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Using Economics for Sustainability, Efficient Management, and Conflict Resolution in Water

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Summary

Consumption amounts for water are projected, supplies estimated, and a balance struck. Where that balance shows a shortage, alarms are sounded and engineering or political solutions to secure additional sources are sought. Disputes over water are also generally thought of in this way. Two or more parties with claims to the same water sources are seen as playing a zero-sum game. The water that one party gets is simply not available to the others, so that one party's gain is seen as the other parties' loss. But there is another way of thinking about water problems and water disputes, both taking account of water ownership and water usage a way that can lead both to dispute resolution and to sustainable, optimal water management.

Résumé

L'eau est généralement une ressource considérée uniquement en termes de quantité. Elle est estimée en termes de consommation et d'approvisionnement de manière à établir un équilibre. Lorsque cet équilibre est rompu ou lorsqu'apparaît une pénurie, les alarmes sont déclenchées et de l'ingénierie

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ou des solutions politiques sont recherchées en vue de trouver des sources supplémentaires. Les contentieux sur l'eau sont généralement pensés de cette manière. Deux ou plusieurs parties ayant des revendications aux mêmes sources d'eau sont considérées comme jouant un jeu à somme nulle. L'eau qu'obtient l'une des parties n'est tout simplement pas disponible pour les autres, de sorte que le gain d'une partie est considérée comme une perte pour l'autre. Mais il y a une autre façon de penser les problèmes d'eau et les conflits de l'eau qui prenne en compte les droits de propriété sur l'eau et les usages de l'eau, une façon qui peut conduire à la résolution des différends et au développement durable, à la gestion optimale de l'eau.

Keywords: Efficient Water Management, Shadow Price.

Mots-clés : Gestion efficace de l'eau, prix implicite.

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1. Introduction

So important is water that there are repeated predictions of water as a casus belli all over the globe.[1] For example, the U.N.-sponsored Third World Water Forum stated in August, 2001 that water could cause as much conflict in this century as oil did in the last. Said Crown-Prince Willem-Alexander of The Netherlands: "Water could become the new oil as a major source of conflict."[2] Similarly, the late United States Senator Paul Simon wrote:[3]

> Nations go to war over oil, but there are substitutes for oil. How much more intractable might wars be that are fought over water, an ever scarcer commodity for which there is no substitute?

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1. This lecture is based on the work of the Water Economics Project (WEP). That work has so far focused on the Middle East, particularly Israel, Jordan, and Palestine. See Fisher, Huber-Lee, *et al.* (2005).
2. Reuters interview reported on Environmental News Network, August 13, 2001.
3. P. Simon, "In an Empty Cup, a Threat to Peace," *New York Times,* August 14, 2001.

He went on to say:

> Last year American intelligence agencies told President Bill Clinton, in a worldwide security forecast, that in 15 years there will be a shortage of water so severe that if steps are not taken soon for conservation and cooperation, there will be regional wars over it.

And these are but two examples of many.[4]

Even apart from the possibility of water wars, water is often considered to be the area in which major crises will arise in the coming years. Such crises are expected to take the form of serious water shortages in different parts of the globe. Further, disputes over water ownership – whether among nations or competing water use sectors within a nation – are commonly expected to be a major source of disputes and stress, if not of war.[5] Such forecasts of conflict, however, stem from a narrow way of thinking about water.

Water is usually considered in terms of quantities only. Consumption amounts for water are projected, supplies estimated, and a balance struck. Where that balance shows a shortage, alarms are sounded and engineering or political solutions to secure additional sources are sought. Disputes over water are also generally thought of in this way. Two or more parties with claims to the same water sources are seen as playing a zero-sum game. The water that one party gets is simply not available to the others, so that one party's gain is seen as the other parties' loss. Water appears to have no substitute, so that it can only be traded for other water.

But there is another way of thinking about water problems and water disputes, a way that can lead both to dispute resolution and to sustainable, optimal water management. Both uses involve thinking about the economics of water and show, in fact, that water can be traded off for other things. Further, it shows that cooperation in water is a far more sensible policy than is autarky (self-sufficiency in water) – provided, of course, that there is someone with whom to cooperate.

2. The Value of Water

Water is an economic good with special attributes. Those attributes include social benefits from water that are not simply private benefits. Two prominent examples are:

4. See, for example, Klare (2001), pp. 56-7, 59-60.

5. It is important to realize that one cannot generally analyze such issues in terms of global water supplies and demands. Water shortages are intrinsically local or regional in nature. A shortage in Africa, for example, is not easily offset by a surplus in the United States. Hence, while inter-country transfers of water are potentially important, including trade in virtual water, analysis of water problems must proceed by looking at particular areas rather than by global supply and demand analyses.

1. environmental effects of water use and
2. subsidization of water for agriculture, which implies that water used for agriculture has a higher value to society as a whole than it does just for the farmers involved.

Despite these special attributes and the fact that water is essential for human life, water can be given a monetary value. [6] In particular, for any country that has a seacoast (or cooperating with neighbors that do), the cost of seawater desalination puts an upper bound on the value of water. Moreover, that upper bound can be surprisingly low, as the following example (first put forward in 1990 by the late Gideon Fishelson of Tel Aviv University) shows [7]:

The cost of desalination on the Mediterranean coast of Israel and Palestine (see Figure 1) is not more than roughly US $0.60 per cubic meter, including capital costs. [8] Hence water in Tel Aviv or Gaza is not worth more than $0.60 per cubic meter. With proper planning, were an alternative to this desalinated water to cost more than $0.60 per cubic meter, it would be inefficient to use it. A large amount of the water in dispute between Israel and Palestine, however, is not on the coast but instead lies underground in the so-called "Mountain Aquifer". To extract it and convey it to the cities of the coast would cost roughly $0.40 per cubic meter, so that the value of ownership of Mountain Aquifer water is not more than $0.20 per cubic meter ($0.60 at the place where it is used - $0.40 to get it there). 100 million cubic meters (MCM) per year of Mountain Aquifer water, however, is a large amount of water in the context of the Israeli-Palestinian dispute over water. That cannot be worth more than $20 million per year (100 MCM x $0.20 per cubic meter). This is a small sum among countries – smaller, of course, to Israel than to Palestine – and does not come close to the cost of one fighter plane. The idea that the next war will be about water is a myth – provided that the disputants will think about the matter rationally.

The wider lesson of Fishelson's example, however, is that water is not beyond price and that thinking about the value of water rather than directly about its quantity can lead to results that may bypass the usual apparent stalemates.

Note also that the desalination upper bound is just that – an upper bound. It should not be thought that the efficient answer to water issues is always, or even generally, desalination. (Indeed, our results imply that desalination on the Mediterranean coast of Israel and Palestine is not now an efficient technology except in times of major drought.)

6. Such value is generally not the same as the technical cost of water production, treatment, and conveyance. This is discussed below.
7. We bring Fishelson's numbers up to date.
8. All monetary values in this paper are in 1995 dollars.

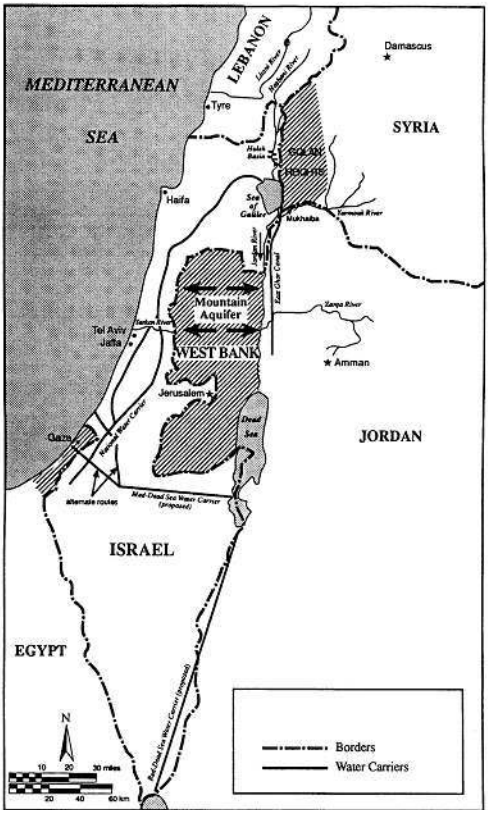

Figure 1 : *Partial Map of Regional Water Supplies and Systems in Israel, Jordan, and Palestine*

The map in Figure 1 shows the name of the large lake on the Jordan River as "Sea of Galilee". That lake is called "the Kinneret" by Israel and "Lake Tiberias" by Jordan and Palestine. The map is adapted from Wolf (1994, p. 27). It will be noticed that we have not marked the map with the names "Israel" and "Palestine". That is because we do not wish to prejudge the ultimate borders that may be agreed upon.

