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OPTIMAL WATER MANAGEMENT AND CONFLICT RESOLUTION:

THE MIDDLE EAST WATER PROJECT

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* As described below, the Middle East Water Project here discussed is the joint work of a very large number of persons, far too many to list all on the title page or even to thank by name. The work that specifically concerned each of Israel, Jordan, and the Palestinian National Authority was carried out bilaterally by a team of nationals and the central (American and Dutch) team. When necessary, coordination sessions were held under the sponsorship of the government of The Netherlands which financed and facilitated the Project, and all teams contributed to the analysis of modeling issues. It should also be noted that not all authors necessarily agree with the specific policy prescriptions discussed in the paper. Of course, the opinions here expressed do not necessarily reflect the views of any government or government official.

1. INTRODUCTION: ACTUAL AND SIMULATED WATER MARKETS

Water is often considered in terms of quantities only. Demands for water are projected, supplies estimated, and a balance struck. Where that balance shows a shortage, alarms are sounded and engineering or political solutions to secure additional sources are sought.

Disputes over water are also generally thought of in this way. Two or more parties with claims to the same water sources are seen as playing a zero-sum game. The water that one party gets is simply not available to the others, so that one party's gain is seen as the other parties' loss. This is true regardless of whether the parties are different countries, different states or regions, or different consumer types.

But there is another way of thinking about water problems and water disputes, a way that can lead to dispute resolution and optimal water management. That way involves thinking about the economics of water.

The late Gideon Fishelson of Tel Aviv University once remarked that "Water is a scarce resource. Scarce resources have value." He went on to point out that the availability of desalination of seawater (together with the costs of conveyance from the seacoast) must put an upper bound on the value of water in dispute to any country that has a seacoast.

Those remarks were a principal impetus to the creation of the Middle East Water Project (MEWP). That Project is a joint endeavor of Israeli, Jordanian, Palestinian, Dutch, and American scholars. It has been heavily at work since October 1993, under different auspices.[1] In the present paper, we discuss the methods that it has developed and the uses to which those methods might be put. While our concentration is naturally on international issues, the methods discussed are also applicable to disputes among states or disputes among consumer groups as well as to optimal management of water systems.

The fact that (save in landlocked countries) desalination puts an upper bound to the value of water in dispute is dramatic and easily understood. It means, for example, that the value of the water in dispute between Israelis and Palestinians lies at most in the range of a few hundred million dollars per year and is most probably far less than that. Such amounts ought not to be a bar to agreement between nations. Even that fact, however, is not as important as the general way of thinking suggested by Fishelson's remarks. The really important insight is that it is possible to think about water and water disputes by analyzing water *values* and not just water quantities. This means thinking about the economics of water (which, as we shall see, by no means implies the ignoring of social and strategic values).

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[1] The Project was originally under the auspices of and supported by the Institute for Social and Economic Policy in the Middle East (ISPME) at Harvard University. Since 1996, it has been supported by the government of the Netherlands. Harvard University now has no connection with the Project, which is currently managed by Delft Hydraulics. Over the life (or, perhaps better, lives) of the Project, a great many people have contributed to it in various ways. They cannot be individually thanked here, but we would be very remiss were we not to thank Aviv Nevo and N. Harshadeep for substantial early contributions and Leonard Hausman, the Director of ISPME, for his tireless and devoted support. We also thank the staff of ISEPME for their many efforts. Finally, we are extremely grateful to the government of the Netherlands for its selfless support of the Project and, especially, to Louise Anten who shares our vision.

This should not come as a surprise. After all, economics is the study of how scarce resources are or should be allocated to various uses. Water is a scarce resource, and its importance to human life does not make its allocation too important to be rationally studied.

In the case of most scarce resources, competitive markets can be used to secure efficient and desirable allocations. This, however, is not generally true of water where at least three of the basic properties needed for reliance on free markets are often absent. These are the following:

1. The proposition that free markets lead to an efficient allocation assumes that markets are competitive, that is, that they include a large number of independent small sellers and a similarly large number of independent small buyers. This is not typically true of water, at least in arid or semi-arid countries, where water sources are relatively few and are likely to be owned by the state.

2. For a free market to lead to an efficient allocation, social costs must coincide with private costs. Water production, however, involves what economists call "externalities." In particular, extraction of water in one place reduces the amount available in another. Further, aquifer pumping in one location can affect the cost of pumping elsewhere. Use or disposal by certain consumers can affect water qualities for others. Such externalities do not typically enter the private calculations of individual producers or consumers.

3. Similarly, if a free market is to lead to a desirable allocation, social benefits must coincide with private ones. If not, then (as in the case of cost externalities) the pursuit of private ends will not lead to socially optimal results. In the case of water, many countries reveal by their policies that they regard water for certain uses (often agriculture) as having a public value that exceeds its private one. Moreover, even a technically efficient allocation may not be deemed a fair one if the rich and powerful obtain much water while the poor and weak are water-deprived.

These conditions for optimal results from a free market do not hold in the Middle East. Further, not all of them will generally hold elsewhere. In particular, attempts to form water markets by distributing water rights to individuals and allowing those rights to be sold, while a great step forward, will often fail. While such markets can meet the first condition above and produce a large number of sellers, they can fail to meet the second and third conditions.[2]

1. If the extraction or use of water in one location does not affect the costs of extraction or the quality of water in another, then all that needs to be distributed are the rights to water quantities. If, however, that condition is not met, as will often be the case, then a market in water rights will not lead to an efficient solution. This will also be the case when there are large, indivisible infrastructure projects that serve many consumers. In the Middle East and elsewhere, conveyance systems are crucial and have this property.

2. Where, as is the case in many countries, water in certain uses is thought to have social value above and beyond its value to the users, a market in water rights will not

[2] It is worth remarking, however, that water markets can nevertheless inject open considerations of efficiency into an otherwise sometimes arbitrary regulatory process. Such considerations are also present in the modeling solution that is the topic of this paper.

