THE ECONOMICS OF WATER AND THE RESOLUTION OF WATER DISPUTES

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1. Introduction: Actual and Simulated Water Markets

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

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

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

The late Gideon Fishelson of Tel Aviv University once remarked that "Water is a scarce resource. Scarce resources have value." He went on to point out that the availability of desalination of sea water must put an upper bound on the value of water in dispute to any country that has a sea coast.

Those remarks were a principal impetus to the creation of the Harvard Middle East Water Project. That Project is a joint endeavor of Israeli, Jordanian, Palestinian, and North American scholars. It has been heavily at work since October, 1993. In the present paper, I discuss the methods that it has developed. Because the Project is still under way, however, and because of the sensitive nature of the subject, the examples that I shall give are illustrative only. While I do not consider those examples to be unrealistic, they refer to imaginary countries and imaginary data.

The fact that (save in landlocked countries) desalination puts an upper bound to the value of water in dispute is dramatic and easily understood. That fact, however, is not as important as the general way of thinking suggested by Fishelson's remarks. The really important insight is that it is possible to think about water and water disputes by analyzing water *values* and not just water quantities. This means thinking about the economics of water.

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

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

1. The proposition that free markets lead to an efficient allocation assumes that markets are competitive, that is, that they include a large number of independent small sellers and a similarly large number of independent small buyers. This is not

typically true of water, at least in arid or semi-arid countries, where water sources are relatively few and are likely to be owned by the state.

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

3. Similarly, if a free market is to lead to a desirable allocation, social benefits must coincide with private ones. If not, then (as in the case of cost externalities) the pursuit of private ends will not lead to socially optimal results. In the case of water, many countries reveal by their policies that they regard water for certain uses (often agriculture) as having a public value that exceeds its private one.

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

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

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

2. Net Benefits from Water -- Private and Social

In order to understand what is meant by an "optimizing model", some description of the underlying economic theory is required.

Figure 1 shows an individual household's demand curve for water, the amounts of water (on the horizontal axis) that the household will buy at various prices (on the vertical axis). The curve slopes down, representing the fact that the first few units of water are very valuable, while later units will be used for purposes less essential than drinking and cooking.

Now consider how much it will be worth to the household in question to have a quantity of water, Q*, as pictured in the diagram. Begin by asking how much the household would be willing to pay for the first small unit of water. The price that would be paid is given by a point on the curve above the interval on the horizontal axis from 0 to 1. (Exactly where does not matter). So the amount that would be paid is (approximately) the area of the leftmost vertical strip in Figure 1 (one unit of water times the price in question). Similarly, the amount that would be paid for a second unit can be approximated by the area of the second-to-left vertical strip, and so on until we reach Q*. It is easy to see that, if we make the size of the units of water smaller and smaller, and the total amount that the household would be willing to pay to get Q* approaches the area under the demand curve to the left of Q*.[1]

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

In Figure 2, the line labeled "marginal cost" shows the cost

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

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

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

As the following example shows, this apparatus can accommodate the fact that the social value of water can exceed its private value. Consider a national policy to subsidize water for agriculture by 10 cents per cubic meter at all quantities -- an unrealistic but simple case. This is a statement that water to agriculture is worth 10 cents per cubic meter more to society than farmers are willing to pay for it. This is represented in Figure

3. The lower demand curve represents the private value of water to agriculture; the upper demand curve also includes the additional public value as reflected in the policy, an additional value of 10 cents per cubic meter. As this illustrates, any consistent water policy can be represented as a change in the demand curve for water. Once such a policy has been included in the demand curves, the methods used above can be used to measure net benefits.

3. Shadow Prices and Scarcity Rents

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

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

As explained above, the Harvard model allocates water so as to maximize the net benefit obtained from it. This maximization of net benefits is done subject to constraints. For example, at each location, the amount of water consumed cannot exceed the amount produced there plus net imports into that location.

It is a general (and important) theorem that when maximization involves one or more constraints, there is a system of prices involved in the solution. These prices, called "shadow prices"[2] are associated with the constraints. Each shadow price shows the rate at which the quantity being maximized (here, net benefits from water) would increase if the associated constraint were relaxed by one unit. In effect, the shadow price is the amount the maximizer should be just willing to pay (in terms of the quantity being maximized) to obtain a unit relaxation of the associated constraint.

In the case of the Harvard model, the shadow price 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 price 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 prices in the model, however, are those of water itself. The shadow price of water at a given location is

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[2] Also "LaGrange multipliers".

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

It is important to note that the shadow price 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 price of that water will not be zero; benefits to water users would be increased if the capacity of the source were greater. Equivalently, buyers will be willing to pay a non-zero price for water in short supply, even though its direct costs are zero.

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

Where direct costs are zero, the shadow price of the resource involved consists entirely of scarcity rent. More generally, the scarcity rent of water at a particular location equals the shadow price at that location less the direct marginal cost of providing the water there.[3] 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 prices 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 Harvard 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.):

1. The shadow price of water used in any location equals the direct marginal cost plus the scarcity rent.

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

3. If water can be transported from location *a* to location *b*, then the shadow price of water at *b* can never exceed the shadow

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

price at *a* by more than the cost of such transportation. Water will actually be transported from *a* to *b* only if the shadow price at *b* exactly equals the shadow price at *a* plus the transportation cost. Equivalently, if water is transported from *a* to *b*, then the scarcity rent of that water will be the same in the both locations.

This situation is illustrated in Figure 4, where water in a lake (*L*) is conveyed to locations *a*, *b*, and *c*. It is assumed that the only direct costs are conveyance costs. The marginal conveyance cost from the lake to *a* is denoted t_{La}; similarly, the marginal conveyance cost from *a* to *b* is denoted t_{ab}; and that from *b* to *c* is denoted t_{bc}. The shadow prices at the four locations are denoted P_L, P_a, P_b, and P_c, respectively. Examination of the diagram shows that each location connected to the lake has a shadow price consisting of the shadow price at the lake, P_L (the scarcity rent) plus the total marginal cost of conveyance from the lake to the given location.

4. At each location, the shadow price 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.

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 buyers value additional water, less the direct costs involved in getting it to them.

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

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

4. Description of the Harvard Model as a Management Tool

To implement these principles requires constructing a model of water supply, water demands, costs, and infrastructure. A brief description of such a model follows.[4]

The area to be studied is divided into a number of districts. Within each district, demand curves for water are defined for each of household use, industrial use, and agricultural use.[5] The

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

[5] In fact, the Harvard Project involves a very sophisticated

annual renewable amount of water from each source is taken into account[6] as is the pumping cost thereof. Allowance is made for recycling of waste water,[7] and the possibility of inter-district conveyance is taken into account. This procedure is followed using actual data for a recent year and projections for future years.

Environmental issues are handled partly by restricting water usage to annual renewable amounts and partly through the imposition of an effluent charge on households and industry.

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

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treatment of agriculture in which cropping patterns are allowed to respond optimally to water prices and available quantities. For simplicity, however, I describe and exemplify the modeling involved using a version of the model as it existed in 1996.

[6] The Harvard model now being developed treats seasonal variations.

[7] In the Harvard model as now being developed, several types of water qualities are involved.

Finally, the user specifies the national policies towards water that he or she wishes. As explained above, this is where the national value of water that is not merely private value is expressed.

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

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

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

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

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

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

Alternatively, the model can be run as a regional one, with cooperation in water among the parties assumed.[8] In this way, the benefits and costs of cooperation in water can be assessed; I shall discuss this in detail below. First, however, let me make this discussion a bit more concrete by means of a model constructed for a hypothetical future situation.