3. Water Ownership and the Value of Water

There are two basic questions involved in thinking about water agreements. These are:

- the question of water ownership and
- the question of water usage.

One must be careful to distinguish these questions.

All water users are effectively buyers irrespective of whether they own the water themselves or purchase water from another. 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 thus 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. The decision of such an owner does not differ from that of an entity that does not own its water and must consider buying needed quantities of water: the non-owner will decide to buy if and only if it values the water at least as much as the money involved in the purchase. *Ownership only determines who receives the money (or the equivalent compensation) that the water represents.*

Water ownership is thus a property right entitling the owner to the economic value of the water. Hence a dispute over water ownership can be translated into a dispute over the right to monetary compensation for the water involved, taking into account social and environmental values.

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 water. While both ownership and usage issues must be properly addressed in an agreement, they can and should be analyzed separately.[9]

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

Every country with a seacoast can have as much water as it wants if it chooses to spend the money to do so. Hence, 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. Disputes over water among such countries are merely disputes over costs, not over life and death.

Note that, in valuing water, one must consider the following:

1. Unless water is very abundant, the value of water does *not* simply consist of the costs of extraction, treatment, and conveyance. In general, water value also includes a *scarcity rent*, reflecting the opportunity cost of its use – the value of using or selling it elsewhere.
2. When we speak of “the value of water”, we are speaking of the value of molecules of H_2O.[10] That is not the only value of importance, however. There may be religious or historical values placed on particular water sources.

9. This is an application of the well-known Coase Theorem of economics. See Coase (1960).

10. In the WAS/MYWAS model discussed below, that value is not simply the economic value narrowly considered. It incorporates the particular values imposed by the user of the model. These can include environmental and social considerations.

Further, water in certain uses (agriculture, for example), may be considered as more valuable to society than is reflected in the private valuations of the users. And water in sources thought to be secure may be considered more valuable than water in less secure sources. In our analyses, we permit the user to take such things into account by constraining the model to reflect such considerations. In that sense, our analysis is not confined to narrowly-defined economic considerations.

4. Why Actual Water Markets Will Not Work

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

1. The markets involved must be competitive consisting only of very many, very small buyers and sellers, so that individual participants cannot affect prices.
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 (in the Middle East or elsewhere). First, water markets will not generally be competitive with many small sellers and buyers.[11] Second (and perhaps more important), 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 its users. The common use of subsidies for agricultural water, for example, implies that the subsidizing government believes that water used by agriculture is more valuable than the farmers, themselves, consider it to be.[12]

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. Its

11. We are not here discussing “after-markets” in water, where water allocations are distributed and the recipients then allowed to trade among themselves. What is under discussion here is how to allocate water efficiently to the ultimate users.
12. Such belief may only reflect the political power of farmers. That makes no difference.

solution, in effect, provides an answer in which the optimal nature of competitive markets is restored and serves as a tool to guide policy makers. [13]

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.

We have created such a tool. The first version was called “WAS” for Water Allocation System; it operated only on one year at a time. The much more powerful present version is called “MYWAS” for Multi-Year Water Allocation System. The WAS tool was first created by the Water Economics Project – a joint venture of Israeli, Jordanian, Palestinian, American, and Dutch experts facilitated by the government of The Netherlands. [14] There are now commitments to proceed with WAS and MYWAS in Israel, Jordan and Palestine, and strong interest in Lebanon as well as elsewhere. The Palestinians [15] are currently in the process of adopting the MYWAS tool.

5. Optimal Sustainable Management

We first illustrate how the WAS and MYWAS models can assist with the efficient and sustainable management of water. (These illustrations and applications are by no means confined to the Israeli-Palestinian situation.) Then we return to the subject of conflict resolution.

As Fishelson’s example shows, rational thinking about water requires thinking about the value of water rather than just its quantity. The WAS and MYWAS models are based on this view.

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13. There is a large literature and much discussion about *actual* free water markets, but it is crucial to understand that what is proposed here is *not* such a market. We do recommend below a system of water trading among (in this case) countries, but even such trading is not at freely bargained prices but rather at prices and quantities prescribed by joint operation of an optimizing model. Hence, we do not discuss the water market literature explicitly.

14. See F. M. Fisher, A. Huber-Lee *et al.* (2005).

15. They are financed by the government of the Czech Republic.

In both models, the region or country studied—whether it is the Middle East, Brazil, China, India, or the US—is divided into districts.

1. The water sources within each district are specified along with the cost of extraction and the sustainable yield.
2. Further, demand properties are specified for different user types (e.g., households, agriculture, and industry). Those properties are not simply the amount of consumption "required"; they consist of demand *curves* showing the quantity of water that would be demanded at different prices. (Water may be essential for life but that does not make water demand totally insensitive to price, particularly once basic needs are covered.)
3. Information on water infrastructure and its costs is also required (treatment plants, desalination plants, storage facilities, and conveyance infrastructure).
4. Finally, as suggested above, the user imposes constraints on the model, constraints that reflect his or her views of social values for water. For example, the user can specify an amount of water to be set aside in a district for environmental purposes. The prices at which water is to be sold to farmers or given to the needy can also be set if desired.

WAS and MYWAS take these inputs and calculate the water flows that will maximize the system-wide net benefits received from the available water. These consist of the gross benefits (measured by the areas under the different demand curves) less the costs. [16] *It should be noted that "efficient water management" does not only mean purely technical efficiency; that is only a part of net- benefit-maximizing allocation of water flows.* [17]

It is very important to realize that the data as to supply, demand, and especially infrastructure can either be for an actual period or for projections for later periods. This latter use provides powerful guidance as to the benefits to be had from contemplated infrastructure projects, a very important application of the model.

Indeed, MYWAS has the following capabilities (among others). 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.

The Timing, Order, and Capacity of Infrastructure Projects: MYWAS allows the user to specify a menu of possible infrastructure projects, such as desalination plants, conveyance lines, treatment plants, or dams, their capital and operating costs and their useful lives. The program then yields the optimal infrastructure plan, specifying which projects should be built, in what order, and to what capacity. This is a major advance.

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16. See Fisher, Huber-Lee, *et al.* (2005), pp. 11-14, for a detailed explanation.
17. Economists will find this perfectly natural; non-economists, especially water engineers are not used to thinking in this way.

Storage Management: It is 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.

Aquifer (and Other Natural Storage) 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 scarce and replenishing the aquifer when water is relatively abundant. By specifying the effects of withdrawal on the state of the aquifer, the user can obtain a guide on the optimal pattern of aquifer use over time, including guidance as to aquifer recharge. *Note that the user can ensure a sustainable program by specifying both the lower limit of the contents of the aquifer and the terminal amount to remain at the end of the planning period.*

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.

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

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.

6. 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 nonnegative 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 objective function would increase if the corresponding constraints were to be relaxed a little.

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

The central shadow values in the model, however, are those of water itself. The shadow value of water at a given location 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. [18]

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

- Shadow values are not necessarily the prices that water consumers are charged. That would be true in a purely private, free market system. But in the WAS/MYWAS 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.
- Related to this is the fact that shadow values are *outputs* of the model solution, not inputs specified a priori. They depend on the policies and values put in by the user of the model.

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

18. 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.

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. [19] 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.

Water shadow values and, accordingly, water scarcity rents depend upon the infrastructure assumed to be in place.

When water is efficiently allocated, as in the solution of the WAS/MYWAS model, the following relationships must hold. Equivalently, if they do not hold, then water is not being efficiently allocated. (All values are per unit of water.)