> produce a social optimum. Suppose, for example, that water in agriculture is believed to have this property. One cannot account for this by giving farmers a large share of the rights since farmers will then sell those rights and the water will be used elsewhere. Similar properties hold for water needed for environmental uses.

The fact that private water markets cannot be expected to lead to socially optimal results does not mean, however, that economic analysis has no role to play in the management of water systems and the design of water agreements. It is possible to build a model of the water economy of a country or region that takes the above factors into consideration and to use that model to guide water policy. Such a model explicitly optimizes the benefits to be obtained from water, taking into account the three points made above. Its solution, in effect, provides a simulated market answer in which the optimal nature of markets is restored and serves as a guide to policy makers.

We emphasize the word "guide." Such a model does not itself make water policy. Rather it enables the user to express his or her priorities and then shows how to implement those priorities in an optimal way. **While such a model can be used to examine the costs and benefits of different policies, it is not a substitute for but an aid to the policy maker.**

Related to this is the following point: **Despite the fact that the models described have their foundation in economic theory, it would be a mistake to suppose that they only take economic considerations (narrowly conceived) into account. In fact, social values and policies are of great importance in the use of such models. As we shall see, the model we have built leaves room for the user to express such values and policies through the provision of low (or high) prices for water in certain uses, the reservation of water for certain purposes, and the assessment of penalties for environmental damage. These are, in fact, the ways that social values are usually expressed in the real world.**

Of course, it will often be true that social values are not explicitly formulated. When that is the case, models such as described below can play a useful role in revealing to the user the consequences of his or her proposed actions. Those consequences, in turn, can lead or even force the user to rethink his or her values. This same iterative role can arise in water negotiations using the same model tool.

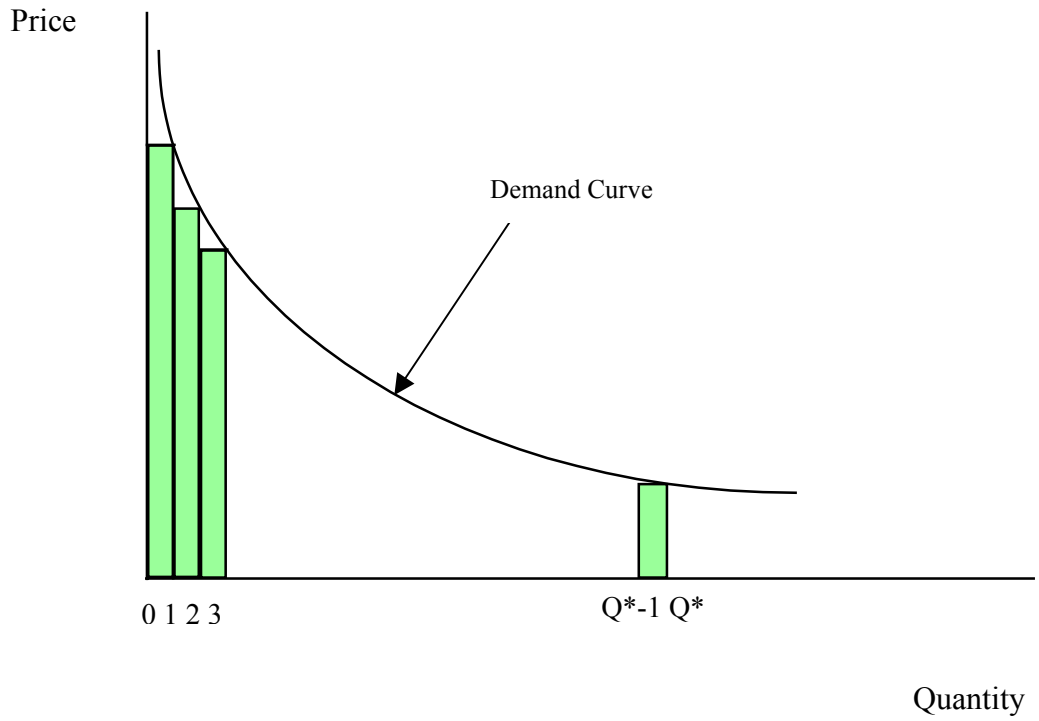
In this paper, we first describe the theory behind such models. We then consider how they can be used to guide decisions about water policy and infrastructure within a single country. Despite the fact that it will take us a while to get there, the focus of this paper is on international conflict resolution and cooperation. The foundation for the discussion of that issue must first be carefully laid.

2. NET BENEFITS FROM WATER — PRIVATE AND SOCIAL

To understand what is meant by an "optimizing model," some description of the underlying economic theory is required. We begin by temporarily ignoring some of the issues raised above and assuming for the moment that there are no social benefits from water beyond private ones. That assumption will be dropped quite soon.

Figure 1 shows an individual household's demand curve for water, the amounts of water (on the horizontal axis) that the household will buy at various prices (on the vertical axis). (Of course, there will be different demand curves for different consumers and for different water qualities, and such curves are likely to change over time.) The curve slopes down, representing the fact that the first few units of water are very valuable, while later units will be used for purposes less essential than drinking and cooking.[3]

Figure 1. Gross Benefits from Water



Now consider how much it will be worth to the household in question to have a quantity of water, Q*, as pictured in the diagram. Begin by asking how much the household would be willing to pay for the first small unit of water. The price that would be paid is given by a point on the curve above the interval on the horizontal axis from 0 to 1. (Exactly where does not matter.) So the

