain Aquifer	117	117	135	89
Yarmouk	5.2	8.5	90	63

3. 2020. Here, for reasons explained below, there is no interest in either the current or the current+ scenarios. We again give the range of values for the other scenarios. We begin with the set of results for the middle Palestinian growth scenario.

Table 3a

Value of Disputed Water: 2020 (1990$/$m^3$)

Middle Palestinian Growth Scenario

	Plausible-	Plausible+
Sea of Galilee	.578	.516
Mountain Aquifer	.518	.452
Yarmouk	.532	.470

The corresponding total values are as follows.

Table 3b

Total Value of Disputed Water: 2020 (millions of 1990$/year)

Middle Palestinian Growth Scenario

	Plausible-	Plausible+
Sea of Galilee	231	206
Mountain Aquifer	207	181
Yarmouk	133	118

Here, however, we encounter a new phenomenon. The results for 2020 (but *not* those for 2010) depend on the assumed cost of desalination at $.80/m^3. While that cost may be achieved by 2020, it is nevertheless prudent to give the results for a higher desalination cost. We choose $1.50/m^3.[44] Only the plausible+ scenario was run.

The results are as follows:

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44 Still higher costs would make no difference (for the middle Palestinian growth scenario), since, save at Aqaba, we do not find desalination efficient at $1.5/m^3. This is not true of the high Palestinian growth scenario, however. We discuss desalination separately below.

Table 3c

Value of Disputed Water: 2020

Middle Palestinian Growth Scenario

Desalination Costs of $1.50/m^3

	1990$/m^3	millions of 1990$/year
Sea of Galilee	.628	251
Mountain Aquifer	.570	228
Yarmouk	.582	146

Finally, we also ran scenarios with the high Palestinian growth scenario.[45] These made no difference (as compared with those of the middle Palestinian growth scenario) in the value of the disputed water for the case of desalination costs at $.80/m^3 but did change things substantially for the case of desalination costs at $1.50/m^3. This is because the lower limit already bounds the value of water in the middle Palestinian growth scenario, while the upper does not. Again, only the plausible+ scenario was

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45 In general, unless the context makes it clear otherwise, all discussion in the text of results for 2010 and 2020 refers to results obtained using the middle Palestinian growth scenario.

run.

The results are as follows:

Table 3d

High Palestinian Growth Scenario

Desalination Costs of $1.50/m^3

Value of Disputed Water: 2020

	1990$/m^3	millions of 1990$/year
Sea of Galilee	1.099	440
Mountain Aquifer	1.065	426
Yarmouk	1.023	256

These are the highest values obtained for the disputed water. They result from a combination of extreme assumptions -- the high Palestinian growth scenario and high desalination costs even in 2020.

The more likely outcome is less extreme. Summarizing the results for the middle Palestinian growth scenario we obtain the following (where the low end of each range comes from the plausible+ and the high end from the plausible- scenario)[46]:

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46 The results for 1990, of course, come from the current or current+ scenarios.

Table 4

Total Value of Disputed Water: (millions of 1990$/year)

	1990	2010	2020
Sea of Galilee	70	119-163	206-231
Mountain Aquifer	36	89-135	181-207
Yarmouk	7.5	63-90	118-133

These seem the most likely of our results, although the projection for 2020 is naturally in some doubt. In any event, the qualitative conclusion to be drawn seems clear and would be no different were we to take the extreme estimates of Table 3d.

These are not negligible numbers.[47] But they are not so high

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[47] We have refrained from expressing these results as present values. We do so for several reasons. First, the discount rate to use is in doubt. (Note that, since we work in constant dollars, it would have to be a real, rather than a nominal discount rate.) Second, the quantities of water in dispute have only roughly been approximated and, in some cases, probably overstated. Third, what really matters is the annual value relative to the size of the economies involved. To express the

as to form a barrier to a peace agreement. Relative to the economy of the region and its probable growth, they are small indeed, far less than one percent. They are also very small relative to the cost of a single day of war.[48]

3. Water for Human Consumption: Will There Be A Drinking Water Crisis?

We now turn to other aspects of the results. The first of these has to do with the most important use of water -- its consumption by households. Does our model suggest that this will be a problem in the years to come?

Another way of getting at the same concern is to ask the following question. Our model envisages trade in water. Do the results obtained involve depriving poorer households (or nations) of the water needed for a decent existence?

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value as a capital sum would produce a number too easily and misleadingly quoted.

48 In this connection, consider the 50 mcm annually that the Israeli-Jordanian treaty calls for Israel to provide. The value of that quantity depends on where it comes from, but seem unlikely to exceed roughly $9 million per year currently, $20 million per year in 2010, and $29 million per year in 2020.

The answer to these questions is resoundingly "No!". With one exception, our runs show water prices to households close to (or even below) current levels[49] and future water consumption per capita well above current levels for Jordan and Palestine. Indeed, Palestinian per capita consumption is predicted to be roughly equal to that of Israel by 2010. This fails to happen for Jordan not because of the system of trade but because the Jordanian country report does not predict so high a per capita demand at current prices as do the two other reports.

Moreover, the exception mentioned is extremely interesting, for it turns out to have nothing to do with water ownership or water trade. It is well worth discussing in detail.

A glance at the results for 2010, for either the current or the current+ scenario, shows a major crisis in the Amman and Northern Highlands regions of Jordan. Whereas the scarcity price of water everywhere else in the system tends to run from \$.40-\$.70 per cubic meter, the scarcity price in Amman is \$8.96/m^3, while that in the Northern Highlands is \$17.70/m^3! The price to households in Amman is somewhat less (\$8.64/m^3) than the scarcity price of fresh water because of the large profits to be made on recycled water in this crisis situation.

How can this be? At first glance, such results seem at odds

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49 The household demand curves were calibrated at \$.90/m^3.

with our findings on the value of disputed water. Does not this mean that water will be very valuable by 2010? Does this not give Jordan (or others) a major interest in the ownership of the disputed water?

To see that this is not so only requires a look at the plausible- scenario. In that scenario, it is assumed that the capacity of the pipeline carrying water from the Jordan Valley to Amman has been greatly expanded, so that there is no longer a capacity constraint. It is also assumed that there are pipelines connecting Amman and the Northern Highlands and the Jordan Valley and the Northern Highlands.[50] When this is done, the crisis disappears. The scarcity price in both Amman and the Northern Highlands drops to $.72/m^3, while the price to households in Amman becomes only $.48/m^3. The conclusion is very clear. *Water is not the truly scarce resource here. The truly scarce resource is the ability to transport water to the affected districts.* Without such transportation facilities, it does not alleviate the crisis in Amman at all for Jordan to obtain (still less to own) additional quantities of the disputed waters. The fact that water will be scarce in Amman will not make water in the Jordan Valley more valuable, because the pipeline to Amman is already predicted to be used to capacity.

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50 The latter pipeline is unused in this scenario.

This is reflected in the fact that the immense reduction in price in the two affected districts does not correspond to a similar increase in the price of the water in dispute. As Table 2a above shows, the effects of adding the pipelines that relieve the crisis is to increase the value of water in the Sea of Galilee and the Mountain Aquifer by only about $\$.04/m^3$. (The value of Yarmouk water increases by $\$.32/m^3$, but, as explained in the footnote, this is somewhat misleading.[51])

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51 The value of Yarmouk water is very low in the current and current+ scenarios because neither Jordan (as explained above) nor Israel have the capacity to transport that water to areas with relatively high prices. If Israel, but *not* Jordan builds such capacity, the value of Yarmouk water rises substantially. In a special scenario (current++), we remove constraints on the ability to transfer water from Bet Shean to the Kinneret district. This raises the value of Yarmouk water by $\$.25/m^3$, producing an increase nearly as large as that of opening pipelines to Amman and the Northern Highlands. (When both Israel and Jordan improve their transportation facilities as described -- the plausible-* scenario -- the value of Yarmouk water is the same as when Jordan alone does so.)

