Thematic Week: Water Economics and Financing

Thematic Axis: Water Markets

Title: Models for Optimal Water Management and Conflict Resolution

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Abstract:

Actual markets only perform efficiently, if they are competitive, with many small buyers and sellers. Further, all social benefits and costs must be private ones. These conditions are generally violated in the case of water markets. But, by thinking about water values rather than simply water quantities, optimizing models can be built which do achieve efficiency. The WAS model is such a tool. It maximizes the net benefits from available water, given demand and supply characteristics and infrastructure, either actual or potential. Further, WAS permits the users to express special values for water by imposing water policies implicitly expressing such values. Among the outputs are of WAS are "shadow values" for each location, giving the extent to which net benefits would increase system-wide if there were an additional cubic meter of water freely available at that location. These provide the same guidance as do actual prices in competitive markets.

WAS can be used as a powerful tool for water management and infrastructure planning. It can also be used to examine the *system-wide* costs and benefits of particular water policies. But, because water ownership can be expressed in money terms, with WAS permitting the user to express social values, WAS is also a tool for the resolution of water disputes for the benefit of all the parties involved.

Keywords: water, shadow value, cost-benefit analysis of infrastructure, conflict resolution, markets.

[1] This paper draws heavily on the work of a number of colleagues (See Fisher, *et al.*, 2005) and especially on work done jointly with Annette Huber-Lee.

1. Introduction: Fishelson's Example

Water is necessary for life. Water is very important. But such importance does not exempt water from the laws of economics. In this paper, I show how somewhat unfamiliar ways of thinking about water lead to some surprising – and surprisingly useful results, both in terms of water management and in terms of conflict resolution.

I begin with an example due to the late Gidon Fishelson of Tel Aviv University. As with other examples in this paper, it is drawn from the Middle East where I have been the Chair of the Water Economics Project (WEP), a joint effort of Israeli, Jordanian, Palestinian, Dutch, and American experts. [2] But it is applicable around the world.

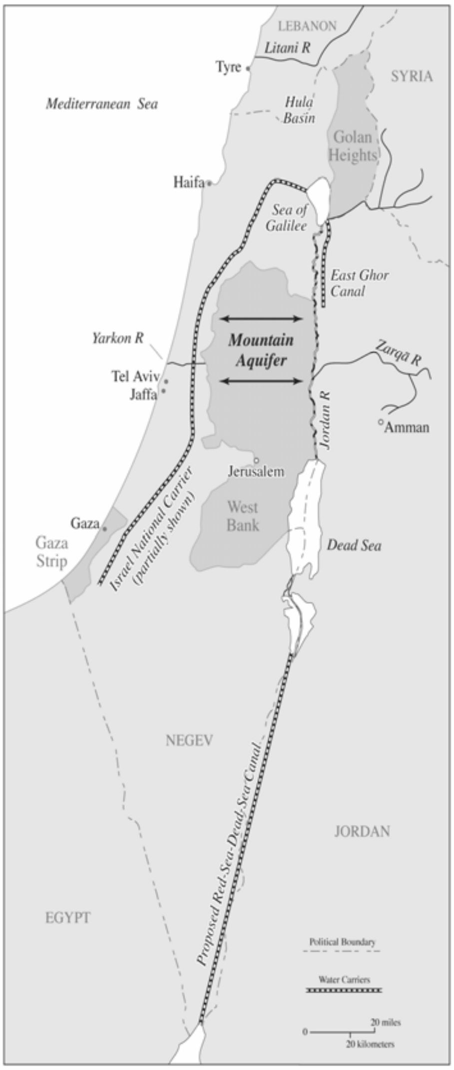

Figure 1: Partial Regional Map

No matter how much one values water, one cannot rationally value it at more than it would cost to replace. Hence, the possibility of seawater desalination places an upper bound on the value of water on the coast. In the case of Israel and Palestine, the cost of desalination on the Mediterranean Coast is roughly $.60 per cubic meter (cm).[3] Hence water in Tel Aviv or Gaza (See Figure 14) is not worth more than $.60 per cubic meter.