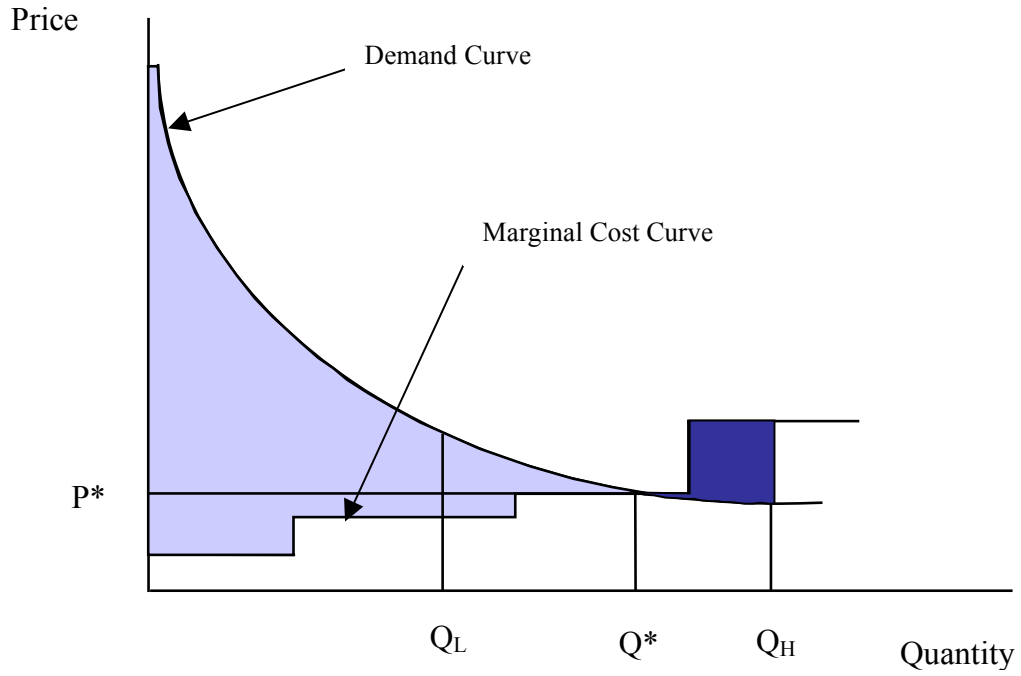
[3] The sensitivity of demand -- in this case, water demand -- to price is measured by "elasticity". The price elasticity of demand is defined as $|d \log Q/d \log P|$, which is approximately the absolute value of the percentage change in quantity induced by a one percent change in price. Where price elasticity is less than one (as is surely true of the demand for water at reasonable prices, the demand curve is said to be "inelastic". In such a case, the total amount paid for the good is higher at higher prices than at lower ones.

amount that would be paid is (approximately) the area of the leftmost vertical strip in Figure 1 (one unit of water times the price in question). Similarly, the amount that would be paid for a second unit can be approximated by the area of the second-to-left vertical strip, and so on until we reach Q*. It is easy to see that, if we make the size of the units of water smaller and smaller, and the total amount that the household would be willing to pay to get Q* approaches the area under the demand curve to the left of Q*.[4]

Now reinterpret Figure 1 to represent not the demand curve of an individual household but the aggregate demand curve of all households in a given district. The gross (private) benefits from the water flow Q* can thus be represented as the total area under the demand curve to the left of Q*. These benefits are gross, however. To derive the net benefits from Q*, we must subtract the costs of providing Q*.

In Figure 2, the line labeled "marginal cost" shows the cost of providing an additional unit of water. That cost increases as more expensive sources of water are used. The area under the marginal cost curve to the left of Q* is the total cost of providing the flow, Q*, to the households involved. Thus the net benefit from providing Q* to these households is the shaded area in the diagram, the area between the demand curve and the marginal cost curve.

Figure 2. Net Benefits from Water

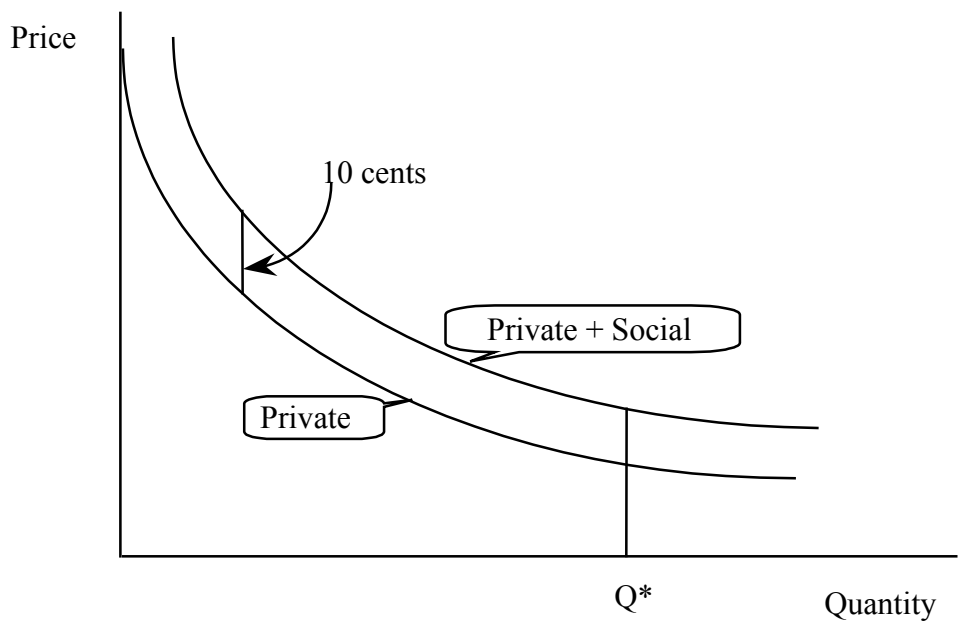


[4] This is an approximation for households, although it is likely to be a good one. For industry and agriculture, the calculation is exact.