We should remark that we understand that transfer of Yarmouk water from Bet Shean to the Sea of Galilee is both seasonal and

Evidently, Jordan should seriously consider adding pipeline capacity to bring water up from below.[52] While we have not investigated the question of how much capacity should be added, the model can be used to address this point.[53]

Thus the potential crisis in and around Amman is a crisis of transport facilities and (except superficially) not of water. In this connection, it is interesting to observe that the other city in which one might expect a crisis -- the city of Gaza -- does not have one in the model predictions.

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limited in years in which water is plentiful. The special scenarios described in this footnote are intended only as illustrative of the effects of improving utilization of Yarmouk water in Israel rather than a recommendation as to how such improvements should be done.

52 In the plausible+ scenario (considered below), additional water also comes to Amman from the Dead Sea district and to the Northern Highlands from Azraq through expanded pipelines. Those expansion should also be considered.

53 As with the runs for 2010, the current and current+ runs for 2020 show that, without such capacity additions, there will be no feasible solution to the model at prices below \$10/m^3. We do not bother to present these runs.

The reason for this is not hard to find. Gaza does not have the same shortage of transport facilities for water that Amman does. Indeed, Gaza can be served through the Israeli National Water Carrier. The model shows this to be efficient in the absence of additional transportation systems, and, unlike the case as regards Amman, the results do not suggest that such facilities need to be built.

To sum up: There is no crisis in water for human consumption anywhere in the region except in Amman and the Northern Highlands. The possible crisis there has nothing to do with ownership or trade in water but with the lack of transportation facilities.

This does not mean that the region will not have a water problem, however. That problem will come in agriculture.[54]

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54 In this connection, note that the building of pipeline facilities to relieve the household crisis in Amman would raise the price of water in the Jordan Valley district from $.16/m^3 (current+) to $.49/m^3 (plausible-). (Note also, however, that the building of facilities by Israel to use Yarmouk water more efficiently, as described in an earlier footnote, would by itself raise the price in the Jordan Valley to $.40/m^3.)

4. Agriculture and Recycled Water

The matter here is simple to state and not very surprising. While there will be enough fresh water for domestic consumption at reasonable prices, the price of fresh water will prove a serious burden to agriculture.[55] It is at best a small exaggeration to state that agriculture will survive unsubsidized only if it can use recycled water -- and even then there will be problems.

This means that we must investigate two aspects of the water problem in agriculture. The first of these, that of the effect of recycling, we discuss now. The second, that of national policies, we consider later.

The effect of recycling can be examined in our results by

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55 The model shows a major reduction in the consumption of water by Israeli agriculture (using the current scenario for 1990 and the plausible- scenario thereafter). The moderate growth shown for Jordan and Palestine is in part a function of improved transportation facilities and in part perhaps due to optimistic predictions in the country report. In any case, that growth would be higher were future prices lower, and a serious problem will certainly arise.

looking at the differences between the plausible- and plausible+ scenarios. Recall that the underlying difference between the assumptions used in these scenarios is in the extent of recycling facilities assumed to exist.[56] In the plausible- runs, only existing recycling facilities and pipelines are assumed. In the plausible+ runs, we add recycling facilities. In every case, the recycled water can either be used locally or transported as about to be described.

We add recycling facilities in Haifa, with a pipeline to Afula, in Netanya, with a pipeline to Lachish and to the Negev, and in Lachish, with a pipeline to the Negev.

We add a facility in Jerusalem for local use only. We add recycling facilities in both Gaza North and Gaza South, with pipeline connections to the Negev. We add recycling facilities in Nablus, Ramallah, Bethlehem, and Hebron, with pipeline connections to the Jericho district.

Finally, we add a recycling facility in the Northern

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56 Capacity constraints on pipelines are also relaxed in the plausible+ scenario, but this plays no role save in transport of water from Jerusalem to Bethlehem and Hebron, of water from the Dead Sea district to Amman and from Azraq to the Northern Highlands. These transfers have little to do with the principal effects found in the plausible+ scenario.

Highlands of Jordan with a pipeline connection to the Jordan Valley.[57]

Of course, it may not be efficient to build all these plants and pipelines; that must be investigated. Note, however, that neither the Negev nor the Jericho district has a groundwater aquifer that can be polluted by the use of recycled water. It is assumed in the model runs that all agriculture can use recycled water. This is not true. Further exploration along these lines requires separating water demand estimates by type of crop.

Despite the theoretical possibility that the opening of recycling facilities can raise the scarcity price of fresh water, this does not happen. The following table gives the average fresh water scarcity prices for the plausible- and plausible+ scenarios.

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57 The term "pipeline connection" in the above should be understood as meaning some sort of transport facility, not necessarily an actual pipeline.

Table 5

Effect of Recycling on Average Fresh Water Scarcity Prices

Middle Palestinian Growth Scenario (1990$/$m^3$)

	2010		2020	
	Plausible-	Plausible+	Plausible-	Plausible+
Israel	.66	.50	.84	.68
Jordan	.72	.64	.81	.77
Palestine	.81	.56	.98	.75

Evidently, the effect of recycling is substantial. Not surprisingly, it is greatest for Palestine where the major new recycling plants are assumed to be located.

The effect of additional recycling is greatly to lower the price to agriculture. In certain districts, the magnitude of the reduction is much greater than that shown in Table 5. To take some of the outstanding examples, in 2010, with 250 mcm of Yarmouk water, the effect of recycling is to lower the price paid by agriculture in the Nablus, Ramallah, Bethlehem, and Hebron districts from \$.58-\$.66 per m^3 to \$.10/m^3. (The price to agriculture in the Jericho district falls from \$.28/m^3 to \$.10/m^3.) The effects in Israel are not so great, largely because of the current existence of recycling plants. The effects in Jordan are also more limited, since the scenario only involves one new Jordanian recycling plant.

The principal recipient of recycled water produced elsewhere is the Negev which uses 137 mcm per year of recycled water. The price there drops from $.68/m^3 to $.29/m^3. Interestingly, 58 mcm per year of the recycled water used in the Negev comes from Gaza.

In 2020, the effects are even stronger, as we should expect. When the recycling facilities are added, the price paid by agriculture on the hills of the West Bank drops from $.76-$.85 per m^3 to $.12/ m^3. (The price paid in Jericho drops from $.30/m^3 to $.13/m^3.[58])

The price paid in the Negev drops from $.86/m^3 to $.20/m^3, as the district uses 164 mcm per year. The major part of this 109 mcm per year) comes from Gaza.

All this suggests that the provision of additional recycling facilities may be quite important (although the assumption in the runs that all agriculture can used recycled water is too optimistic). Indeed, all the assumed new recycling facilities are

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[58] Incidentally, Jericho is the serious agricultural area with the lowest fresh water price in all predictions. The Jordan Valley district of Jordan is typically next without the added recycling facilities, but not with them. Recycling lowers the price there in 2010 from $.49/m^3 to $.38/m^3 and in 2020 from $.66/m^3 to $.60/m^3. The results suggest that the Jordan Valley district will use relatively little recycled water.

profitably in use by 2010.[59] This makes the construction of such facilities a matter worth investigating, but does not itself imply that some or all of them should be built.[60]

5. The Effects of National Policies

We now turn to the investigation of the effects of national policies towards water. Here our investigation so far is only intended to illuminate certain major points rather than to be detailed. In particular, we have made no attempt to use the model to investigate the question of what policies would be optimal. Nor have we investigated the effects of actual existing or proposed policies. Such uses of the model lie in the future.

One comment may be appropriate in this regard, however. We have seen that there will be no crisis as regards water for human consumption and that future problems are likely to involve agriculture. It may be considered socially desirable to preserve agriculture that would be privately unprofitable, but this does

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[59] They do not all ship water outside of their local area, however. In particular, the Northern Highlands plant in Jordan does not send any recycled water to the Jordan Valley.

[60] We have also not investigated the optimal capacity for such facilities.

not imply a water subsidy. As a general proposition, it is more efficient directly to subsidize the activity in which one is interested than to do so by subsidizing one of its inputs. A direct subsidy to agriculture is therefore likely to be more efficient in preserving that activity than a water subsidy that distorts the input choices of farmers. Nevertheless, we ignore this in what follows and investigate the effects of direct water subsidies.