- The shadow value of water used in any location equals the direct marginal cost plus the scarcity rent. For water *in situ*, the shadow value is the scarcity rent. The scarcity rent of a particular water source is *not* the cost of extraction, treatment and conveyance. Indeed, when there are adequate extraction, treatment, and conveyance facilities, the shadow value of water from that source in the place where it is used is equal to the scarcity rent at the source less the direct costs of getting it there. We have already seen this in Fishelson's example, where the value at the coast ($0.60 per cubic meter) less the conveyance and extraction cost ($0.40 per cubic meter) equaled the upper bound on the ownership value of the water *in situ* ($0.20 per cubic meter) – the scarcity rent. Thus the scarcity rent is the pure value of the water itself as opposed to the cost of the facilities used to provide it. It is also the (marginal) opportunity cost of using the water.
- Water will be produced at a given location only if the shadow value of water at that location exceeds the marginal cost of production. Equivalently, water will only be produced from sources whose scarcity rents are nonnegative.
- If a new source of water is to be developed, then the shadow value of water in the district where the source will, be running the model in the absence of the project should be compared with the cost per cubic meter of using the new source. Only if that cost is less than the relevant shadow value will developing the source be efficient. It is this property that leads to results as to the target cost of desalination required for desalination plants to be efficient.
- If water can be transported from location *a* to location *b*, then the shadow value of water at *b* can never exceed the shadow value at *a* by more than the cost of such transportation. Water will actually be transported from *a* to *b*

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

Figure 2 : *Efficient Water Allocation and Shadow values*

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 both locations.

– Similarly, shadow values at different times (properly discounted) show whether additional water should be stored for future use. Indeed, storing water can be regarded as a form of conveyance, where the conveyance moves water over time rather than over space.

The situation as to spatial conveyance 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. The marginal conveyance cost from the lake to *a* is denoted t_{La}; similarly, the marginal conveyance cost from *a* to *b* is denoted t_{ab}; and that from *b* to *c* is denoted t_{bc}. The shadow values at the four locations are denoted P_L, P_a, P_b, and P_c, respectively.

To see that the equations in Figure 2 must hold, begin by assuming that $P_a > P_L + t_{La}$ and that there is extra conveyance capacity from *L* to *a* at the optimal solution. Then transferring one more cubic meter of water from *L* to a would have the following effects. First, since there would be one cubic meter less at *L*, net benefits would decline by P_L, the shadow value of water at *L*. (That is what shadow values measure.) Second, since conveyance costs of t_{La} would be incurred, there would be a further decline in net benefits of that amount. Finally, however, an additional cubic meter at *a* would produce an increase in net benefits of P_a, the shadow value of water at *a*. Since, by assumption, $P_a > P_L + t_{La}$, the proposed transfer would increase net benefits; hence, we cannot be at an optimum.

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

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

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

Note that shadow values play a guiding role in the same way that actual market prices do in competitive markets. 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 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 inference 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 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 maximizing solution include such opportunity costs, taking into account system-wide effects. (This is particularly important in using WAS/MYWAS 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.

7. Some Examples

We now present some illustrative results. In considering them (and later quantitative results), one should bear in mind that they are taken from runs of the WAS model made in the late 1990's, and the forecasts then used may not match actual conditions or forecasts that would now be made. They are presented to show the kind of results that can be generated and the kinds of questions that can be asked and answered.

7.1. Israel

Figure 3 shows the predicted shadow values for Israel for 2010.[20] These are calculated with Israel's fixed-price policies of the mid-1990's (the prices charged to users) assumed to be in effect.

The upper shadow values are for a year of normal hydrology in which the natural freshwater sources yield the average amount of water; the lower values are for a year with a substantial drought in which such yields are all 30% less than average. (Such a drought has occurred historically in roughly 13% of years.)

Look first at the upper values. The striking fact is that none of the coastal districts have a shadow value even close to $0.60 per cubic meter, roughly the cost of desalination per cubic meter. (Indeed, the highest such value is $0.32 per cubic meter). This means that, under the assumed conditions, desalination would not be an economically efficient technology.

20. Taken from Fisher, Huber-Lee, *et al.* (2005), p. 102.

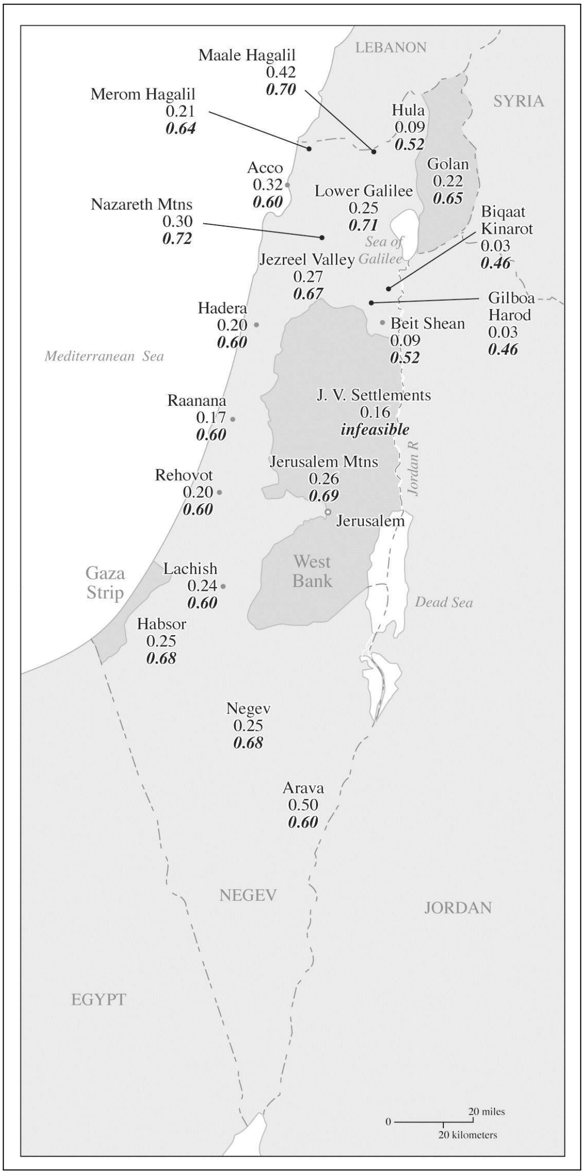

Figure 3 : *Shadow Values for Israel with Desalination, 2010*

Normal Hydrology (Upper Values) vs. 30% Reduction in Naturally Occurring Freshwater Sources (Lower Values). Fixed Price Policies in Effect

On the other hand, the lower values on the coast are all $0.60 per cubic meter. This indicates that desalination would be desirable in years of severe drought.[21]

Does that mean that Israel should build desalination plants for use only in drought years? Unfortunately, the question of what to do is more complicated than that. A great deal of the cost of desalination consists of capital costs, so that a plant, once built, will be efficient to use whether or not the capital costs can be recovered. Whether to build such a plant depends on the distribution of expectations as to natural water yields over the life of the plant.

Hence, while the shadow values shown, which were obtained from WAS[22], are suggestive as to whether desalination is needed (and illustrate one way of determining the usefulness of a new source of water), MYWAS would be the desired technique for examining the really complicated question of the effects on the decision of different patterns of rainfall and hydrology.

7.2. Palestine

The results for Palestine reveal a different result and one of some interest.

Consider Figure 4.[23] Here, Palestine is assumed to have built a good deal of recycling and conveyance infrastructure (not actually constructed as yet). The lower shadow values show results with Palestine only having the Mountain Aquifer water it is now permitted to take. The lower shadow values show results with double that quantity taken.

The interesting property is that, while with the lesser amount of aquifer water, desalination plants are definitely needed (Note the shadow values of $0.60 per cubic meter in the Gaza districts.), with double that amount, the need for desalination disappears. And this result also appears in our runs for 2020. What is going on here is that desalination is not needed to supply the increasing Gaza population; rather, it is needed to supply the West Bank, with the water being pumped *uphill* to Hebron.

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21. The results are more favorable to desalination than necessary, since Israel typically restricts low-priced water for agriculture in years of severe drought.

22. At this time, it is appropriate for us to correct a minor error in Fisher, Huber-Lee, *et al.* (2005) pointed out to us by Yoav Kislev, whom we thank (not desiring to shoot the messenger). In that work, all prices are meant to be at the city gate, so to speak. But, when dealing with Israeli fixed-price policies for households and industry, we mistakenly set the fixed price for urban and industry at the prices charged at the user tap. We also calibrated the household and industry demand curves using those too-high prices. Correction of this slip has almost no effect on our important qualitative statements (indeed, it strengthens the finding that desalination is not yet an efficient technology except in times of extreme drought), but it does affect the numerical results in Figure 3. (The other results reported below are not affected.)