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[8] One can also analyze the effects of cooperation between two or more parties with others left out.

5. Examples from a Hypothetical Model

The example that I have constructed concerns the mythical region of Oz. A map is given in Figure 5. Oz has three principal countries, Winkie, Munchkin, and Quadling. Winkie is more developed than the other two countries and has a considerably higher per capita income. Correspondingly, its per capita water consumption is also considerably higher than that of the other two, although this may also have to do with its use of disputed water.

In addition to undisputed water, there are two water sources over which conflicting claims have been asserted: one river, the Rubicon with an annual renewable amount of roughly 810 million cubic meters (MCM), and one aquifer, the "Shared Aquifer" with an annual renewable amount of roughly 430 MCM. Each of the three parties has some claim to the river water, but only Winkie and Quadling claim the water of the Shared Aquifer. The two disputed or partially disputed water sources account for about 60% of Oz water consumption of 2 billion cubic meters per year.[9]

There are some other points that must be noted. First, Winkie has an extensive seacoast and Quadling a small one, while

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[9] For simplicity, I assume that there are understandings with any non-Oz upstream or downstream riparians so that the total river water available to Oz is fixed.

Munchkin is landlocked. Second, except for the Winkie cities in the coastal plain (not shown in Figure 5) and Quadling City, all principal cities are high on hills overlooking the Rubicon. Third, some years ago Winkie built an extensive pipeline system to convey Rubicon water from the North to the cities of the Coastal Plain; that system currently takes most of the water of the upper Rubicon. Because of the topography and the fact that relations between Winkie and Quadling were strained, the Winkie system also supplies Winkie City through a quite circuitous route.

Conveyance facilities in Munchkin and, especially, Quadling are much less extensive. In particular, while there is a pipeline to carry water from the lower Rubicon to Munchkin City, it is fairly small. River water in Munchkin is principally used for agriculture in the fertile Rubicon valley. Quadling currently uses essentially no river water.

Figure 6 shows the main menu that an Ozite user sees. The user can choose to run either a model that optimizes for all of Oz or one that optimizes for a particular country with that country using only a specified amount of water.

I begin with the following example. Suppose that the model is run by a Munchkin user for a particular future year, say 2010. If that user wishes to have an exclusively Munchkin result, then, in addition to specifying policies, infrastructure, and so forth, the user must also specify how much of the disputed river water he or she assumes that Munchkin will have.

In the run that I shall use as an example, the user specifies that Munchkin has 250 MCM per year from the Rubicon. The user also assumes that, although the run is for 2010 with demand conditions projected for that year, the only infrastructure in place will be that of the base year.

The results in terms of shadow prices for water are shown as the upper (dark blue) prices in Figure 7. The feature that immediately attracts the eye is the great disparity in prices between District M1 (the Rubicon Valley) on the one hand and Munchkin City and District M2 on the other. Water in the valley of the Rubicon is predicted to be worth far less than on the hilltops. In particular, water in the Rubicon Valley (District M1) will be worth only $.13 per cubic meter, whereas water in Munchkin City will be worth more than $19 per cubic meter.

It is important to note that this should not be taken as a prediction that consumers in Munchkin City will pay such a high price for water in 2010. Rather it is an indication that, with the assumed infrastructure, there will be a major water crisis. In effect, such high prices signal an infeasible result.

Now, how can this be? The answer is easy to find. Such a great disparity in shadow prices strongly suggests that it would be desirable to improve the conveyance system that brings water from the low-price district to the high one. After all, with an appropriate conveyance structure in place, the difference in prices cannot exceed the cost of conveyance.

So it is in this case. As already mentioned, the base-year pipeline for taking water from the Rubicon Valley to Munchkin City is assumed to be of very limited capacity. The situation for 2010 depicted in Figure 7 is one in which that capacity is entirely full. The difference in value between the two districts reflects the shadow price of pipeline capacity and not merely the conveyance cost involved.

This can be seen very clearly by examining the lower (red) prices in Figure 7. These show the results of another run done with all the same conditions save that a very large capacity pipeline is assumed to connect District M1 and Munchkin City.[10] One sees immediately that the great disparity in prices has disappeared (as has the crisis in Munchkin City). The price in that city has now fallen to $.974 per cubic meter; the price in the Rubicon Valley has risen to $.745 per cubic meter reflecting the fact that there is now a feasible way to transport the water from that location to Munchkin City. The remaining price difference of $.229 per cubic meter simply reflects the operating costs of the conveyance system.

This example readily demonstrates one of the ways in which a model of the type described can be used for cost-benefit analyses, and there are others as well. For example, it would be possible to take the runs performed and calculate the increase in Munchkin benefits that results from the construction of the expanded pipeline. The present value of such increases can then be

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[10] No pipeline has been assumed to bring water to M2, however.

compared with the capital cost of the expansion to decide on whether such a project would really be worthwhile. (Under the assumed conditions it definitely would be.)

But the usefulness of this approach for internal decision making is not the only thing that is being exemplified here. Note that, in the original run (Figure 7), the value to Munchkin of water in the Rubicon Valley is only $.13 per cubic meter. Thus, despite the predicted crisis in Munchkin City (and District M2), it does Munchkin little good to obtain further Rubicon water. Even when the conveyance system is expanded (Figure 8), the value of water in the Rubicon only becomes $.745 per cubic meter. This is high enough to matter, but is nothing like the crisis value in Munchkin City of $19.658 per cubic meter. Munchkin's problems lie in its infrastructure and not primarily in an overall water shortage.

That is not to say that Munchkin would not benefit from additional water. For it to obtain such benefits will require negotiations with its neighbors. As we shall now see, there are considerable advantages to conducting such negotiations in the light of the model results as to water values.

5. Water Ownership and the Value of Water

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

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

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

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[11] If water and money are equally valued, then the entity will be indifferent between selling and using the amount of water in question. A similar statement applies to the description of the actions of a non-owning buyer later in the paragraph.

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

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

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

So far as water is concerned, every country with a seacoast can be self-sufficient in its food supply if it chooses to spend the money to do so. As a result, disputes over water among such countries are merely disputes over costs, not over life and death.

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

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

How valuable, then, are the water resources claimed by the countries of Oz? We have already seen that the value of Rubicon water to Munchkin is limited. This remains true even when an expanded conveyance system is built and even when Munchkin agriculture is subsidized. Now consider bilateral negotiations between Munchkin and Winkie over Rubicon water. (For purposes of this example, I ignore Quadling's claims.) Consider a proposed allocation of ownership rights between the two countries. Given that allocation, perform (separate) "countrified" runs for Winkie and for Munchkin and calculate the present discounted value of Rubicon water to each of them. Ignoring uncertainties, there are three possibilities: a. the value of Rubicon water to Winkie is less than it is to Munchkin; b. the value of Rubicon water to Winkie is greater than its value to Munchkin; c. the value of Rubicon water is the same to both countries.

Consider first the possibility that, at the proposed allocation, the value of Rubicon water to Winkie is less than it is to Munchkin. In such a case, *both* countries would benefit from an agreement in which the proposed allocation were altered to transfer water to Winkie with Munchkin receiving monetary (or other) compensation in exchange. In the reverse case, a similar statement is true.

In the case in which the values are the same (or nearly so), the direction of the result suggested by the model will not be clear. But (as in all the cases), the fact that water values have been calculated should assist negotiations. The parties will be negotiating over money and money can be readily measured.

Indeed, the principal point of this section is not that the model can be used to help decide how allocations of property rights should be made. Rather the principal point is that water can be traded off for non-water concessions. The model provides a way of measuring such trade-offs.