Our study concerns the effects that the policies of one party are likely to have on the others. This involves two issues. The first of these is that of the effect of national policies on the value of the disputed water. The second is more subtle.

If one country subsidizes water for agriculture, it will thereby increase its own farmers' demands for water.[61] That increased demand will tend to raise the price of water in the region. As a result, consumers of water in the other countries involved will face higher prices and will be worse off. Producers of water in the other countries (national or private) will face higher prices and be better off. Since an arbitrary increase in

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61 This will not happen if the subsidy is accompanied by a tight ration so that farmers buy more than the rationed amount. In that case, the policy is equivalent to a cash payment to farmers and will have no effect on demand.

price typically reduces consumer surplus by more than it increases producer surplus, producing a net "deadweight" loss, one would think that the non-subsidizing countries would be made worse off. This would make the question of national policies towards agriculture a matter for continuing negotiation.

For reasons explained below, this view is mistaken *so far as water is directly concerned*. Water subsidies by one country may affect the others adversely because of competition in agricultural outputs, but, as we shall see, they are very likely actually to benefit the other countries *in the market for water itself*.

We begin, however, with the effect of policies on the value of the disputed water and on water prices generally. To study this, we ran three scenarios. Each is for 2010, with 250 mcm of Yarmouk water and the middle Palestinian growth scenario. In each case, the facilities in place are those of the plausible+ scenario. We study in turn the effect of a 50% subsidy to agriculture of each of the three countries. No claim is made that this represents either current or likely policies of the parties. The use of such a simple (and pretty drastic) policy does enable us to outline the general effects that more realistic policies are likely to have.

We turn first to the value of the water in dispute.

Table 6

Effects of 50% Agricultural Water Subsidies

on Value of Disputed Water:2010 (1990$/$m^3$)

Middle Palestinian Growth, Plausible+ Scenario

Subsidizing Country	None	Israel	Jordan	Palestine
Sea of Galilee	.298	.365	.342	.327
Mountain Aquifer	.222	.287	.265	.252
Yarmouk	.252	.289	.296	.261

Obviously, the effects are not negligible. The largest is that of the fictitious Israeli subsidy, as we should expect given the large size of Israeli agriculture. Nevertheless, the first thing to note is that *even national policies such as these do not make the disputed water so valuable as to make it an insuperable obstacle to agreement.*

The Israeli subsidy raises the price of the disputed water by \$.067/m^3 for both the Sea of Galilee and the Mountain Aquifer, and by \$.037/m^3 for the Yarmouk. Taking as before 400 mcm per year as a rough measure of the amount of water in dispute from each of the first two sources and 250 mcm per year as a similar measure for the Yarmouk, this means that the effects of a pretty drastic subsidy are to raise the value of the three disputed waters by \$26.84 million per year for each of the Sea of Galilee and the Mountain Aquifer and \$9.25 for the Yarmouk.The qualitative conclusions reached above remain unchanged.[62]

We now turn to an examination of the effects of such policies on the non-subsidizing country. The following table gives the results in terms of the average fresh water prices. (As before, the columns indicate the country imposing the subsidy. The rows show the country to which the indicated prices apply.)[63]

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62 We have not made similar runs for 2020, but is is clear that the qualitative results would be the same. Note that the closer one gets to the price limit imposed by desalination the smaller will be the effects of such subsidies on the value of the disputed water.

63 It should come as no surprise that the average water prices shown are considerably greater than the prices of the water in dispute. The average water prices reflect transportation and pumping costs and thus the fact, for example, that water is more valuable in Gaza than it is in the Mountain Aquifer. The averages are weighted by consumption.

Table 7

Effects of 50% Agricultural Water Subsidies on Average Fresh Water Prices 2010 (1990$/m^3) Middle Palestinian Growth, Plausible+ Scenario

Subsidizing Country	None	Israel	Jordan	Palestine
Consuming Country				
Israel	.50	.43	.54	.53
Jordan	.64	.67	.48	.65
Palestine	.56	.60	.60	.51

Note that the effects of the subsidies can be less here than on the value of the water in dispute. That is because the subsidies cause the subsidizing country to increase its consumption of the water in dispute and thus bear much of the costs itself. We shall now see that this effect is even more important than at first appears.

To fix ideas, suppose that there are only two countries, which we shall call A and B, respectively. Suppose that their water systems are connected at a lake. Now suppose that A subsidizes agriculture. This raises the demand for water in A, causing A to use (and pay for) an increased amount of water from the joint lake. Naturally, this raises the price of water in the lake and hence the price of water in the connected water system of B. These are the effects we have just been exploring.

But something else happens as well. While, as we shall see, the additional effect is present regardless of how property rights in the water of the lake are divided, it will be easiest to see what is involved by considering two extreme cases.

In case 1, suppose that B owns all the water in the connecting lake. Then the increased demand on the lake from A means that A purchases more water from B than before the subsidy. *But that water has a scarcity rent*. That is, the water of the lake has a value above its cost of extraction. Hence the increased sales of water from B to A involve a profit. That profit offsets the damage to B from the subsidy, in whole or in part.

Now, to see that the presence of this effect does not depend on the question of who owns the lake water, suppose (case 2) that A rather than B owns that water. We can safely suppose that B was taking water from the lake before the subsidy in A; otherwise, increased demand for that water from A cannot affect prices in B. But this means that, before the subsidy, B was purchasing water from A and A was receiving the profit involved in the scarcity rent of that water. Now, with A taking more of the water, B must take less.[64] Hence there is less outflow of money from B to A. This is a benefit to B which offsets the damage from the subsidy in whole or in part.

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64 If this were not so, the water would not be scarce, and increased demand by A could not affect the price of the water.

Thus there is an offsetting balance-of-trade effect
regardless of who originally owns the water in the connecting
lake. This effect must be added to the increase in producers'
surplus (profits) and the decrease in buyer surplus in B to
determine the net effect.

There is a practical problem in doing this precisely in our
results. Since we do not assume any specific settlement of the
property-rights disputes, it is not possible to assign profits on
disputed water to an owner. This means that the calculation of
changes in producer surplus can only be done approximately. In
terms of the example just considered, while the existence of
the international trade effect discussed is independent of who
owns the water, the allocation of the profits on pre-subsidy water
sales cannot be done without an ownership allocation.[65]

Another way of putting this is as follows. The loss in B's
buyer surplus consequent on the increased price of the disputed

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65 Note, however, that the evaluation of the size of the effect
does depend on the ownership allocation. To see this, observe
that if B is a net exporter to A, the effect consists of the
change in exports valued at the subsidy-induced price. If B is a
net importer, the effect is the change in imports valued at the
no-subsidy price. (The case in which B switches from being a net
importer to being a net exporter is left to the reader.)

water will be the same regardless of who owns the water. To the extent that B, rather than A owns the disputed water some of that loss will be offset by the increased profits earned on B's own post-price increase consumption of the disputed water.[66] We cannot decide how much of those increased profits belong to B rather than to A, however, without knowing the resolution of the property-rights involved.

Fortunately, this will not deter us from reaching some conclusions. In the worst case for B, B owns none of the water in dispute. By examining this case, we can see the maximal size of any negative impact on B of A's subsidy. Similarly, the best case for B is that in which it owns all of the water in dispute. By examining that case, we can see the minimal size of any negative impact on B of A's subsidy. In practice, however, it turns out not to be necessary to estimate the latter bound. Instead, we calculate how much of the disputed water must be owned by B to make the total effect zero. This amount typically turns out to be relatively small.

In practice, the calculations are complicated by the fact that there are three parties rather than two. Further, the water systems of two of them -- Israel and Palestine -- are quite

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66 This is wholly aside from the international trade effect just discussed.

intertwined. This will not prevent us from proceeding, but it will be simplest to begin by presenting results treating Israel and Palestine as one unit and Jordan as another.[67] This has the advantage of permitting us to include Jerusalem in the composite unit. Separate results are presented below.[68]

We begin with the case of a Jordanian 50% subsidy. As shown in Table 7, above, this causes an increase in fresh water prices west of the Jordan of roughly $\$.04/m^3$. The resulting decrease in consumer surplus is \$54.8 million per year for Israel, \$23.5 million per year for Palestine, and \$4.3 million per year for Jerusalem. The total loss in consumer surplus is \$82.6 million per year.[69]

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[67] Of course, no political statement is intended here.