23. Taken from Fisher, Huber-Lee, *et al.* (2005), p. 148. No account is taken of the present split between the government of the West Bank and that of Gaza.

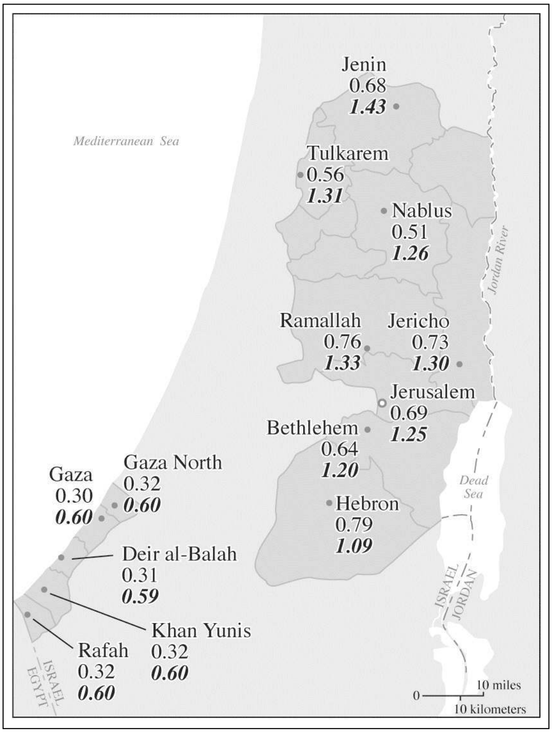

Figure 4 : *Comparison of Full-Infrastructure Scenario with (upper values) and without (lower values) Double the Quantity from the Mountain Aquifer, 2010 Desalination*

Obviously, this is not very efficient. We shall see below that, with cooperation, such a measure is not required. It is noteworthy, and somewhat distressing, however, that, some years ago, Israel proposed to build a desalination plant just north of Gaza and have the water similarly pumped to the West Bank. It would, of course, be more efficient to permit the Palestinians to pump more water from the Mountain Aquifer and use any desalination plant to supply Israel, if necessary. The Israeli offer was an instance of Israel's uncompromising position that it will retain all the water it now has and will only assist the Palestinians by helping them find new sources of water. When such new sources turn out to be Israeli-controlled desalination plants, needless to say, such an outcome is unacceptable to Palestine. We shall see below how both countries would benefit – Israel as well as Palestine – if Israel were to offer genuine cooperation as we suggest.

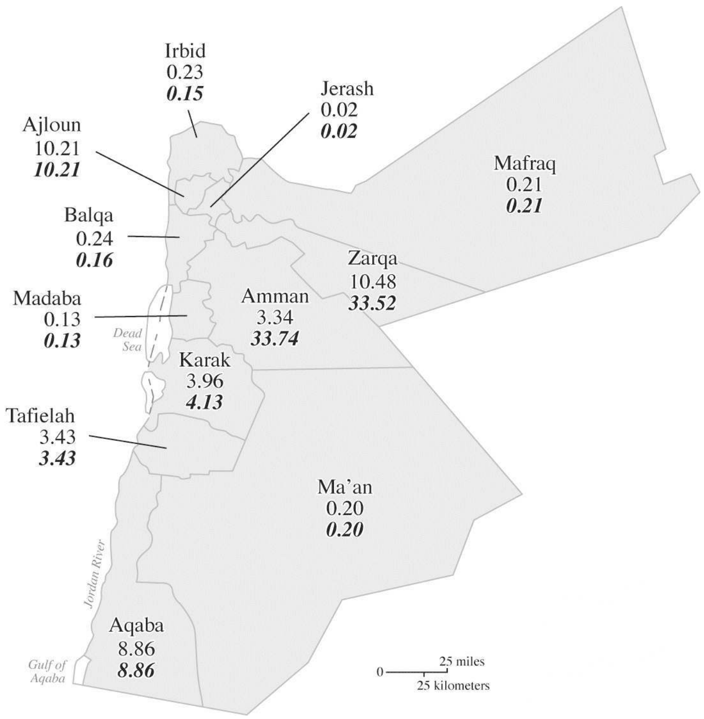

Figure 5 : *Results with (upper values) and without (lower values) Expanded Infrastructure (2020)*

7.3. Jordan

We have also obtained results for Jordan. Here, two results appear particularly interesting.

The first of these comes from runs in which Jordan is assumed not to have built new water conveyance lines and other infrastructure after the mid-nineties. Consider Figure 5 which shows shadow values for 2020.[24] The lower shadow values show the effects that would occur. Look at the shadow value in Amman; it is $33.74 per cubic meter! Obviously, this is not to be taken as predicting that such a price will be paid by consumers; rather, it signals what would be a catastrophe if some action were not taken,

It is instructive to use those same (lower) shadow values to see at least part of what is needed. Although the shadow value in Amman is $33.74, the shadow value in the Jordan River Valley (Balqa) is only $0.13 per cubic meter. Plainly, something is preventing water from being conveyed from the Jordan River to Amman. In

24. Taken from F. M. Fisher, A. Huber-Lee, *et al.* (2005), p. 171.

fact, the existing conveyance line had a 45 million cubic meter (MCM) capacity, and, were it not expanded, that line would be far too inadequate.

The upper shadow values show what happens when that conveyance line is doubled in capacity (a project that has now been completed).[25] The shadow value in Amman has dropped to $3.34 per cubic meter – still high, but not catastrophic. Further, the shadow value of Jordan River water at Balqa has risen to $0.24 per cubic meter as there is now more use for that water than in the original (lower values) run. Further runs (not shown) show that other projects can bring the shadow value in Amman down to a bit over $1 per cubic meter.

One lesson here is that it need not be a shortage of water sources that leads to serious problems; it can be a shortage of infrastructure. In 1994, at our first meeting in Amman, when our project was just beginning, Dr. Munther Haddadin, now a major colleague in our work, asked the rhetorical question, "If the two of us were lost in the desert east of here, what then would be the value of a bottle of water?" The answer is that the value of water in the desert would be very high, but the value of water in the Jordan River would not rise. In such a case, what would be involved would not be a shortage of the amount of river water owned, but a shortage of infrastructure to convey that water from the river to the travelers in the desert.

The second (still quite preliminary) result that we shall discuss involves the proposed Red Sea – Dead Sea Canal, where the gravity flow of water is used to generate electricity, and the electricity used to desalinate some of that water and to pump the desalinated water uphill to Amman. It appears that the desalination project would bring benefits large enough to pay for itself and have some amount left over to contribute to the building of the canal itself.

There is another effect, however. Jordan is building a major conveyance line to carry water from the large Disi fossil aquifer in the South to Amman. Our preliminary results indicate that, in the absence of the canal, that would be a worthwhile project. On the other hand, if the canal and the accompanying desalination project were to be built, it would not be efficient to use the conveyance line from Disi to Amman.

Note, however, that this does not mean that the Disi conveyance line should not have been built. The Red-Dead Canal has been under discussion for years, and, even if and when construction begins, completion will take a long time. It may well be that the benefits of the Disi line in the interim will pay for its construction.

MYWAS is well suited to answer that question, and also to calculate the net contribution to Canal construction costs that would be provided from the

25. They are also affected by a project bringing 35 MCM per year of desalinated brackish water from Balqa to Amman at a cost of $0.47 per cubic meter.

desalination plant. This is a good example of how the ability of MYWAS to select the optimal order in which infrastructure should be built can be valuable.

8. Conflict Resolution: Negotiations and the Gains from Trade in Water Permits and Mutually Beneficial Cooperation

We now return to the discussion of the use of our tools to resolve water disputes. Indeed, WAS/MYWAS can also be used to resolve a broad range of water conflicts and to guide mutually beneficial cooperation.

By using the WAS/MYWAS model to value water in dispute, water disputes can be monetized *after accounting for the special values and social benefits of water*. This may be of some assistance in resolving them, since negotiations over money should be less emotional and easier than negotiation over water quantities.

