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Optimal water management and conflict resolution: The Middle East Water Project

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[1] In many situations, actual water markets will not allocate water resources optimally, largely because of the perceived social value of water. It is possible, however, to build optimizing models which, taking account of demand as well as supply considerations, can substitute for actual markets. Such models can assist the formation of water policies, taking into account user-supplied values and constraints. They provide powerful tools for the system-wide cost-benefit analysis of infrastructure; this is illustrated by an analysis of the need for desalination in Israel and the cost and benefits of adding a conveyance line. Further, the use of such models can facilitate cooperation in water, yielding gains that can be considerably greater than the value of the disputed water itself. This can turn what appear to be zero-sum games into win-win situations. The Middle East Water Project has built such a model for the Israeli-Jordanian-Palestinian region. We find that the value of the water in dispute in the region is very small and the possible gains from cooperation are relatively large. Analysis of the scarcity value of water is a crucial feature. *INDEX TERMS:* 6304 Policy Sciences: Benefit-cost analysis; 6329 Policy Sciences: Project evaluation; 6334 Policy Sciences: Regional planning; 6344 Policy Sciences: System operation and management; 9320 Information Related to Geographic Region: Asia; *KEYWORDS:* optimal management, cost-benefit, conflict resolution, Middle East, cooperation

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1. Introduction: Actual and Simulated Water Markets

[2] Water is usually considered in terms of quantities only. Demands for water are projected, supplies are estimated, and a balance is 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.

[3] 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.

[4] 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). The Project is a joint endeavor of Israeli, Jordanian, Palestinian, Dutch, and American scholars. It has been heavily at work since October 1993, under various auspices. (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. Since 1998, Harvard University has had 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 former Director of ISPME, for his tireless and devoted support. We also thank the former staff of ISEPME for their

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many efforts and Dennis McLaughlin for very helpful advice. 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.) In the present paper we discuss the methods that it has developed and the uses to which those methods can 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.

[5] 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 is unlikely to exceed \$100 million yr^{-1} and, as our results below show, is in fact far less than that. (Of course, if energy prices rise in the future, the level of the desalination upper bound will rise also, but that is very unlikely to matter to qualitative statements such as those in the text. Present projections for the medium run show a decrease rather than a rise in desalination costs on the Mediterranean coast of Israel and Palestine.) 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).

[6] 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.

[7] 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 semiarid 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.

[8] 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. (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.)

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 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. (Note, however, that this problem could be solved by a free market in water rights with agricultural output directly subsidized.) Similar properties hold for water needed for environmental uses.

[9] 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.

[10] 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.

[11] 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.

[12] 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 such models as tools.

[13] Before proceeding, we note the following: The use of optimizing models to analyze water problems is not new. (See, for example, *Brown and McGuire* [1967], *Dandy et al.* [1984], and *McCarl et al.* [1999]. The works of these authors go beyond mere cost minimization.) The most familiar use of such models, however, is that of minimizing cost in connection with fixed demand quantities. The models described below go beyond that in more than one respect.

[14] First, they take account of demand considerations and the benefits to be derived from water use rather than fixing water quantities to be delivered.

[15] Second, they permit the user to impose social values that differ from private ones and to impose policies that the optimization must respect.

[16] Third, we show how such models can be used in conflict resolution, an area highly important in water issues. We show that such models can be used to value disputed water, thus effectively monetizing and de-emotionalizing the dispute. Moreover, for international disputes, we show how one can analyze the territory of each party separately, testing options of links to other parties, or analyze the combined territory of two or more parties as one. This provides an estimate of the benefits of cooperation, which can then be weighed against the political issues involved in such cooperation. While we use the Middle East (here, Israel, Jordan, and Palestine) as an example, the methods described are obviously far more widely applicable.

[17] In this paper we first describe such models and the theory behind them. 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. The WAS Tool

[18] The model that has been developed is called "WAS" for "Water Allocation System." (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].) At present, it is a single-year, annual model, although the conditions of the year can be varied and different situations can be evaluated. (Ongoing development plans for the WAS model involve both the construction of a multiyear version and the treatment of seasonal variations.) We begin by describing such a model for a single country; the international extension is discussed later.

[19] The country 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. (The demand curves are specified as having constant price elasticity up to a high-price (\$100 m^{-3}) cutoff. This requires specifying a single point on each demand curve and an elasticity. In our empirical work, reported below, points on the demand curves were specified by specifying the quantities that were or were projected to be demanded at a given price; these were either taken from historical data or constructed from standard quantity forecasts with population growth the most important factor. The demand elasticities were specified as low as indicated in the very sparse literature, and the results are not very sensitive to the precise elasticities chosen. 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.) The annual renewable amount of water from each source is taken into account, as is the pumping cost thereof. The fact that different districts may draw from the same source is modeled by restricting the total amount that can be drawn from that source. Allowance is made for recycling of wastewater (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.) and the possibility of interdistrict conveyance. This procedure is followed using actual data for a recent year and projections for future years.

[20] 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; third, the use of recycled water in agriculture can be restricted; fourth, water can be set aside for environmental (or other) purposes. Other environmental restrictions such as limits on the use of brackish water except in combination with sweet water or restricting pumping to protect aquifers can also be introduced.

[21] 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.

[22] Finally, the user specifies the national policies toward water that he or she wishes. This is where the fact that the national value of water need not be 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; imposing penalties when water for certain uses falls short; imposing environmental restrictions; and so forth.

[23] 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 becomes an iterative process in which the user interacts with the model.

[24] 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 WAS tool provides the user with the means to examine how the user's policies can be efficiently implemented and what the consequences are.

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

[26] In more precise terms (see Appendix A), since a point on the demand curve gives that amount the consumer is just willing to pay for an additional unit of water, the total amount that consumers are willing to pay is the sum over all districts and consumer types of the integrals of all inverse demand curves:

$$P_{id} = B_{id} \times (QD_{id} + QFRY_{id})^{ALPHA_{id}}. \tag{1}$$

Here i denotes the user type; d is the district; P_{id} is price; QD_{id} and $QFRY_{id}$ are the quantities of fresh water and recycled water consumed, respectively; and B_{id} and $ALPHA_{id}$ are parameters. $ALPHA_{id}$ is the reciprocal of the price-elasticity of demand. The integral is taken from the total water quantity corresponding to a price of \$100 m^{-3} to the amount to be supplied to user type i in district d. (See above. Some such cutoff is necessary with price-elasticities less than unity in absolute value to prevent the integral from being improper. Of course, this reflects the fact that constant elasticities less than unity in absolute value cannot possibly hold at very high prices.) The model for Israel, Jordan, and Palestine takes less than 2 min to converge on a fast Pentium laptop.