The amount of water that should be delivered so as to maximize the net benefits from water is Q*, where the two curves intersect.[5] If one were to deliver an amount Q_L, less than Q*, then one would have a smaller shaded area reflecting the fact that households consuming Q_L would be willing to pay more for additional units (marginal value) than the cost of such additional units (marginal cost). If one were to deliver an amount of water, Q_H, greater than Q*, then one would have a negative value (the darker area) to subtract from the shaded area, reflecting the fact that households consuming Q_H would not be willing to pay the costs of providing the last few units. Hence, Q* is the optimal amount of water to deliver.

As the following example shows, this apparatus can accommodate the fact that the social value of water can exceed its private value. Consider a national policy to subsidize water for agriculture by 10 cents per cubic meter at all quantities — an unrealistic but simple case. This is a statement that water to agriculture is worth 10 cents per cubic meter more to society than farmers are willing to pay for it. This is represented in Figure 3. The lower demand curve represents the private value of water to agriculture; the upper demand curve also includes the additional public value as reflected in the policy, an additional value of 10 cents per cubic meter. As this illustrates, any consistent water policy can be represented as a change in the demand curve for water. Once such a policy has been included in the demand curves, the methods used above can be used to measure net benefits.

Figure 3. Social Value of Water as Revealed by a Subsidy



[5] This statement may appear to assume no constraints on the capabilities of the delivery system, but that is not correct. Any such constraint would cause the marginal cost curve to become vertical at delivery capacity.

3. SHADOW VALUES AND SCARCITY RENTS

In competitive markets, prices measure both what buyers are just willing to spend for additional units of the good in question (marginal value) and the cost of producing such additional units (marginal cost). A price higher than marginal cost signals that an additional unit is worth producing, since the value placed by buyers on that unit is greater than the cost of production; similarly, a price less than marginal cost is a signal to cut back on production. Prices and the profits and losses they generate serve as guides to efficient (optimal) resource allocation.

As already discussed, purely private markets and the prices they generate cannot be expected to serve such functions in the case of water. Nevertheless, prices in an optimizing model play an important role — a role very similar to that which they play in a system of competitive markets.

As explained above, the MEWP model, called "WAS" for "Water Allocation System," allocates water so as to maximize the net benefits obtained from it summed over all consumers and all districts. This maximization of net benefits is done subject to constraints. For example, at each location, the amount of water consumed cannot exceed the amount produced there plus net imports into that location.

It is a general (and important) theorem that when maximization involves one or more constraints, there is a system of prices involved in the solution. These prices, called "shadow values,"[6] are associated with the constraints. Each shadow value shows the rate at which the quantity being maximized (here, net benefits from water) would increase if the associated constraint were relaxed by one unit. In effect, the shadow value is the amount the maximizer should be just willing to pay (in terms of the quantity being maximized) to obtain a unit relaxation of the associated constraint.

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

The central shadow values in the model, however, are those of water itself. The shadow value of water at a given location is the amount by which the benefits to water users (in the system as a whole) would increase were there an additional cubic meter per year available free *at that location*. It is also the price that the buyers at that location who value additional water the most would just be willing to pay to obtain an additional cubic meter per year, given the optimal water flows of the model solution. (In Figure 2, the price, P*, would be the shadow value if Q* were the maximum amount of water available.)

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

1. Shadow values are not necessarily the prices that water consumers are charged. That would be true in a purely private, free market system. But, in the WAS model as in

[6] Also "LaGrange multipliers."

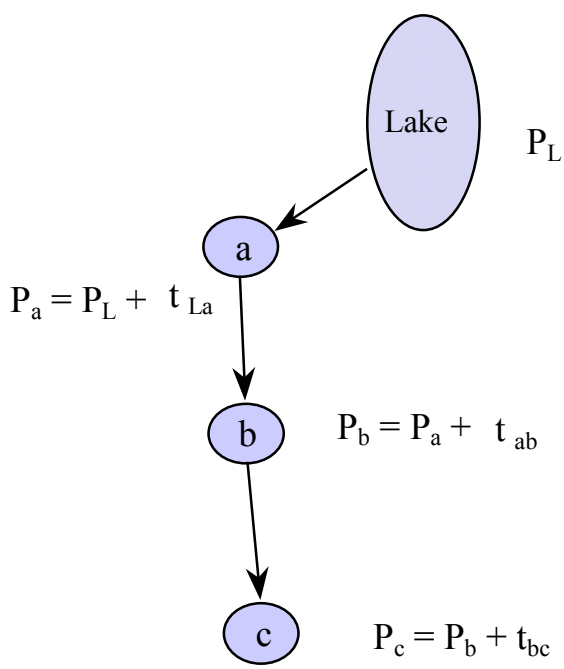
reality, the prices charged to some or all consumers can (and often will) be a matter of social or national policy. When such policy-driven prices are charged, the shadow values of water will reflect the net benefits of additional water given the policies adopted.

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

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

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

Figure 4: Efficient Water Allocation and Shadow Values



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

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

3. If water can be transported from location *a* to location *b*, then the shadow value of water at *b* can never exceed the shadow value at *a* by more than the cost of such transportation. Water will actually be transported from *a* to *b* only if the shadow value at *b* exactly equals the shadow value at *a* plus the transportation cost. Equivalently, if water is transported from *a* to *b*, then the scarcity rent of that water will be the same in the both locations.

   This situation is illustrated in Figure 4, where water in a lake (L) is conveyed to locations a, b, and c. It is assumed that the only direct costs are conveyance costs. The marginal conveyance cost from the lake to a is denoted t_{La}; similarly, the marginal conveyance cost from a to b is denoted t_{ab}; and that from b to c is denoted t_{bc}. The shadow values at the four locations are denoted P_L, P_a, P_b, and P_c, respectively.

   To see that the equations in Figure 4 must hold, begin by assuming that $P_a > P_L + t_{La}$ and that there is extra conveyance capacity from L to a at the optimal solution. Then transferring one more cubic meter of water from L to a would have the following effects: First, since there would be one cubic meter less at L, net benefits would decline by P_L, the shadow value of water at L. (That is what shadow values measure.) Second, since conveyance costs of t_{La} would be incurred, there would be a further decline in net benefits of that amount. Finally, however, an additional cubic meter at a would produce an increase in net benefits of P_a, the shadow value of water at a. Since, by assumption, $P_a > P_L + t_{La}$, the proposed transfer would increase net benefits; hence, we cannot be at an optimum.