Moreover, such trade-offs are not large, even in real-life examples. Recall that desalination puts an upper bound on the value of water in dispute. Moreover, because naturally occurring sweet water must be pumped, treated, and transported, the upper bound on the value of a cubic meter of such water *in situ* will be considerably less than the cost of desalination per cubic meter. At the limit (in this example), 100 MCM of Rubicon water cannot be worth more than (very roughly) $100 million per year. Moreover, as can be seen from examining the results of scenarios with cooperation in water (Figure 10 below), the value is likely to be far less even than this. Such sums are small relative to most Gross Domestic Products. They are certainly small relative to the cost of modern military equipment. By monetizing water conflicts, they can cease to seem insoluble.

6. The Gains from Trade in Water Permits

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

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

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

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

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

To illustrate the gains involved, I again consider the hypothetical example of the countries of Oz. This time, however, I explore the possible arrangements between Winkie and Quadling.

Suppose, for simplicity, that an arrangement is reached between Winkie and Quadling according to which Quadling gives up its claims to all disputed water except that of the Shared Aquifer. I begin by analyzing in detail a case in which Quadling receives a relatively small share of the Shared Aquifer water and later consider cases in which its share is relatively large.

To begin with a small Quadling share, assume that it is agreed that Quadling receives twenty percent of the disputed aquifer water. Winkie, whose water consumption in the base year was far larger than Quadlings, gets the remaining eighty per cent. In addition, Winkie retains ownership rights to 560 MCMs per year of Rubicon water (the remaining amounts going to Munchkin).

Now, it may be that, for a time, these allocations are fairly reasonable. But suppose that Quadling experiences a major growth in population by some future year, say 2010. Suppose that such growth takes place in two areas: one of these is in the hills above the Shared Aquifer, and the other is in Quadling City, where it is possible to desalinate seawater at a cost of $1.00 per cubic meter. Then, if there exists no method to rearrange water usage allocations, there may be a serious situation in Quadling, and this may put a strain on any peace agreement in Oz.

To analyze this, I have performed two runs of the model under the assumed conditions. The first of these runs assumes that the fixed quantity agreement described remains in place with no change. The other assumes the same distribution of water *ownership* but permits Winkie and Quadling to trade in water permits at model prices.[13] Moreover, to concentrate on the gains from trade as purely as possible, I assume that only one piece of trade-facilitating infrastructure is built, namely, a short, large-diameter pipeline from the Winkie conveyance system to carry sold Rubicon water to Quadling City.

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[13] Munchkin is excluded for simplicity.

The model is then used to estimate the resulting increase in net benefits and the distribution of those benefits between the two parties involved. The results are given in Table 1 and pictured in the upper left-hand portion of Figure 8.

Table 1

Gains from Winkie-Quadling Trade in Water Permits in 2010: Eighty Percent Winkie Ownership of Shared Aquifer (Millions of 1990 Dollars Per Year)

Quadling:	72
Winkie:	13
TOTAL:	85

These gains are quite substantial, about $85 million per year. Not surprisingly, Quadling would receive the largest benefit ($72 million per year), partly through its ability to purchase water for Quadling City at prices substantially below the assumed seawater-desalination cost of $1.00 per cubic meter, and partly through increased consumption. It is not hard to expand the details of this example to show that trade in water permits can generate a major improvement in Quadling per-capita water consumption allowing it to approach that of Winkie.

Note, however, that Winkie also benefits, even though its consumers would have to make do with slightly less water than in the case of no trade. The net gain to Winkie would be about $13 million per year *over and above* the amount needed to compensate its consumers for the relinquished water.

Note that, in this example, it is relatively rich Winkie that is the seller and relatively poor Quadling that is the buyer, contrary to the often expressed belief that a system of water trade would result in relatively rich countries buying from relatively poor ones. This reflects the fact that not all uses of water are equally valued. The fact that rich consumers could afford to pay high prices for low-priority water uses does not mean that they will want to do so. In this example, Quadling buys 119 MCM per year from Winkie at a cost of $23 million. (See the right-hand side columns of Figure 9.)

To complete the example, Figure 10 shows the effect of trade on the shadow price of water in the the various districts of Winkie and Quadling. The no-trade prices are the lower (red) ones, and the prices with trade are the upper (blue) ones. Not surprisingly, there is a large price decrease (about $.50 per cubic meter) in Quadling City where the costs of desalination are avoided, but there are even larger decreases (often over $1.00 per cubic meter) in other Quadling locations. By contrast, trade produces only minor increase in water shadow prices in Winkie -- typically only about $.03 per cubic meter. The effect of such increases are easily offset by the profits on sales to Quadling.

Of course, the size of the gains from trade depends on the initial allocation of property rights assumed. Were we to assume more water to be owned by Quadling and correspondingly less by Winkie, Quadling would have less to gain from trade in 2010. Indeed, so would Winkie. On the other hand, a distribution far more favorable to Quadling and unfavorable to Winkie would yield gains with Quadling selling and Winkie buying.

These propositions can be illustrated by performing the same experiment with the fraction of Shared Aquifer water owned by Winkie decreased in twenty percent increments until it reaches twenty percent. Table 2 and Figure 8 show the resulting gains from trade received by each of the two countries

Table 2

Gains from Winkie-Quadling Trade in Water Permits in 2010:
Varying Ownership of Shared Aquifer

Winkie Ownership	Quadling Gains	Winkie Gains
(Percent)	(Millions of 1990 Dollars Per Year)	
80	72	13
60	44	9
40	58	8
20	72	12

The total gains from trade are always at least $53 million per year, and they are almost the same at the two extreme allocations of ownership. That symmetry is somewhat misleading, however, because as shown in Figure 9, while with Winkie ownership of the Shared Aquifer at eighty or sixty percent, there are net sales of water from Winkie to Quadling, that reverses when Winkie ownership is forty or twenty percent. In the latter cases, Quadling sells more water than it buys. It gains from trade in part because of its continued purchases of Rubicon water for Quadling City (about 80 MCM per year) and in part from the profits it makes on the sale of Shared Aquifer water to Winkie. That sale raises (relatively low) no-trade prices in Quadling (except for Quadling City[14]) by about $.08 per cubic meter and lowers them in Winkie by about the same amount. (See Figure 11.)

Table 3

Water and Money Transfers in Winkie-Quadling Trade in Water Permits in 2010: Varying Ownership of Shared Aquifer

Winkie Ownership Percentage	Water Sold to Quadling (MCM per year)	Money Received by Winkie (Millions of 1990 Dollars)
80	119	23
60	31	8
40	-57	-8
20	-145	-24

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[14] Of course, in the no-trade scenario with eighty percent Quadling ownership of the Shared Aquifer, Quadling might well find it efficient to build a pipeline to convey water from the Shared Aquifer to Quadling City. If so, then the gains from trade would be less than given in Table 2. But I have also chosen a trade scenario with essentially no infrastructure constructed to facilitate trade.

The main point should be clear. Given a particular resolution of the property-rights question, an agreement to trade in water permits cannot be worse and will almost always be better than a fixed quantity agreement. Only if the property-rights settlement happened to assign the same amounts of water to the respective parties as the model shows to be optimal would there be no improvement. Even there, such a situation would be ephemeral as populations and economies change.

In fact, the the gains from trade given in Tables 1 and 2 are understated. This is true for two reasons. The first and less important reason is that I assumed desalination costs to be near the low end of the range of current estimates. With a higher desalination cost, the gains for Quadling would be higher, with those for Winkie remaining the same.[15]

More important is the fact that the comparison just given assumed almost no trade-facilitating infrastructure. Further results of our model suggest quite strongly that cooperative ventures in infrastructure would produce additional gains of the same scale as those shown in Table 1, *and the gains from such cooperative projects would also be present in the other cases considered in Table 2; they are independent of the allocation of water ownership.*

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[15] Winkie does not desalinate seawater in any scenario, and the Trade scenario has no such desalination by either party.