[27] Note that there are two ways of thinking about the restrictions imposed by the user. The first of these is as rules or constraints that the model must obey. The second and subtler way is to think of the government (in effect represented by the user) as purchasing water and supplying it to the users. The government's demand curve for water then replaces the private demand curves in the optimization process, and the government's willingness to pay (which reflects the social value of water in excess of private value) is used to determine water benefits. A simplified version of the WAS model is given in mathematical form in Appendix A.

3. Shadow Values and Scarcity Rents

[28] 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.

[29] 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.

[30] As is well known, when maximization involves one or more constraints, there is a system of prices involved in the solution. These prices, called "shadow values" (also "LaGrange multipliers") 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.

[31] The central shadow values in the WAS model are those of water itself, and they play a very important role. 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 (possibly the government, as represented by the model user) would just be willing to pay to obtain an additional cubic meter per year, given the optimal water flows of the model solution.

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

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

[34] 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."

[35] Shadow values and scarcity rents have the following properties:

1. The shadow value of water used in any location equals the direct marginal cost plus the scarcity rent. (The simple version of this statement and the ones that follow assumes that capacity constraints on infrastructure are not binding. If such constraints are binding, then the shadow values corresponding to those constraints should be considered as part of marginal cost, and the statements continue to hold.) 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 is at least as great as the marginal cost of production. Equivalently, water will only be produced from sources whose scarcity rents are nonnegative.
3. If (additional) 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.

Note that shadow values play a guiding role in the same way that actual market prices do in competitive markets. An activity that is profitable at the margin when evaluated at shadow values is one that should be increased. An activity that loses money at the margin when so evaluated is one that should be decreased. In the optimal solution, any activity that is used just breaks even at the margin. Finally, profits, evaluated at shadow values, are maximized at the optimum.

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

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 would be just willing to sell an additional unit of water.

[36] 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.

[37] 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. (Strictly speaking, such valuation applies directly only to small changes in water quantities. Valuation of large changes can be accomplished by running the WAS model with different water quantities and comparing the resulting net benefits. This was done in obtaining the results on the value of changes in disputed water ownership presented in sections 7 and 8, below.)

[38] 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, discussed below.

[39] Note, further, that the shadow values and the calculation of benefits do not merely involve costs. The optimization problem solved by WAS is not that of delivering fixed amounts of water in the most cost-efficient way. The benefits brought by that water as represented by the demand curves of the consumers and the social policies described by the user of the model play a crucial role.

[40] 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. The fact that the benefits derived from the first units are greater than the marginal value, however, 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.

[41] 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.

[42] Among other things, WAS 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.

[43] 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.

[44] 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. (We exemplify this below.) 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.

[45] 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.

[46] The use of WAS 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.

[47] WAS models have been built for the Israeli, Jordanian, and Palestinian governments. Each of those govern-

ments has expressed its interest in examining the tool for use in its own domestic water planning process (We must emphasize, however, that none of the governments has yet committed itself to the use of such methods for regional cooperation in water; this subject is considered in section 8.), and, indeed, each of the private teams working on the Project has used the tool to investigate questions of interest, including (1) the need for desalination or imports on Israel's Mediterranean coast, (2) a cost-benefit analysis of the reduction of leakage in the city of Amman; and (3) the relationships among desalination at Gaza, a pipeline between Gaza and the West Bank, and the amount of water owned by the Palestinians.

[48] We shall illustrate the use of the WAS tool in such matters, but it will first be helpful to give a brief sketch of the water situation in the Middle East.

4. An Overview of the Region's Water Resources

[49] We concentrate on Israel, Jordan, and Palestine, referring to them collectively (and inaccurately) as the "Middle East." A simplified map of the region, its major water resources, and major conveyance infrastructure is given in Figure 1.

[50] The Middle East is a semiarid to arid region. Rainfall distribution maps show that 90% of the region receives less than 200 mm yr^{-1} and 70% receives less than 100 mm yr^{-1}. Significant precipitation, ranging from 200 to over 1000 mm yr^{-1}, only occurs in the mountains at the eastern and western side of the Jordan Valley. On average, some 90% of the precipitation is lost to evapotranspiration. Water resources in the region comprise surface water (transboundary rivers and local streams) and groundwater (renewable and fossil aquifers), as well as brackish sources and reuse of treated urban wastewaters. The annual average replenishable water resources of Israel, Jordan, and the Palestinian territories are of the order of $10^9 \times 3.5$ m^{-3}.

[51] With a population of some 14.5 million the available quantity of fresh water per capita is only some 240 m^3 yr^{-1}, far less than is considered enough to be self-sufficient in food production.

[52] Surface water resources bringing water from outside the region mainly comprise the Jordan river (640×10^6 m^3 yr^{-1}) and the Yarmuk (about 480×10^6 m^3 yr^{-1}, of which only about 250×10^6 m^3 yr^{-1} flows downstream of Syria). Israel uses 45×10^6 m^3 yr^{-1} of Yarmuk water in return for 20×10^6 m^3 yr^{-1} she pumps back to Jordan in the summer months. The rest of the Yarmuk flow south of Syria is used by Jordan according to its 1994 treaty with Israel. Local flows and streams, mainly wadis with very irregular discharges, comprise some 150×10^6 m^3 yr^{-1} in Israel and the Palestinian territories and some 175×10^6 m^3 yr^{-1} in Jordan.

[53] Renewable groundwater resources in Israel and the Palestinian territories are estimated at approximately 1200×10^6 m^3 yr^{-1}. Some 50% of this quantity is found in aquifers in the West Bank (collectively called the "Mountain Aquifer"). Renewable groundwater resources in Jordan are estimated at only about 275×10^6 m^3 yr^{-1}, although there is also considerable fossil aquifer water. Since water resources are scarce, some aquifers are overabstracted. In Gaza, for example, the renewable quantity of groundwater is estimated as about 100×10^6 m^3 yr^{-1}, whereas abstractions are reported at well above that figure. In 1993 the total abstraction from renewable groundwater resources in Jordan was even estimated as approximately 450×10^6 m^3.

[54] As indicated, in addition to renewable groundwater resources, Jordan has important fossil aquifers. The most important of these is located in the geological sandstone underlying the entire country and extends southward and eastward into Saudi Arabia. That sandstone crops out in the Disi area in the south of Jordan, thereby acquiring the name "Disi Formation." The last major recharge to this aquifer occurred 10,000 years ago. The Water Authority of Jordan (WAJ) estimates the potential capacity of the Disi aquifer at some 125×10^6 m^3 yr^{-1}, assuming an acceptable drawdown of 250 m, which will be reached in 50 years.