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

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

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

Note that shadow values play a guiding role in the same way that actual market prices do in competitive markets. As the above proof illustrates (see also point 2, above), an activity that is profitable at the margin when evaluated at shadow values is one that should be increased. An activity that loses money at the margin when so evaluated is one that should be decreased. In the optimal solution, any activity that is used has such shadow marginal profits zero, and, indeed, shadow profits are maximized at the optimum.

That shadow values generalize the role of market prices can also be seen from:

4. Where there are only private values involved, at each location, the shadow value of water is the price at which buyers of water would be just willing to buy and sellers of water just willing to sell an additional unit of water.

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

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

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

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

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

4. DESCRIPTION OF THE WAS MODEL AS A MANAGEMENT TOOL

To implement these principles requires constructing a model of water supply, water demands, costs, and infrastructure. A brief description of such a model follows.[7]

The area to be studied is divided into a number of districts. Within each district, demand curves for water are defined for each of household use, industrial use, and agricultural use.[8] The annual renewable amount of water from each source is taken into account[9] as is the pumping cost thereof. Allowance is made for recycling of wastewater,[10] and the possibility of inter-district conveyance is taken into account. This procedure is followed using actual data for a recent year and projections for future years.

Environmental issues are handled in several ways. First, water extraction is restricted to annual renewable amounts; second, an effluent charge can be imposed on households and industry; finally, the use of recycled water in agriculture can be restricted.

The model permits experimentation with different assumptions as to the infrastructure that will be in place in the future. For example, the user can install treatment plants near cities, expand or install conveyance systems, and create seawater desalination plants in any district that has a seacoast. The costs and capacities of these facilities can also be specified.

Finally, the user specifies the national policies toward water that he or she wishes. As explained above, this is where the national value of water that is not merely private value is expressed and where non-narrowly economic factors are considered. Among other possibilities, such policies can include: specifying particular price structures for particular users; reserving water for certain uses; expressing penalties when water for certain uses falls short; imposing environmental restrictions, and so forth.

In this connection, it is important to note the following. It may very well happen (especially with a model as complicated as this one) that the user does not fully understand the implications of his or her initial specification of social water value or water policy. This may be particularly likely when the model is used in negotiations or agreements among countries, as described below. Hence the user may very well wish to experiment with different choices. In this case, the specification of social value or water policy becoming an iterative process in which the user interacts with the model.

In any event, the model does not make water policy. The user imposes his or her values or policies on the model which then respects them absolutely. The use of the WAS tool provides the

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

[8] In fact, the Middle East Water Project involves a very sophisticated treatment of agriculture in which cropping patterns are allowed to respond optimally to water prices and available quantities. See Amir and Fisher (1999). For simplicity, however, we shall not go into this in the present paper.

[9] Ongoing development plans for the WAS model involve both the construction of a multi-year version and the treatment of seasonal variations.

[10] Brackish water can also be handled, and seawater desalination is explicitly modeled. Future development of the WAS model may involve a finer treatment of water quality issues.

user with the means to examine how the user's policies can be efficiently implemented and what the consequences are.

Given the choices made by the user, the model allocates the available water so as to maximize net benefits, measured as previously explained. Shadow prices are generated as part of the solution. The model uses GAMS software and takes about two minutes on a fast Pentium laptop to converge.

Among other things, the model provides a powerful tool for the analysis of the costs and benefits of various infrastructure projects. This can be done in more than one way.

First, where two districts not connected by pipeline, river, or canal have shadow values that differ by more than the estimated operating and maintenance cost of conveyance would be in the presence of a pipeline, the construction of such a pipeline warrants investigation. Similarly, where shadow values do not differ by so much, then such a pipeline would not be used if it were built.

Second, shadow values can be used for other purposes. For example, if one runs the model without assuming the existence of seawater desalination facilities, then the shadow values in coastal districts provide a cost target that seawater desalination would have to meet to be economically viable. Similarly, shadow values in districts to which imported water would come from outside or which would receive desalinated water as a result of canal construction show the cost targets at which the water in question would have to be made available in order to provide additional benefits.

Finally, by running the model with and without a projected infrastructure project, one can find the increase in annual benefits that the project in question would bring. Taking the present discounted value of such increases gives the net benefits that should be compared with the capital cost of project construction.

The use of the model does not require a policy of cooperation among the parties to a dispute. The user can choose to run the model for his or her own country. In that case, the model becomes an aid to domestic water policy, yielding a simulated efficient market solution as a guide for allocation among competing domestic uses and for the planning of domestic infrastructure projects.

Such a tool has now been built for the Israeli, Jordanian, and Palestinian governments. Each of those governments has expressed its interest in examining the tool for use in its own domestic water planning process, and, indeed, each of the private teams working on the Project has used the tool to investigate questions of interest. These include:

1. A cost-benefit analysis of the infrastructure that would be required to bring additional water to Israel from the Litani River in Lebanon;

2. A cost-benefit analysis of the reduction of leakage in the city of Amman;

3. The relationships among desalination at Gaza, a pipeline between Gaza and the West Bank, and the amount of water owned by the Palestinians.

We must emphasize, however, that none of the governments has yet committed itself to the use of such methods for regional cooperation in water -- the subject to which we now turn.

5. WATER OWNERSHIP AND THE VALUE OF WATER

The view of water as an economic, if special, commodity has at least two implications for the design of a lasting water arrangement that is to form part of a peaceful agreement among neighbors. The first of these has to do with negotiations over the ownership of water quantities. The second, and, we believe, the more important implication has to do with the form that a water agreement should take.

