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THE HARVARD MIDDLE EAST WATER PROJECT: MODEL OVERVIEW AND RESULTS SO FAR

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1. Introduction: Principles and Goals of the Project[2]

This paper surveys the state of the project to date and reports on the results so far achieved. I begin with a summary discussion of the principles on which the model is based and the purposes for which it is intended.[3]

The question of the ownership of water (referred to in what follows as the "property rights" question) is important. Its resolution is required in any peace settlement and for future cooperation in regional water management. But it is important to

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[1] Portions of this report are based on the very hard work of others, particularly Aviv Nevo and N. Harshadeep. Robert Dorfman, Hillel Shuval, and Atif Kubursi also contributed in writings and discussions. It goes without saying that the work of all the country teams was essential.

[2] In order to make this report more self-contained, the early sections partly repeat or summarize material from earlier project documents.

[3] For a more extensive discussion, see "An Economic Framework ...".

understand just what the economics of that question do and do not involve. In particular, the property rights question of who *owns* the water and the important question of who *uses* the water are not the same. Indeed, they are analytically independent questions.

To see this observe the following. A country owning a certain amount of water certainly has the right to use the water itself. If it does so, however, it forgoes the money that it could have had by selling the water to others. It will rationally do this if and only if it values the water more than the money.

Now suppose that the same country did not own the water. It might then wish to purchase the water from others. It would rationally do this if and only if it valued the water more than the money that it would take to purchase it.

These two situations are analytically the same. In each, the country in question ends up using the water if and only if the water is more valuable to it than the money it could otherwise have. The only difference is that in the first case the country chooses water over money by refusing to sell, while in the second it does so by buying. In both cases, one can think of the water as being offered for sale by its owner. In both cases, the country in question buys the water. The only difference lies in the fact that, in the first case, the country buys the water from itself, so to speak, while, in the second case, it buys it from others.

There are two important implications of this:

1. The answer to the question of the socially beneficial and efficient use of water does not depend on who originally owns the water.

2. The original property rights question -- the question of who owns the water -- is the question of who receives the money that represents the value of the water. This is independent of the question of how or by whom the water gets used.

Please do not misunderstand me. I am not saying that these questions are unimportant. On the contrary, both the question of who owns the water and especially the question of who uses the water are major issues. I am merely saying that they are not the *same* issue and that they can be analyzed independently.

Direct resolution of the property rights question is not the province of this project. We do, however, have a significant contribution to make to those who must resolve it. We make that contribution not by suggesting who properly owns the water but by valuing what that ownership is worth. The first aim of the project is that valuation.

This is not a simple enterprise. In particular, valuation of water is not to be accomplished assuming that water only has private value. That is not the case. Water may well have social value beyond its use as an input in profitable agriculture, say. For social and ideological reasons which we do not question, countries often show through their water policies that water has value above and beyond its value in such private uses.

We recognize this fact and take it into account. In particular, the fact that I have referred to buying and selling of water does not mean that we are recommending a free market in water with private purchases and sales. Such a market would only represent private values for water.

Our model, however, does make substantial use of prices and trade (and of the results of economic analysis). This reflects the following fact: Having *itself* said what the value of water is, a country cannot rationally refuse to sell water if offered more than that value. If it does so refuse, it is saying that its own initial valuation was too low.

To make this a bit more concrete, we are not recommending a system in which a rich country can buy water from another country's poor farmers. Such trades may properly be resisted by the second country on the grounds that the water has value above and beyond the price at which the poor farmers are willing to sell (value because of the implication for farm workers and social stability, for example). The trades we envisage are trades at prices *which incorporate that extra value*. At such prices, there is no reason to refuse to sell.

Accordingly, our model seeks to value water taking into account the social values expressed by the parties themselves. As we shall see, such values are implicit in the policies adopted towards water.

I shall be more explicit below as to how this is done. But one illustration will be of aid here. It cannot be true that the value of water is so great as to be beyond price. For example, if water in Amman were really thought to be worth large enough amounts, Jordan would be building desalination facilities at Aqaba and pumping the water all the way to the capital. It does not do this because of the cost involved. But this implies that water in Amman is not worth that cost.

This is an extreme case of the following principle. However valuable water is, it cannot be more valuable than the cost of producing it.[4] Hence a limit is put on the value of the property rights by the costs of desalination and transportation. An easy calculation shows that this makes the value of the property rights in dispute low enough to make the dispute resolvable through negotiations.[5] Moreover, the results of our model show that the

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[4] Of course it may be the case that Jordan does not take the indicated action because it believes that water can be supplied to Amman more cheaply in other manners (for example, as the result of negotiations over Jordan's claims to the waters of the Jordan and Yarmuk). If so, this does not change the conclusion. Water in Amman is still not worth the cost of desalination at Aqaba plus transport. The value of such water is still bounded above by the cost of obtaining it through whatever mechanism is least costly.

[5] Roughly, water can be desalinated for about $.80 per cubic meter. (More precise estimates are discussed below.) So the water in dispute cannot be worth more than this amount plus some

actual value is considerably lower than this upper limit. We do not find water prices above desalination costs for some considerable time.

Valuation of the property rights dispute is not the only aim of our project (and perhaps not the most important aim in the long run). There are two others.

The first of these also involves dispute resolution. As already observed, an important feature of our model is that it takes into account the social value of water as revealed through national policies. But one must also realize that the policies of one entity can affect the welfare of others by affecting the price of water. If Israel subsidizes agriculture, for example, demand for water by Israeli agriculture will be stimulated. This will raise the price of water to other consumers in Israel, and it may

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transport costs. In fact, the water in dispute must be worth less than this, since the naturally occurring water also has costs. Even at $.80 per cubic meter, 300 million cubic meters per year would be worth only $240 million per year. The difference between proposed solutions of the property rights disputes is somewhat less than 300 million cubic meters per year. These are large sums, but they are surely of an order of magnitude that the parties can negotiate over in the context of a peace settlement. Moreover, as we shall see, the actual value is far less than $.80 per cubic meter.

very well raise the price of water in Jordan and Palestine.[6]

Such a price increase may be harmful or beneficial. It will certainly harm consumers and may reduce social benefits as revealed by national policies. On the other hand, a price increase will benefit water owners. In any event, the water policies of the countries may have to be the subject of ongoing negotiations. Our model can assist here by evaluating the effects of the policies involved.

This, however, is but a small part of the potential usefulness of our model. Its greatest long-run usefulness may very well lie in the area of water management. As we shall see, our model generates the most efficient use of water taking into account the values expressed by national policies. It thus provides a guide for regional water management. Indeed, as we shall see, the model can be used to guide such management in

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[6] A disclaimer is required here. This project neither resolves nor expresses opinions on political questions in dispute outside the water area. I refer to "Palestine" for convenience, meaning whatever political entity eventually emerges. Because it is awkward to do otherwise, I refer to "countries" or "national" policies again without implying any particular outcome to negotiations yet to be resolved. Similarly, no political content is intended by inadvertent usage elsewhere. Any unfortunate language should be called to my attention.

deciding what capital projects (pipelines, canals, desalination or recycling plants) should be built.

The use of the model in this way is not restricted to regional management, however. Within each country, the model provides a tool with which to evaluate the costs and benefits of projects and of changes in policy. Moreover, that tool is a flexible one; changes in assumptions or forecasts are easy to incorporate.

The analysis of how a regional authority might operate is largely a future task. Further, it is not the principal focus of the present paper.[7] But I shall have more to say about it as we go along.

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 the 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 the project differ in several respects. The most important one so far

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7 Zvi Eckstein is preparing a paper on the use of the model in this way.

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, I 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.[8]

(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.

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[8] Of course I understand that this statement is in fact being made.

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-policy demand curves are taken into account.) 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.[9]

Statements (b) and (c) are also analytically independent. Regardless of whether or not it is more efficient to pump the

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[9] I am fully aware that the authors of the two reports mean to assert their respective property-rights claims. The statements in the text do not contradict this.

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, I do not mean to suggest that they are not important -- far from it. I 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 to translate the dispute into a form which makes it susceptible to negotiation.

Statement (b) is not a claim of rights, but an assertion of fact. To evaluate that statement ultimately requires a full model of the hydrology.[10] However, even lacking a full hydrological model, we can shed some light on whether the assertion is true. (You may be surprised here. The question of where the water is efficiently pumped depends not merely on the hydrology but also on

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[10] Such a study has now been started.

the entire configuration of supply, demand, and transportation costs.)