[55] Reuse of treated urban and industrial wastewater is very important in Israel, where almost all large urban wastewater flows now receive secondary or tertiary treatment. The largest treatment plants are in the Dan/Tel Aviv area, providing tertiary treatment to about 140×10^6 m^3 yr^{-1}, and the Jerusalem area, providing secondary treatment to about 40×10^6 m^3 yr^{-1}. The remaining flows total approximately 250×10^6 m^3 yr^{-1}, out of which 100×10^6 m^3 yr^{-1} is already being reused, while the rest will be connected to the reuse net work within 5–10 years.

[56] In Jordan a substantial part of the wastewater from Amman is reused for irrigation in the Jordan Valley. The total capacity of the recycling links between the Northern Dead Sea district and the Jordan Valley is estimated at 65×10^6 m^3 yr^{-1}. Wastewater treatment plants have been built elsewhere in the country (Irbid, Mafraq, Kufrinja, Madaba, Ma'an, and Aqaba), and their effluent is being used in irrigation.

[57] Conveyance infrastructure is only highly developed in part of the region. In Israel a water distribution system, most important, the Israel National Carrier, brings water from the Sea of Galilee (also called "Lake Kinneret" and "Lake Tiberias") to most urban centers and to agricultural areas throughout the country. The carrier runs along the foothills of the central mountain ridge, where groundwater from the relatively rich Mountain Aquifer can be added to the system, as can water from the coastal aquifers, thus creating a nationwide integrated network allowing maximum flexibility in the use of the various resources in dry and wet years. Jordan has a conveyance system, mainly to bring fresh water from remote areas to the densely populated areas of Amman, Zarqa, Irbid, Aqaba, and others. In the Palestinian territory some conveyance links exist in Gaza. On the West Bank, however, water conveyance systems, other than for local water distribution, are still being developed.

5. Illustration I: Will Israel Need Desalination?

[58] We now illustrate the use of the WAS tool by using it to analyze the need for desalination on the Mediterranean coast of Israel in two future years: 2010 and 2020. In so doing, we assume that in those years, the cost per cubic meter for desalinated water will be \$0.60 m^{-3} (in 1995 dollars), including capital costs. This is somewhat below current cost figures, so that our results are somewhat biased toward a finding that desalination will be efficient.

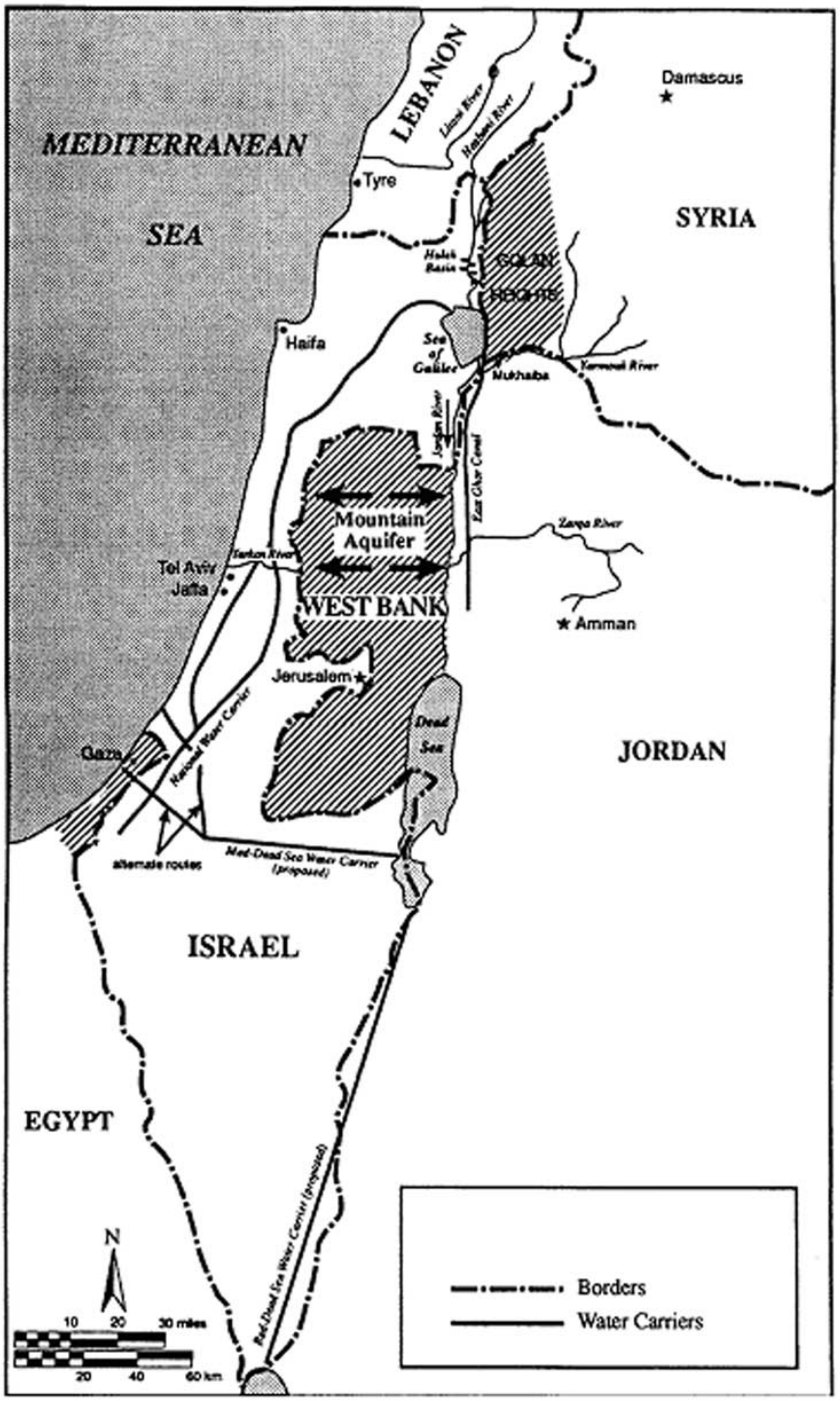
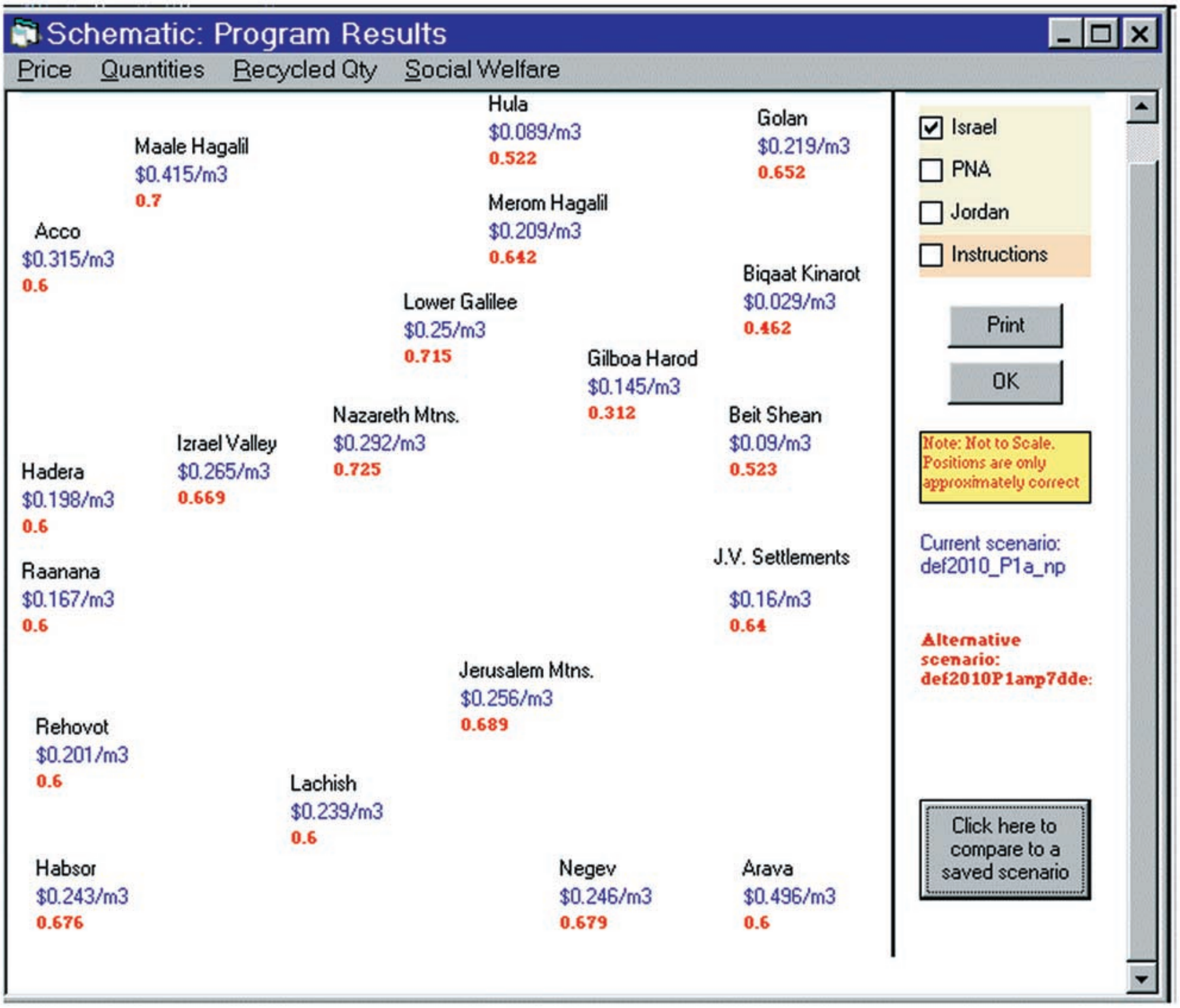