[68] The number of cases to be considered is large, and the principal results are summarized in tabular form below. But the results obtained are so important and so surprising that we describe each of the calculations in some detail.

[69] A technical word of caution here. Because the demand curves used are inelastic, the area under them is infinite. (Of course, this merely means that they cannot be inelastic throughout the entire range of prices.) This makes no difference for our

Offsetting this are two effects. The first of these is the increase in producer surplus west of the Jordan. As explained above, to obtain a minimal estimate for this increase, we assume that all of the water in dispute between Jordan and the composite entity belongs to Jordan. This means excluding from producer surplus for the composite entity all profits made on Yarmouk or Jordan water. To do this, we exclude all profits in the Hacola, Kinneret, and Bet Shean districts of Israel. When this is done, the (worst case) increase in producer surplus west of the Jordan induced by the Jordanian subsidy is seen to be \$53.7 million per year.

We now turn to the international trade effect. Without the subsidy, Jordan takes 212.21 mcm per year of water from the Yarmouk and 4.72 mcm per year from the Sea of Galilee. With the

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purposes, since we are interested in policy-induced *changes* in consumer surplus. Accordingly, we only take the integral from a fixed low quantity, Q_L, to the equilibrium quantity, starting at Q_L rather than at 0. (Q_L is chosen as the quantity for which the corresponding demand price would be \$10/m^3.) We thus omit part of the consumer surplus. This means that one cannot use the results to compare buyers' surplus across districts, countries, or years. (Note that this procedure can make the reported consumer surplus negative.)

subsidy, these figures become 214.45 mcm per year and 83.74 mcm per year respectively. The subsidy thus causes Jordan to take approximately an additional 2.2 mcm per year from the Yarmouk and an additional 79.0 mcm per year from the Sea of Galilee.

The additional 2.2 mcm per year of Yarmouk water comes from reduced lifting by Israel at Bet Shean. The no-subsidy profits on that water (the scarcity rent) are $\$.248/m^3$ for a total of \$.7 million per year.[70]

The effects as regards the Sea-of-Galilee water are much larger. The no-subsidy price of that water is $\$.298/m^3$, and this is entirely scarcity rent. Hence the total profits involved on 79.0 mcm per year are \$23.5 million per year.

The total size of the international trade effect is therefore \$25.2 million per year.

Combining these effects, we see that the worst-case effect of the Jordanian subsidy on Israel and Palestine together is a negative \$5.4 million per year.

But this is the worst case, the case in which all Sea of

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70 The figures do not match exactly because of rounding. Note that it is the no-subsidy price that should be used here, since we are assuming the West-of-Jordan composite entity to be a net importer.

Galilee and Yarmouk water is owned by Jordan. We can readily calculate the amount of such water that would have to be owned by the West-of-Jordan composite entity to make the effect of the Jordanian subsidy zero or positive. This is easily done. Table 6 above shows that the Jordanian subsidy raises the scarcity price of both Sea of Galilee and Yarmouk water by $.043/m^3. So ownership of only 126 mcm per year of such water (from both sources combined) would add sufficient gain in profits west of the Jordan to wipe out the effect of the Jordanian subsidy. Since any settlement will surely result in Israel and Palestine together owning much more than that, we can conclude that the effect of a Jordanian subsidy will be to *benefit* the composite of the other two countries! That is, the gains from the subsidy will be more than sufficient to recompense the consumers for their loss.

We now similarly explore the effects on Jordan of subsidies west of the Jordan (and we now drop the fiction of a composite West-of-Jordan entity). We begin with the effect of an Israeli 50% subsidy. As shown in Table 7, this raises prices in Jordan by about $.03/m^3. This reduces consumer surplus by $20.6 million per year.

Offsetting this in part is the increase in producer surplus in Jordan. To obtain the worst-case estimate for the effect of the subsidy, we assume that Jordan owns none of the water in dispute and exclude all profits from Yarmouk water. The remaining increase in producer surplus is $12.9 million per year.

The international trade effect here is smaller than before.

The imposition of the Israeli subsidy causes Jordan to cease taking water from the Sea of Galilee, thus reducing its take from that source by 4.72 mcm per year. The no-subsidy scarcity rent on this water is $\$.298/m^3$, so the international trade savings involved here are $1.4 million per year.

The use of Yarmouk water by Jordan is also reduced. It falls by 11.46 mcm per year. This water has a no-subsidy scarcity rent of $\$.248/m^3$,[71] so the international trade savings here are $2.8 million per year.

The total international trade effect is thus $4.4 million per year.

Combining these effects, we see that the worst-case effect of a 50% Israeli subsidy on Jordan is a negative $3.5 million per year. This is quite small. It would be offset by ownership by Jordan of 95 mcm per year of Yarmouk water or 53 mcm per year of Sea of Galilee water.[72]

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71 This differs from the average value of Yarmouk water given earlier because of extraction costs.

72 The difference in the two figures comes because the effect of the Israeli subsidy on the two scarcity rents are not the same. As shown in Table 6, the subsidy increases the price of Yarmouk water by $\$.037/m^3$ and the price of Sea of Galilee water by $\$.067/m^3$. So

The case of the effects on Jordan of a 50% Palestinian subsidy is similar, although the numbers are much smaller.[73] Here the total worst-case effect is a negative $.4 million per year. This would be offset by Jordanian ownership of only 14 mcm of Sea of Galilee water or 45 mcm of Yarmouk water.

We now turn to the somewhat more complicated task of assessing effects on Israel and Palestine separately.[74] We begin with the question of the effects of a 50% Jordanian subsidy on Palestine.

Here the analysis is similar to those already given, save that (to get the worst-case estimate) we must exclude increased profits on Mountain Aquifer water as well as on Yarmouk and Sea of Galilee water. This is tedious but doable from the tables printed out by the computer program. We find the decrease in Palestinian buyers' surplus to be $23.5 million per year, whereas the increase in undisputed profits is $8.5 million per year. Hence the net worst-case effect is a negative $15.0 million per year before accounting for the international trade effect.

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it matters which disputed water is owned by Jordan.

73 The details of the calculation are also similar and need not be given separately.

74 This time we exclude Jerusalem.

To calculate the international trade effect, we first observe that the imposition of the Jordanian subsidy leads Palestine to reduce its consumption of fresh water by 9.14 mcm per year. With a little effort, this can all be traced to reduced Palestinian takings from the Israeli National Carrier and hence identified as Sea of Galilee water. Valuing that water at the no-subsidy price of \$.298, we find that the international trade effect is \$2.7 million per year.

This makes the net worst-case effect of the Jordanian subsidy on Palestine a negative \$12.3 million per year. This would be offset by Palestinian ownership of 286 mcm per year of all disputed water combined.[75]

To estimate the worst-case effect of a 50% Jordanian subsidy on Israel, we must assume that all profits on Mountain Aquifer water belong to Palestine and that Israel owns no water in either the Sea of Galilee or the Yarmouk. There is a decrease in consumer surplus in Israel of \$54.8 million per year. This is partially offset by an increase in undisputed profits of \$26.3 per year. The result is a net worst-case decrease of \$28.5 million per year, but this is largely offset by a large international trade effect.

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75 The quantity is very slightly less (280 mcm per year) if ownership is only of Mountain Aquifer water.

To estimate the size of the latter effect, observe that the Jordanian subsidy produces a decrease in Israeli fresh-water consumption of 38.6 mcm per year. Of this, 2.24 mcm per year comes from the Yarmouk, and the remainder from the Sea of Galilee. Further, Israel produces an additional 27 mcm per year (in the Haifa district) which replaces an equal amount of Sea of Galilee water. Hence the total decrease in Sea of Galilee water is 63.3 mcm per year. At no-subsidy prices, the total international trade effect is $19.4 million per year.