Consider bilateral negotiations between two countries, A and B. Each of the two countries can use its WAS/MYWAS 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.) [26].

Of course, the positions of the parties will be expressed in terms of ownership rights and international law, often using different 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/MYWAS.

In addition to monetizing water disputes, WAS/MYWAS 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

26. If trading off ownership rights considered sovereign is unacceptable, the parties can agree to trade short-term permits to use each others' water, as discussed below.

flows from the mountains of the Golan is one of the three principal sources of the Jordan River.[27] By running the Israeli WAS/MYWAS 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 have been 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 well over $200 billion per year or to the cost of military conflict.

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.[28]

9. 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/MYWAS can promote agreement. Indeed, WAS/MYWAS 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

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

28. 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/MYWAS model for those two countries, we cannot answer that question. Both countries would surely profit from such a model.

quantities and at prices (shadow values) given by an agreed-on version of the WAS/MYWAS model run jointly for the two (or more) countries together. (The fact that such trades would take place at WAS/MYWAS-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.

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.

We now present results for Israel, Jordan, and Palestine, illustrating the gains from cooperation – and especially those from participation in the grand (tripartite) coalition. We concentrate on predictions for 2010. Predictions for 2020 are generally qualitatively similar, and we comment on them only when that seems instructive.

We 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:

1. Israel 92%, Jordan 8%; Palestine 0. (This is approximately the existing situation.)
2. Israel 66%; Jordan 17%; Palestine 17%.
3. 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. [29]

We first present results on two-way cooperation. These differ from those in Fisher *et al.* (2005) primarily because of the expanded set of ownership assump-

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

tions.[30] We assume 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.

9.1. Israel-Palestine Bilateral Cooperation

We begin with bilateral Israeli-Palestinian cooperation. Figure 6 shows the gains from such cooperation in 2010 as a function of the different ownership assumptions. (Note that cooperation here is not merely cooperation on the Mountain Aquifer but full cooperation in water including new water infrastructure.) Effectively, this and the similar figures that follow represent slices of multi-dimensional diagrams. (In the figures starting with Figure 6, Israel is represented by black, Jordan by white and Palestine by grey.)

Look first at Figure 6(I) – the case of an 80-20 Israel-Palestine division of the Mountain Aquifer. As we should expect, in Case A of Jordan River ownership, where Israel has most of the river and Palestine has none, it is Palestine that benefits most from cooperation – far more than relatively water-rich Israel. Further, the same is true for the other cases of Jordan River ownership. But an interesting phenomenon appears. As expected, Palestine gains more from cooperation in Case A in which it owns no Jordan River water than it does in Case B, in which it has 17% of the river. When we move to Case C, however, where Palestine has 33.3% of the river, the gains to Palestine once again increase being very nearly as high ($171 million dollars per year) as in Case A ($172 million dollars per year), even though Palestine has considerably more water in case C than in Case A.

The reason for this is not hard to find. Palestine has considerably more water in Case C than in Case A, but Israel has considerably less. Both buyer and seller gain from WAS-guided cooperation, and, in Case C, Palestine gains by selling water to Israel, despite its low share of the Mountain Aquifer. Correspondingly, Israel, whose gains as a seller decrease slightly from Case A to Case B, has increased gains as a buyer in Case C.

This phenomenon becomes even more pronounced in the other panels of Figure 6, in which Palestine has increased shares of the Mountain Aquifer. In each of those panels, Palestine's gain from cooperation increases as it owns more and more Jordan River water; that is because it gains as a *seller*. Correspondingly, Israel gains as a buyer.

30. In F. M. Fisher, A. Huber-Lee, *et al.* (2005), we examined the gains from cooperation for each of the two water sources separately while assuming that Israel had most or all of the other source.

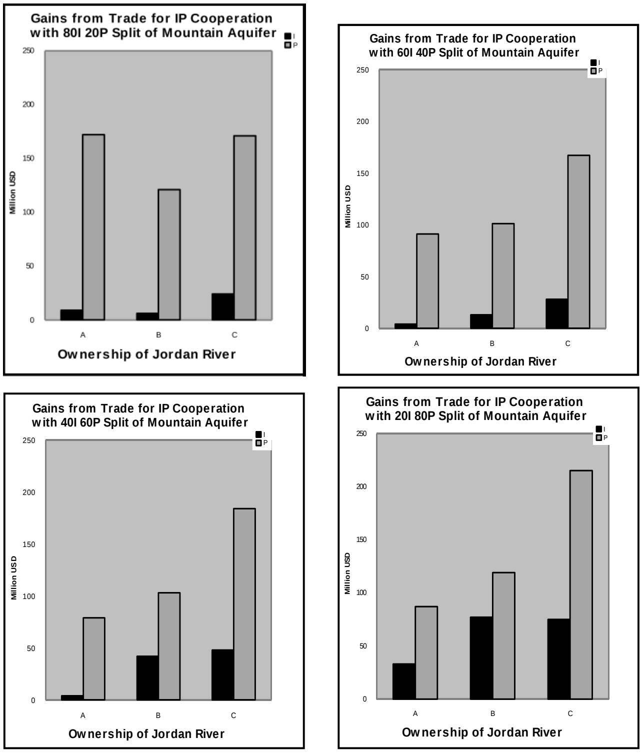

Figure 6 : *Gains from Bilateral Cooperation between Israel and Palestine in 2010*

The results for 2020 (no figure shown, but see Table 2 below) are similar except that gains are larger.

9.2. Israel-Jordan Bilateral Cooperation

Figure 7 shows the gains from bilateral cooperation between Israel and Jordan for 2010. Here the gains are generally lower than in the Israel-Palestine case. The interesting phenomenon is as follows:

Where Israel has the lion's share of the Mountain Aquifer (Figure 7(I) and Figure 7(II)) and also 92% of the Jordan River (Case A), there are no gains from cooperation at all. Neither Israel nor Jordan gains from trading Jordan River water – despite Jordan's small share thereof. When we stay with the same shares of the Mountain Aquifer and move to Case B for the Jordan River, small gains do appear and the gains are quite a bit larger in Case C. In Figure 7(III) and Figure 7(IV), where Israel has 40% and 20% of the Mountain Aquifer, respectively, there are

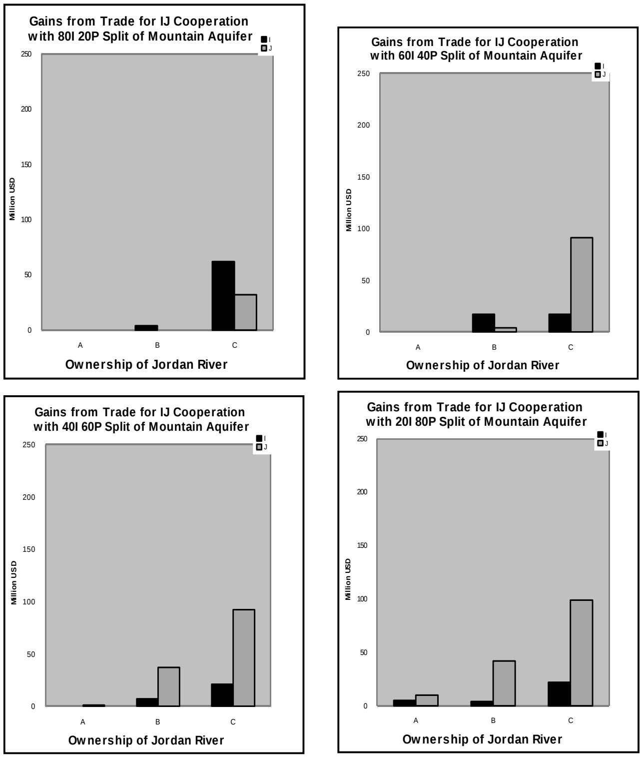

Figure 7 : *Gains from Bilateral Cooperation between Israel and Jordan in 2010*

larger gains for Jordan, the increase being most noticeable in Case B (although the gains remain largest in Case C).

What is going on here is that, as Jordan owns more and more of the river, it pays both parties for Jordan to transfer water to Israel by selling water permits. This is even true when Israel owns 92% and Jordan only 8% of the river , but is more pronounced in Cases B and C as Israel's share of the river goes down and Jordan's goes up. This reflects the finding, discussed above, that Jordan has a major problem of conveyance infrastructure in using Jordan River water.