Figure 1. Regional map. Adapted from *Wolf* [1994, p. 27].

[59] In this illustrative analysis we assume that Israel has (and continues to have) all the fresh water sources that it currently uses, ignoring any effect of a future agreement as to water ownership. Naturally, however, we assume that the population will increase. Estimates of future population are taken from Israeli governmental sources. In total, the population is forecast to increase from 5.6 million people in 1995 to 7.4 million in 2010 and 8.6 million in 2020.

[60] Israel traditionally pursues a policy of fixed water prices. These prices are the same all over the country but



Note: Not to Scale. Positions are only approximately correct

Current scenario: def2010_P1a_np

Alternative scenario: def2010P1anp7dde:

Figure 2. Year 2010 shadow values with desalination: normal hydrology versus 30% reduction in natural fresh water sources; fixed-price policies in effect.

vary by user groups. In 1995, households and industry were charged \$1.00 m^{-3}. Agriculture, on the other hand, was heavily subsidized with a system of increasing block rates, the prices ranging from \$0.17 m^{-3} on the first step, through \$0.20 m^{-3} on the second step, to \$0.27 m^{-3} on the third (unlimited) step. In what follows, "fixed-price policy" refers to these same prices. It is important to note that while in drought years, Israel reduces the amount of water available to agriculture at such low prices, our experiments do not do this, thus creating a case favorable to the need for additional water and desalination.

[61] Demand for each user group was taken as a constant-elasticity curve in the relevant range of prices, with elasticities of 0.2, 0.3, and 0.5 for households, industry, and agriculture, respectively. The positions of each demand curve in each district were estimated by forecasting what demand would be at the prices of 1995. Obviously, the biggest effect here is from projected population growth.

[62] The upper shadow values in Figure 2 are those obtained for 2010 when a normal hydrology is assumed and desalination on the Mediterranean coast (Acco, Hadera, Raanana, Rehovot, and Lachish) is assumed to be available at \$0.60 m^{-3}. The same fixed-price policies as in 1995 are assumed to be in effect.

[63] Note that the upper shadow values for the coastal districts are all well below \$0.60 m^{-3}. They show that in a year of normal hydrology, desalination plants are not efficient save at a cost of around \$0.30 m^{-3} or less. The same applies to imports from Turkey to the coastal districts.

[64] This changes when there is a drought involving a 30% lessening of all naturally occurring fresh-water sources, and the lower shadow values in Figure 2 apply. Those shadow values are all \$0.60 for the coastal districts, showing that desalination plants are being used. Indeed, without some extra source of water such as desalination or imports, there is no feasible model solution, indicating that the water demands cannot be met. (With a reduction in natural fresh water of 20%, desalination is still not required save at costs of roughly \$0.50 m^{-3}.)