Statement (c) is a statement of policy which may reflect national security considerations or other goals. Obviously, the model cannot characterize that policy as correct or incorrect, but it can calculate the costs of that policy both to Palestine and to the other participants.

3. What the Model Maximizes: Efficiency and Prices

I now turn to a general description of the model and its operation. A similar discussion, more extended in some respects, as well as technical details are given in the paper, "The Water Allocation System: a Computational Device".

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 calculates that allocation of water flows and uses that 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. 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 values each unit of that water at more than the price at which it could be sold; anyone who does not purchase additional water values additional units of water 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, I discuss them further. I 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 called now 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 (at least until we come to an explicit national policy), it is obviously desirable to produce quantities and charge prices for water that generate large consumer surpluses. 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.[11] 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. In the figure, this is the lower part of the shaded area (assuming

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[11] The fact that the curve is step-like is reflective of the cost functions used in the model but is not required for the discussion in the text.

water is priced at P_c). In general, 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 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.[12] One 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

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[12] This corresponds to what is perhaps the deepest and most important result of microeconomic analysis, the equivalence between efficiency and 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 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 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 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 equivalency between the solution to the efficiency problem and the free-market intersection of supply and demand curves has now become the equivalency 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*.

4. The Model Itself: An Overview

I now turn to a description of the setting in which this maximization takes place, to a closer description of the model itself. Here there are two things to say before proceeding.

First, as before, a more precise description can be found in the paper, "The Water Allocation System: a Computational Device."

Second, I shall describe the general framework of the model. Specific assumptions correspond to specific runs of the model and will be taken up later. Indeed, 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 countries is divided into districts with transportation costs within districts assumed negligible. (Jerusalem and the Golan are treated separately and are not assigned to any country.[13])

The model finds that allocation of water (and associated prices) that maximizes 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.

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

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13 The reason for this separate treatment is that the 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.

reports.[14] Many of the interesting runs for future years, however, 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 on 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.

5. 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

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[14] 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 current prices, they yield the quantities demanded given in the country reports for each year. In the case of Israel and of Jordan with the exception of the Jordan Valley, it is not quite clear from the reports what current prices are (since more than one price is charged to agriculture), and we have approximated the necessary prices. (We took $.173 per cubic meter for Israel and 90 *fils* per cubic meter for Jordan. Because elasticity is low, results are not sensitive to this.

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.

As already observed, the construction of such a model is in its early stages and will be discussed at the Cyprus meeting. 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[15] assigned Palestinian and Israeli districts into sets with the total Mountain Aquifer water pumped in each set fixed.[16] The model

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15 Or, more specifically, Hillel Shuval has.

16 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

chooses optimal pumping patterns subject to this constraint.

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 presented below do not do this.

6. 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 deciding where recycling plants are or are to be located.

In the model runs reported below, it is assumed that recycled water comes only from households and industry and is used only by agriculture.[17] Recycled water is assumed usable either in the district of origin or in districts to which it can be transported.

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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).

17 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.

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.[18]

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 all districts.

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[18] 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 plants, the sum of the two Israeli costs seems pretty close to the total operating costs. The Jordanian team is invited to experiment with other figures.

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 -- 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 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.[19]

Now consider the profits from recycling. Here consumption of

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[19] 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.

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.[20]

Another way to say this is that, if recycled water is 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 a corollary that at first seems paradoxical. Placing a profitable recycling plant in operation lowers the price paid by consumers whose water is recycled, but it actually *raises* the shadow price of the fresh water in the district -- the price received by producers. This is so even though recycled water competes with fresh water in agricultural

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

use, so that one might suppose that the demand for fresh water would be decreased.

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.

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.

7. 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, I consider the case of a pipeline as an example, but, of course, the principles are not so restricted. I 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. 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 operating costs per cubic meter.[21] 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 it is built, it costs nothing to use. Once the bridge is in existence, it is not efficient to charge a toll for its use.

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

Consider therefore a pipeline that does not now exist but which may be constructed in the future. Once it is constructed, the case becomes that already considered. Hence it cannot be optimal to plan to recover the capital costs in the price of the water.

The first question to be answered is that of whether or not the pipeline should be constructed at all. To analyze this, we must run the model both with and without the proposed pipeline. The pipeline is worth constructing if and only if the increase in

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21 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.

the sum of buyer and producer surplus[22] caused by the pipeline discounted at an appropriate interest rate over the life of the pipeline exceeds the capital costs of construction.[23] (The same principle applies when considering whether or not an existing pipeline is worth replacing.)

Now, if the pipeline is not worth constructing, then the capital costs should not be expended and need not be raised. If the pipeline is worth constructing, then the capital costs should be expended. In that case, we have arrived at two propositions. First, it is suboptimal to raise the capital costs by increasing the water rates to cover them. Second, there exists *some* way of raising the necessary funds and making everyone at least as well off as before.

As a practical matter, that way may be hard to find or at least to implement. It is even possible that the regional management authority will have to resort to raising water rates. But there is no reason to suppose that this is necessarily so.

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[22] 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.

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

The model will predict who will gain from the construction of the pipeline. Those people can pay for it in ways not directly related to their water usage. For example, hook-up charges can be used. If these are to be spread out over time (a perfectly reasonable proposition), we obtain two-part tariffs consisting of a fixed charge per year (or month) and a charge (operating costs) varying with the amount of the water. Alternatively, the taxing power can be used and the pipeline built with government funds.

There are two complications to note here. First, some of the gain from having the pipeline may lie in producer surplus. In that case, a windfall tax would have to be used.

Second, some groups may lose through having the pipeline, and those groups may live in a country other than those in which the pipeline is built. For example, a pipeline permitting transport of water from a particular source may raise the price of water to those who would use that source in any case. In such a case, one might consider lump-sum recompense to the losers as part of the capital costs, but this may be difficult to implement.

In any case, such problems need not concern us at this stage. For the present, the conclusion seems clear. Capital costs should not be assumed included in water ccsts. Rather the model should e run with and without a specified capital project; the question of whether overall benefits are sufficient to pay for the project should be analyzed (as should the question of the distribution of gains and losses); and separate accounting of capital costs should be done in calculating net benefits.

It is important to emphasize that the conclusion that capital costs should not be recovered in water rates does not mean that such costs should not be recovered at all. On the contrary, either such costs must be recovered or a deliberate decision made to subsidize consumers. The proposition merely states that capital costs should not be recovered in the *per cubic meter* charge for the water. The use of the model to discover what capital projects are worth building is potentially an important tool for regional (or national) management. As already mentioned, consideration of the use of that tool and the study of how (and whether) regional management should operate is the subject of other papers and of further work.

The results presented below illustrate one of the ways the tool can be used. We permit the use of various projects using only operating costs. If those projects do not get used in the model solution, then the benefits from their use do not exceed the operating costs involved. In such a case, their construction cannot possibly be worth undertaking when capital costs are added on.

We use this device largely in considering possible transportation links and desalination plants.

8. How to Read the Output Tables

We are now nearly ready to discuss the results of the model runs done so far. In order to do so, however, a guide to reading the tables produced by the model (appended to this paper) must be the tables produced by the model (appended to this paper) must be given.

Each run of the model produces seven tables.[24] The first four of these organize results by country (with the Golan and Jerusalem presented separately, as already discussed).

The first table show the prices generated by the model. All prices are in 1990 dollars per cubic meter. The column headed "FPRICE" gives the shadow price of fresh water. This is the value of that water *after being brought to the surface.* In effect, it is the price paid to the owners of the water.

The second column, "RPRICE", gives the price of recycled water. The remaining three give the prices paid by households ("PURB"), industry ("PIND"), and agriculture ("PAGR"), respectively. These prices can (and often do) differ from the first two prices because of effluent charges and recycling profits and because of national policies towards agriculture. Moreover, where agriculture uses both fresh and recycled water, the price given is the average price paid (weighted by the appropriate quantities).

At the bottom of this table the value of water in the Sea of Galilee is given as is the average net price of disputed water in the Mountain Aquifer. Note that the latter is not the value of water at the surface but is that value less the associated

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24 Figures and schematic diagrams can also be produced.

extraction costs. It is thus the value of water underground.

The two values at the bottom of the table are to be used to value water in dispute from the two sources.

The second table shows production of fresh water in each district ("PRODN"), the net export of water from that district ("NET EXP") and the total demand for water from the three types of users ("URBDEM", "INDDEM", and "AGRDEM"). Note that the latter figures include recycled water. All quantity figures are in millions of cubic meters per year.

Production and use of recycled water are shown in the third table. The amount of recycled water ultimately coming from each of the three uses is given as is the amount going to agriculture and the amount leaving the district. (The headings here are self-explanatory).