This makes the total net worst-case effect of the Jordanian subsidy on Israel a negative $9.1 million per year. This would be offset by Israeli ownership of only 212 mcm per year from all disputed sources combined.[76]

We turn next to the effect of a 50% Israeli subsidy on Palestine. Here the change in consumer surplus is $23.9 million per year. The increase in profits on undisputed water is $12.9 million per year, so that the net decrease before the international trade effect is $11.0 million per year.

Palestinian consumption of fresh water is reduced by about 8 mcm per year, essentially all water from the Sea of Galilee. Valuing this at the no-subsidy price of $.298/m^3$, the

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76 As before, slightly less would be required if all the water involved were from the Yarmouk and the Sea of Galilee.

international trade effect is seen to be $2.4 million per year.

The net worst-case effect of the Israeli subsidy on Palestine is thus $8.6 million per year.[77] This would be offset by Palestinian ownership of either 129 mcm per year of Sea of Galilee water, 133 mcm per year of Mountain Aquifer water, or 233 mcm per year of Yarmouk water.

Finally, we explore the effects of a 50% Palestinian subsidy on Israel. The decrease in consumer surplus is $36.9 million per year. The increase in profits on undisputed water is $16.8 million per year, producing a negative effect of $20.1 million per year before accounting for the international trade effect.

The calculation of the latter effect is a bit more complicated this time. Israeli consumption of fresh water is reduced by 22.61 mcm per year. Of this, .5 mcm per year comes from the Yarmouk, 18.77 mcm from the Sea of Galilee, and the remaining 3.34 mcm per year from the Mountain Aquifer. The latter reduction in turn can be divided: 2.32 mcm per year comes from the Netanya district, and 1.02 mcm per year from the Ramla district.[78]

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77 Note that this is less than the effect of a comparable percentage subsidy in Jordan.

78 This division is necessary for complete accuracy because the scarcity rents in the two districts are not quite the same.

Evaluating all these amounts at no-subsidy scarcity prices gives an international trade effect of $6.5 million per year.

This leaves the total net worst case effect on Israel a negative $13.6 million per year. This would be offset by Israeli ownership of 469 mcm per year of water from the Sea of Galilee and the Mountain Aquifer combined.[79]

These results (except for those involving the composite entity) are summarized in Tables 8 and 9. Table 8 shows the net worst-case effect involved. Table 9 shows the amount of water ownership required to outweigh that effect. (In the latter table, the three water sources are identified by the letters S, M, and Y, respectively, where the abbreviations are obvious.) *Note that the figures given are the amount necessary to offset the effect if only ownership in the source indicated is assumed.*

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[79] This is the figure for Sea of Galilee water. The figure for Mountain Aquifer water is slightly less (453 mcm per year). Yarmouk water is worth much less here, since the subsidy-induced increase in the price of such water is only $\$.009/m^3$ as compared to $\$.029/m^3$ for Sea of Galilee water and $\$.030/m^3$ for Mountain Aquifer water. Since this means that Israel would have to own an impossible amount of Yarmouk water (1512 mcm per year) to offset the effect through such ownership alone, we do not bother giving this figure in Table 9 below.

Table 8

Net Worst Case Effect of 50% Agricultural Subsidies Middle Palestinian Growth, Plausible+ Scenario (millions of 1990 dollars/year)

	Subsidizing Country		
Affected Country	Israel	Jordan	Palestine
Israel	----	- 9.1	- 13.6
Jordan	- 3.5	----	- 0.4
Palestine	- 8.6	- 12.3	----

Table 9

Amount of Water Ownership Needed to Offset Negative Effects of 50% Agricultural Water Subsidies Middle Palestinian Growth, Plausible+ Scenario (mcm/year)[a]

	Subsidizing Country		
Affected Country	Israel	Jordan	Palestine
Israel	----	212 S 207 M 212 Y	460 S 453 M
Jordan	53 S 95 Y	----	14 S 45 Y
Palestine	129 S 133 M 233 Y	286 S 280 M 286 Y	----

a. *Figures given are the amount necessary to offset the indicated effect if only ownership in the source indicated is assumed.*

The conclusion is clear. Even the worst case effects found are quite small. In all cases, they are likely to be completely or more than completely offset in any property rights allocation. Subsidies by one country are likely to benefit the others, *so far as water alone is concerned*. . This means that (*so far as water alone is concerned*), the agricultural policies of one party do not require negotiation with the others.[80]

Of course, this does not mean that agricultural water subsidies cost nobody anything. The party imposing the subsidy pays quite a lot both in direct government payments and in lost international trade receipts. Presumably, such costs are thought worth incurring.[81]

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80 The reader is reminded that we have *not* considered effects on competition and trade in agricultural outputs.

81 Note that one cannot use the social welfare pages of the results to evaluate the net effect on the subsidy-imposing country (as opposed to the other two). This is because the imposition of a subsidy reflects a change in the value placed on water by national policy. Hence the metric for buyer surplus changes. Of course, one can evaluate the direct effect on consumers of water, and countries may wish to use the model in this way when

6. Water Flows

In the preceding discussion, we have occasionally referred to the results on who uses what water. There seems some point in remarking on the more important aspects here. *It must be kept firmly in mind that in reporting results on where it is efficient to use the water we express no opinion on the quite different question of who owns the water.*

1. The Yarmouk. In practically all runs most of the flow of the Yarmouk permitted to be used in the system is used in Jordan. The exceptions occur (for the reasons already discussed) only in the current and current+ scenarios where the capacity to transport water out of the Jordan Valley district is severely limited. The effects can be seen by examining the results for 2010.

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formulating policy. We have not done this here, however.

Table 10

Use of 250 mcm per year of Yarmouk Water, 2010 (mcm/year)

	Current+	Plausible-	Plausible+
Jordan V. (K. Abdullah)	100	100	100
Jordan V. (via Jordan R.)	3.2	117.1	112.2
Bet Shean	108.2	32.9	37.8
Jericho	38.6	0	0

Note that the availability of recycled water in Israel and Palestine leads to less extraction of Yarmouk water in Israel and hence more in Jordan. Note also that, save when transport in Jordan is limited, Palestine uses no Yarmouk water. This is true with and without the recycling facilities of the plausible+ scenario.

2. The Jordan River. Almost without exception, the water of the Jordan river is taken into the Israeli National Carrier. That transportation system is then used to supply both Israel and Palestine. In particular, Gaza is supplied in this manner. Only when Jordan heavily subsidizes agriculture does this pattern change at all. It never turns out to be efficient to use this water in the Jericho district.

3. The Mountain Aquifer. The efficient pattern of pumping

the water of the Mountain Aquifer[82] depends not only on relative pumping costs but also on the distribution of population. That pattern does not appear to depend on what recycling and pipeline facilities are assumed, but it does change over time. Table 11 gives the optimal pattern for each of the three years. The 1990 results are from the current+ scenario; those for the other two years are from the plausible+ scenario.

82 Recall that these results do not yet incorporate a serious hydrological model of the Mountain Aquifer.

Table 11

Efficient Pumping Patterns for the Mountain Aquifer

Middle Palestinian Growth Scenario (mcm/year)

District	1990	2010	2020
Afula	40	40	40
Hadera	7	7	7
Netanya	132	132	132
Ramla	150	150	150
Lachish	37	0.4	0.4
Negev	18.9	0	0
Jenin	0	31.2	31.2
Tulkarem	0	0	0
Nablus	0	18.6	18.6
Bethlehem	0	3.7	3.7
Hebron	0.7	56.3	56.3

Evidently, the higher prices and greater Palestinian populations of the later years call forth additional pumping at Palestinian locations.[83]

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83 The result is not due to the switch from the current+ to the plausible+ scenarios. The pumping pattern for the current+ scenario for 2010 is the same as that shown for the plausible+ scenario.