But the water sources in the region are mostly not on the Mediterranean Coast. In particular, a good deal of the water in dispute between Israel and Palestine is underground in the (ineptly named) Mountain Aquifer. To extract it and convey it to the Coast would cost roughly $.40 per cm. Hence ownership of that water is worth no more than about $.20 per cm ($.60 - $.40).

Now, 100 million cubic meters (MCM) per year is a large amount of water in the dispute. But 100 MCM per year is worth no more than $20 million per year (and, in fact, is often worth considerably less). Such a sum is not worth fighting about. More dramatically put, it is not worth the cost of a single fighter plane. Israel's GDP is nearly $200 billion. Water is not worth war.

The point of this example is not that desalination is the efficient answer to the world's water problems. It isn't. The point is rather that thinking about the value rather than only the quantity of water can produce useful results – in particular, the result that water is not beyond price and can be traded off for other things.

As we shall now see, that way of regarding water can both serve to inform the sustainable management of water resources and also for the resolution of conflicts over water ownership.

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[2] The most complete discussion of the work and history of the WEP is Fisher, *et al.* (2005). See also Fisher and Huber-Lee (2006).

[3] This ignores the environmental consequences of desalination, but the same principles would apply were those consequences to be included.

[4] Figure 1 is adapted from Wolf (1994).

2. Why Actual Water Markets Do Not Work?

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

1. The markets involved must be competitive consisting only of very many, very small buyers and sellers.

2. All social benefits and costs associated with the resource must coincide with private benefits and costs, respectively, so that they will be taken into account in the profit-and-loss calculus of market participants.

Neither of these conditions is generally satisfied when it comes to water. First, water markets will not generally be competitive with many small sellers and buyers. Second (and perhaps more important), because water in certain uses – for example, agricultural or environmental uses – is often considered to have social value in addition to the private value placed on it by private users. For example, in Chile, the preservation of the wetlands habitats of flamingos is not a matter that private markets consider. More generally, the very widespread use of subsidies for agricultural water implies that the subsidizing government believes that water used by agriculture is more valuable than the farmers, themselves, consider it to be.

This does not mean, however, that economic analysis has no role to play in water management or the design of water agreements. One can build a model of the water economy of a country or region that explicitly optimizes the benefits to be obtained from water, taking into account the issues mentioned above.[5] Its solution, in effect, provides an answer in which the optimal nature of markets is restored and serves as a tool to guide policy makers.

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

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

I first briefly describe the theory behind such tools applied to decisions within a single country. I then consider the implications for water negotiations and the structure of water agreements.

3. The WAS Tool

The tool that I shall principally discuss is called WAS for "Water Allocation System". It is a single year, or steady-state annual model, although the conditions of the year can be varied and different situations evaluated. A related but more powerful tool – MYWAS for "Multi-Year Water Allocation System" -- permits consideration of a sequence of years or seasons. I discuss WAS first.

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[5] 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).

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

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

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

Finally, the user specifies policies toward water. Such policies can include: specifying particular price structures for particular users; reserving water for certain uses; imposing ecological or environmental restrictions, and so forth. This is where social values that are not simply private values come in.

Given the choices made by the user, the model allocates the available water so as to maximize total net benefits from water. These are defined as the total amount that consumers are willing to pay for the amount of water provided less the cost of providing it.[6]

4. Shadow Values and Scarcity Rents

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

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

The central shadow values in the WAS model, however, are those of water itself. The shadow value of water at a given location corresponds to the constraint that the quantity of water consumed in that location cannot exceed the quantity produced there plus the quantity imported less the quantity exported. That shadow value is thus the amount by which the benefits to water users (in the system as a whole) would increase were there an additional cubic meter per year available free at that location. It is also the price that the buyers at that location who value additional water the most would just be willing to pay to obtain an additional cubic meter per year, given the net-benefit maximizing water flows of the model solution.[7]