The additional infrastructure projects that appear promising would involve the construction of a major pipeline to bring Rubicon water up to the hill district of Quadling, thence to Winkie City and a connection with the Winkie system. (See Figure 5.) In addition, it appears that sewage and recycling facilities in Quadling City with conveyance of treated water to southern Winkie for use in agriculture would benefit both parties. *It should not escape attention that this gives Winkie an interest in assisting Quadling to construct such facilities.*

Indeed, the gains from trade are so large as to dwarf the value of ownership transfer of reasonable amounts of water. Instead of squabbling endlessly about water quantities, Winkie and Quadling would do far better by agreeing to cooperate in the manner described.

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

7. Possible Objections

There are, however, possible doubts or objections to be raised to such a plan. One of these, of course, has to do with the question of whether gains of the sort here exemplified are likely to prove realistic. Here the results for each case will be different and separate analyses must be performed. I can only say here that I have reason to believe that the example here given, while imaginary, does not depart enormously far from the facts of one actual water dispute. (Recall that the availability of seawater desalination puts an upper limit on the value of water property rights.)

I now discuss three objections that may be raised in principle.

A. Deciding on Property Rights: An Interim Escrow Fund

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

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

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

B. Commitment and Uncertainty

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

There is a two-fold answer here. First, while the present model is a single-year one, it may be possible to build a multi-year model. Even in the context of a single-year model, however, repeated runs can yield information as to the value of water in situations of climatic uncertainty.

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

C. Security Considerations: Hostages to Fortune

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

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

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

Consider, for example, the trade-facilitating infrastructure developments described above for Winkie and Quadling. Water would flow from the Rubicon River into Quadling, thence to Winkie City and into the Winkie conveyance system. From the Winkie conveyance system, Rubicon water would flow to Quadling City and then, retreated, back into Winkie for use in agriculture. This is a system in which each party sits upstream of the other and in which the interests of both lie heavily in cooperation rather than conflict.

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 case of Winkie and Quadling in our example? I begin with the case of Winkie. If there were to be an agreement with Quadling along the lines I have suggested, it would make sense for Winkie to invest in trade-facilitating infrastructure. Were trade to cease, that investment would be largely 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 Winkie. Winkie 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.

Quadling, by contrast, has more exposure in the form of hostages to fortune. Without water-permit trade, and with the unfavorable agreement on water property rights studied in Table 1, Quadling would soon be forced to build desalination plants to supply Quadling City. In the presence of trade, such plants would be unnecessary for a long time to come. Hence, if a Winkie-Quadling agreement takes the form of water-permit trade and cooperation, the Quadlings 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 Winkie would abrogate such an agreement and on the situation that one believes would then arise. For example, in such an event, presumably the Quadlings would feel justified in extensively pumping the Shared Aquifer, even if that were not the regionally efficient or agreed-on thing to do. They might then consider supplying Quadling City with Shared-Aquifer water, while desalination facilities were being constructed. If so, then it might be wise to put the pipeline in place even in the presence of a water-permit-trade agreement, provided that the post-agreement situation was not expected to be so serious that Winkie would attempt to cut such a pipeline. Alternatively, the PNA might seek alternative sources of supply from Munchkin or its non-Oz neighbors -- sources that might be efficient even in the presence of trade.

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

8. Concluding Remarks

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

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

There is another implication of this approach that is of at

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

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

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

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Eckstein, Z., D. Zackay, Y. Nachtom, and G. Fishelson (1994). "The Allocation of Water Resources between Israel, the West Bank and Gaza: An Economic Analysis", *Economic Quarterly*, Vol. 41, 331-69 (Hebrew).