There are two basic questions involved in thinking about water agreements: the question of water *ownership* and the question of water *usage*. We shall now see that one must be careful to distinguish these questions.

All water users are buyers in effect irrespective of whether they own the water themselves or purchase it from another party. An entity that owns its water resources and uses them itself incurs an opportunity cost equal to the amount of money it could otherwise have earned through selling the water. An owner will use a given amount of its water if and only if it values that use at least as much as the money to be gained from selling.[11] The decision of such an owner does not differ from that of an entity that does not own its water and must consider buying needed quantities of water: the non-owner will decide to buy if and only if it values the water at least as much as the money involved in the purchase. Ownership only determines who receives the money (or the equivalent compensation) that the water represents.

Water ownership is thus a property right entitling the owner to the economic value of the water. Hence a dispute over water ownership can be translated into a dispute over the right to monetary compensation for the water involved.

The property rights issue of water ownership and the essential issue of water usage are analytically independent. For example, resolving the question of where water should be efficiently pumped does not depend on who owns the property. While both issues must be properly addressed in an agreement, they can and should be analyzed separately.[12]

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

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

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[11] If water and money are equally valued, then the entity will be indifferent between selling and using the amount of water in question. A similar statement applies to the description of the actions of a non-owning buyer later in the paragraph. Note that the statements made in the text do not assume that water users value water only for pure economic reasons; they assume that users can consistently choose between water and money.

[12] This is an application of the well-known Coase Theorem of economics. Coase (1960).

Of course, self-sufficiency in agriculture can be quite expensive. That makes naturally occurring water more valuable than would otherwise be the case. But such water cannot be worth more than the cost at which it could be replaced by desalination. Indeed, it is typically worth less, since there are costs associated with naturally occurring water as well.

Now, the fact that disputes over water can be expressed as disputes over money may be of some assistance in resolving them (although, as we shall see this is not the principal point as regards the analysis of and the benefits from cooperation.)

Consider bilateral negotiations between two countries, A and B and different proposed allocations of ownership rights between them. Each of the two countries can use its WAS tool to investigate the consequences to it (and, if data permit, to the other) of each of the allocations. This should help it in deciding what terms for which to settle, possibly trading off water for other, non-water concessions. Indeed, if, at a particular proposed allocation, A would value additional water more highly than B, then both A and B could benefit by having A get more water and B getting other things which it values more. Note that this does *not* mean that the richer country gets more water. That only happens if it is to the poorer country's benefit to agree.

Of course, the positions of the parties will not be expressed along such lines. Their positions will run in terms of ownership rights and international law. The use of the methods here described in no way limits such positions. Indeed, the principal point of this section is not that the model can be used to help decide how allocations of property rights should be made. Rather the principal point is that water can be traded off for non-water concessions. The WAS tool provides a way of measuring such trade-offs.

Moreover, such trade-offs will frequently not be large. Recall that desalination puts an upper bound on the value of water in dispute. Moreover, because naturally occurring fresh water must be pumped, treated, and transported, the upper bound on the value of a cubic meter of such water *in situ* will be considerably less than the cost of desalination per cubic meter. At the limit (in this example), 100 MCM annually of disputed water (a large amount of water in the Israeli-Palestinian dispute) cannot *ever* be worth more than (very roughly) $50 million per year, and our results show that, in fact, the value is far less even than this. Such sums are small relative to most Gross Domestic Products. They are certainly small relative to the cost of modern military equipment. By monetizing water conflicts, they can cease to seem insoluble.

A specific example will help to illustrate these points[13]:

Water on the Golan is often said to be a major problem in negotiations between Israel and Syria. By running the model with different amounts of water, this question can be evaluated. We have done so. **In 2010, the loss of an amount of water roughly equivalent to the entire flow of the Banias springs (125 MCMs annually) would be worth no more than $10 million per year to Israel in a year of normal rainfall and only around $40 million per year in the event of a thirty percent drought. At worst, water can be replaced through desalination, so that such water (which has its own costs) can never be worth more than about $75 million per year.**

[13] **It must be emphasized that these results (and those below) were obtained using data not officially approved by the authorities. Further, not all authors necessarily agree with all the policy prescriptions implied or discussed.**

These results take into account Israeli policies towards agriculture.

Note that it is *not* suggested that giving up so large an amount of water is an appropriate negotiating outcome, but water is not an issue that should hold up a peace agreement. These are trivial sums compared to the Israeli GDP or to the cost of fighter planes.

6. COOPERATION: THE GAINS FROM TRADE IN WATER PERMITS

The above is not the main point as to cooperation, however, and, in fact, there is a good deal more to be said. The simple and final allocation of water quantities in which each party uses what it "owns" is not an optimal design for a water agreement. As we shall now see, it is possible to improve on such a fixed-quantity agreement, and the potential gains from doing so can be so large for all parties as to make the question of water property rights a matter largely of symbolic significance.

As we have seen, efficient allocation of water simulates a market solution. In such a solution, if shadow values in two locations differ by more than the cost of conveyance, then there are gains to be had from conveying water from one location to the other. That is true even if the two locations are inhabited by citizens of different countries. Hence, a tool such as the WAS model can not only serve as a guide for water allocation within a country, it can also serve as a guide for water allocation among countries.

How would this work? Suppose for the moment that property rights issues have been resolved. Since, as we have seen, the question of water ownership and the question of water usage are analytically independent, it will generally not be the case that it is optimal for each party just to use its own water. Instead, consider a system of trade in water permits — short-term licenses to use each other's water. No sale of sovereign rights would be involved. The purchase and sale of such permits would be in quantities and at prices given by an improved and agreed-on version of our optimizing model.

It is not hard to see that there would be mutual advantages from such a system, and the economic gains would be a natural source of funding for water-related infrastructure.