The fourth table shows profits to fresh-water owners, the costs to the government of subsidies, the buyer surplus and ("SOC. WEL.") the sum of buyer surplus and profits. These are given by district and totaled by country. These figures are in millions of 1990 dollars per year.[25]

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[25] Note that where government policy involves subsidizing a use that would otherwise pay effluent charges, the amount of such charges are included in government costs. One can think of this either as foregone collections for such charges or in terms of accounting for the environmental damage that is not escaped by

A word of warning here. The total surplus ("SOC. WEL.") figures measure the net benefits each country (or district) gets from water. Those benefits, however, are measured using the values set by each country's own national policies. It is entirely appropriate to compare the total surplus for a given country over runs that differ in various assumptions including differences in the national policies of *other* countries. It is *not* appropriate, however, to compare the total surplus for a given country across runs that differ in the national policies of that *same* country. This is because the yardstick used to measure benefits changes across such runs. Different national policies imply different social values of water.[26]

The fifth table shows the movements of fresh water between districts (and countries). Points beginning with the prefix "NC" are locations on the Israeli national carrier. These represent intermediate points for water transport, not locations at which the water is used. To fully trace a water movement may require looking at several lines.

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having the use subsidized.

[26] AN ADDITIONAL (BUT TEMPORARY) WORD OF WARNING. As of this writing, I am not certain that the figures in this table are correct (except for government costs). There has not been time to fix the problem (if there is one) before the Cyprus conference.

The sixth table shows movements of recycled water. It is assumed that such water has its own transportation system and is not mixed with fresh water.

The seventh table shows the pattern of pumping of the disputed water in the Mountain Aquifer. For each source, the quantity pumped is given as is the maximum amount that the model would permit for that source (taken from the Israeli and Palestinian reports).

9. How to Interpret Results

Some of the results presented below may seem surprising. In that case, there are several possibilities.

1. You disagree with the assumptions of the country models.

2. You disagree with the scenario assumptions made.

3. You have not fully understood what is going on.

4. There is a mistake in the computer program or in my interpretation.[27]

In any event, a surprising result or a disagreement needs to be understood and, if necessary, resolved. It is not enough to say that something cannot be right.

This point is related to a further one. The runs reported

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[27] I have been known to make mistakes. I am indebted to numerous friends, colleagues, and family members for drawing my attention to this point.

provided to the country teams (and hence to the parties). They are not only invited but urged to exercise it and to do their own runs. In effect, we are providing what we believe to be a highly useful tool. The discussion below is that of the tool's first uses.

10. Runs, Scenarios, and Policies Examined

In what follows, I shall speak of "runs", "scenarios", and "policies". These are slightly loose terms with the following meanings:

1. A "run" simply means a running of the model in which the optimal solution is found given the assumptions.

2. A "scenario" is an exercise (one or more runs) in which assumptions are specified or altered. For example, a scenario might involve assuming the operation of a recycling plant not now in existence.

3. A "policy" is a national policy towards water use, generally involving a subsidy or other treatment of agriculture. National policies towards water *supply* are treated in terms of scenarios.

The results reported below involve the following runs, scenarios, and policies.

1. The model is an annual model and assumes average water supply conditions. There are three years examined, 1990, 2010, and 2020.

2. For each year, several different scenarios are examined.

These differ in terms of transportation links, recycling plants, desalination plants. For 2010 and 2020, there are three scenarios for Palestinian growth, but, with one exception discussed below the results use only the middle scenario.

a. In all scenarios (except the "Current" scenario for 1990), desalination is assumed possible in any district with a seacoast. Operating costs are assumed to be $.80 per cubic meter.

b. In the "Current" scenario, only facilities currently in operation are assumed. (This is run only for 1990, since it is assumed that in the future there will at least be flows from the Sea of Galilee to the lower Jordan Valley.)

c. In the "Current+" scenario, the possibility of such flows are added. It is assumed that this is done by pipeline (either to the Jordan Valley district of Jordan or the Jericho district of Palestine) at a total cost of $.08 per cubic meter.[28]

d. In the "Plausible+" scenario, in addition to the Jordan River links, several more things are done.

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28 The pipeline option is chosen as environmentally safe and easy to cost. The general results are insensitive to these transportation charges, although they may have a relatively minor effect on the value of the disputed water as discussed below.

First, capacity constraints on existing water transport links in Jordan are removed. Second, recycling plants are assumed in possible operation in the principal West Bank cities, with the recycled water permitted to be transported to the Jericho district. Third, a recycling plant is assumed in possible operation in Gaza, with recycled water permitted to be transported to the Negev district of Israel.

e. In the "All" scenario, all transport links for water in Jordan (both fresh and recycled) are assumed possible and unconstrained. Further, recycling is assumed possible in every district, with recycled water having a transportation system west of the Jordan that parallels the Israeli national carrier (in addition to the transport links available in the "Plausible+" scenario.)

Note that most of the experimentation with transport links for fresh water is done for Jordan. I shall return to this below.

I have described various links and facilities as "possible" for the following reason. As already discussed, capital costs are not being recovered in the per-unit price of water, but operating costs are. An important potential use of the model is to decide what projects would be worth building. One way of beginning such use is to ask what projects would be used *if they were built*. When we allow possible use of a facility, the model solution decides whether or not it is efficient to use it (given the other assumptions of the run). If a facility is used in the model solution, that facility may or may not repay its capital costs; to find out requires further investigation. If a facility is *not* used, however, then we can be sure that it is not worth building.

There is another way to use the model to investigate possible transport facilities. Where nearby districts have very different shadow prices for water and no transport link has been permitted between them, such a link is a prime target for investigation. This shows up below in the case of direct links between Jerusalem and the southern West Bank cities.

Note that since the "All" scenario assumes the possibility of a great many facilities, some of which may not be worth building, the results it generates must be interpreted with caution. There seems little point in running such a scenario for 1990, and, indeed, the only scenarios reported on for that date are the "Current" and "Current+" scenarios. (Interest obviously attaches to what difference it would make if water could be transported down the Jordan River valley.)

3. The principal national policies examined are for Jordan. These are: a. Subsidization of agriculture in the Jordan Valley with a fixed water charge of 6 *fils* per cubic meter; b. Free water for industrial use. (Of these, the first is the more important for the results.) In addition, we experiment with a 30% subsidy of agriculture in Israel (and with one extreme case of a 75% subsidy.)

11. The Results: the Value of Disputed Water

I begin by discussing the question whose answer was described above as the first aim of the project. This is the valuation of the water in dispute.

As already discussed, the price tables in each run give the price of water in the Sea of Galilee and also the average *net* price of the disputed water in the Mountain Aquifer (net of extraction costs).[29] These prices should be multiplied by the respective amounts of water in dispute to obtain the total value (per year) of those amounts.

a. The Water of the Jordan River

There is one possible exception to this. The water of the Jordan River has been valued in the Sea of Galilee. As already mentioned, it is assumed that transportation of that water either to the Jordan Valley district of Jordan or to the Jericho district of Palestine will have operating costs of $.08 per cubic meter. Jordan and Palestine may very well wish to claim that they are entitled to water in the Jordan River bed free of transport costs and that the assumed use of pipelines is the result of Israel's actions over the years.

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29 We have not explicitly presented the price of water in the Yarmuk, but this can be read as the price in the Northern Highlands region of Jordan less any necessary treatment or extraction costs.

We take no position as to whether such claims are correct. If they are correct, then $.08 per cubic meter should be added to the price in the Sea of Galilee to obtain the value per cubic meter delivered to Jordan and Palestine.

The price of water in the Sea of Galilee is $.175 per cubic meter in the "Current" scenario for 1990. Given the Jordanian national policy of subsidizing agriculture in the Jordan Valley at 6 *fils* per cubic meter, that value would rise to $.209 if the water could be transported to Jordan.

For 2010, using the middle Palestinian growth scenario, the value in question is $.357 (given Jordan's national policies) in the "Current+" scenario. In the "Plausible+" scenario, the value is $.293, and, in the "All" scenario, it is $.235.

For 2020, using the same assumptions, there is no feasible solution to the model using only the links of the "Current+" scenario.[30] For the "Plausible+" scenario, the value in question is $.386; for the "All" scenario, it is $.281.