[65] The 2010 requirements for desalinated (or imported) water in the coastal districts with a 30% reduction in natural fresh-water sources are given in Table 1. They are fairly

Table 1. Desalination (or Import) Requirements in Mediterranean Coastal Districts in 2010 with 30% Reduction in Natural Fresh Water Sources and Fixed-Price Policies in Effect

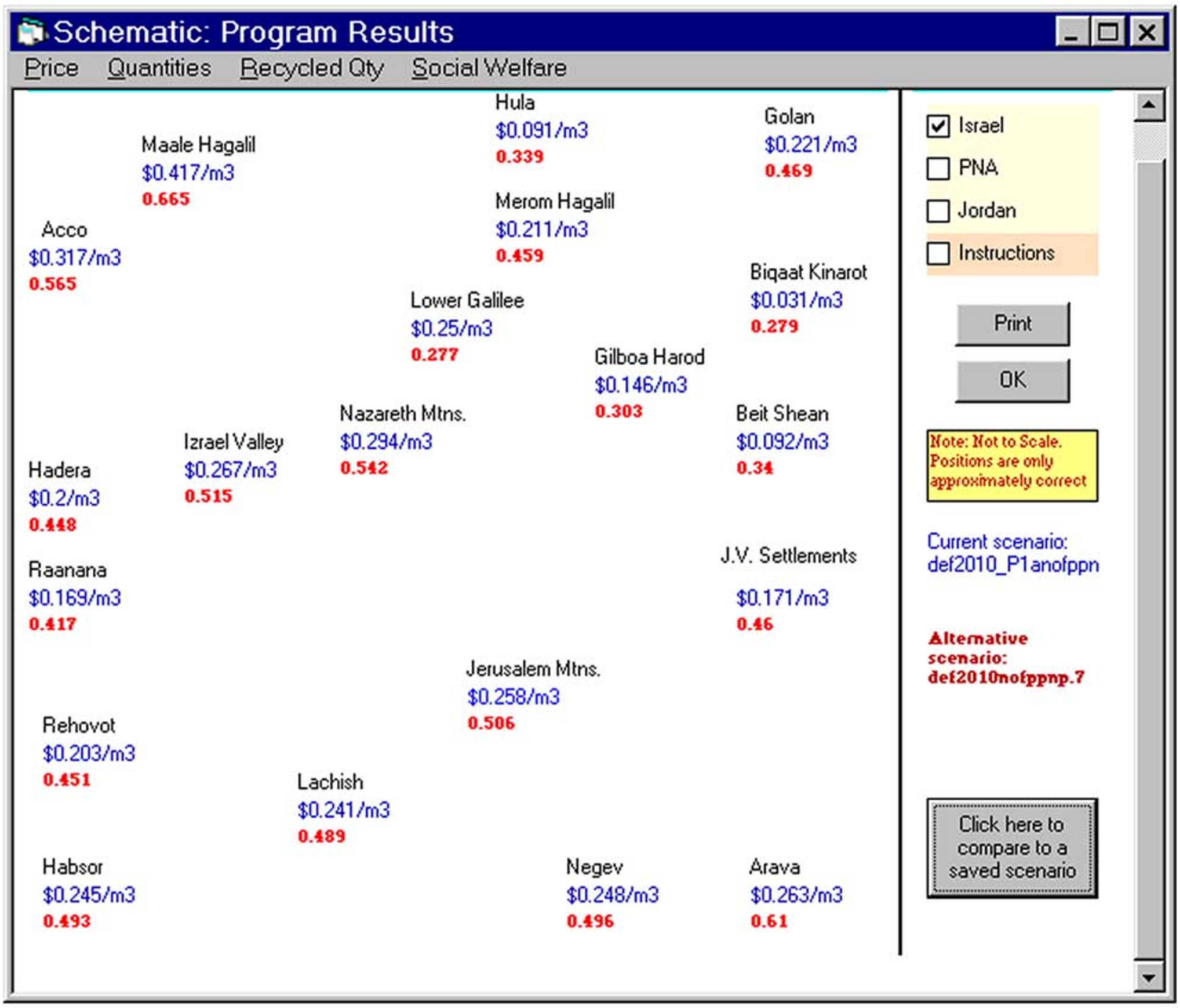
District	Water Requirements, 10^6 m^3 yr^{-1}
Acco	80
Hadera	64
Raanana	9
Rehovot	51
Lachish	29
Total	233

substantial. Note that the model suggests larger plants farther up the coast than the Lachish district, which contains Ashkelon (just north of Gaza), often mentioned as the efficient site.

[66] The situation is even less favorable to desalination with consumers charged the shadow values for water, even though demand by households and industry would be much larger than at the high fixed prices. Figure 3 gives shadow values corresponding to those in Figure 2 but with no fixed-price policies. Desalination at \$0.60 m^{-3} is not efficient even with a 30% drought. Acco (just north of Haifa) is the district which comes closest; there, desalination at \$0.56 m^{-3} would be efficient.

[67] For 2020 the results are similar, but more favorable to desalination, as we should expect. We find the following:

1. Perhaps surprisingly, in years of normal hydrology, desalination on the Mediterranean coast is still not efficient at costs above \$0.32 m^{-3}, with or without fixed-price policies.
2. In drought years in which natural fresh-water sources are reduced by 20%, desalination becomes efficient with or without fixed-price policies. In both cases, a plant at Acco produces a bit more than 80 × 10^6 m^3 yr^{-1}, but with fixed-price policies, plants in all the other coastal districts are efficient, jointly producing approximately an additional 62 × 10^6 m^3 yr^{-1}, reflecting the tilt of the fixed-price policies toward southern agriculture where shadow values are high because of conveyance costs.
3. In drought years with a 30% reduction in natural fresh-water sources, 192 × 10^6 m^3 yr^{-1} are produced without fixed-price policies and 296 × 10^6 m^3 yr^{-1} with such policies.



Note: Not to Scale. Positions are only approximately correct

Current scenario: def2010_P1anofppn

Alternative scenario: def2010nofppnp.7

Figure 3. Year 2010 shadow values with desalination: normal hydrology versus 30% reduction in natural fresh water sources; no fixed-price policies.

Table 2. Desalination (or Import) Requirements in Mediterranean Coastal Districts in 2020 with 20% and 30% Reduction in Natural Fresh Water Sources

	Water Requirements, 10^6 m^3 yr^{-1}			
	20% Drought		30% Drought	
District	No Fixed-Price Policies	Fixed-Price Policies	No Fixed-Price Policies	Fixed-Price Policies
Acco	84	81	96	93
Hadera	0	0	2	67
Raanana	0	0	0	54
Rehovot	0	37	74	53
Lachish	0	25	20	29
Total	84	133	192	296

[68] Table 2 summarizes the efficient amounts of desalination in the drought cases.

[69] Evidently, at least some of the pressure for early building of desalination plants comes from the expected maintenance of the fixed-price system, and (as is no surprise) from the perceived needs of agriculture, particularly in the South.

6. Illustration II: Constructing an Additional Pipeline to Jerusalem

[70] As a second example, we examine the costs and benefits of expanding the pipeline that Israel uses to bring water to Jerusalem from the National Carrier. (Note that all our examples should be treated as such. They depend on numbers that may not reflect actual future facts. The methods, however, are applicable and powerful.)