To see that such gains would exist, consider the fact that both parties to a voluntary trade gain. The seller would not sell unless it valued the money received more than the water given up; the buyer would not buy unless it valued the water obtained more than the money it paid. While it is true that one party may gain more than the other, such a trade is not a zero-sum game but rather a win-win opportunity. *Moreover, the fact that such trades would take place at model-produced prices would keep out any aspects of monopolistic exploitation.*

Indeed, particularly if cooperative infrastructure is built to facilitate trade, the gains from cooperation in this matter appear so large as to dwarf the value of ownership transfer of reasonable amounts of water.

While we cannot go into detail here, some of the results obtained with the current version of the WAS model for Israeli-Palestinian cooperation can be summarized as follows:

1. Cooperation is a "win-win" policy that can be worth $50 - $150 million dollars *per year* by 2010. It is far more valuable than are any likely changes in the ownership of the water itself.
    a. While the exact gains from cooperation naturally depend on the assumed allocation of ownership rights, both parties would always gain from cooperation. Note, in particular, that the gains to the selling party are over

and above the amounts necessary to compensate its consumers for higher-priced or less water.

b. In plausible runs, we find water permit sales going in both directions, depending on the geographic distribution of ownership rights, demands, and infrastructure, especially conveyance systems.

c. With co-operation, the value of the *entire* Mountain Aquifer will be considerably less than $100 million per year in 2010. The value of the possible differences between the parties' ownership claims will be far less even than that.

2. Desalination on the Mediterranean coast will not be needed in normal years. With cooperation in water and the construction of infrastructure (recycling plants and conveyance systems, largely for the Palestinians), there will only be a need for additional sources of water in 2010 in years of considerable drought.

3. The need for desalination will crucially depend on the status of cooperation in water, however. Without such cooperation and with the 1995 ownership allocations, the Palestinians will find desalination at Gaza an attractive option by 2010.

4. The construction of recycling plants in the West Bank, and, particularly in Gaza, will be highly beneficial regardless of water ownership or co-operation.

   a. Among the gains that would arise from cooperation and joint infrastructure is the following: The model strongly suggests that, even in the presence of current Israeli plans, it would be efficient to have a water treatment plant in Gaza with treated effluent sold to Israel for agricultural use in the Negev where there is no aquifer to pollute. (Indeed, we are informed that since this suggestion arose in model results, there has been discussion of this possibility.) Both parties would gain from such an arrangement. *This means that Israel has an economic interest in assisting with the construction of a Gazan treatment plant.* This would be a serious act of cooperation.

This and other possible projects would, of course, have to be more carefully evaluated than has so far been possible. But there can be little doubt but that valuable joint projects benefiting all parties can be located and built.

Beyond pure economics, moreover, the parties to a water agreement would have much to gain from an arrangement of trade in water permits. Water quantity allocations that appear adequate at one time may not be so at other times. As populations and economies grow and change, fixed water quantities can become woefully inappropriate and, if not properly readjusted, can produce hardship. *A system of voluntary trade in water permits would be a mechanism for flexibly adjusting water allocations to the benefit of all parties and thereby for avoiding the potentially destabilizing effect of a fixed water quantity arrangement on a peace agreement.* It is not optimal for any party to bind itself to an arrangement whereby it can neither buy nor sell permits to use water.

7. POSSIBLE OBJECTIONS

We now discuss several objections that may be raised in principle to such a plan.

A. Money Cannot Buy Water

The first possible objection is that it is offensive to suppose that historic water rights can or should be traded for money. This is an objection of form rather than one of substance.

In the first place, the system of trade suggested would not in fact trade sovereign water rights. It would trade short-term permits to use water. Ownership, and hence symbolic control, would not be traded.

Second, the trade need not be for money itself. Rather, it makes sense that short-term water permits should be granted in exchange for infrastructure development. Such infrastructure development could be of the type that benefits all parties or it could be simply for the benefit of the party granting the water permits. Such an exchange can be thought of as water-for-water, at least in the long run. Money is only the way one keeps score.

B. Deciding on Property Rights: An Interim Escrow Fund

The second objection is that the system here described does not settle the property-rights issue. Indeed, it does not pretend to do so, although this way of thinking about water should make negotiations more tractable. But does not the institution of trade in water permits and cooperation in infrastructure require that property rights be first settled?

The answer to this is "No," although settlement of property rights issues is very desirable. While property rights negotiations are still proceeding, trade in water permits could begin with payments being made into an escrow fund. That fund would be jointly managed and would provide a source of financing for mutually desirable infrastructure. Negotiations over water property rights would effectively become negotiations over shares of or obligations to the fund plus entitlements to future payments. This is as it should be, since water property rights are a matter of money.

The fact that the gains from trade in water permits can be quite large relative to the value of water property rights themselves means that it is foolish to wait to reap the benefits from such trade because it is difficult to settle a matter of relatively small monetary magnitude.

C. Commitment and Uncertainty

A third possible problem is the following. If a commitment is made to sell at model prices, and unforeseen events such as droughts occur, would not that commitment be regretted and harmful to carry out?

There is a two-fold answer here. First, while the present model is a single-year one, it appears entirely possible to build a multi-year model and to study the effects of climatic uncertainty. Even in the context of a single-year model, however, repeated runs can yield information as to the value of water in unusually dry or wet situations.

Second, even without a precise estimate of such value, the user can place a positive value on the retention of a reserve. This would form part of the social value and then be incorporated into the prices at which sales take place. Recall that only *willing* sales (and purchases) are involved. Nobody is forced to sell.

D. Model Commitment: Data, Domestic Policies, and National Values

A fourth possible objection has to do with the consequences of committing to the use of such tools in a regional context. Does not the user give up data security? What happens to domestic water policies and national values?

It is the latter issue that appears the more important one. Data, in the sense of data on actual water supplies and actual consumption, cannot (or ought not to be) very sensitive. No agreement of any sort is likely to be possible without an agreement as to the facts.