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

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

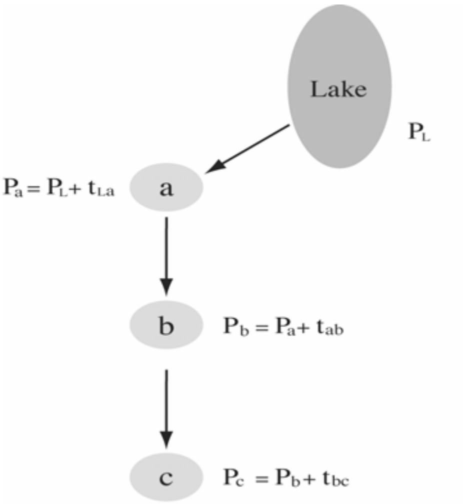

Figure 2: A Use of Shadow Values

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

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

Where direct costs are zero, the shadow value of the resource involved consists entirely of scarcity rent. More generally, the scarcity rent of water at a particular location equals the shadow value at that location less the direct marginal cost of providing the water there.[8] Just as in a competitive market, a positive scarcity rent is a signal that more water from that source would be beneficial were it available.

An important use of shadow values is illustrated in Figure 2, 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 and that the capacity of the conveyance lines is not a binding constraint.[9] The marginal conveyance cost from the lake to a is denoted tLa; similarly, the marginal operating conveyance cost from a to b is denoted tab; and that from b to c is denoted tbc. The shadow values at the four locations are denoted PL, Pa, Pb, and Pc, respectively.

To see that the equations in Figure 2 must hold, begin by assuming that Pa > PL + tLa 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 PL, the shadow value of water at L. (That is what shadow values measure.) Second, since conveyance costs of tLa 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 Pa, the shadow value of water at a. Since Pa > PL + tLa by assumption, the proposed transfer would increase net benefits; hence, we cannot be at an optimum.

Similarly, assume that Pa < PL + tLa. 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, Pa = PL + tLa, and a similar demonstration holds for conveyance between any two points.

Q.E.D.

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

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

[9] This is the simplest case, but results similar to that given in the text hold in any case.

one that should be increased. An activity that loses money at the margin when so evaluated is one that should be decreased. In the solution to the net-benefit maximizing problem, any activity that is used has such shadow marginal profits zero, and, indeed, shadow profits are maximized in the solution.

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

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

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

Note that such water shadow values take full account of the fact that using or processing water in one activity can reduce the amount of water available for other activities and thus has opportunity costs. The shadow values include such opportunity costs, taking into account systemwide effects. (This is particularly important in using WAS for cost-benefit analysis.)

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

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

5. Cost-Benefit Analysis of Infrastructure

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

Consider the discussion of the lake and the conveyance line (Figure 2). Suppose that there were no existing conveyance line to carry water from the lake to city a. Suppose further that, if the WAS model were run without such a conveyance line, the resulting shadow values would be such that Pa < PL + tLa, where tLa is the per-cubic-meter conveyance operating cost that would be incurred were such a conveyance line in place. Such a result would show that the conveyance line in question should not be built, because it would not be used even if it were. On the other hand, if the inequality were reversed, so that Pa >PL + tLa, then that conveyance line might well be worth building – but whether it should be built would depend on the capital costs involved.

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

I illustrate this for the case of desalination plants in Israel, using projections made in the mid-1990's. Figure 3 shows the shadow values obtained for 2010 both in a situation of normal availability of natural resources ("normal hydrology") – the upper numbers – and in a severe drought when that availability is reduced by 30% -- the lower numbers. Israel's price policy ("Fixed Price Policies") of 1995 are assumed to remain in effect. These policies charge each user class the same amount in all districts and heavily subsidize water for agriculture while charging higher prices to household and industrial users. Note that Israel's practice of reducing the quantity of subsidized agricultural water in times of drought has not been modeled, so the results are more favorable to the need for desalination than would be the case in practice.[10]