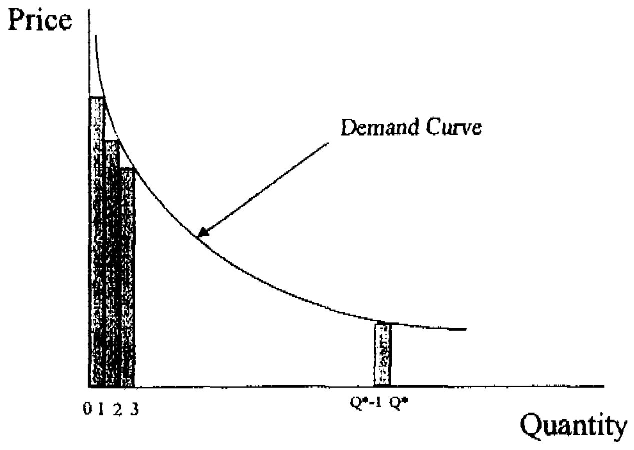


Figure 1: Gross Benefits from Water

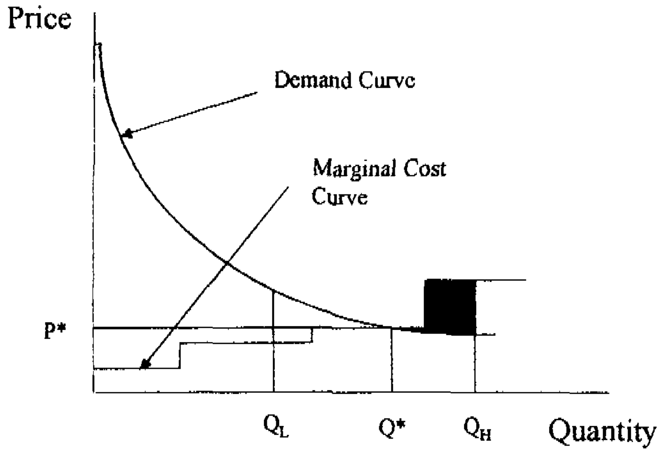


Figure 2: Net Benefits from Water

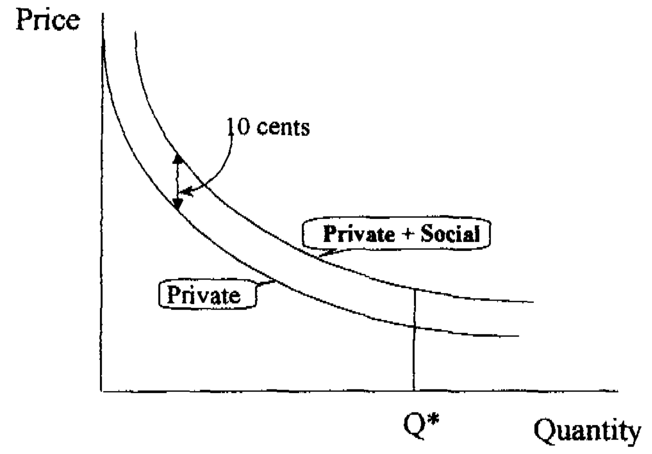


Figure 3: Social Value of Water as Expressed by a Subsidy

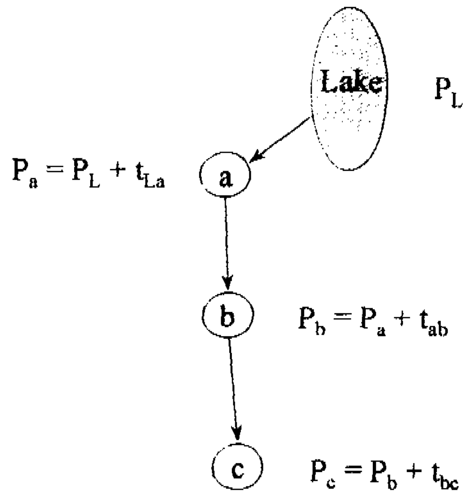


Figure 4: Efficient Water Allocation and Shadow Prices

Figure 5: Map of Oz

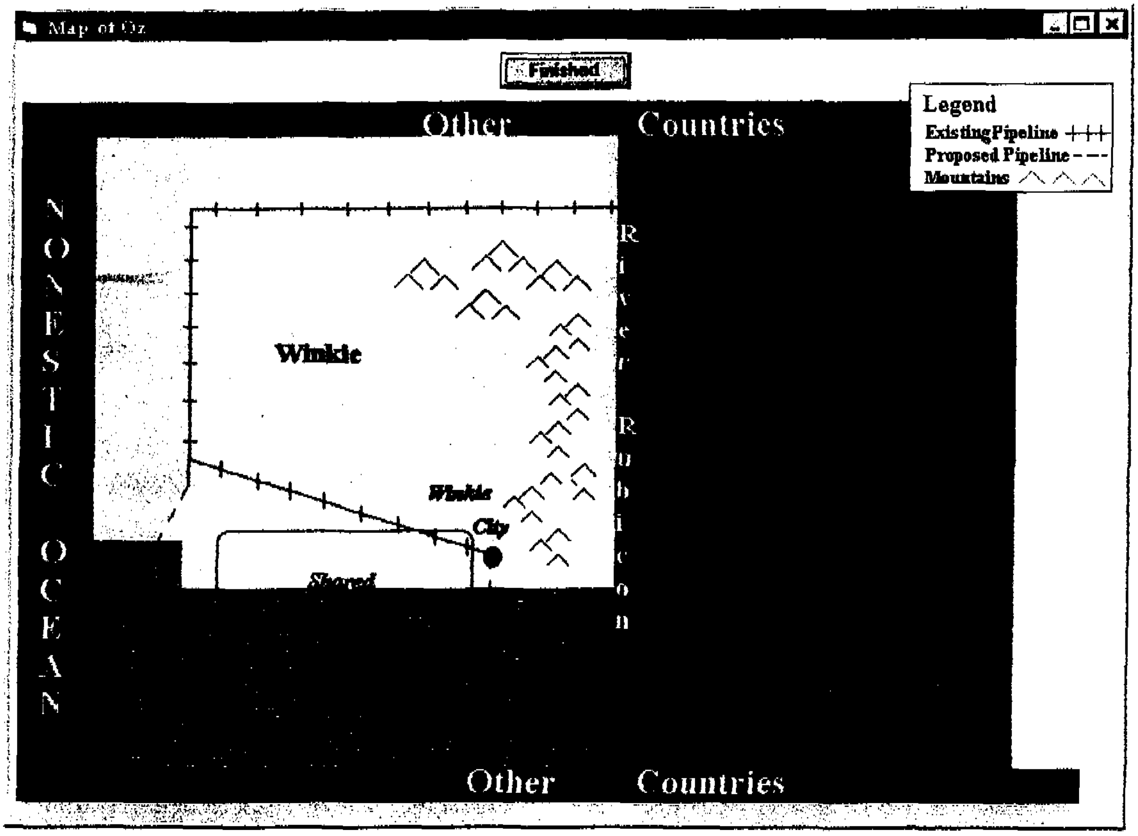
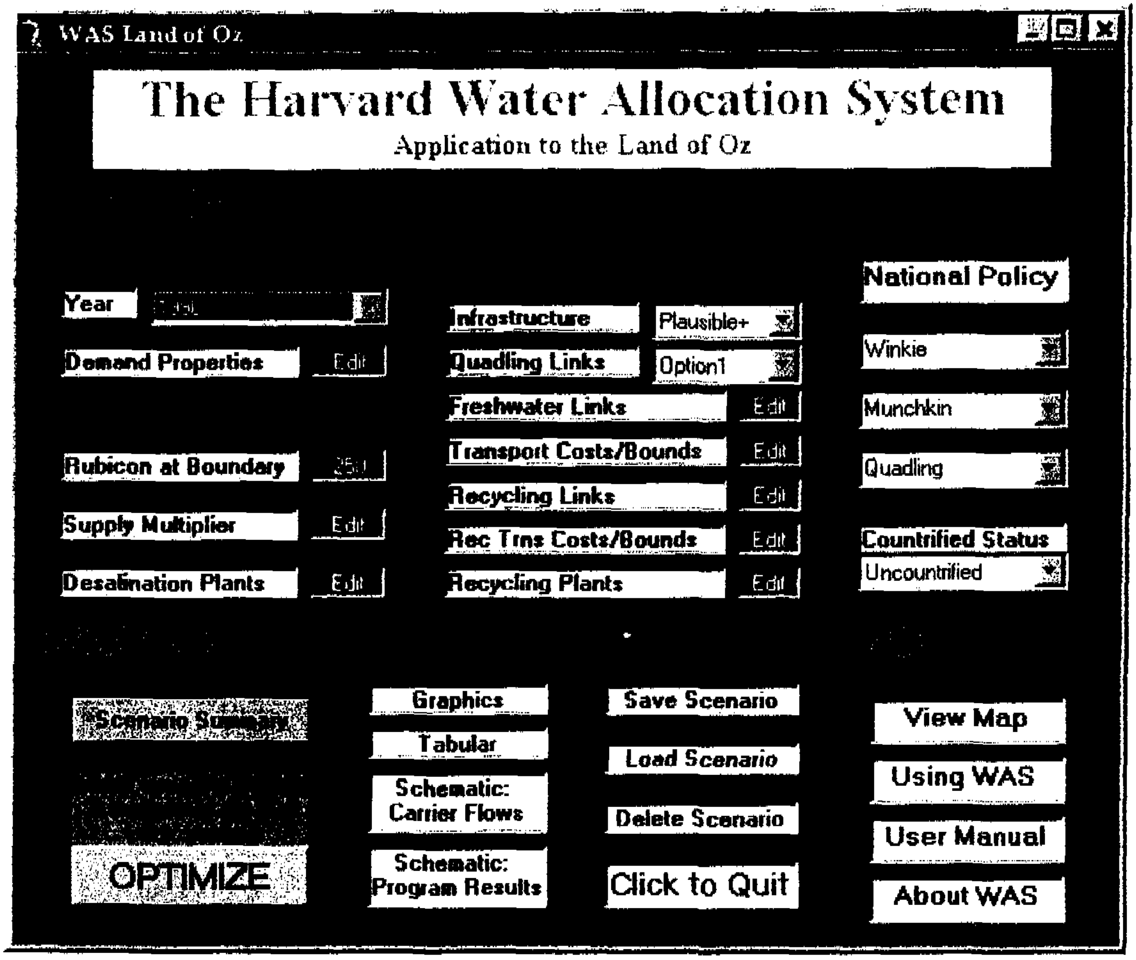


Figure 6: Main Menu



Year [illegible]