It is also interesting to note that Israel's gains from such purchases in Case C are greatest when it owns 92% of the Mountain Aquifer (Figure 7(I)) and hence presumably needs the Jordan River water less than it does when it has less Mountain Aquifer water. The explanation is that Figure 7(I) shows a case in which Israel has sufficient water to make the shadow value of the Jordan River water lower than in the other cases. Hence the price that Israel pays for such water is also lower, and this benefits Israel (while correspondingly reducing Jordan's gains as a seller).

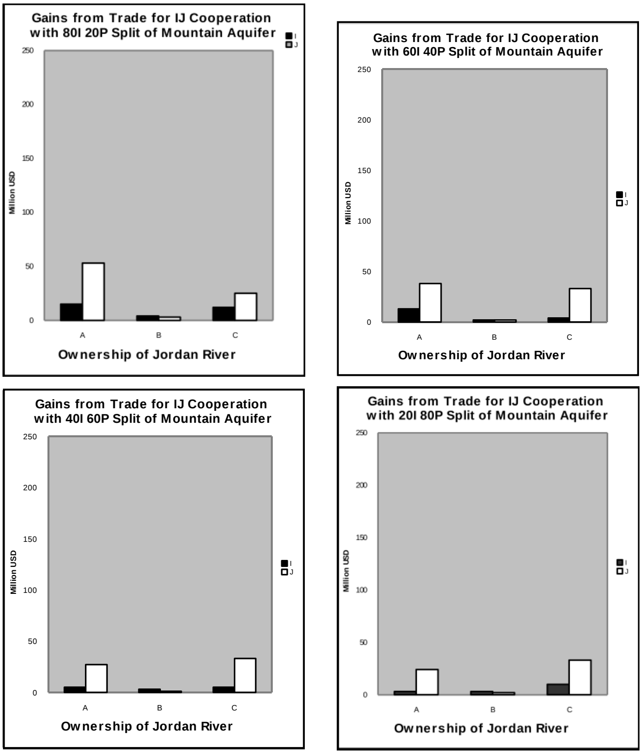

Figure 8 : *Gains from Bilateral Cooperation between Israel and Jordan in 2020*

By 2020, a somewhat different picture emerges (Figure 8). By that year, Jordan's water situation worsens. As a result, when it owns only 8% of the river and Israel owns 92% (Case A), Jordan always buys water permits from Israel, gaining from so doing. When Jordan and Israel each own 33.3% of the river (Case C), Jordan always sells water permits to Israel, again gaining from so doing. In the middle case of Jordanian ownership of 17% and Israeli ownership of 66% (Case B), very little trade in water permits takes place (so little that the column for Jordan is barely visible). This pattern is qualitatively independent of the ownership of the Mountain Aquifer, although the quantitative amount of the gains is not.

9.3. Jordan-Palestine Bilateral Cooperation

The case of bilateral cooperation between Jordan and Palestine can be handled quickly and does not require diagrams for 2010. Here the only possible beneficial trades are those that involve Jordan River water – and both countries have relatively little water to trade. As a result, for 2010, the only case in which gains

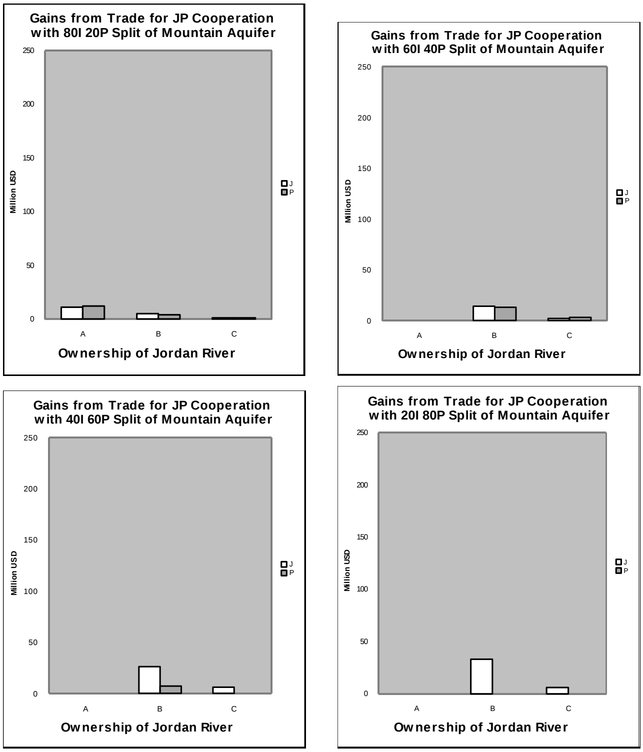

Figure 9 : *Gains from Bilateral Cooperation between Jordan and Palestine in 2020*

from cooperation are not totally negligible is that where Palestine owns only 20% of the Mountain Aquifer and none of the Jordan River (Case A). There, even though Jordan only owns 8% of the river, it gains $10 million per year by selling a permit to Palestine to use river water, and Palestine has a net gain of $12 million per year from buying it.

By 2020, however, the situation becomes more interesting and is shown in Figure 9. Here there are gains in all of the panels. Consider Figure 9(I). As in 2010, when Palestine owns only 20% of the Mountain Aquifer, and none of the Jordan (Case A), the two parties gain by Jordan selling Jordan River water to Palestine. As Palestine's share of the Jordan River rises (Cases B and C), those gains decrease and almost disappear, but, unlike the result for 2010, there are still some visible gains in Case B. This is surely due to the predicted increase of the Palestinian population between 2010 and 2020.

Moreover, when Palestine owns 40% or more of the Mountain Aquifer (Figures 9(II)-9(IV)), gains from cooperation no longer occur when Palestine owns no Jordan River water, but do appear when it does. Here, Palestine gains by selling additional

Jordan River water to Jordan (which it can afford to do because of the additional Mountain Aquifer water it owns). By the case pictured in Figure 9(IV), in which Palestine owns 80% of the Mountain Aquifer, it owns enough water that it sells to Jordan very cheaply, so that the pictured gains are all Jordanian (and are quite substantial in Case B).[31] (Note that this does not occur in the parallel ownership situation under trilateral cooperation.)

9.4. Trilateral Cooperation (Grand Coalition)

Figures 10 and 11 give the results for trilateral cooperation for 2010 and 2020, respectively.

Here what stands out 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 10(I)), when Palestine owns relatively little Mountain Aquifer water, it also benefits as a buyer.

In 2020 (Figure 11), the main thing to notice is that the gains to all parties – Israel, Jordan and Palestine – from cooperation are larger than they are in 2010.

For 2010 and 2020, respectively, Tables 1 and 2 show numerically the gains for each party from trilateral cooperation and for each case of bilateral cooperation.[32] The following points appear:

- As can be proved[33], there is no bilateral coalition in which the two members both do better than they do in the corresponding grand coalition.
- On the other hand, it is not generally true that *both* members of a bilateral coalition do better in the grand coalition. However, the total increase in gains

31. In fact, Case C with Palestine owning 80% of the Mountain Aquifer is quite extreme. Without cooperation, Palestine has so much water that it does not use all the Jordan River water that it owns. Jordan, on the other hand, would benefit moderately from additional river water. Under cooperation, the model transfers water from Palestine to Jordan (in the form of water permits), and, while Jordan benefits from that transfer, at its end, neither Jordan nor Palestine would benefit from additional river water. The shadow value of such water is zero in both countries, and the model assumes that the transfer takes place at a zero price. In practice, of course, were such an extreme situation to arise, the needed transfer would presumably take place at a very low price.

32. The numbers in Tables 1 and 2 are not the total benefits achieved but rather the gains achieved by each form of cooperation. For technical reasons, the level of total benefits as measured using the particular form of the demand curves that appear in WAS/MYWAS does not have a natural origin, and only changes in benefits are meaningful. (See F. M. Fisher, A. Huber-Lee, *et al.*, 2005., p. 26, n. 1.)