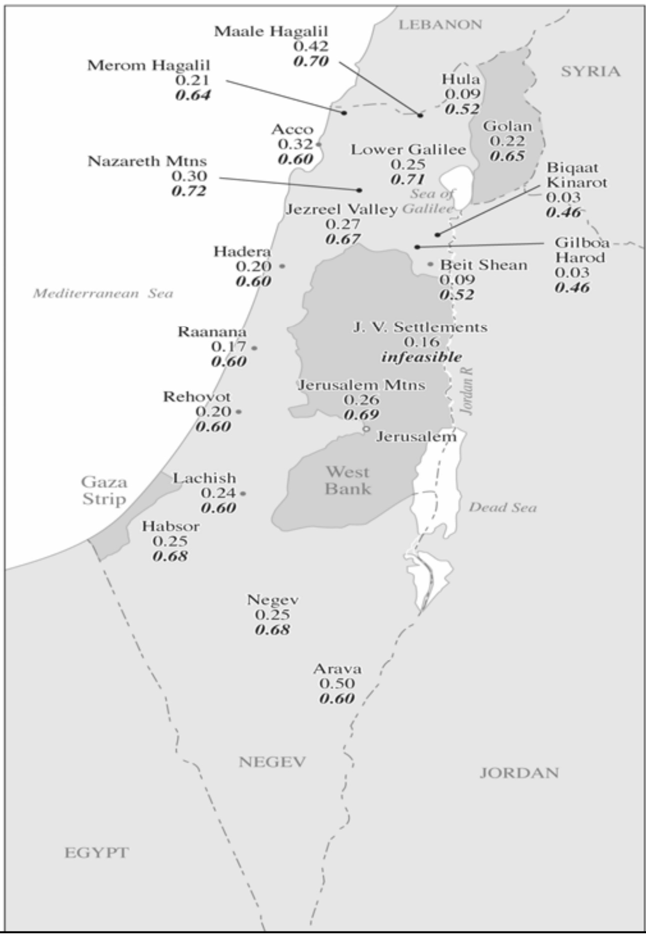

Figure 3. 2010 Shadow Values with Desalination: Normal Hydrology vs. 30% Reduction in Naturally Occurring Fresh Water Sources; Fixed-Price Policies in Effect

The important result with which to start can be seen in the upper shadow values for the coastal districts: Acco, Hadera, Raanan, Rehovot, and Lachish. The highest shadow value is at Acco (near Haifa) and is only \$.319/m3 – well below the cost of desalination. This means that desalination plants would not be needed in years of normal hydrology.

On the other hand, such plants would be desirable in severe drought years. In the lower numbers in Figure 2, desalination plants operate in all the coastal districts at an assumed cost of \$.60/m3. The required sizes of such plants can be obtained by running WAS without restricting plant capacity and observing the resulting plant output.

[10] The infeasibility listed for the Jordan Valley Settlements in the drought case reflects the fact that the full amount of subsidized water required for the supply of agriculture there cannot be delivered.

Results for 2020 are similar, although, as one should expect, it does not take so severe a drought to make desalination efficient, and the required plant sizes in each district are larger.

Of course, much of the cost of desalination consists of capital costs – here included in the price (or target price) per m3. Such costs are largely incurred when the plant is constructed. After that, the plants would be used in normal years unless the operating costs were above the upper shadow values in Figure 3 (highest $.319/m3). Israel therefore needed to consider whether the insurance for drought years provided by building desalination plants is worth the excess capital costs. (Note that the system of Fixed Price Policies contributes substantially to the need for desalination; without such policies, the plants required for severe drought would be far smaller and some would not be required at all.) In fact, WAS can be used to estimate the plant capacities required

The second option is more direct. One runs the WAS model with and without the proposed infrastructure.[11] This generates an estimate of the annual increase in benefits that would result from having such infrastructure in place. Given the estimated life of the projected infrastructure, one can repeat the exercise for the expected conditions of the various years of that life. Then, choosing a discount rate, one calculates the present value of such benefits and compares that with the capital costs.

6. MYWAS

MYWAS offers a much more convenient treatment and moves away from the single-year, steady-state treatment of WAS. MYWAS deals readily and directly with problems over time by maximizing the present value of net benefits over a number of future years or time periods using a discount rate specified by the user. Capital costs are treated as cash outflows when they occur.