7. Desalination

We have already had occasion earlier to mention the viability of desalination. In general, we find that, except at Aqaba[84], desalination will not be efficient even at a cost of $\$.80/m^3$ before 2020. But, at this cost, desalination does appear in our results for 2020 at Gaza South and, in some scenarios, in Gaza North and Lachish.[85]

Whether this assumed desalination cost is too optimistic is hard to say. There are 25 years before 2020 in which to achieve such costs. We have, however, investigated the question of whether desalination would still come on stream in 2020 if the costs were considerably higher, say $\$1.50/m^3$. This also allows us to discover how low desalination costs would have to be to compete with fresh water prices.

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84 This is the Wadi Araba district in the tables of the Appendix.

85 In the combination of the high Palestinian growth and plausible- scenarios, small amounts of recycling appear in the Rehovot district and in Tel Aviv, but these are too small to be practical when capital costs are taken into account.

Here the results depend on the population assumptions made.[86] Using the middle Palestinian growth -- plausible+ scenario, we find that the price in Gaza South (the most favorable location for desalination of any on the Mediterranean coast[87]) is only $.92/m^3. For the high Palestinian growth scenario, the comparable price is $1.41/m^3. With the facilities of the plausible+ scenario, one does not get desalination even in Gaza at $1.50/m^3.

On the other hand, that result does depend on the use of the plausible+ scenario. If we use the plausible- scenario, which lacks the major new recycling facilities of the plausible+ scenario, desalination does occur in Gaza South at $1.50/m^3 in 2020 even with the middle Palestinian growth scenario. With the high Palestinian growth, plausible- scenario, desalination occurs in Gaza North as well, and locations further north have prices fairly close to the desalination limit. Evidently the efficiency of desalination will be affected by the extent to which recycling facilities are built.

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86 Except for Aqaba, of course.

87 Fresh water prices are highest in Gaza South because it is at the end of the transportation system.

8. Drought and Surplus

As the last referred-to result reflects, the quantity of water in the system makes a serious difference. A full model for water management would require an investigation of optimization under uncertainty, because of the stochastic nature of rainfall. While this is a feasible undertaking with an extension of our model, we have not so far done it.[88] Instead, we have briefly explored the consequences of drought and surplus years.

We do this by taking the plausible+ - middle Palestinian growth scenario for 2010 and reducing all sources of water by 25%,[89] obtaining a "drought" scenario. Alternatively, we increase all sources by 25%, obtaining a "surplus" scenario. We give the results in terms of the average fresh water prices in the three countries.[90]

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88 We have also not investigated the question of interyear storage or, indeed, other interyear effects. This would require a substantial extension of the model and may be a suitable subject for further research.

89 Including the Yarmouk.

90 There are corresponding effects on the value of the water in dispute. They do not change the general conclusion as to the manageably low value of those resources, however.

Table 12

Effect of Drought and Surplus on Average Fresh Water Prices

Middle Palestinian Growth, Plausible+ Scenario (1990$/mcm)

	Normal	Drought	Surplus
Israel	.50	.70	.42
Jordan	.64	.80	.59
Palestine	.56	.74	.49

Obviously, the effects are considerable, especially so when we observe that the Drought scenario makes desalination efficient in both Gaza South and Gaza North at $.80/mcm, thus capping the price. If desalination costs are assumed to be $1.50/$m^3$ rather than $.80/$m^3$, the average price for Israel becomes $.80/$m^3$, that for Jordan becomes $.98/$m^3$, and that for Palestine becomes $.84/$m^3$.

This makes it appear that desalination facilities should be considered before 2020 as standby capacity, but the usefulness of such facilities will depend on the cost of desalination. In the drought year scenario for 2010 with desalination costs assumed to be $1.50/$m^3$, desalination is not efficient anywhere on the Mediterranean coast. The highest price on that coast is at Gaza South, where it is only $.95/$m^3$. This is the cost that desalination would have to have in order to be efficient even in such a drought year.

9. Capital Facilities and Other Projects

In the course of the above analysis, we have already commented on questions involving the possible construction of new facilities. It should be emphasized that we have not fully examined the capital costs of such facilities, so that a conclusion that a particular facility appears desirable merely means that it deserves serious study.[91] A conclusion that a particular facility does *not* appear desirable, on the other hand, is a stronger one. If a facility would not be efficient ignoring capital costs, it cannot be efficient with them.

1. Transportation facilities in Jordan. This is our strongest finding as to the need for new facilities. More pipeline capacity appears urgently needed to carry water to Amman and the Northern Highlands. Without such facilities, Jordan cannot avoid a major crisis no matter how much water its secures in other places.

2. Recycling facilities. The results of the plausible+ scenario suggest strongly that recycling plants will be desirable in all Palestinian cities as well as in various locations in Israel and Jordan and in Jerusalem. Here, however, we cannot give

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91 Although the conclusion as to the need for additional transportation facilities in Jordan is so strong as to be pretty persuasive.

an unqualified recommendation, since the results depend on the assumptions made concerning agriculture as well as on the capital costs involved.

3. Desalination plants. As already discussed, for normal years, it is unlikely that desalination will be an efficient technology before 2020 (except at Aqaba). Whether it is efficient on the Mediterranean coast at that date depends on its cost. Nevertheless, attention should be paid here before 2020 because of the possible need for standby facilities in drought years.

We now use our results to comment on certain other possible projects.

4. The Northern ("Gur") canal. This project would cut a canal from the Mediterranean to the Sea of Galilee, use the downfall of water to generate electricity and desalinate the water before it enters the lake. It is reported that the cost of the desalinated water will run from $\$.40/m^3$ to $\$.60/m^3$, and there are likely to be considerable environmental costs as well.

Our results suggest that this is a very doubtful project. In the presence of the facilities of the plausible+ scenario, the price of water at the Sea of Galilee does not rise above $\$.40/m^3$ by 2010. Indeed, the price in 2010 is only $\$.30/m^3$ (with the middle Palestinian growth scenario). The price does get into the feasible range by 2020 (on the same assumptions, it is \$.52 with the middle Palestinian growth scenario and \$.63 with the high Palestinian growth scenario), but 2020 is a long way off and cost projections are uncertain. When we add in environmental considerations, it seems likely that this canal should not be built.

5. The Red-Dead canal. This project would cut a canal from the Red Sea to the Dead Sea. The water flow would be used to generate electricity (and to assist in maintaining the level of the Dead Sea). Desalination of water is also planned.

We can only comment here so far as desalination is concerned. If the project provides a cheap method of generating electricity, then that electricity can be used for other purposes (or for desalination on the sea coast). It seems unlikely that desalination of water in the Dead Sea district will prove fruitful, since that is not where the water is needed. Our findings give a price of water in the Dead Sea district of Jordan (on the same assumptions as used for the Northern canal) of only $\$.36/m^3$ in 2010 and $\$.58/m^3$ in 2020. The project would have to beat these prices to be viable for the desalinated water provided to be a net benefit.

6. Imports of water. There are various suggestions as to the importation of water into the region. These include a pipeline from Turkey, sales from the Litani, and shipment of water in medusa bags to the Mediterranean coast. We do not know whether such projects will be viable, but (aside from any other difficulties) to be so they would have to sell water into the system at the prices indicated in our results for the district into which the imports are to go. For the most part, this means the prices in the North, and the value of water per cubic meter in

the Sea of Galilee given in an earlier section are a good indication that import costs will have to be fairly low.

10. Security and Cooperation

We cannot close this report without a word on security considerations.

Our model presupposes a situation of international cooperation, cooperation that can prove very fruitful to all parties. Nevertheless, there will be some apprehension lest one party be able to threaten another by limiting water flows.

We do not believe this is likely. In the first place, the positions of the parties are somewhat symmetric when we consider different water sources. Thus, Israel is upstream of Palestine and Jordan on the Jordan river; Jordan is upstream of Israel and Palestine on the Yarmouk. In a sense, Palestine is upstream of Israel on the Mountain Aquifer. Further, while Israel could refuse to supply Gaza, doing so would cut off the flow of recycled water from Gaza to the Negev that we predict to be valuable.

Moreover, the value of cooperation is high. Water, as we have shown, is an economic commodity. Refusing to sell it means foregoing the money value that it represents. Further, such refusals are likely to be met by the withdrawal of other, non-water trades or agreements by the injured party.