[71] When the model is run for 2010 (normal hydrology), with no constraints on the capacities of conveyance lines (Note that our earlier results as to desalination and water imports would only be strengthened if we introduced such constraints. With a lower ability to convey water from the coast, the shadow values of water in coastal districts will be lower, with additional water there even less valuable than reported above.), the solution involves conveying 71 × 10^6 m^3 yr^{-1} from the National Carrier to Jerusalem in the presence of fixed-price policies and 82 × 10^6 m^3 yr^{-1} in the absence of those policies. (Naturally, such estimates and the specific numerical results below depend on the population forecast for the district containing Jerusalem. That population is projected as growing from 639,000 1995 to 798,000 in 2010 and 892,000 in 2020.) With the conveyance system as it was in the late 1990s, this would be impossible, since the conveyance line in question had a capacity of only 17 × 10^6 m^3 yr^{-1}.

[72] This does not make the model result ridiculous, however. What it shows is that if the conveyance line had a capacity of 71 (82) × 10^6 m^3 yr^{-1}, it would be efficient to convey that amount at the conveyance cost of the existing line: \$0.107 m^{-3} (exclusive of capital cost). That suggests that an expansion of the existing line is worth investigating.

[73] Such investigation must consider the following, however:

1. The efficient way to add capacity is not literally to expand the existing line but to add an additional one.
2. It appears that the additional line would be larger than the existing one, and pumping of larger quantities of water would be required. We assume that this will raise conveyance costs of the new line (again without capital costs) to \$0.183 m^{-3}.
3. Finally, the new line would have capital costs. The question is whether the increase in net benefits it would bring would be worth those costs.

[74] To investigate the benefits of such a project requires comparing the benefits of a conveyance system with the line in question constrained to 17 × 10^6 m^3 yr^{-1} and conveyance costs of \$0.107 m^{-3} with those obtained with the line increased to a capacity of, say, 82 × 10^6 m^3 yr^{-1} and a conveyance cost of \$0.183 m^{-3}.

[75] It is important to note one thing here. Of course, the first 17 × 10^6 m^3 yr^{-1} would be conveyed at the existing cost of \$0.107 m^{-3}. The amount to be conveyed, however, will be determined by the marginal cost of conveyance. We must adjust the benefits to reflect the fact that 17 × 10^6 m^3 yr^{-1} are carried at a lower cost. This is easily done with a small side calculation.

[76] The results are somewhat surprising. For 2010 the new conveyance line brings essentially zero additional net benefits. This is because the higher cost of using the new line greatly reduces the amount that it is efficient to convey below the amounts found at the lower cost with no capacity constraint. Without fixed-price policies, that amount is reduced from 82 × 10^6 m^3 yr^{-1} to 24 × 10^6 m^3 yr^{-1}. With fixed-price policies, the new line is not used at all. Hence, for the conditions of 2010, such a new line should not be built.

[77] The situation is different when we look at 2020. Here the amounts conveyed at the old cost without capacity constraints are lower than for 2010: 64 × 10^6 m^3 yr^{-1} with fixed-price policies and 50 × 10^6 m^3 yr^{-1} without such policies. When the line is constrained to a capacity of 17 × 10^6 m^3 yr^{-1}, there is no feasible solution in the presence of fixed-price policies, while without those policies, such a solution exists. This reflects the fact that with fixed-price policies, the prices charged to all sectors, especially agriculture, cause a greater demand in the Jerusalem area than can be supplied with the constrained pipeline, while without such policies, the high shadow value of water in the district (\$1.159 m^{-3}) is greater than the fixed-price charges, thus reducing demand.

[78] Hence the continuation of fixed-price policies into 2020 calls for an expansion of the line. It is interesting to note, however, that not much expansion is required. At the higher conveyance cost of \$0.183 m^{-3}, only 24 × 10^6 m^3 are conveyed.

[79] Without fixed-price policies, a quantitative assessment of the net benefit increase from the new line is possible. Here we find an increase in net benefits of \$6 million yr^{-1}. If the project has a 40-year life and the discount rate is 5%, then the present value of such benefits under 2020 conditions is \$102 million. This means that under the assumed conditions, an additional line would be worth building if its capital costs were less than \$102 million. (If one expects the relevant population to increase after 2010, the present value of net benefits and the target capital costs will be greater than \$102 million.)

[80] Again, however, the size of the new pipeline is not so great as one might suppose. Only about 34 × 10^6 m^3 in total is conveyed from the National Carrier to Jerusalem in the optimal solution, suggesting a new pipeline about the size of

the old. Of course, if the reduced size implies a conveyance cost different from the assumed figure of \$0.183 m^{-3}, the analysis becomes more complicated.

7. Water Ownership and the Value of Water

[81] We now turn to our major topic, the discussion of water disputes and conflict resolution.

[82] 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.

[83] 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.

[84] 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. (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 nonowning 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 only assume that users can consistently choose between water and money.)

[85] 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 nonowner 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.

[86] 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.

[87] 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. (This is an application of the well-known Coase theorem of economics [*Coase*, 1960].)

[88] 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:

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

[90] Of course, self-sufficiency in agriculture can be quite expensive. That makes naturally occurring water more valuable than would otherwise be the case. Such water, however, 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. (In fact, in the region we have studied, profitable agriculture that uses unsubsidized fresh water does not exist whether or not the fresh water is naturally occurring or desalinated. As seen above, desalination only becomes efficient when the scarcity rent of naturally occurring fresh water is sufficiently high.)

[91] 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).

[92] 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 proposed allocations. This should help it in deciding on what terms to settle, possibly trading off water for other, nonwater 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.

[93] 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 nonwater concessions. The WAS tool provides a way of measuring such trade-offs.

[94] 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), 100×10^6 m^3 annually of disputed water in the Mountain Aquifer (a large amount of water in the Israeli-Palestinian dispute) cannot ever be worth more than (very roughly) \$50 million yr^{-1}, and our results below show that, in fact, the value is even less than this. Such sums are small relative to most gross domestic products (GDPs). They are certainly small relative to the cost of modern military equipment. By monetizing water conflicts, they can cease to seem insoluble.

[95] A specific example will help to illustrate these points. (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.)

[96] 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.

[97] In 2010 the loss of an amount of water roughly equivalent to the entire flow of the Banias springs (125×10^6 m^3 annually) would be worth no more than \$5 million yr^{-1} to Israel in a year of normal water supply and less than \$40 million yr^{-1} in the event of a reduction of 30% in naturally occurring water sources. At worst, water can be replaced through desalination, so that the water in question (which has its own costs) can never be worth more than about \$75 million yr^{-1}. These results take into account Israeli fixed-price policies toward agriculture.

[98] 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 with the Israeli GDP (about \$100 billion yr^{-1}) or with the cost of fighter planes.

8. Cooperation: The Gains From Trade in Water Permits

[99] 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.