Here is a (presumably partial) list of applications. In all of them, as in all WAS applications, system-wide effects and opportunity costs are automatically dealt with, and the user's own decisions and values are implemented.

a. The Timing, Order, and Capacity of Infrastructure Projects: MYWAS allows the user to specify a menu of possible infrastructure projects, their capital and operating costs and their useful life. The program then yields the optimal infrastructure plan, specifying which projects should be built, in what order, and to what capacity.[12] This is a major advance.

b. Storage Management: Most obviously, it is now easy to deal with storage issues, in particular the decisions as to how much water should be stored or released from reservoirs. The decisions involved can be for inter-year or for inter-seasonal storage.

c. Aquifer Management: Man-made storage is not the only kind. Water can also be transferred between time periods by increasing aquifer pumping when water is relatively abundant and reducing it when water is relatively scarce. This means that the use of aquifers and other natural water sources no longer needs to be restricted to the average yearly renewable amount in the model (with that average adjustable by the user). Rather, by specifying the effects of withdrawal on the state of the aquifer, the user can obtain a guide to the optimal pattern of aquifer use over time, including guidance as to aquifer recharge.

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

[12] This problem was encountered in Fisher, et al. (2005) in the analysis of Jordanian issues in Chapter 7.

d. Fossil Aquifers: The rate at which a fossil aquifer should be pumped can also be determined endogenously through the use of MYWAS rather than being specified exogenously by the user. That rate will generally vary over time as conditions change.

e. Climatic Uncertainty: Of course, optimal planning over time will depend on the climate, and climate – especially rainfall – is variable and uncertain. MYWAS enables the systematic study of the effects of such uncertainty on optimal planning by providing the means to examine optimal decisions as a non-linear function of climate variables. Other uncertainties, such as those involved in population forecasts, can also be dealt with.

f. Global Warming: Of course, the multiyear nature of MYWAS makes it suitable for examining the effect of different global warming scenarios on optimal infrastructure.

g. Water Quality: If desired, MYWAS (or WAS) can be adapted to permit a more sophisticated treatment of multi-dimensional aspects of water quality than available in the original version of WAS.

h. Effect of Discount Rate: Obviously, MYWAS can be used to examine the effects of the choice of discount rate on all aspects of the optimal solution.

7. Using WAS for Policy Examination

It is important to understand, however, that infrastructure issues are not the only ones that can be examined with the use of WAS (or MYWAS). WAS can also be used to evaluate contemplated water policies. Such policies, directly or indirectly, will typically involve water reallocation, and this will have both costs and benefits. As with infrastructure, because WAS looks at the entire water system of a country, those costs and benefits can be estimated and analyzed. Moreover, the distribution of the effects – both geographically and by water user type – can be measured, so that the policy makers can find out who gains and who loses and can consider whether taxes or subsidies should be used to mitigate undesirable effects.

While WAS does not make or require specific water policies, it does provide a powerful tool that can inform and assist decision makers in the formulation of rational policies. A country contemplating serious changes in its water system or water policies would do well to construct a WAS model.

8. Conflict Resolution: Negotiations and the Gains From Trade in Water Permits

Optimal infrastructure planning is not the only use of WAS, however. By using WAS (or MYWAS) to value water in dispute, water disputes can be monetized, and this may be of some assistance in resolving them.

Consider bilateral negotiations between two countries, A and B. Each of the two countries can use its WAS tool to investigate the consequences to it (and, if data permit, to the other) of each proposed water allocation. This should help in deciding on what terms to settle, possibly trading off water for other, non-water concessions. Indeed, if, at a particular proposed allocation, A would value additional water more highly than B, then both countries could benefit by having A get more water and B getting other things which it values more. (Note that this does not mean that the richer country gets more water. That only happens if it is to the poorer country's benefit to agree.)[13]

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

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

Water on the Golan Heights (see Figure 1) is sometimes said to be a major problem in negotiations between Israel and Syria, because the Banias River that flows from the mountains of the Golan is one of the three principal sources of the Jordan River.[14] By running the Israeli WAS model with different amounts of water, we have evaluated this question.