Finally, we attempted to obtain an upper bound on the value in question by seriously increasing the demand for water. We did

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30 The infeasibility is due to the policy of providing free water to industry. This cannot be done given the 2020 forecasts of industrial demand unless transportation links are improved. If industry is not subsidized, the "Current+" scenario yields a value of $.431 per cubic meter.

this by adopting the "High" Palestinian growth scenario for 2020 and adding an Israeli policy of a 75% subsidy to agriculture.[31] When this is done, the value of water in the Sea of Galilee becomes $.591 in the "Plausible+" scenario and $.400 in the "All" scenario.[32]

There are (at least) two conclusions to be drawn from these results. First, the value of the property rights at issue is limited. While the parties will know best how much water is truly in dispute (in the sense of how much difference there is among their positions), an good idea of what is involved can be gotten by taking 400 million cubic meters per year as the amount. Using the scenarios described, this makes the value of the water in 1990 no more than $82 million per year. In 2010, the value is less than $143 million per year. For 2020, the value is less than $173 million per year. Even stressing the system to produce a high value for 2020 only results in a value less than $266 million per

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[31] We are *not* suggesting that Israel can be expected to adopt such a policy. It would essentially involve prices to agriculture very close to existing levels.

[32] As before, the Jordanian policy of free water for industry is infeasible in 2020 without additional transport links. With industry unsubsidized, the "Current+" scenario yields a value for water in the Sea of Galilee of $.683.

year.[33]

Even with 400 million cubic meters per year in dispute, these are not huge sums even though the social value of water as exhibited by Jordan's national policies is included. It should be possible to negotiate over them and to settle the property rights dispute in the context of an overall peace settlement.

Second, it should be noted that the value of the water in the "All" scenarios is substantially less than in the others. This reflects the fact that a more extensive transportation system in Jordan would have large effects. I return to this below.

Before leaving the question of the value of Jordan River water, one other issue seems worth discussing. That issue is how much Jordanian national policies contribute to raising that value. I shall give the answer (in part because the figures are relevant to a later discussion), but it is important not to overstate the importance of what is, in fact, a quite minor point.

The point is minor for two reasons. First, this project does not make policy. As promised, the values given above include the social value of water as revealed in (in this case) Jordan's national policies. While there is some point in the other parties being interested in how those policies affect themselves (and I

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[33] Again, these are all values at the Sea of Galilee. The value of water delivered to Jordan or Palestine would be $32 million per year higher in each case.

shall comment on this later), there is no point in saying that Jordan should not put as much value on water as in fact it does.

Second, the effects in question are not large, although they do become non-negligible for future years. For 1990, abandonment of the two Jordanian policies would reduce the value of 400 million cubic meters of water in the Sea of Galilee by about $14 million per year in the "Current+" scenario. For 2010, the comparable figures are about $49 million per year ("Current+), $23 million per year ("Plausible+") and $24 million per year ("All"). For 2020, the reduction would be about $42 million per year ("Plausible+") and $24 million per year ("All").

Noone should be surprised at the fact that the value placed by Jordan on agriculture in the Jordan Valley raises the value of Jordan River water. What one should focus on is that, even taking that effect into account, the value of the disputed water is still so low.

b. The Water of the Mountain Aquifer

If the value of Jordan River water is low enough to permit dispute resolution, the value of water in the Mountain Aquifer is even more so. This is because of the extraction costs involved -- costs which are sufficiently high that (in the 1990 runs, at least) it does not pay to extract all the water.[34]

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[34] As already noted, these results use only a crude model of the

Using the same scenarios as before, the net price of water in the Mountain Aquifer in 1990 is $.087 per cubic meter in the "Current" scenario. In the "Current+" scenario, the value is $.106.

For 2010, for the "Current+" scenario, the value in question is $.290. For the "Plausible+" scenario, it is $.234. For the "All" scenario, it is $.193.

For 2020, the value for the "Plausible+" scenario is $.317. For the "All" scenario, it is $.233.[35]

Stressing the system as before to generate a high price yields $.487 for the "Plausible+ scenario for 2020 and $.334 for the "All" Scenario in that year.[36]

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hydrology involved. The qualitative results as to value will not change when that is improved, however.

35 As already mentioned, Jordan's policy of free water for industry is not feasible for 2020 without an improved transportation system. This makes the "Current+" scenario infeasible for that year with that policy. If that policy is changed to one of no subsidy for industry, the value of water in the Mountain Aquifer for the "Current+" scenario for 2020 becomes $.359 per cubic meter.

36 As before, the "Current+" scenario is infeasible given the Jordanian policy of subsidizing industry. If Jordanian industry

As before, these figures can be used to value the property rights dispute. I shall again take 400 million cubic meters per year as the amount to be valued. Obviously, the difference between the Israeli and Palestinian reports suggests a figure of about 470 million cubic meters per year as the total amount of water involved, but the difference between various solutions that may be suggested is certainly much less. In any case, the reader can easily adjust the figures given.

Using 400 MCM per year, then, gives a value of no more than $43 million per year for 1990; no more than $116 million per year for 2010; and no more than $144 million per year in 2020. Even using the stressed scenario, the value for 2020 is no more than $222 million per year.

Again, even using a high estimate of the amount of water really at issue, the value of the property rights dispute is not great. This is so even with a very large social value of water to agriculture represented by a (fictitious) 75% subsidy by Israel. This dispute should be resolvable.

Again it is evident that transport and recycling links make a difference to the value involved. So do national policies. In particular, by increasing Jordanian demand, *Jordan's* policies

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is not subsidized at all, the "Current+" scenario yields a value of disputed water in the Mountain Aquifer of $.555 per cubic meter.

increase the value of water in the Mountain Aquifer.

The effect is as follows (still using 400 cubic meters per year). For 1990, the effect is to raise the value of the disputed water by about $8 million per year in the "Current+" scenario.[37]

For 2010, the effects are greater. They are: approximately $39 million per year for the "Current+" scenario; approximately $18 million per year for the "Plausible+" scenario; and approximately $16 million per year for the "All" scenario.

For 2020, the effect for the "Plausible+" scenario is about $26 million per year. That for the "All" scenario is about $19 million per year.

Please note. In focusing on Jordanian policies, I do not intend either to criticize those policies or, indeed, to single out Jordan. I mean only to illustrate the issues that can be involved, and these are the policies that have been most investigated. Policies by Israel and Palestine also have effects on Jordan (as well as on the other parties), and I shall discuss this later.

Moreover, a rise in the value of the water of the Mountain Aquifer may be either good or bad for Israel and Palestine. It is

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[37] There can be no effect in the "Current" scenario, since Jordanian demand can only affect the other two countries by raising the price of Jordan River water delivered from the Sea of Galilee.

bad for users and good for owners of water. We shall see this again in what follows.

12. Jordan and the Importance of Transport Links

I turn now to a closer examination of the results and to other uses of the model beyond valuation of the water in dispute. I begin with the results for Jordan. As before, I assume the two Jordanian national policies mentioned above to be in place (although I shall comment occasionally on their effects).

Begin with 1990. In the "Current" scenario, the shadow price of fresh water is about $.52 per cubic meter in the Jordan Valley, Northern Highlands, and Amman districts. The price to households, however, differs over those districts. In the Jordan Valley, that price is $.82 because of the effluent charges. In Amman and the Northern Highlands, however, the price is only $.54. This is because recycled water produced in those districts is quite valuable -- offsetting most of the effluent charges.

It is worth noting that Jordanian national policies have an effect here (as they must). With no subsidies, the shadow price of fresh water in Amman would be only $.36 per cubic meter. On the other hand, recycling would not be as valuable, so the price paid by households would not decline much, being $.49 per cubic meter. The direct cost of the policies to the government is about $175 million per year, most of it spent in the Jordan Valley.

The other interesting fact to note concerning the "Current" scenario is the clear suggestion that it would be beneficial to have a recycling plant at Aqaba. Without such a plant, the shadow price of fresh water in the Wadi Araba district is about $5.00 per cubic meter (with or without the subsidy to industry).[38]

Turn now to the "Current+" scenario in which water is permitted to flow from the Sea of Galilee to the Jordan Valley. This relieves much of the pressure on prices in the Jordan Valley, with 167 million cubic meters being transferred there. The shadow price of fresh water in that district now drops to about $.29 per cubic meter. The shadow price in Amman also drops (to about $.44 per cubic meter). This makes recycled water produced in Amman less valuable, however, so that the price to households in that city barely changes, dropping only by $.02 per cubic meter.

What is greatly affected is the direct governmental cost of the two policies which drops from about $175 million per year to about $100 per year as the price paid by the government for water in the Jordan Valley falls substantially.