[100] 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, but it can also serve as a guide for water allocation among countries.

[101] 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 simply 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 WAS model.

[102] 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.

[103] 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.

[104] 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.

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

[106] First, cooperation is a "win-win" policy that can be worth \$35–80 million yr^{-1} by 2010 in years of normal water supply. It is far more valuable than are any likely changes in the ownership of the water itself.

1. In years of severe drought, the gains from cooperation are larger, not smaller. This corresponds to the fact that when water is more valuable, it is more important to manage it efficiently.
2. 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.
3. 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.
4. With cooperation, the value of the entire Mountain Aquifer will be less than \$100 million yr^{-1} in 2010 in years of normal water supply and less than \$150 million with a 30% reduction in natural water sources. The value of the possible differences between the parties' ownership claims will be far less even than these amounts.

[107] Some of these results are dramatically illustrated in Figures 4 and 5. In these figures we have arbitrarily varied the fraction of Mountain Aquifer water owned by each of the parties from 80% to 20%. (We have equally arbitrarily assumed in these figures that Israel owns 100% of the water of the Jordan River. None of these assumptions is intended to convey a political message as to the appropriate allocation of water ownership.)

[108] The two line graphs in Figure 4 show the gains from cooperation in 2010 for Israel and Palestine, respectively, as functions of ownership allocations. (Here and later, the results refer to a year of normal hydrology. Results for drought years are not qualitatively different, although all numbers are larger.) Israeli price policies for water are assumed to be the same as in 1995, with large subsidies for agriculture and much higher prices for households and industry.

[109] Starting at the left, we find that Palestine benefits from cooperation by about \$68 million yr^{-1} when it owns only 20% of the aquifer. In the same situation, Israel benefits by about \$13 million yr^{-1}. As Palestinian ownership increases (and Israeli ownership correspondingly decreases), the gains from cooperation fall at first and then rise. At the other extreme (80% Palestinian ownership),

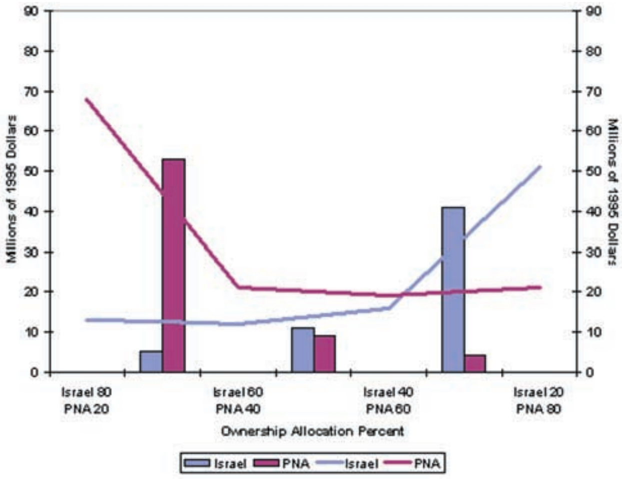


Figure 4. Value of cooperation and value of ownership of Mountain Aquifer without cooperation: year 2010, fixed-price policies.

Palestine gains about \$21 million yr^{-1} from cooperation, and Israel gains about \$51 million yr^{-1}. In the middle of the figure, joint gains are about \$34 million yr^{-1}.

[110] It is important to emphasize what these figures mean. As opposed to autarky, each party benefits as a buyer by acquiring cheaper water. Moreover, each party benefits as a seller by tens of million of dollars per year over and above any amounts required to compensate its people for increased water expenses.

[111] Why do the gains first decrease and then increase as Palestinian ownership increases? That is because, at the extremes, there are large gains to be made by transferring water from the large owner to the other party. Israel has large benefits at the right-hand side of the diagram because it can obtain badly needed water; it has large gains at the left-hand side because it can there sell relatively little needed water to the Palestinians. The same phenomenon holds in reverse for Palestine.

[112] One might suppose that the gains would be zero at some intermediate point, but that is not the case. The reason for this is as follows:

[113] It is true that a detailed, noncooperative water agreement could temporarily reduce gains to cooperation to zero. That would require that the agreement exactly match in its water-ownership allocations the optimizing water-use allocations of the optimizing cooperative solution. That is very unlikely to happen in practice (and, if it did, would only reach the optimal solution for a very short time, as explained below). In our runs, it does not happen for two reasons.

1. We have not attempted to allocate ownership in the Mountain Aquifer in a way so detailed as to match geographic demands. Instead, we have allocated each common pool in the aquifer by the same percentage split.

2. There are gains from cooperation in these runs that do not depend on the allocation of the Mountain Aquifer. It is always efficient for Gaza to be supplied from the Israeli National Carrier, and (as discussed below) it is always efficient for treated wastewater to be exported from Gaza to the Negev for use in agriculture.

[114] There are further results to be read from Figure 4. The heights of the various bars in the figure show the value to the parties without cooperation of a change in ownership of 20% of the Mountain Aquifer (about 130×10^6 m^3 yr^{-1}). These are calculated by looking at the changes in ownership used in the results, so that, for example, the leftmost set of bars shows the value to the parties of changes between an Israeli–80%–Palestinian–20% and an Israeli–60%–Palestinian–40% allocation of ownership; the next set of bars examines the value of a change from 60–40 to 40–60.

[115] Note that the value of cooperation generally exceeds the value of such ownership changes. Note also that a great deal of water is involved.

[116] Further, now look at Figure 5. This differs from Figure 4 only in the height of the ownership-value bars. In Figure 5 the height of those bars represents the value of shifts of 20% aquifer ownership in the presence of cooperation. That value is about \$7 million yr^{-1}. The lesson is clear: Ownership is surely a symbolically important issue, and symbols really matter; but cooperation in water reduces the practical importance of ownership allocations, already not very high, to an issue of very minor proportions.

[117] We also obtain other results:

1. 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. (It is worth noting, however, that the building of desalination plants is likely to contribute to the realization that water ownership is just a matter of money. That may be a good reason for building them.)

2. 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.