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

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

Similarly, a few years ago, Lebanon announced plans to pump water from the Hasbani River – another source of the Jordan. Israel called this a *casus belli* and international efforts to resolve the dispute were undertaken. But whatever one thinks about Lebanon’s right to take such an action, it should be understood that our results for the Banias apply equally well to the Hasbani. The effects on Israel would be fairly trivial.[15]

Water is not worth war!

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

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

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

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

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

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

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

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

I now present results for Israel, Jordan, and Palestine, illustrating the gains from trilateral cooperation.[16]

I concentrate on two sources of water that are the subjects of conflicting claims. These are the Jordan River and the so-called Mountain Aquifer (see Figure 1). Both of these are (very roughly) of equal size, each yielding about 650 million cubic meters a year. The Jordan River is claimed by all three countries, while the Mountain Aquifer is claimed only by Israel and Palestine. Since the gains from cooperation are a function of the water ownership assumptions made, we obtain results for selected varying assumptions about such ownership. *It must be emphasized that such assumptions are not meant as a political statement. They are illustrative only.*

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

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

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

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

For the Mountain Aquifer, we examine ownership cases varying from Israel 80%-Palestine 20% (close to the existing situation) to Israel 20%-Palestine 80% by shifts of 20% at a time.[17]

It is assumed that, both for Israel and for Jordan, the fixed-price policies of the late 1990's are in place. For both countries, this means subsidies for agriculture and, for Israel, higher fixed prices for the other sectors. The Palestinian water price in each district is assumed to equal the corresponding shadow value.

Figure 4 shows the results for 2020. In it, Israel is represented in black, Jordan in white, and Palestine in white with diagonal black stripes. Each of the four panels corresponds to a different ownership of the Mountain Aquifer, while the three positions on the horizontal axis (A, B, and C) correspond to the three different assumptions as to Jordan River ownership. The heights of the bars show the gains from WAS-guided cooperation in millions of (1995) U.S. dollars.

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

Like Jordan, Palestine presents a mixed picture. It also tends to benefit more from cooperation the larger is its share of the Jordan, selling permits to use river water to Israel. On the other hand (Figure 4(I)), when Palestine owns relatively little Mountain Aquifer water, it also benefits as a buyer.

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

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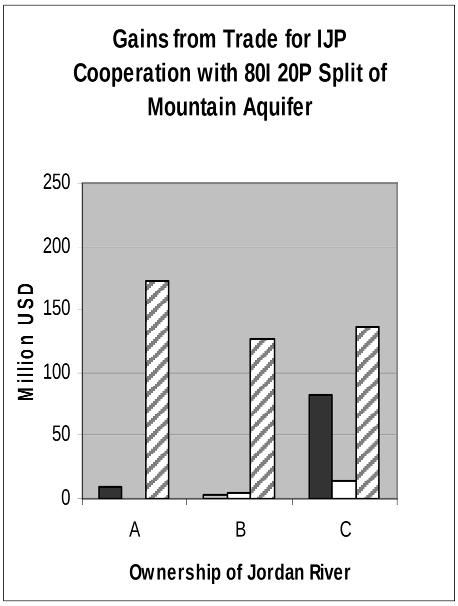
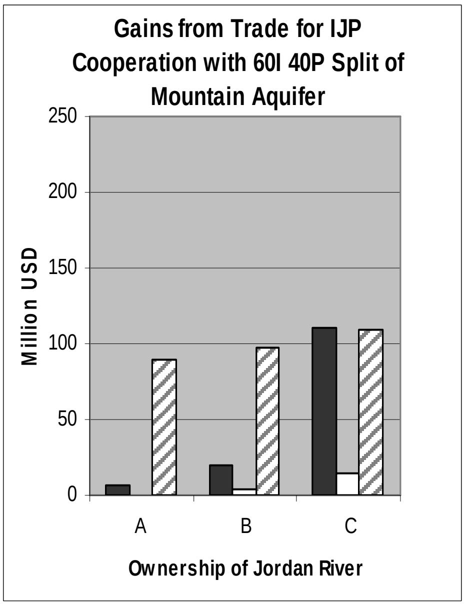
[16] Results for bilateral cooperation have also been obtained, but there is no room to present them here.