Turn now to 2010. With only the current transportation system and water from the Sea of Galilee, Amman's water shortage shows up sharply. The shadow price of fresh water in the Amman district becomes $1.29 per cubic meter, with households paying $1.35. Prices elsewhere, however, do not rise so dramatically; in the Northern Highlands, for example, urban consumers pay $.51

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38 The subsidy to Jordan Valley agriculture has no effect here.

per cubic meter as opposed to $.46 in the same scenario for 1990.[39]

One does not have to look far to see why Amman is so affected. The reason lies in the lack of additional transportation links. In particular, all existing links into Amman are being used to capacity, but they are not enough. When those capacity constraints are relaxed (in the "Plausible+" scenario), the price to consumers in Amman is cut by over 50%, and a further cut comes (in the "All" scenario) when additional links are permitted.

It is interesting to note that the high price in Amman in the "Current+" scenario has almost nothing to do with the subsidy of agriculture in the Jordan Valley. It is caused in large part, however, by the subsidy to industry. Recall that with only the transport links of the "Current+" scenario, that policy becomes infeasible by 2020. In 2010, the policy is not infeasible, but it puts a considerable strain on the existing system for transporting water to Amman resulting in the high price. Were industry not subsidized, the price to Amman urban consumers in the scenario in question would fall from $1.35 per cubic meter to $.72 per cubic meter. Removal of the Jordan Valley subsidy would only reduce the

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39 The shadow price of fresh water in the Northern Highlands, however, rises from about $.28 to about $.43 per cubic meter. Urban customers are largely sheltered from this because of the increased profits from recycling.

price by an additional $.02 per cubic meter.

The direct governmental cost of the two policies examined increases from 1990 to 2010. In the latter year, with the "Current+" scenario, that cost is about $267 per year. In the "Plausible+" scenario, it is $226 million per year. In the "All" scenario, the cost is $190 million per year.

In 2010, water flow from the Sea of Galilee increases. That flow is 332 million cubic meters per year for the "Current+" scenario, 314 MCM for the "Plausible+" scenario, and 346 MCM for the "All" scenario.

By 2020, the effects of the transport system have become even more important. As already noted, maintenance of the subsidy to industry becomes infeasible without improved transport. In the "Plausible+" scenario, prices to urban consumers in Amman are $.68 per cubic meter, while in the "All" scenario, they are only $.63.

It is interesting to note that the principal transport of fresh water into Amman in both scenarios in 2020 is transport from the Dead Sea district. This suggests that expanding the capacity of transport from that district by that date is a project worth investigating.

The direct governmental costs of the national policies are $228 and $205 million per year, respectively, for the two scenarios.

Water flow from the Sea of Galilee is less than in 2010 (because recycled water from Amman is heavily used in the Jordan Valley). The flow is 233 million cubic meters per year for the

"Plausible+" scenario and 309 million cubic meters per year for the "All" scenario. Recall that this has *nothing* to do with property rights. What is involved is where water is efficiently *used*, not who owns it.

On the other hand, the flow of water from the Sea of Galilee does have something to do with Jordanian policies. Indeed, without the 6 *fils* price to agriculture in the Jordan Valley, it does not pay to transport water from the Sea of Galilee to the Jordan Valley in all but one of the scenarios under discussion.[40] This reflects the fact that prices to agriculture in the Jordan Valley in the absence of the policy almost never exceed the value of water in the Sea of Galilee by as much as $.08 per cubic meter and sometimes even fall short of the value at the Sea. Without the subsidy, prices paid by agriculture in the Jordan Valley would be roughly comparable to prices paid by agriculture in the other countries.

All this merely says that the value that Jordan puts on agriculture in the Jordan Valley is a principal factor in its water policy. That fact should surprise nobody.

13. The Effects of Jordanian Policies on Israel and Palestine

I have commented above on the direct governmental costs of

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[40] The exception is the "All" scenario for 2020 in which only 19 million cubic meters are transported.

Jordanian policies. There are other costs as well, and also benefits.

Begin with the case of Jordan itself. The policies involved increase buyer surplus as seen by industrial and agricultural users. They decrease the buyer surplus of households. Of course, households may very well experience an indirect increase in buyer surplus through a reduced price of food. Further, social benefits may be substantial. If the Jordanian government did not believe that the benefits were greater than the costs, it would not pursue the policies. The model can be used to inform such judgments but not to override them.[41]

The model can be used more directly to evaluate the effects of the national policies of one country on net benefits in another. We do so for Jordanian policies because those are the ones we have studied so far. The model can and should be used to evaluate effects in the other direction.

Jordanian policies increase Jordanian demand for water. This raises the price of water in Israel and Palestine. That price increase has both costs and benefits. Buyer surplus is reduced, but producer surplus is increased as water becomes more valuable.

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41 Recall that the model cannot be used to evaluate changes in surplus in a country whose national policies cause the change. The measuring rod by which surplus is measured itself changes in such a case.

As mentioned in an earlier footnote, I am not certain that the figures on profits, buyer surplus, and social welfare are correct.[42] Hence I shall discuss the results in terms of the effects on prices.

For 1990, those effects are small. In the "Current+" scenario, the Jordanian policies increase prices in Israel and Palestine by about $.02 per cubic meter.[43]

In 2010, the effect is much greater in some locations.

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[42] My uncertainty arises from the following phenomenon. When examining the effect of Jordanian policies, it appears for some scenarios ("Current+" for 2010, for example), that those policies produce a net benefit Israel and Palestine taken together even after one subtracts the increase in value of water in the Sea of Galilee. I do not believe this is possible (although the effects on recycling profits make it a bit complicated). The matter is under study. I am quite sure that the main results are unaffected by any problem here.

[43] The exception is in Jericho where prices are not affected at all. This reflects the fact that it does not pay to deliver water to Jericho from the Sea of Galilee. This lack of effect disappears when recycled water from the cities of the West Bank is permitted to flow to Jericho. That flow is itself affected by an increase in the price of water in the Sea of Galilee.

In the "Current+" scenario, prices in Israel north of Rehovot and in Palestine north of Bethlehem are increased by about $.12 per cubic meter by Jordanian policies.[44] Prices further south are generally unaffected, in part because of the introduction of desalination in Gaza. In the "Plausible+" and "All" scenarios, the effect is smaller, being reduced to roughly $.06 per cubic meter in the North (defined as above).

For 2020, the effects are a bit smaller than in 2010 (in part because of additional desalination). For the "Plausible+" scenario, prices are increased by roughly $.09-$.11 per cubic meter in the "North". In the "All" scenario, the effect is again about $.06 per cubic meter.

14. Israel, Palestine, Recycling and Desalination

I now turn to a discussion of what the same runs show for Israel and Palestine. (The reader is reminded that these are runs in the presence of Jordanian policies but without Israeli or Palestinian policies. Some discussion of these is given later.)

Begin with 1990. In the "Current" scenario, shadow prices in Israel range from about $.18 per cubic meter near the Sea of Galilee to $.55 per cubic meter in the Negev with prices paid by households generally $.30 per cubic meter higher, reflecting

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[44] The increase in the West Galilee district of Israel is only about $.09 per cubic meter.

effluent charges. Recycled water moves from Tel Aviv to Lachish, and this reduces prices in Tel Aviv by about $.10 per cubic meter.

Shadow prices in Palestine range from about $.28 per cubic meter in the North to about $.56 in South Gaza with urban customers again paying $.30 per cubic meter in additional effluent charges. The Jericho district has a much lower price, the shadow price there being about $.19 per cubic meter.

The opening of the transport link down the Jordan Valley (the "Current+" scenario) raises prices in both countries as water is transferred to Jordan. The effect is an increase of about $.02-$.03 per cubic meter everywhere but in Jericho which (because it was not previously connected to the Sea of Galilee) experiences no change.

The opening of the link has a small effect on pumping from the Mountain Aquifer, increasing extraction slightly in Ramla and Bethlehem. Generally, optimal pumping involves extraction in Israel, rather than Palestine in the North, with the effect somewhat reversed in the South.

By 2010, prices rise substantially. In the "Current+" scenario in Israel, the shadow price of fresh water ranges from about $.36 per cubic meter near the Sea of Galilee to $.78 in Lachish and $.84 in the Negev. Urban consumers pay about $.30 more per cubic meter except in Haifa, Netanya, Lachish, and the

Negev, where recycling profits reduce the charge.[45] Note that the shadow price in Lachish is just under the point at which desalination would be profitable (at the assumed operating costs of $.80 per cubic meter).

Desalination is profitable in both North and South Gaza, however, and this holds the shadow price to $.80 per cubic meter in those districts. Shadow prices in the North of Palestine are roughly $.46-$.50 per cubic meter, with urban consumers paying $.30 more per cubic meter, as before.