3. The construction of recycling plants in the West Bank, and particularly in Gaza, will be highly beneficial regardless

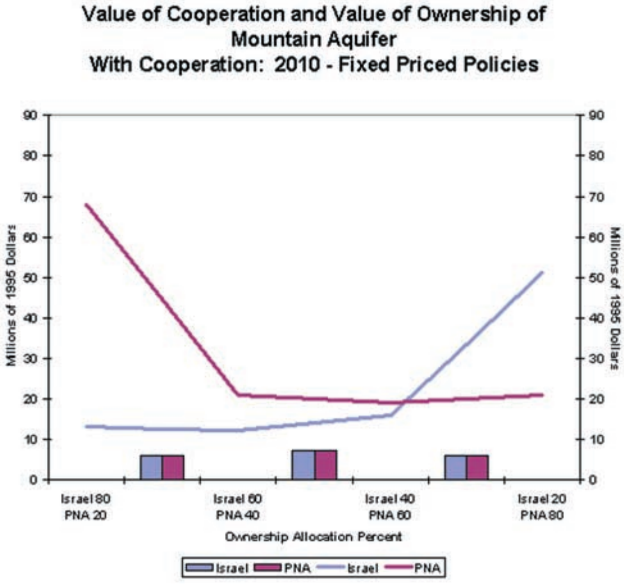


Figure 5. Value of cooperation and value of ownership of Mountain Aquifer with cooperation: year 2010, fixed-price policies.

of water ownership or cooperation. 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.

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

[119] 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.

9. Possible Objections

[120] Of course, in the present state of relations between Israel and Palestine, such a plan seems impossible for reasons that have nothing to do with water. In better times, though, this need not be so. Further, not all water disputes are carried on in a general atmosphere of conflict. We now discuss several objections that may be raised in principle to such a plan were it to be considered.

9.1. Money Cannot Buy Water

[121] 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.

[122] 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.

[123] 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.

9.2. Deciding on Property Rights: An Interim Escrow Fund

[124] 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. However, does not the institution of trade in water permits and cooperation in infrastructure require that property rights be first settled?

[125] The answer to this is no, although early settlement of property rights issues is very desirable and ultimate settlement is probably crucial. 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, worth what the highest bidder (including the owner) will pay for them.

[126] Of course, this is not meant to imply that property rights are worthless. They certainly represent an economic gain to their owners. That gain, though, can be measured in monetary terms, and our results show that, at least in the Middle East, such gain is not remarkably large. Hence 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.

9.3. Commitment and Uncertainty

[127] 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?

[128] There is a twofold answer here. First, while the present model is a single-year one, it appears entirely possible to build a multiyear 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.

[129] 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.

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

[130] 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?

[131] 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 be (or ought not to be) very sensitive. No agreement of any sort is likely to be possible without an agreement as to the facts.

[132] The right of each country to set its own national policies toward water, however, should not be questioned. The WAS tool, however, permits such policies to be set and examined and rethought. 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.

[133] 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 permits will necessarily lead to constant negotiations over what domestic water pricing policies can be permitted?

[134] Concerning 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.

[135] 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 ''deadweight'' 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.

[136] There is also a third effect, though. 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.

[137] 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 require continual renegotiation over domestic water policies.

9.5. Misrepresentation and Gaming

[138] 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.

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

[140] How important this phenomenon is likely to be may depend in part on the overall atmosphere in which trading in water permits takes place. Such misrepresentation, though, 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.

[141] 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.

9.6. Security Considerations: Hostages to Fortune

[142] 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?

[143] 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.

[144] 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.

[145] 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.

[146] 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.

[147] 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.

[148] 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.

[149] 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 postagreement situation was not expected to be so serious that Israel would attempt to cut such a pipeline. (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.) Alternatively, the Palestinians might seek alternative sources of supply from Egypt or others, sources that might be efficient even in the presence of trade.

[150] However, 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.

10. Concluding Remarks

[151] 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.

[152] 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. (In our examples, the desalination upper bound considerably overstates the value of such property rights.) If this is realized, negotiations over water should be facilitated.

[153] 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.

[154] Moreover, such gains need not be only 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.

[155] While hostile actions involving water can occur in wartime, our methods and results show that water itself should never become a casus belli. Water is not worth war.

Appendix A: Mathematics of the WAS Model

[156] Here we outline the mathematical form of the WAS model (with the omission of various constraints that can be specified by the user). The model is presented below in the standard form for optimization, namely, the objective function followed by the constraints. In mathematical terms the model is as follows:

$$
\begin{aligned}
MAX\ Z = & \sum_i \sum_d \left(\frac{B_{id} \times (QD_{id} + QFRY_{id})^{ALPHA_{id}+1}}{ALPHA_{id} + 1} \right) \\
& - \sum_i \sum_s (QS_{is} \times CS_{is}) - \sum_i \sum_j \left(QTR_{ij} \times CTR_{ij}\right) \\
& - \sum_i \sum_j \left(QRY_{ij} \times CR_{ij}\right) - \sum_i \sum_j \left(QTRY_{ij} \times CTRY_{ij}\right) \\
& - \sum_i \sum_j [CE_{id} \times (QD_{id} + QFRY_{id})]
\end{aligned}
$$

subject to

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

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

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

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

with the following bounds:

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

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

and all variables positive.

[157] Variables are as follows:

Z	net benefit in from water in millions of dollars;
QS_{is}	quantity supplied by sources in district i, in 10^6 m^3;
QD_{id}	quantity demanded by sector d in district i, in 10^6 m^3;
$QTRij$	quantity of fresh water transported from district i to j, in 10^6 m^3;
$QTRYij$	quantity of recycled water transported from district i to j, in 10^6 m^3;
$QRYid$	quantity of water recycled from use d in district i, in 10^6 m^3;
$QFRYid$	quantity of recycled water supplied to use d in district i, in 10^6 m^3;
PR_{id}	percent of water recycled from sector d in district i, in 10^6 m^3.

Indices are as follows:

i	district;
d	demand type (urban, industrial, or agricultural);
s	supply source or steps.

Parameters are as follows:

$ALPHA_{id}$	exponent of inverse demand function for demand d in district i;
B_{id}	coefficient of inverse demand curve for demand d in district i;
CE_{id}	unit environmental cost of water discharged by demand sector d in district i (\$ m^{-3});
CR_{id}	unit recycling cost of water supplied from demand sector d in district i (\$ m^{-3});
CS_{is}	unit cost of water supplied from supply step s in district i (\$ m^{-3});
CTR_{id}	unit cost of water transported by demand sector d in district i (\$ m^{-3});
$CTRY_{id}$	unit cost of recycled water transported by demand sector d in district i (\$ m^{-3});
$PMAX_{id}$	maximum price of water from demand sector d in district i;
$PRMAX_{id}$	maximum percent of water from demand sector d that can be recycled in district i;
$QSMAX_{is}$	maximum amount of water from supply step s in district i (10^6 m^3);
P_{id}	shadow value of water for demand sector d in district i (computed) in dollars.

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

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

[159] The first two constraints are the continuity constraints for fresh and recycled water, respectively, stating that water consumed in a district must equal water produced there plus net imports. These are the constraints whose associated LaGrange multipliers give the important shadow values of water in the different districts.

[160] The third constraint states that recycled water must come originally from fresh water. The last constraint restricts water demand to be greater than that demanded at a price of \$100 m^{-3}.

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