Rubicon at Boundary 250

Infrastructure Plausible+

Quadling Links Option1

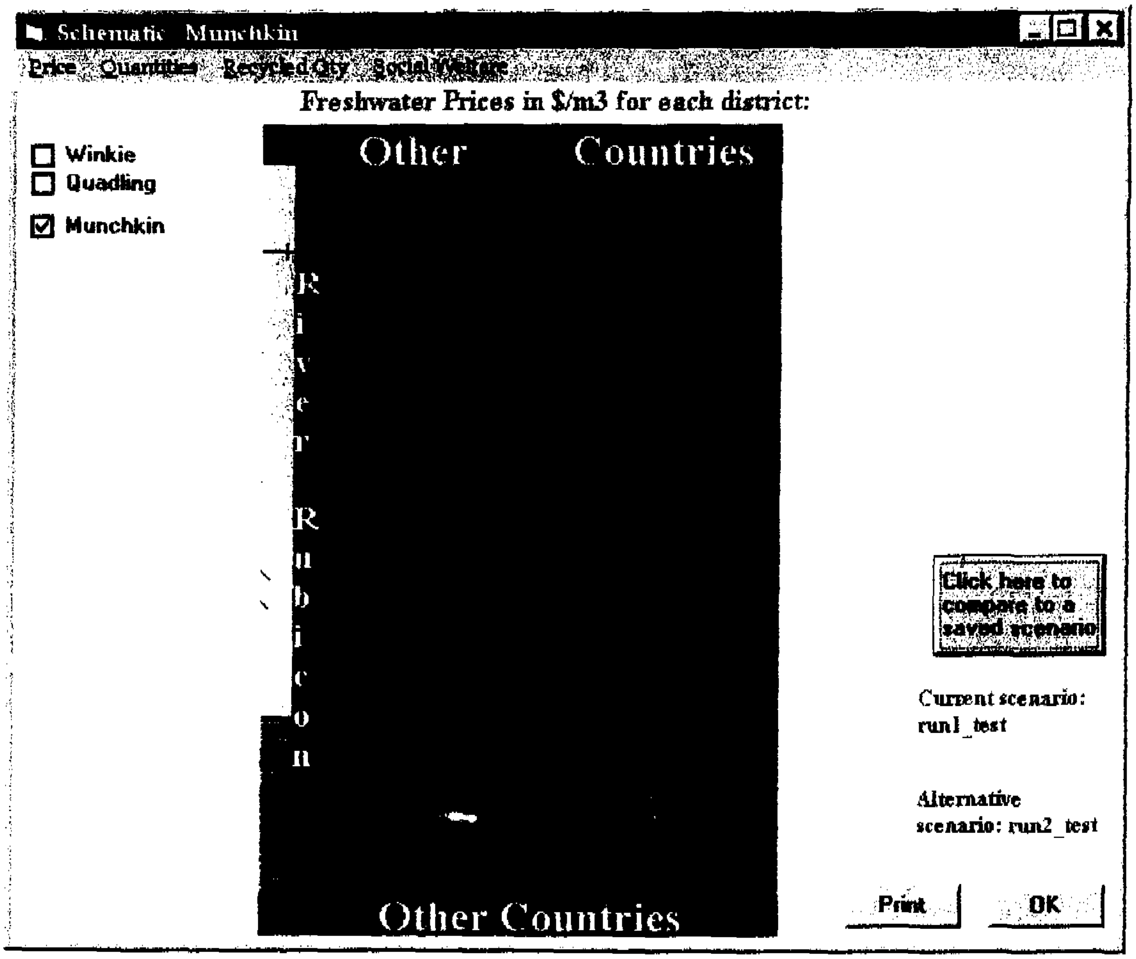
Winkie

Munchkin

Quadling

Countrified Status Uncountrified

Figure 7: Changes in Shadow Prices in Munchkin



Freshwater Prices in $/m3 for each district:

☐ Winkie
☐ Quadling
☑ Munchkin

Current scenario: run1_test

Alternative scenario: run2_test

Figure 8: Change in Social Welfare With And Without Trade with Different Ownership of the Shared Aquifer