We now encounter another phenomenon, however. In this (and later) scenarios, prices in Bethlehem and Hebron are quite high. (In the scenario under discussion, the shadow price in Bethlehem is $.73 per cubic meter, while that in Hebron is $.83 per cubic meter). This occurs even though the price in Jerusalem, not far away, is only $.50 per cubic meter.

The reason for this apparent anomaly is not hard to find. The model has no direct transportation link from Jerusalem to Bethlehem (or from Bethlehem to Hebron). For that matter, there is no direct transportation link from the Palestinian cities of the northern West Bank to those of the South. All transport goes

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[45] Recycling in Tel Aviv just breaks even. This is because the recycled water is transported to Lachish at a high transportation charge. Recycled water in Haifa or Netanya is used locally, however. The same phenomenon continues in 2020.

through the Israeli National Water Carrier. Plainly, investigation of the construction of such links is called for. While we do not currently have operating cost estimates for such links (and hence do not directly investigate them), the model suggests quite strongly that they would be beneficial projects to build.[46]

The same phenomenon continues when we consider the "Plausible+" scenario for 2010. Here, prices in Israel are about $.06 per cubic meter lower than in the "Current+" scenario, except for Lachish and the Negev, where they are the same.

The Palestinian story is more interesting. Recycling becomes economic in the major hill cities, with much of the water sent to Jericho. This reduces the shadow price of water in Jericho from $.28 to $.20 per cubic meter, with an even greater reduction in the price paid by agriculture ($.28 to $.11 per cubic meter). Nevertheless, recycling just breaks even, so that urban consumers in the hill cities still pay the full effluent charge.

This is not true in Gaza, however (either district). The export of recycled water from Gaza to the Negev is profitable, so that urban consumers in Gaza pay $1.01 instead of $1.10 per cubic meter.

Note that the reduction in price in Jericho coming from the

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[46] Note that this is not (or not only) a question of national pride. We are talking here of an optimal system for the region.

use of recycled water makes it inefficient to send fresh water to Jericho from the Sea of Galilee.

In the "All" scenario, prices are lower in Israel north of Rehovot by about $.06 per cubic meter than they were in the "Plausible+" scenario. This is also true of prices in Palestine north of Hebron. (In Rehovot and Hebron, the change is about $.03 per cubic meter.) The price in Jericho is lower by more than $.08 per cubic meter.

The pattern of pumping from the Mountain Aquifer has changed somewhat.[47] Principally, this involves extraction in the southern West Bank which was zero in 1990. There is also a small reduction in the Negev. Note, however, that this shift is at least partly induced by the high shadow price of fresh water in Bethlehem and Hebron. Were the transport links discussed above to be introduced, the pumping pattern might well be different.

Turn now to 2020. In the "Plausible+" scenario, the shadow price of fresh water in Israel ranges from about $.39 per cubic meter near the Sea of Galilee to roughly $.50 per cubic meter in the center of the country. The recycling pattern is as in 2010. Desalination becomes efficient in Lachish.[48]

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47 The pattern is similar for all three scenarios.

48 It should not come as a surprise that economic desalination first occurs in the South rather than near Haifa or Tel Aviv.

Palestinian shadow prices are about $.49-.53 per cubic meter from Jenin to Ramallah. As before, Bethlehem and Hebron have much higher prices ($.75 and $.85 per cubic meter, respectively). Recycling profits are still quite small. The shadow price in Jericho is now $.29 per cubic meter, and no water is transported there from the Sea of Galilee.[49] Desalination continues in Gaza as does recycling, with recycled water shipped to the Negev at a profit.

The "All" scenario has shadow prices about $.10 per cubic meter lower than does the "Plausible+" scenario for every district that draws on the Sea of Galilee through the Israeli National Carrier. Otherwise, the only interesting change is that recycling profits are greater than before in the Palestinian cities and Tel Aviv and much less in Haifa and Netanya. (Of course, recycling plants appear now in every district).

The pumping pattern of the Mountain Aquifer remains the same as in 2010.

To summarize as to facilities that seem worth investigating,

The latter cities are relatively close to the Sea of Galilee and hence have lower prices for fresh water than occurs in the South.

[49] Please remember. This result has nothing to do with whether Palestine is entitled to ownership of the water of the Jordan River. We are talking here of efficient use, not of ownership.

these are: 1. Desalination in Gaza and later in Lachish; 2. Recycling facilities in the principal West Bank cities with pipelines to the Jericho district; 3. A recycling plant in Gaza with a pipeline to the Negev.[50]

15. The Possible Effects of Israeli Policies on Palestine and Jordan

The last matter to be investigated is that of the possible effect of Israeli policies on Palestine and Jordan. I use the word "possible" because the policies to be investigated are not in fact in place. Hence interest really lies in the extent of linkage, the extent to which Israeli policies might affect prices in the other two countries, rather than on the extent to which they do. Examination of real or likely policies is a topic for further use of the model.

The policy investigated is one of a 30% subsidy to Israeli agriculture. Again, I assume that the Jordanian policies are in place.[51]

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50 This latter facility has the added attraction that, as I understand it, there is no aquifer to be damaged by the recycled water.

51 This reduces the number of scenarios that must be examined and makes relatively little difference.

For 1990, in the "Current" scenario, the Israeli subsidy can have no effect on Jordan. The effect of the Israeli subsidy on prices in both Israel and Palestine is minor in many districts, raising prices by about $.02 per cubic meter in Israel north of Lachish and in Palestine north of Bethlehem. This occurs because the subsidy brings slightly higher-cost water sources into play.

In the South, however, matters are different. Here the subsidy raises prices by about $.09 per cubic meter in Bethlehem, Hebron and Gaza as well as in Lachish and the Negev. There is no effect in Jericho.

When the links down the Jordan River are opened, the effect is about the same in the North and a bit less in the South (about $.07 per cubic meter).

For 2020, in the "Current+" scenario, the effect in Israel is again about $.03 per cubic meter north of Lachish. There is no effect in Lachish or the Negev, largely due to the presence of recycled water.

In Palestine, the effect is about $.03 per cubic meter north of Bethlehem. There is no effect from Bethlehem southward.

The effect in Jordan is also an increase of $.03 per cubic meter, this time in the Jordan Valley and the Northern Highlands. Other districts are not affected.

In the "Plausible+" scenario, the effect in all countries is a bit larger, $.05 rather than $.03 per cubic meter.

The geographic pattern is the same.[52]

For 2020, the same general pattern appears in Israel and Palestine with the effect less than $.02 per cubic meter in the North. In Jordan, the effect now occurs everywhere except in the last three districts (Wadi Araba, Ma'an Disi, and Hammad). The size of the effect is roughly the same as in the other two countries.

In the "All" scenario, the effects are generally the same or less. In Jordan, the effect is restricted to the Jordan Valley.

The surprising absence of large effects here is probably due to the presence of recycled water that is generally available at a low price.

16. General Conclusions

The results discussed above are interesting. Many, perhaps all of them, will remain after more detailed investigation. Whether individual results are correct in detail is less important, however, than the general conclusions that they illustrate.

The model is a useful policy tool. Either used by a regional management authority or by individual governments, it can point the way to problems and possible solutions. I listed above a

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52 There appears to be a problem with the run of the "All" scenario here for 2010, so I omit it.

number of capital projects that the model suggests should be investigated. These included: specific transport links in Jordan and Palestine; desalination plants in Aqaba, Lachish, and Gaza; and recycling plants in Gaza and the major cities of the West Bank as well as transport facilities for recycled water. Sale of recycled water from Gaza to the Negev appears profitable.

Related to the investigation of possible future projects is a point not yet mentioned. The shadow prices of water generated by the model for specific locations are a guide to the delivered costs at which it would pay to import water at those locations. This can assist in evaluating projects such as the purchase of water from Lebanon or Turkey.

Sensible management of the water resources of the region, however, can only take place in an atmosphere of agreement and trust. The model can assist in creating that atmosphere in two ways.

First, as we have seen, the model can be used to investigate the effect of the policies of one country on the others. If, as appears true in the examples examined, those effects are small, then their monetization should assist negotiation.

Second, and perhaps most important in the short run, the model can assist in the resolution of the underlying property-rights dispute. *Even taking the social value of water into account through the value set on water by national policies, the value of the water in dispute is quite low.* To remind the reader, the value of 400 million cubic meters of water in the Sea of Galilee ranges from $82 million in 1990 to $173 in 2020 in the sensible scenarios. The value of the same amount in the Mountain Aquifer ranges from $43 million in 1990 to $222 million in 2020. Even an extreme scenario produces values (for 2020) of only $266 million and $222 million, respectively.