Of course, in the event of war, water may be used as a weapon. But we have shown that, properly considered, water itself is an unlikely cause of war. In the peaceful context that we hope will arise and be sustained in the future, cooperation rather than conflict in water management should be both desirable and possible.

FIGURE 1

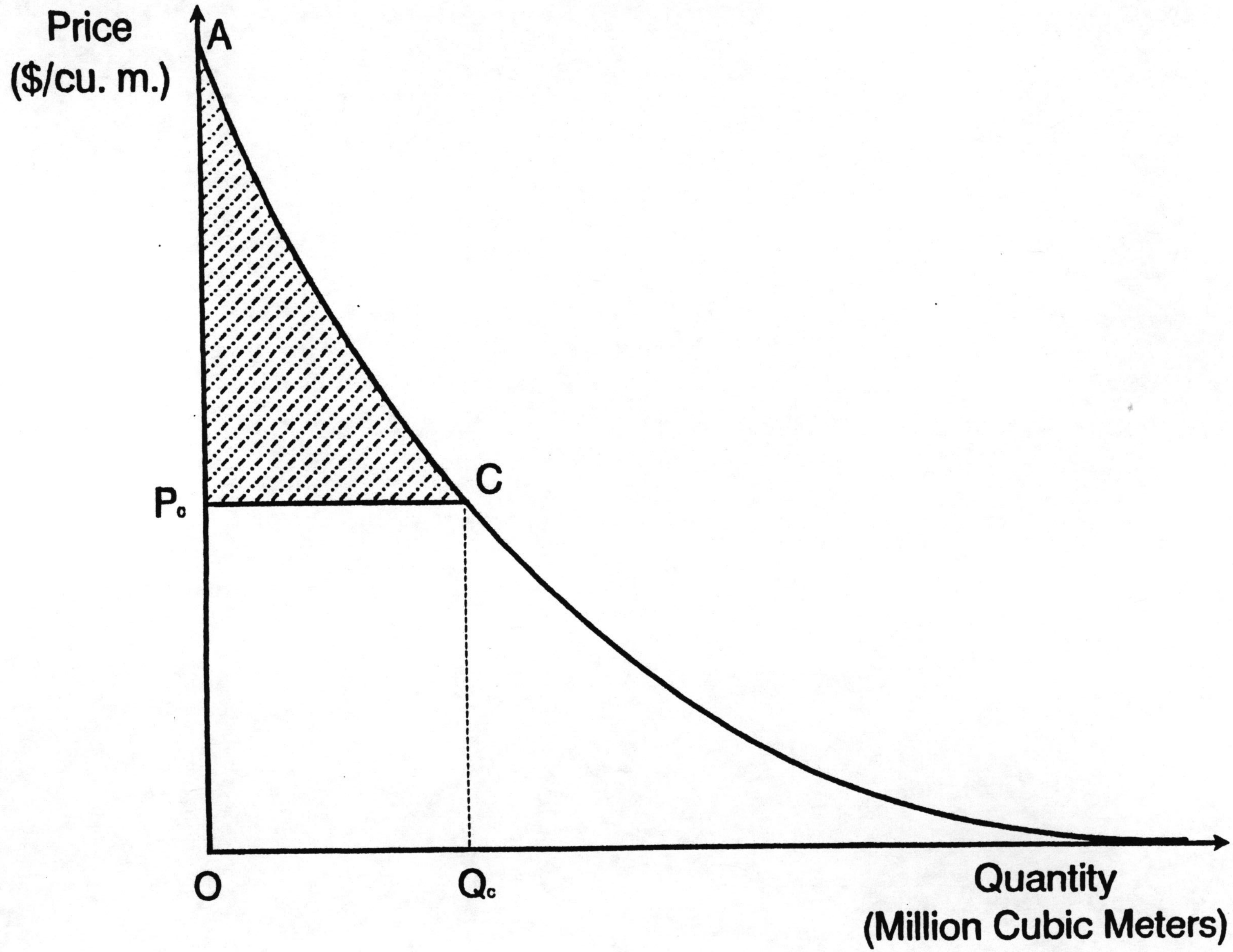

FIGURE 2

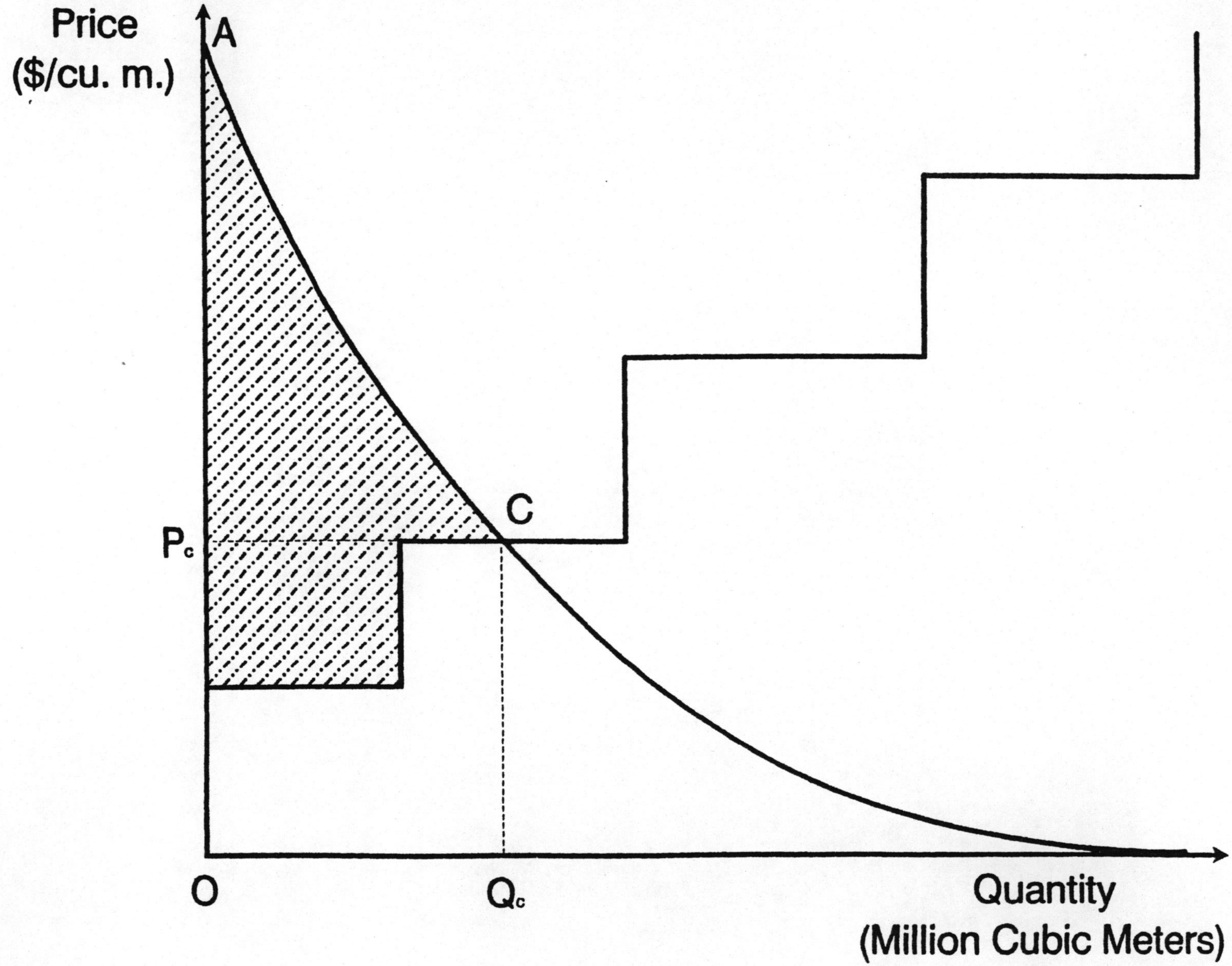

Figure 3

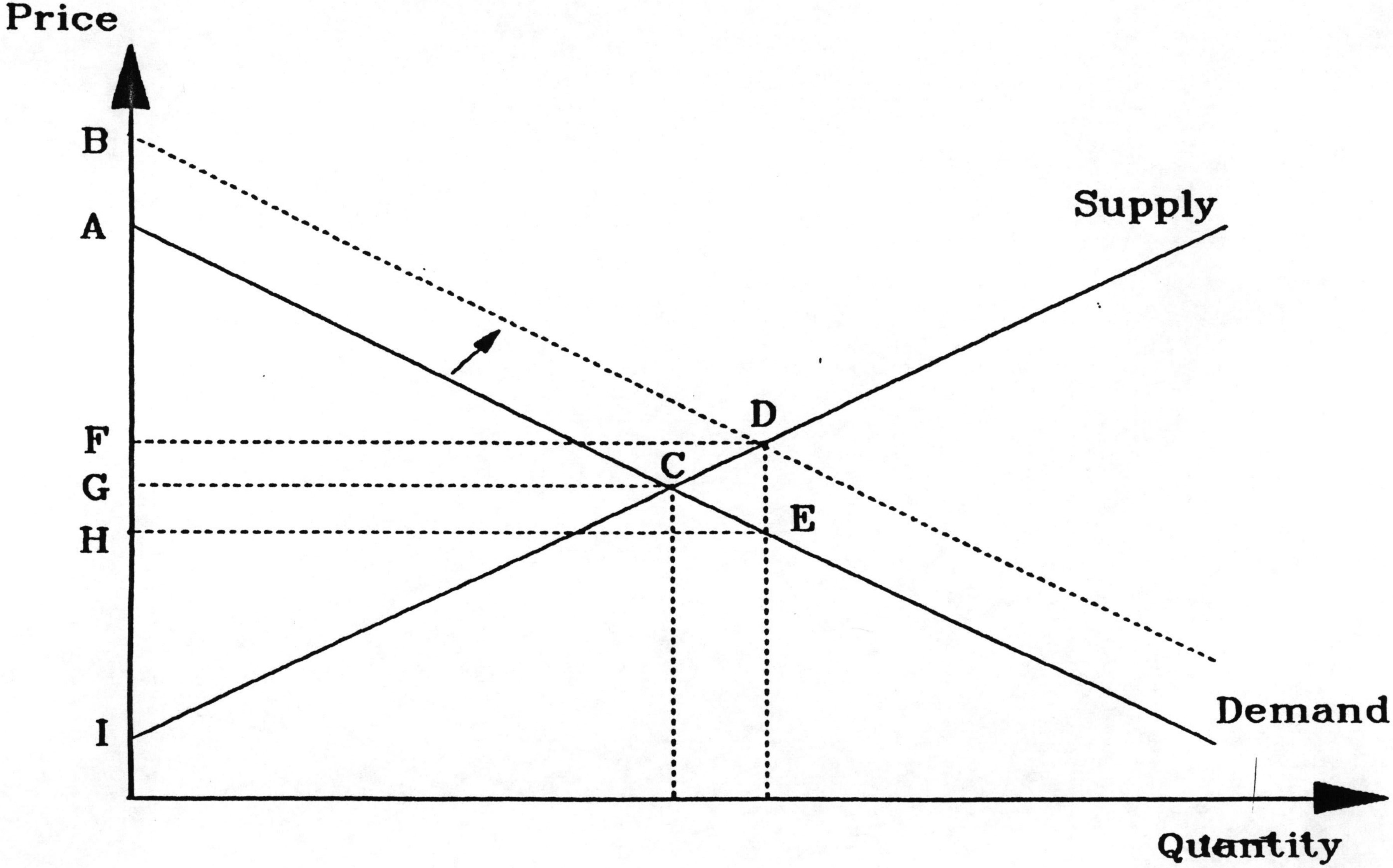

Fig-3

Appendix B
The Harvard Middle East Water Project: Brief Description

Water disputes are usually thought of in terms of the ownership rights to quantities of water. But economic analysis suggests that, however important such rights may be, the question of water ownership rights and the question of water usage are analytically independent and should not be confused. This is because the owner of water who uses the water itself incurs an opportunity cost -- he gives up the money that could have been received by selling the water. As with any purchaser, such an owner will use the water if he values it more than the money involved; he will let others use it if he values the money more highly than the water. Owners of water who use it themselves should be thought of as purchasers who buy from themselves. The right of ownership is then just the right to the money that the water represents.

Further, analysis of water scarcity rents -- of efficiency prices for water in different locations -- can assist in resolving disputes over ownership rights by producing estimates of their monetary value. Such analysis also provides a powerful tool for efficient water management, in particular, for the evaluation of various projects such as pipeline, dam, recycling plant, or desalination plant construction.

Such an analysis is being performed by the Harvard Middle East Water Project. That project is a joint effort of Israeli, Jordanian, Palestinian and American hydrologists, agronomists, and economists. It is under the auspices of the Institute for Social and Economic Policy in the Middle East (ISEPME) at Harvard's Kennedy School and has been in full operation since October, 1993. The project has built a model of the water economy of Israel, Jordan, and the Palestinian areas, using actual or forecast data for three years: 1990, 2010 and 2020. We put particular emphasis on the scarcity price of water in different locations and take account of the fact that water may have social value beyond its private economic value.

While the model continues to be refined, certain conclusions so far reached seem unlikely to change. They are:

1. The value of the water in dispute among the parties is not great. It is currently a maximum of $110 million per year (all figures in 1990 dollars) and will rise to a maximum of less than $500 million per year by 2020. These are small magnitudes compared to the economies involved or (perhaps more pointedly) compared to the cost of military equipment.

2. There will be no crisis of water for human consumption in the region. What is required here is not more water but better conveyance facilities permitting more efficient use of the existing water. Facilities for conveying water to Amman and neighboring regions in Jordan appear to be especially important.