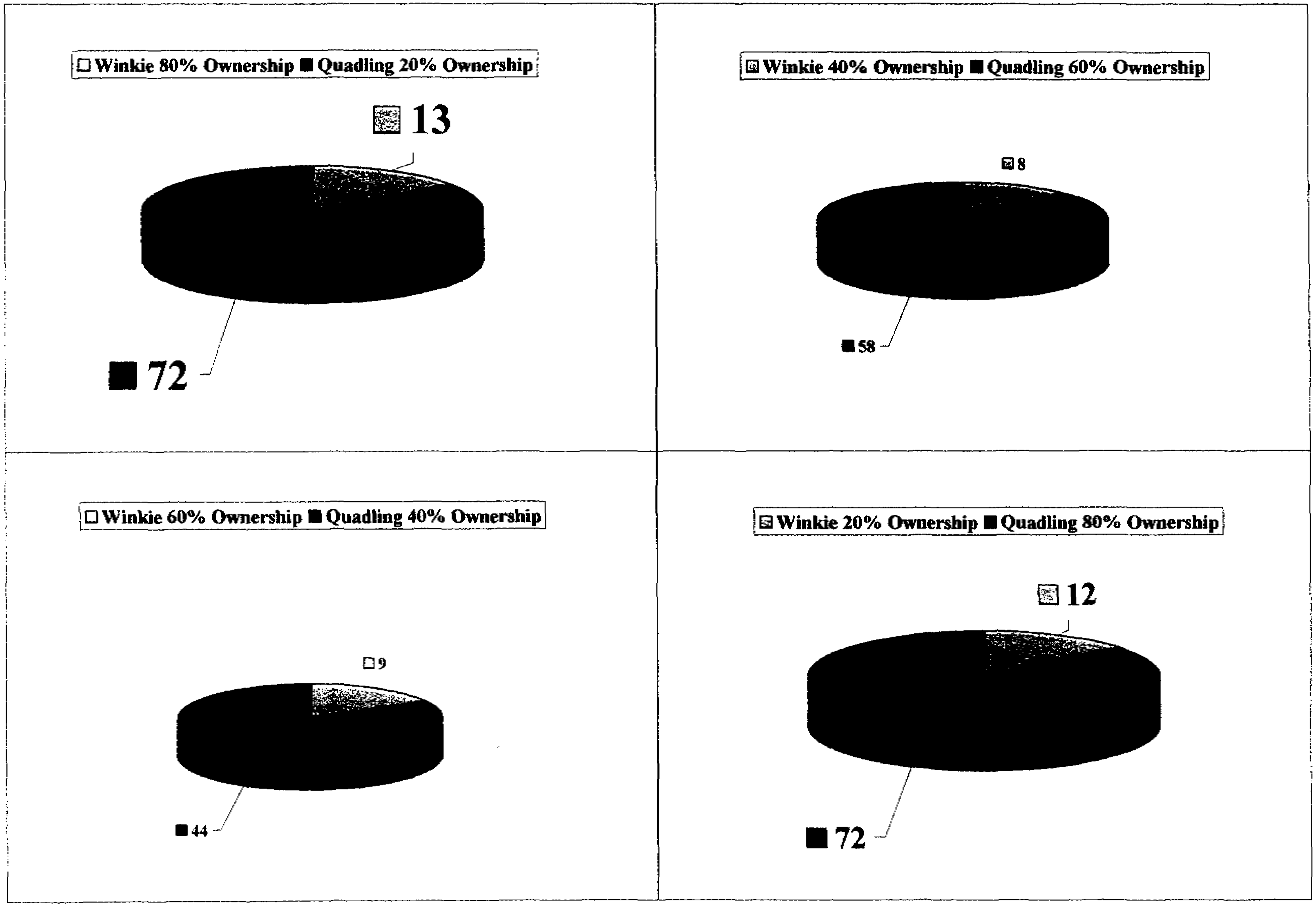


Figure 9: Transfers of Water and Dollars in Trade Scenarios

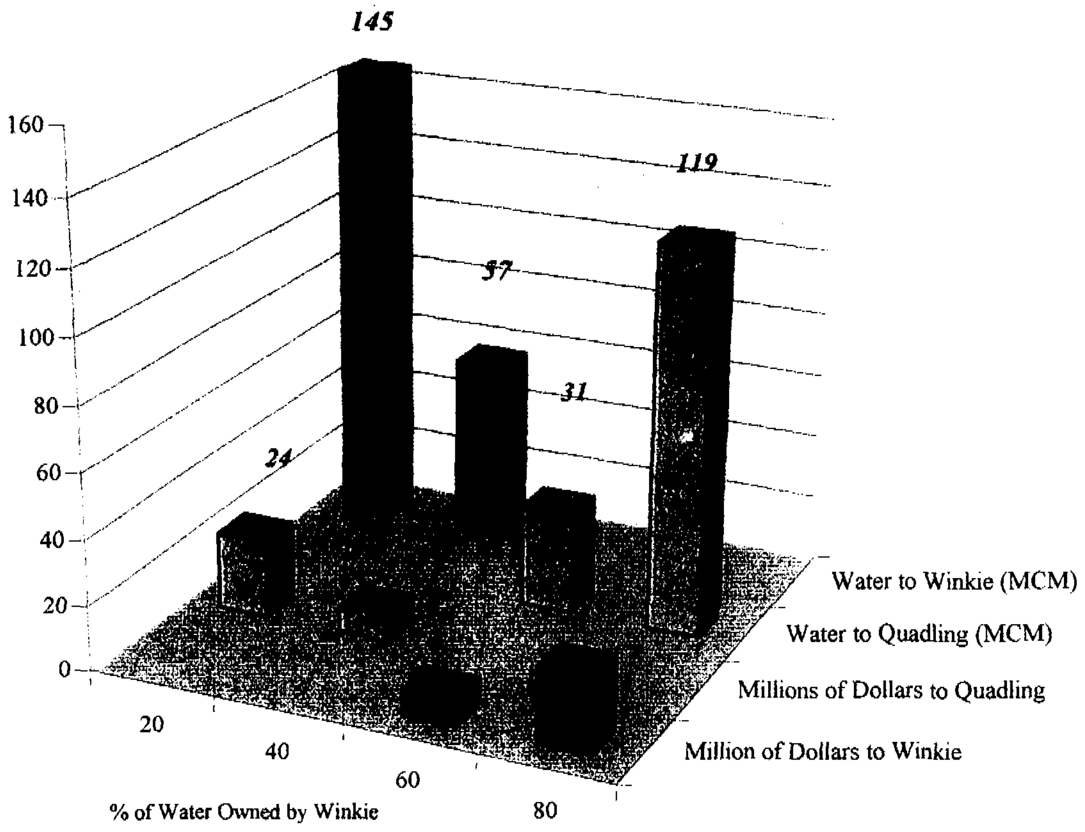
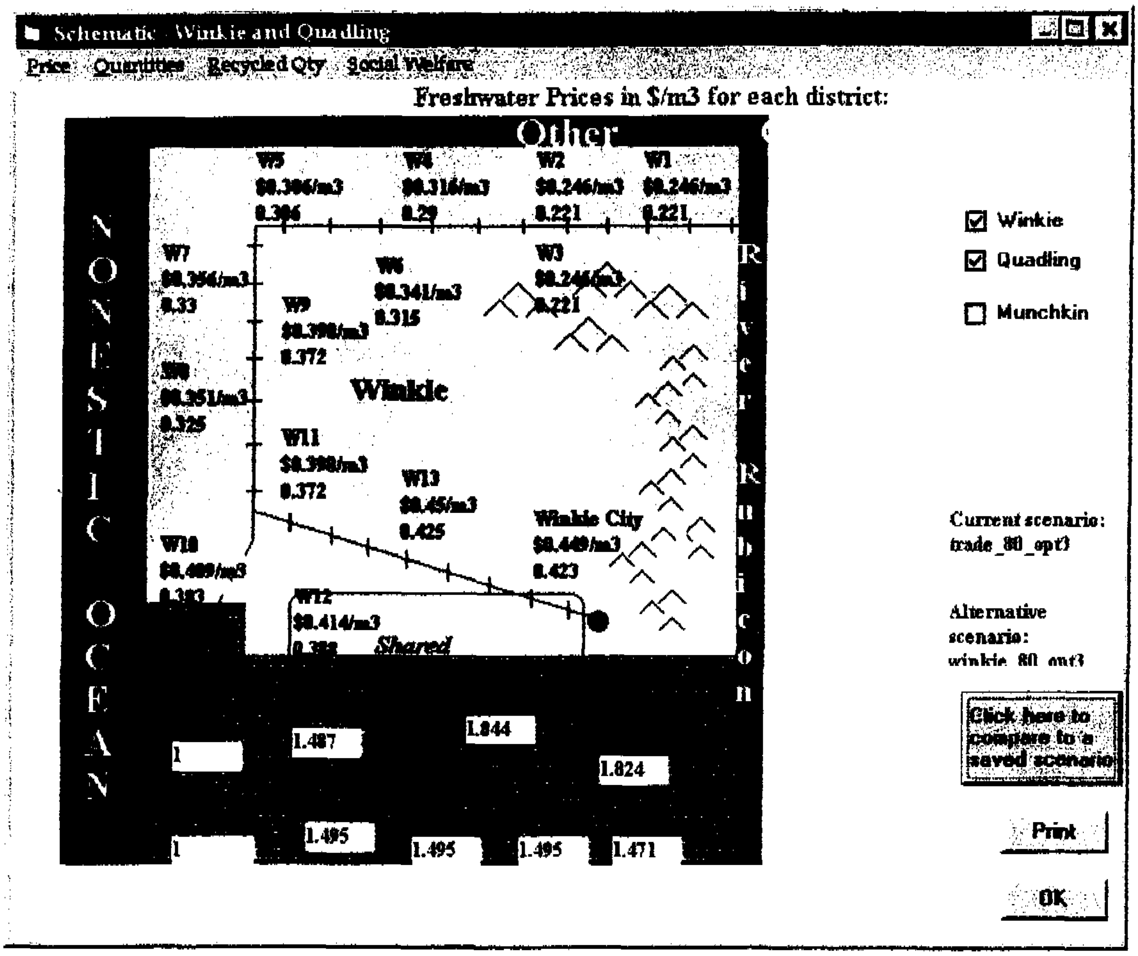