Of course these values are worth bothering about, and, of course the property-rights dispute must be resolved. But the magnitudes involve surely make it resolvable in the context of an overall settlement.

My colleagues and I offer our work and further assistance in the hope and belief that we are providing a tool that can be used both to assist the resolution of the dispute and in the management of the water resources of the region for the benefit of all those who inhabit it.

FIGURE 1

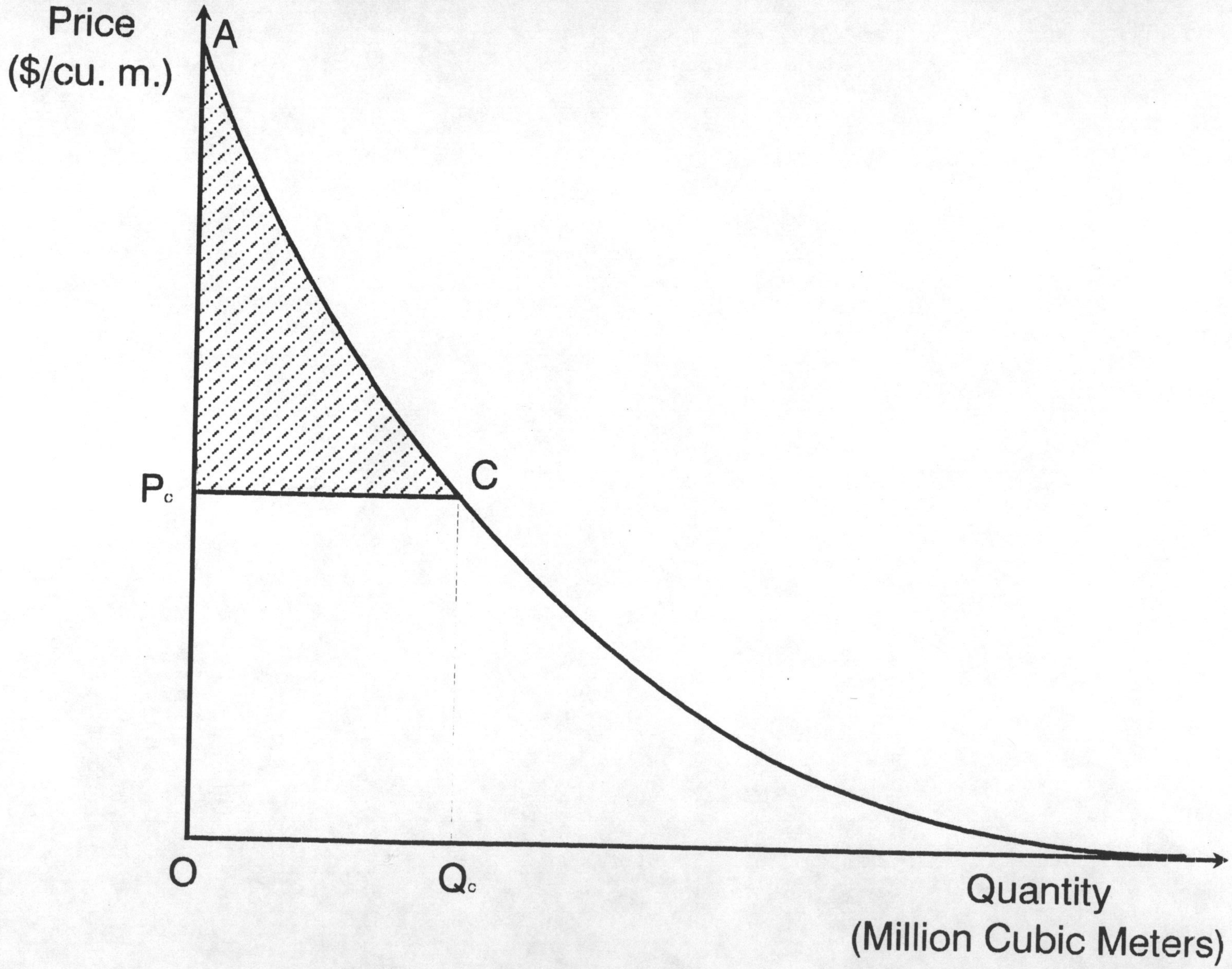


FIGURE 2

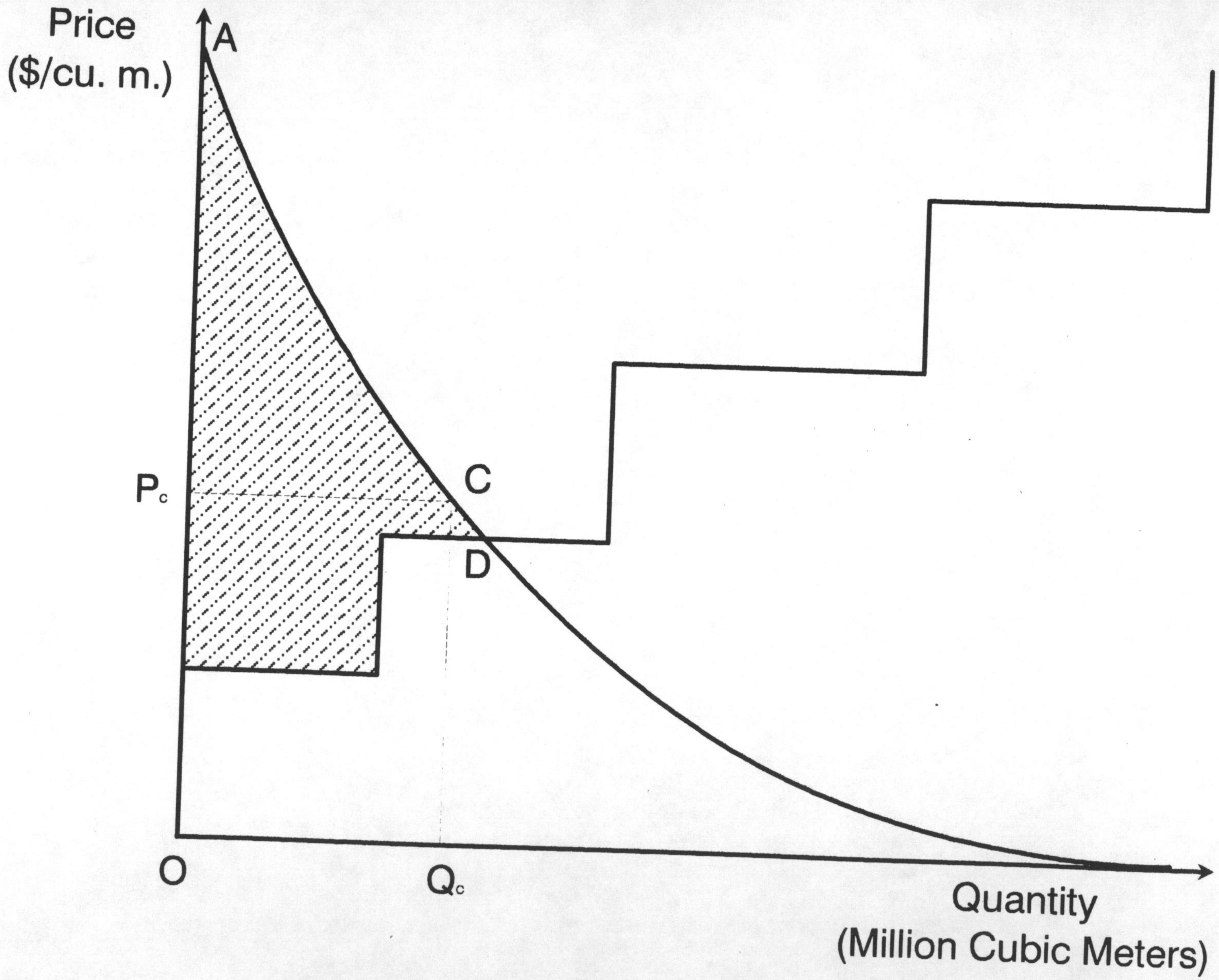
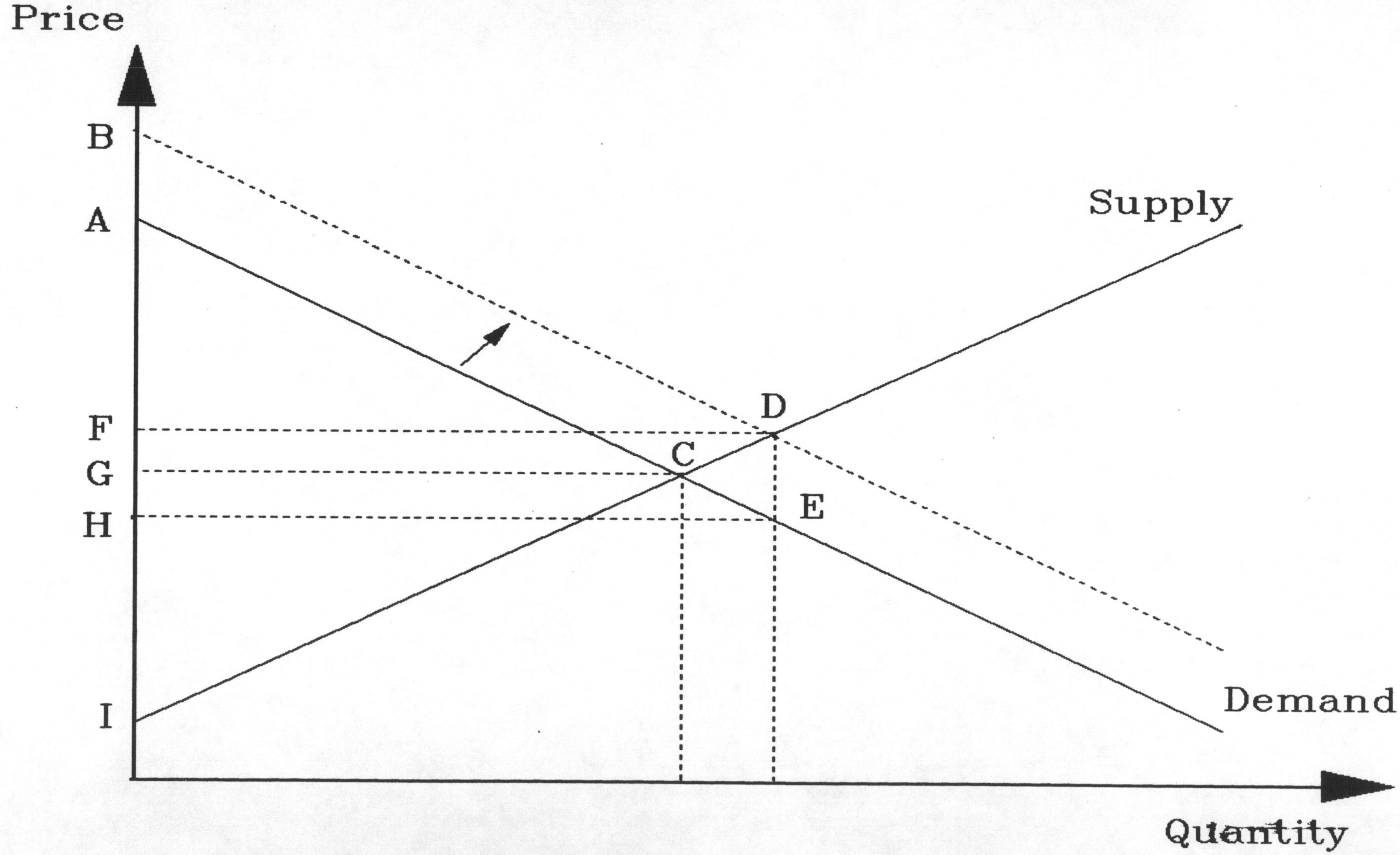