33. See F. M. Fisher and A. Huber-Lee (2009).

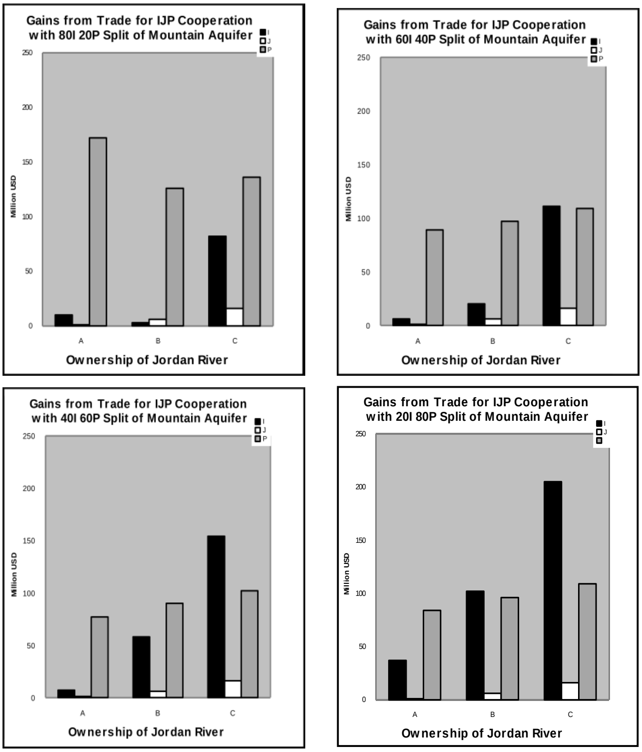

Figure 10 : *Gains from Trilateral Cooperation (Grand Coalition) in 2010*

to the two members achieved in the grand coalition are always positive. This reflects the fact that, where there are two countries in the grand coalition that are net buyers and one that is a net seller of water permits, it can easily happen that each of the net buyers would be better off without the presence of the other in the coalition competing to buy. The single net seller, however, is always better off in such circumstances and so much better off that (if the bilateral coalition is already operating), the seller could profitably pay its existing partner to permit the new entry. A similar phenomenon can arise when there is a single net buyer and two net sellers.

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

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.

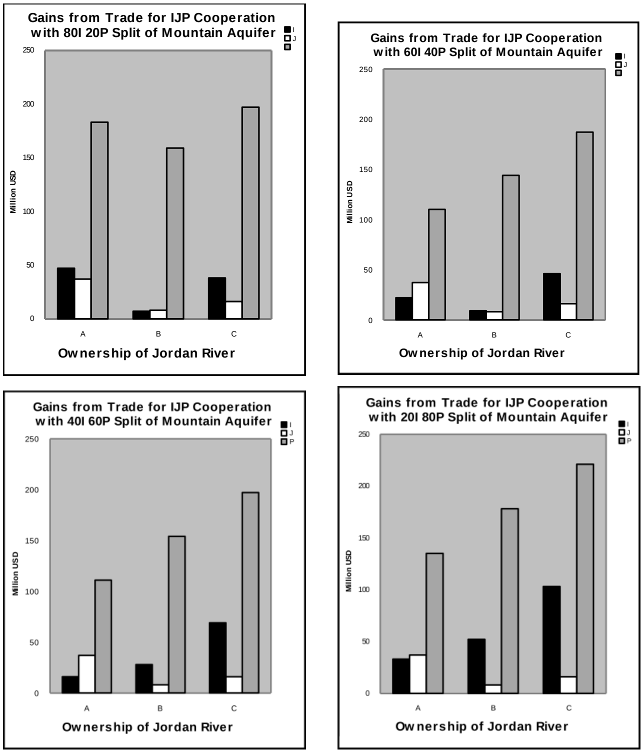

Figure 11 : *Gains from Trilateral Cooperation (Grand Coalition) in 2020*

We measure the gains from ownership shifts 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 [34].

34. Note, however, that this is not true for bilateral cooperation, since water ownership by the excluded party affects the amount of water which is available for bilateral cooperation.

Table 1 : *Gains for all Coalitions, 2010*
(millions of 1995 dollars)

Jordan River / Mountain Aquifer		I 92% J 8% P 0%			I 66% J 17% P17%			I 33.3% P 33.3% J 33.3%		
		I	J	P	I	J	P	I	J	P
I 80% P 20%	IJP	10	1	172	3	6	126	82	16	136
	IJ	0	0	–	4	0	–	62	32	--
	IP	9	–	172	6	–	121	24	–	171
	PJ	–	10	12	–	0	1	–	0	0
I 60% P 40%	IJP	6	1	89	20	6	97	111	16	109
	IJ	0	0	–	17	4	–	17	91	--
	IP	4	–	91	13	–	101	28	–	167
	PJ	–	1	1	–	1	1	–	0	1
I 40% P 60%	IJP	7	1	77	58	6	90	154	16	102
	IJ	0	1	–	7	37	–	21	92	--
	IP	4	–	79	42	–	103	48	–	184
	PJ	–	0	0	–	1	1	–	0	0
I 20% P 80%	IJP	37	1	84	102	6	96	205	16	109
	IJ	5	10	0	4	42	0	22	99	0
	IP	33	–	87	77	–	119	75	–	215
	PJ	--	0	0	--	2	0	--	0	0

The occasional appearance of gains of 0 for one party and positive gains for another in cases of bilateral cooperation is due to rounding error.

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. [35]

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.

35. In the case of the Jordan River, there is a single scarcity rent. In the case of the Mountain Aquifer, however, scarcity rents can vary with geography as there is more than one pool from which to draw. However, our shifts in Mountain Aquifer ownership always transfer the same percentage of each pool, hence the average scarcity rent of what is being transferred remains constant.

Table 2 : *Gains for all Coalitions, 2020*
(millions of 1995 dollars)

Jordan River / Mountain Aquifer		I 92% J 8% P 0%			I 66% J 17% P 17%			I 33.3% P 33.3% J 33.3%		
		I	J	P	I	J	P	I	J	P
I 80%	IJP	47	37	187	7	8	159	38	16	197
	IJ	15	53	–	4	3	–	12	25	--
P 20%	IP	28	–	197	5	–	159	24	–	206
	PJ	–	11	12	–	5	4	–	1	1
I 60%	IJP	22	37	110	9	8	144	46	16	187
	IJ	13	48	–	2	2	–	4	33	--
P 40%	IP	11	–	117	12	–	140	23	–	204
	PJ	–	0	0	–	14	13	–	2	3
I 40%	IJP	16	37	111	28	8	154	69	16	197
	IJ	5	27	–	3	1	–	5	33	--
P 60%	IP	11	–	110	34	–	145	38	–	222
	PJ	–	0	0	–	26	7	–	6	0
I 20%	IJP	33	37	135	52	8	178	103	16	221
	IJ	3	24	–	3	2	–	10	33	--
P 80%	IP	35	–	127	62	–	165	64	–	254
	PJ	--	0	0	--	33	0	--	6	0

The occasional appearance of gains of 0 for one party and positive gains for another in cases of bilateral cooperation is due to rounding error.

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.

For 2010, the value of a 10% shift in Mountain Aquifer ownership ranges from $3 million per year to $34 million per year. The low figure occurs for Palestine when it already owns 33.3% of the Jordan River and moves from 60% to 80% ownership of the Mountain Aquifer. The high figure also comes for Palestine when it owns none of the Jordan River and moves from 20% to 40% ownership of the Mountain Aquifer. With a more equal division of both water sources, the value of a 10% shift in Mountain Aquifer ownership ranges from $8 million per year to $24 million per year. For 2020, the corresponding figures are similar, but a bit higher.

For the Jordan River, there are more extreme cases. For 2010, without cooperation, the value of a 10% ownership shift in Jordan River ownership ranges from $0 per year to $38 million per year. Again the low point occurs for Palestine when it owns at least 60% of the Mountain Aquifer,[36] but the higher values occur for Israel. Most of the values for Jordan and Palestine are below $2 million per year, the principal exception being a value of $34 million per year starting from an ownership level of no Jordan River water and 20% of the Mountain Aquifer.

For 2020, however, the picture changes. Here the lowest value of a 10% shift in Jordan River ownership is still $0 per year (occurring for Palestine when it owns 60% or more of the Mountain Aquifer), but the highest value is now $58 million per year and occurs when Jordan goes from 8% to 17% ownership of the river.