The right of each country to set its own national policies toward water, however, should not be questioned. But the WAS tool permits such policies to be set and examined and re-thought. Given those policies, the model can then be used to support trade in water permits. Any sort of cooperation must take such policies into account.

Furthermore, we have obtained a result that may seem surprising. Consider the situation of two countries, A and B, trading in water permits as described. Suppose that A now chooses to subsidize water for agriculture. This will apparently have two effects on B. First (the "output" effect), if A's agriculture competes with B's, this will give A's agriculture an advantage. Second, (the "water effect"), the increased demand for water in A as a consequence of the subsidy will raise the shadow value of water in both countries, and this will disadvantage B and its consumers. Does not this mean that an agreement to trade in water policies will necessarily lead to constant negotiations over what domestic water pricing policies can be permitted?

About the output effect, we can only say the following. A could also give its agriculture a competitive advantage through a direct subsidy. Hence, to some extent, this is not a matter of water policy even though the result may be brought about through water.

In the case of the water effect, the situation is not what it appears. The subsidy-induced increased demand in A will indeed raise water shadow values in B. (In what follows, we assume that B's consumers are charged those shadow values. To deal with other cases would only complicate the exposition without changing the basic results.) Consumers in B pay higher prices, reducing the benefits they obtain from water. Some of that loss is simply a greater payment to (public or private) water sellers in B itself. As such, it is a transfer within B and not a loss to B as a whole. The remaining loss (called by economists a "dead-weight" loss) is a loss to B as a collective entity; it involves the fact that B's water consumers reduce their water consumption as a result of higher prices.

But there is also a third effect. If A is importing water from B, then it will be paying higher prices for those imports as a result of its own subsidy. This is a net gain to B, and one that can be used to compensate B's consumers. Call this the "international trade" effect.

We have experimented to see the net results of all this**. We find that, for any reasonable pattern of ownership, the effects on Israel or Palestine of an agricultural subsidy by the other are either negligible or slightly positive, the latter cases being due to the international trade effect. While the costs of subsidy policies can be high, those high costs are born by the party doing the subsidizing. As a result, within a wide range, an agreement to trade in water permits need not be an agreement to repeatedly negotiate domestic water policies**.

E. Misrepresentation and Gaming

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

This does not end the matter, however. Since water demand is likely to be inelastic at reasonable prices, a party that is a seller might gain by overstating its demand. In such a case, the selling party would retain some water that it values less than the price, but it might succeed in earning sufficiently greater revenue from the water it does sell to leave it better off. In effect, such a seller would be exercising market power by withholding water from the market and exploiting the fact that it faces a declining (and inelastic) demand curve. (An analogous statement holds for a buying party understating its demand.)[14] The fact that trade leads to gains shows that there is a surplus to be split among the parties; behavior of the sort described could affect the way in which that surplus is divided.

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

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

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

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

F. Security Considerations: Hostages to Fortune

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

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

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

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

Are such cases likely in the Israeli-Palestinian case? we begin with the case of Israel. If there were to be an agreement with the Palestinians along the lines we have suggested, it would make sense for Israel to invest in trade-facilitating infrastructure. Were trade to cease, that investment would largely be lost. This does not seem a major problem, however.

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

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

What that choice should be depends on how likely it is that Israel would abrogate such an agreement and on the situation that one believes would then arise. For example, in such an event, presumably the Palestinians would feel justified in extensively pumping the Mountain Aquifer, even if that were not the regionally efficient or agreed-on thing to do. They might then consider temporarily supplying Gaza from the Southern West Bank, while desalination facilities were being constructed. If so, then it might be wise to put the pipeline in place even in the presence of a water-permit-trade agreement, provided that the post-agreement situation was not expected to be so serious that Israel would attempt to cut such a pipeline.[15] Alternatively, the Palestinians

[15] If relations were to deteriorate to such an extent, however, then it might also become a matter of concern that desalination facilities are easily targeted for bombing.

might seek alternative sources of supply from Egypt or others — sources that might be efficient even in the presence of trade.

But a principal reliance for the Palestinians to induce them to participate in the win-win kind of agreement that we have described must lie in their belief in two other points. First, they must believe that it is very much in Israel's own interest to continue participation in such an agreement. Second, they must believe that Israel understands its own interest sufficiently well to abide by the commitments it makes. The generation of that kind of trust must be a principal feature of any peace negotiations.

8. CONCLUDING REMARKS

We summarize the main points. First, careful attention to the economics of water and to the difference between water ownership and water usage leads to the construction of a powerful analytic tool — an optimizing model of the water system or systems at issue. Such a model can be an important aid to policy makers in their water management and policy decisions.

The usefulness of this approach does not end at the international border, however. Such modeling effort and the analysis accompanying it can also be used in the resolution of water disputes. That use has at least two aspects. First, property rights in water are seen to be reducible to monetary values. If this is done, negotiations over water can cease being limited to water itself and be conducted in a larger context in which water is measured against other things. Moreover, the availability of seawater desalination means that the monetary value of disputed water property rights will generally not be very large.[16] If this is realized, negotiations over water should be facilitated.

There is another implication of this approach that is of at least equal importance, however. Water agreements that simply divide water quantities are not optimal and may be very bad agreements indeed. Such fixed-quantity agreements are zero-sum games in which the gain of one party is the loss of the others. Instead, it is possible for disputants to engage in a win-win arrangement where permits to use water are traded among them. Especially when such cooperation involves the construction of mutually beneficial infrastructure, the gains to all parties can be quite large, considerably larger than the value of the water property rights themselves.

Moreover, such gains need not only be economic ones. Such cooperative arrangements can provide the kind of flexibility that can keep changing water needs from disrupting a peace agreement. Further, cooperation in water and in water-related infrastructure can be a confidence-building measure. In this way, water can cease to be a source of continued conflict and instead become a source of cooperation and trust.

[16] In our examples, the desalination upper bound considerably overstates the value of such property rights.

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