Figure 3



Draft -- 6/23/94

THE HARVARD MIDDLE EAST WATER PROJECT: MODEL OVERVIEW AND RESULTS SO FAR: ADDENDUM

In the main paper, it is twice observed (p. 34, n. 26 and p. 54, including n. 42) that there appears to be a problem with the tables giving the results on profits, buyer surplus, and social welfare. I am pleased to say that this problem has been found and corrected. Replacement tables will be available at the Cyprus conference.

This note discusses the inferences that can be drawn from those tables (together with the other results). These concern the effects of the policies of one country on welfare in the other countries.

I begin with the effect of Jordanian policies on Israel and Palestine. (The direct effect on prices is discussed in the main paper at pp. 54-55.) One must be careful as to what is involved.

The need for care arises from the property-rights disputes. When Jordan subsidizes agriculture (and, in principle, when it subsidizes industry), it demands more water from the Sea of Galilee. (This occurs regardless of who owns the water involved.) The result is an increase in water prices in Israel and Palestine. That increase causes a decrease in buyer surplus and an increase in profits in the latter two countries. But some of the profits involved are profits on the water sold to Jordan, and some, all, or more than all of those profits belong to Jordan itself, depending on the resolution of the property-rights dispute. The profits belonging to Jordan must be subtracted before calculating total surplus in Israel and Palestine.

Similarly, the rise in water prices raises the value of water in the Mountain Aquifer (main paper, p. 47). This increases profits from such water. The attribution of the profit increase to Israel and Palestine, respectively, depends on the resolution of the property-rights dispute.

All of this makes precise calculation impossible. Nevertheless, general conclusions are easy to state.

Begin with 1990 and the "Current+" scenario. Here Jordanian policies reduce Israeli buyer surplus by about $25 million per year, Palestinian buyer surplus by about $2 million per year, and buyer surplus in Jerusalem by about $.6 million per year. This is more than offset in the tables by the rise in profits. If we attribute *all* the profits in the Kinneret district of Israel to Jordanian owned water,[1] the net effect on Israel and Palestine together (including Jerusalem) would be slightly negative, about $4 million per year. This is a very small effect, especially considering that the subtraction is too large. Even the effects on buyer surplus are fairly small.

When we move to the same scenario for 2010, the effects on buyer surplus are larger: $79 million per year for Israel; $20

[1] The tables list profits at the point of extraction independently of ownership. In this case, that happens to be counted as in the Kinneret district of Israel. But such a listing does not imply that the profits properly belong there.

million per year for Palestine; and $3.5 million for Jerusalem.

Here, however, we encounter a surprising phenomenon. The increase in profits produced by Jordanian policies more than offsets the loss in buyer surplus, and this remains true even if all profits from the water of the Sea of Galilee are attributed to Jordan.

This phenomenon may seem impossible at first (as it did to me), but it is quite real. With Jordanian policies in place, water flows from the Sea of Galilee to Jordan; without those policies, it does not. Those policies therefore benefit domestic water producers in the other two countries, as it were, by transferring profits to them that would otherwise be earned by Jordan. There is no reason that this (together with other increases in profits) cannot more than offset the decrease in buyer surplus in Israel and Palestine. It is a though foreign competition is removed and domestic products substituted.

The same phenomenon continues in the other scenarios for 2010, but the effects are smaller with better transport links and recycling. So are the direct effects on buyer surplus.

For 2020, the results are essentially similar. For the "Plausible+" scenario, Jordanian policies reduce buyer surplus in Israel ($80 million per year), Palestine ($25 million per year), and Jerusalem ($4 million per year). These effects are more than offset by the increase in profits. Similar, but smaller results hold for the "All" scenario.

On balance, then, Jordanian policies do not hurt the other countries involved. If anything, they benefit those countries. Of course, this happens because the other countries indirectly receive some of the subsidies paid by the Jordanian government as those subsidies cause them to "import" less water.

I turn now to the effect of a 30% subsidy of agriculture by Israel on Jordan and Palestine (assuming Jordanian policies in place). For the 1990 "Current+" scenario, the subsidy reduces buyer surplus in Jordan by about $2 million per year. Profits, however (excluding water in the Sea of Galilee), are increased by about $6 million per year, while government costs are increased by about $5 million per year. Evidently, the total effect is likely to be positive when increased profits from Jordanian water in the Sea of Galilee are included.

The effect on Palestine is a reduction in buyer surplus of about $5 million per year. This is partly or totally offset by an increase in profits, the size of which depends on the ownership of Mountain Aquifer water.

Similar results occur in the latter two years. In the "Plausible+" scenario for 2010, Jordanian buyer surplus is reduced by the Israeli subsidy by about $9 million per year, and governmental costs are increased by about $15 million per year. Profits (not counting the Sea of Galilee) increase by about $16 million per year.

In Palestine, buyer surplus is reduced by about $7 million per year. This is offset (or more than offset) by the increase in profits.

The results for 2020 are similar.

The conclusion to be drawn is that the policy under examination does not have very large deleterious effects on the other two countries. Depending on the resolution of the property rights question, it may even benefit them.