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

Note that it is *not* the case (see Tables 1 and 2 and Figures 10 and 11) 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. A good example of this can be seen in Tables 1 and 2, where the largest Palestinian gains from trilateral cooperation occur both in the upper left-hand corner where Palestine has very little water and in the lower right-hand corner where it has a good deal. Indeed, in Table 2, the Palestinian gains in the lower right-hand corner are greater than those in the upper left-hand corner.

Moving onward, the gains from WAS/MYWAS-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/MYWAS-guided cooperation provides a flexible means of readjusting water usage in a way that all parties benefit.[37]

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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36. Except when Palestine moves from 0 to 17% of Jordan River water and owns 60% of the Mountain Aquifer. In that case, the value to it of the ownership shift (averaged over the 17% increase) is $3 million per year for 10%.

37. Note that this applies even if the initial ownership allocation just happens to be that of the WAS/MYWAS optimizing solution – an unlikely event.

10. Possible Objections

Of course, there are possible objections to such a plan, however. Some of those are without merit, but others need to be more carefully considered. We begin with the less meritorious ones.

10.1. Forced Sales

Throughout the history of the Water Economics Project, some have raised the objection that "You are going to force us to sell our water." or "Why should we give water to our neighbors?" [38] This is simply a misunderstanding of what is being proposed.

In the first place, with a finite number of countries involved and no outside trades, it is literally impossible for all of them to be net sellers. But put that aside. The more important point is that WAS/MYWAS-guided permit sales are *never* "forced". The selling country sells only when it is to its advantage to do so. Both parties gain.

10.2. "The Richest Country Will Buy all the Water"

A related objection is that the richest country will end up buying all the water or that the disparity in the economies involved makes water-permit trading either somehow impossible or, at least, unfair.

The primary reason that this is not valid is as before. The poorer countries only sell when it benefits them. If they do that, then they gain from the sale. Naturally, as they sell more and more water, the remaining water becomes more valuable to them, and, sooner or later, they will stop selling.

The other reason is the mirror image of this. The rich country may have a lot of money, but why should it want to buy all the water in sight. Water is valuable when it is scarce and needed for essential uses (drinking, for example). But it becomes less valuable as its scarcity decreases and additional water is used for less important uses (washing cars several times a week, for example). Just as the price at which poor countries gain from sales goes higher and higher the more is sold, so the price at which the rich country gains from purchases goes lower and lower the more that is bought. Once these two prices pass each other, nothing further is to be gained from the transactions and the sales stop.

38. Indeed, that objection has repeatedly been publicly voiced by an Israeli water expert who should certainly know better.

We now examine two of the more interesting issues.

10.3. What Happens to Claims of Ownership Rights?

Agreeing to WAS/MYWAS cooperation would not prevent the parties from asserting their claims as to water ownership rights. Indeed, not only would such cooperation benefit both parties once water rights are agreed upon, *but such benefits need not wait for such an agreement.* The parties could establish a neutral or jointly managed escrow fund into which they would each pay (at WAS/MYWAS shadow values) when using the disputed water sources. The resolution of the ownership question would then become a matter of resolving the ownership of the escrow fund.

In this connection, we recognize that, although, as we have seen, the economic value of ownership rights is not high – especially under cooperation – the symbolic value may be very large indeed. (This is particularly clear to us in the case of the Palestinians, but is not restricted to them.) But our methods permit such rights to be asserted but not to be a bar to mutually beneficial cooperation.

10.4. Security Considerations: Hostages to Fortune

The major objection to trade in water permits among previously hostile neighbors 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 cooperative trade? What if the water were to be cut off?

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

A system of trade in water permits, however, makes this less likely to happen, because it is a system in which continued cooperation is in the interest of all parties. When joint infrastructure has been constructed and gains from water-permit trade are large, withdrawal from the trade scheme will hurt the withdrawing party. Nevertheless, parties (particularly in the Middle East) do not always act in their own best interest.

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

Are such cases likely in the Israel-Palestine case for either bilateral or trilateral cooperation? [39] We begin with the case of Israel. If there were to be an agreement with Palestine along the lines we have suggested, it would make sense for Israel to invest in trade-facilitating infrastructure. Were trade to cease, that investment would largely be lost. This does not seem a major problem, however.

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

Palestine, 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, Palestine would soon be forced to build desalination plants in Gaza. In the presence of trade, such plants would be unnecessary for a long time to come. Hence, if an Israel-Palestine agreement takes the form of water-permit trade and cooperation, the Palestinians will have to consider whether they should build such desalination plants in any case. If they do, they will lose a good deal of the economic benefits from trade. If they do not, then there may be a problem should trade cease.

What that choice should be depends on how likely it is that Israel would abrogate such an agreement and on the situation that one believes would then arise. For example, in such an event, presumably the Palestinians would feel justified in extensively pumping the Mountain Aquifer, even if that were not the regionally efficient or agreed-on thing to do. Surprisingly, however, we have found, as discussed above, that, in the absence of cooperation, the Palestinian need for desalination would stem not directly from the need to use desalinated water in Gaza itself but from the need to (inefficiently) supply the Southern West Bank from the Gazan desalination plants by piping it uphill to the area of Hebron. Hence, the apparent crisis caused by an Israeli abrogation of a cooperative water treaty could be overcome by Palestinian pumping of Mountain Aquifer water beyond the amounts permitted by the water treaty, doing so until the needed desalination facilities can be built. [40]

39. It does not seem likely that Jordan would have a major problem.

40. Alternatively, the Palestinians might seek alternative sources of supply from Egypt or others – sources that might be efficient even in the presence of trade.

11. Where Can These Tools Be Used?

Although WAS and MYWAS were developed in connection with the Middle East, *their use and usefulness are not restricted to that region.* Indeed, every country in the world could benefit from the application of the tools to the economically efficient management of its own water system, especially the planning of infrastructure projects in the presence of broader social values regarding water.

At least as important as this is the use of WAS/MYWAS to resolve water conflicts. That use also is not restricted to the Middle East; it applies to all cross-border and cross-sector water disputes. Water can and should be removed, globally, as a possible *casus belli* or even as a a cause of intense inter-regional or inter-sectoral tension, such as that found in the western United States among environmental, agricultural, and urban uses of water..

In the Middle East itself, Jordan, Palestine, and probably Lebanon are committed to the use of the tools. (Palestine, in particular, is far along in applying the MYWAS model.) At present, Israel is not. There is a serious prospect that Syria and Saudi Arabia can be interested. Not only would all the participants gain simply from the purely domestic use of the tools, but also regional cooperation could come into play. There would then be a prospect of involving Israel once more in connection with the Arab Peace Initiative.

The problems for peace in the Middle East are many. *Water should not be among them; rather, it should be a source of beneficial cooperation.*

The same lessons apply globally. Where there is regional cooperation and economically efficient management, the problems of water shortages can be greatly alleviated.

Properly sponsored and understood, there is a great opportunity here, both in the Middle East and around the world.

12. A Closing Quotation

We close with a biblical quotation which contains a very old example of trading water for other things in the interests of peace.

"'And it came to pass at that time, that Abimelech and Phicol the captain of his host spoke unto Abraham, saying: God is with thee in all that thou doest. Now therefore swear unto me here by God that thou wilt not deal falsely with me, nor with my son, nor with my son's son; but according to the kindness that I have done unto thee, thou shalt do unto me and to the land wherein thou hast sojourned.' And Abraham said: 'I will swear.'

And Abraham reproved Abimelech because of the well of water which Abimelech's servants had violently taken away. And Abimelech said: 'I know not who hath done this thing; neither didst thou tell me, neither yet heard I of it but today.' And Abraham took sheep and oxen and gave them to Abimelech; and they two made a covenant. And Abraham set seven ewe-lambs of the flock by themselves. And Abimelech said unto Abraham: 'What mean these seven ewe-lambs which thou hast set by themselves?' And he said: 'Verily, these seven ewe-lambs shalt thou take out of my hand, that it may be a witness unto me that I have digged this well.' Wherefore that place was called Beer-Sheba [Well of the Seven], because there they swore both of them. ... And Abraham sojourned in the land of the Philistines many days." *Genesis* 21: 22-34

Of course, Abraham and Abimelech did not know of computers, constrained optimization, or shadow values. But we like to think that they would approve of what we are trying to do.

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