3. There will, however, be a crisis in unsubsidized agriculture unless further infrastructure facilities are built. That crisis can largely be cured by the construction of recycling and water treatment plants.

4. National policies that subsidize water for agriculture are expensive for the subsidizing country but do not have a negative effect on the other parties so far as water prices are concerned. (Effects on competition in agriculture itself are not studied.)

5. In the absence of considerable technological improvement, desalination facilities on the Mediterranean coast will not be needed by 2020 if the infrastructure described above is put in place and water optimally managed.

6. It is doubtful that the major canal projects now under discussion will be economically justified as far as water is concerned.

7. On the other hand, certain facilities stand out as candidates for construction (although a full cost-benefit analysis has not yet been performed). In addition to the recycling facilities already mentioned, these include: (a) Pipeline facilities to bring water from the Jordan Valley to Amman and neighboring regions of Jordan; (b) Storage facilities to capture the excess winter flow of the Yarmouk River; (c) Pipeline facilities to bring Jordan River water to the Nablus region of the West Bank and then to other areas; (d) Larger capacity connection of Gaza to the Israeli National Water Carrier. It is interesting to note that plans for (a) and (b) are already underway. One should also observe that the combination of (c) and (d) could create a situation of mutual interdependence and hence of cooperation for Israel and the Palestinian entity.

The project has two principal aims. First (see conclusions 1 and 4), it aims to assist negotiations among the parties. It does so by monetizing the value of the property rights in dispute and thus evaluating the rate at which such rights can be traded off for other concessions. There is reason to believe that ownership rights are not, in fact, tremendously valuable.

Second (see conclusions 2, 3, 5, 6 and 7), the Project provides a powerful tool with which the parties, either separately or together can evaluate proposed projects and infrastructure improvements.

The Project has aroused considerable (if often carefully unofficial) interest among the parties in the region, as well as among analysts and policy makers outside of it. We have been given some reason to believe that it has already indirectly affected the peace negotiations in a positive manner. At present, there is great interest among Israelis, Jordanians, and Palestinians in further developing the model so as to make it an even better tool for water policy planning.

It has not escaped our attention that the water system of Israel, Jordan, and the Palestinian territories is connected to that of Syria and Lebanon and that the water systems of those countries are in turn connected to those of Turkey and Iraq. It is possible that the model will be extended to a wider system.

It has also not escaped our attention that the methods used by the Project are applicable to other water systems and other water disputes around the world.