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

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





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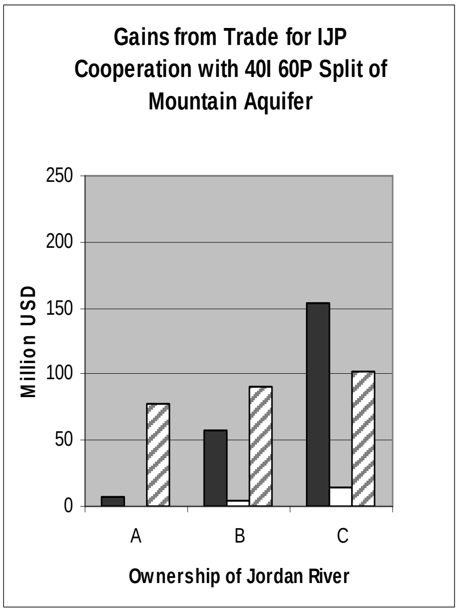

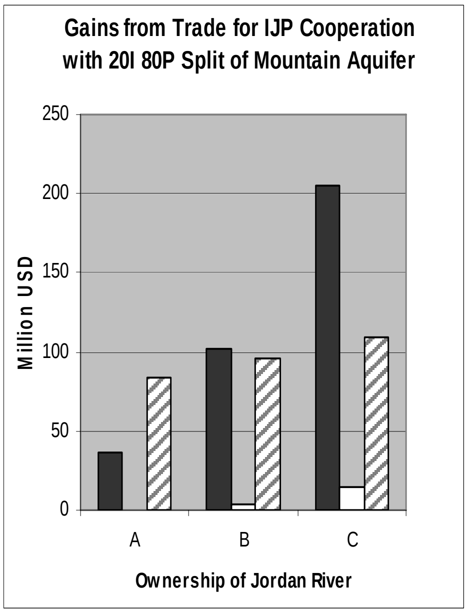

III

IV

Figure 4. Gains from Trilateral Cooperation in 2020

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

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

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

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

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

Note again that it is *not* the case that the gains from cooperation are high only when the party receiving those gains has little water and the value of ownership shifts are high to it. That phenomenon naturally tends to occur when the big gainer is a *buyer* of water permits. But large gains also occur when the party receiving those gains has a large amount of water and the value of ownership shifts are low to it. In such cases, the big gainer is a *seller* of water permits. In fact, the largest Palestinian gains from trilateral cooperation occur both when Palestine has very little water and when it has a good deal.

Moving onward, the gains from WAS-guided cooperation would be greater in other ways than are shown above. In particular, as populations and other factors change, a quantity agreement that is adequate when signed can easily become out of date and a source of new tension. WAS-guided cooperation provides a flexible means of readjusting water usage in a way that all parties benefit.[18]

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

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

10. Concluding Remarks

Of course, there are issues to be settled in all this -- security among them -- and space does not permit me to deal with them here. But the main points should be clear:

- While actual markets will not work efficiently, the use of economic models such as WAS or MYWAS can handle the issues that lead to the failure of actual markets. Such models do not only deal narrowly with money but also permit the user to express social values for water that are not private ones. They can be a powerful tool for water management and infrastructure planning.

- While WAS does not make or require specific water policies, it does provide a powerful tool that can inform and assist decision makers in the formulation of rational policies, showing the costs and benefits from contemplated policies, both direct and indirect through water reallocation. A country contemplating serious changes in its water system or water policies would do well to construct a WAS model.

- Such models also point the way to the transformation of water conflicts into "win-win" situations. They show that disagreement over water ownership can be made a minor issue and the benefits from cooperation in water *usage* can be considerably larger than those from shifts in water ownership.

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