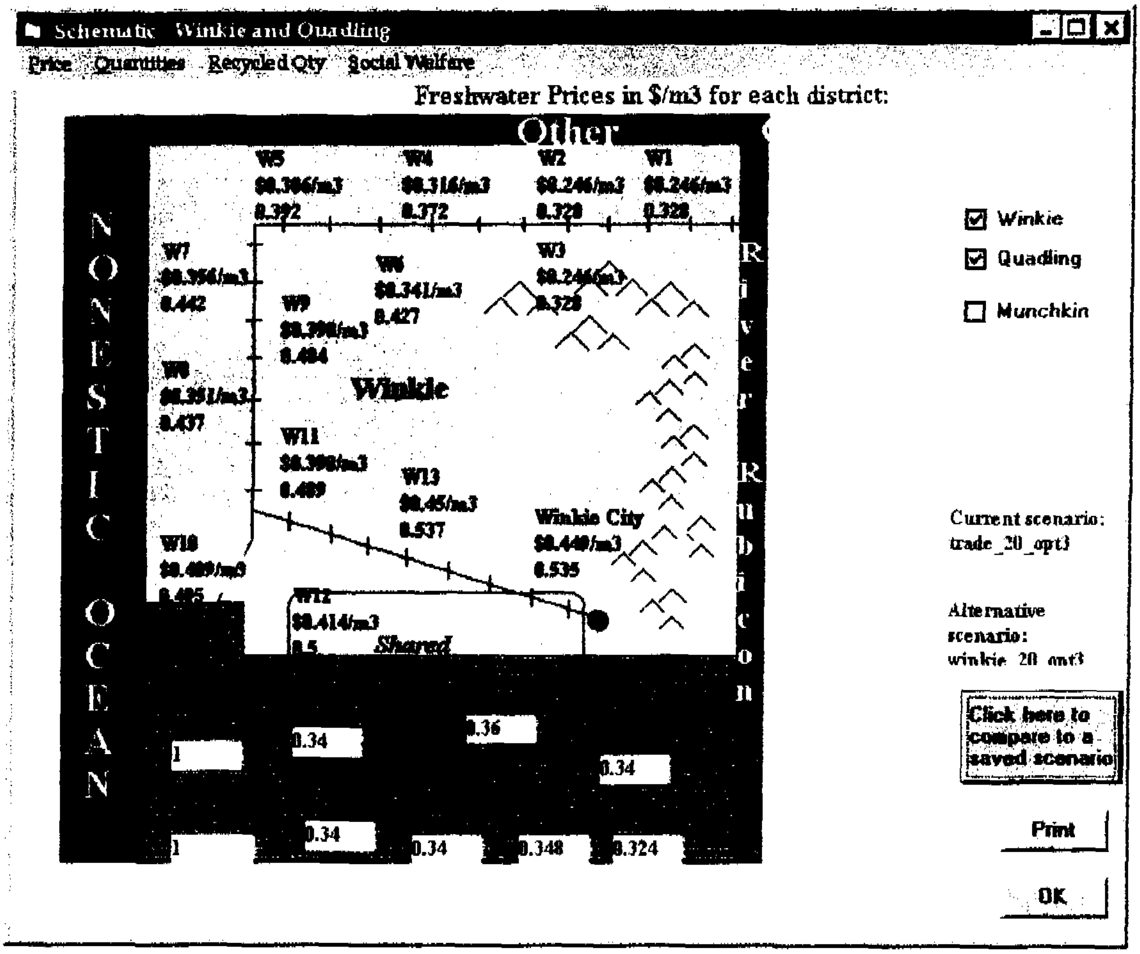
Figure 10: Shadow Prices in Winkie And Quadling with and without Trade at 80% Ownership of Mountain Aquifer by Winkie



Current scenario: trade_80_opt3

Alternative scenario: winkie_80_opt3

Figure 11: Shadow Prices in Winkie And Quadling with and without Trade at 20% Ownership of Mountain Aquifer by Winkie



Current scenario: trade_20_opt3

Alternative scenario: winkie_20_opt3

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ICN - The Israel Center for Negotiation and Conflict Management
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A UNESCO Workshop

on

NEGOTIATION ON WATER IN AREAS OF CONFLICT

Sunday to Tuesday, May 25 - 27, 1997
The Neaman Institute, Technion City, Haifa, Israel

The Workshop is conducted under the UNESCO International Hydrological Program V. It is designed to bring together water resources experts with a group of internationally leading authorities on negotiation and conflict management, so that they can, together, develop the approaches relevant to water management under conditions of conflict. Various aspects of negotiation will be discussed in relation to the conflict: hydrological, psychological, sociological, cultural, environmental and legal aspect. Case Studies will be presented and discussed. A research project, including an economic model for optimal water allocation will be introduced as an alternative means for regional water management. It is expected that deliberations of the workshop will provide essential information and recommendation of universal interest..

Keynote Speaker:

Dr. Elyakim Rubinstein	Attorney General, Israel.

Water Experts:

Mr. Frank Hartvelt	UNDP, USA.
Dr. Keith Hipel	Waterloo University, Canada.
Mr. Le Huu Ti	The Mekong River Commission and ESCAP, Thailand.
Dr. Jan Leentvaar	Rhine Basin Commission, RIZA, The Netherlands.
Dr. Peter Nachtnebel	Universitat fur Bodenkultur, Vienna, Austria.
Dr. Uri Shamir	Water Research Institute, Technion, Israel.

Experts on Negotiation:

Dr. Max Bazerman	Northwestern University, USA.
Mr. Jerome Deli Priscoli	U.S. Army Corps of Engineers, USA.
Dr. Guy Faure	Sorbonne, Paris, France.
Mr. Joe Montville	Center for Strategic & International Studies, USA.
Dr. Howard Raiffa	Harvard University, USA.
Dr. Martin Trolldalen	Center for Environmental Studies and Resource Management, Norway.
Prof. Joseph Dellapenna	Villa Nova University, USA.

Guest Speaker:

Dr. Frank Fisher	MIT, (Harvard Water Project) USA.

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Sunday to Tuesday, May 25 - 27, 1997
The Neaman Institute, Technion City, Haifa, Israel

WORKSHOP SCHEDULE

Sunday, May 25

09.30-10.00	Registration Coffee - get together
10.00-10.30	*Greetings* **Prof. Arnan Seginer** - Director, The S. Neaman Institute **Dr. Andras Szollosi-Nagy** - Director, Water Sciences, UNESCO **Dr. Miriam Waldman** - Head of Agricultural and Environmental Division, Ministry of Science **Yona Shamir**, Executive Director, ICN
10.30-11.00	**Prof. Howard Raiffa** "*Negotiating for Mutual Gains*"
11.30-12.30	**Prof. Keith Hipel** "*Applying the Decision Support System GMSRII to Negotiating Over Water*"
12.30-13.30	Lunch
13.30-15.30	**Prof. Frank Fisher** "*The Economics of Water and the Resolution of Water Disputes*"
15.30-16.00	Coffee Break
16.00-17.00	**Prof. Joseph Dellapenna** "*Why Markets for Water Fail*"
17.00-17.30	Discussion

Monday, May 26

09.00-10.00	**Prof. Martin Trolldalen** "*The Role of Mediator/Facilitator in Water and Environmental Conflict Resolution: Dilemmas and Opportunities*"
10.00-10.30	Coffee Break

10.30-11.30	**Mr. Elyakim Rubinstein - Israel Attorney General** *"Peace with Jordan: Anatomy of the Negotiation Process"*
11.30-12.30	**Prof. Uri Shamir** *"Water Agreements between Israel and Its Neighbors"*
12.30-13.30	Lunch
13.30-14.30	**Mr. Jerry Delli Priscoli** *"Conflict Resolution and Collaboration in Transboundary Water Resources Management: Linking Alternative Dispute Resolution (ADR) Theory to the Practice of Water Management"*
14.30-15.30	**Mr. Joseph V. Montville** *"Psychology and Healing in Water Diplomacy"*
15.30-16.00	Coffee Break
16.00-17.00	**Mr. Le Huu Ti** *"Water as Community Builder: An Asian Experience"*
17.00-17.30	Discussion
Tuesday, May 27	
09.00-10.00	**Prof. Max Bazerman** *"Psychological Difficulties Involved in Resolving Water Disputes"*
10.00-10.30	Coffee Break
10.30-11.30	**Prof. Peter Nachtnebel** *"View on an International Water Conflict: The Referee's Position and the Bilateral Agreement"*
11.30-12.30	**Prof. Guy Olivier Faure** *"Negotiating Over Water Rights: Cultural Issues"*
12.30-13.30	Lunch
13.30-14.30	**Mr. Frank Hartvelt** *"Water Diplomacy: Level The Playing Field*
14.30-16.00	**Open Session** Observers will be invited to provide written submission, and those interested may be invited to make a brief oral presentation in this session.
16.00-16.30	Coffee Break
16.30-17.30	Closing Session