The Water Allocation System (WAS)

Version 3.6

Developed by the

Water Economics Project

October 2007

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1. Introduction

This user guide explains the theory, installation and execution of the Water Allocation System (WAS) model, version 3.6, developed by the Water Economics Project Team. It also provides useful hints on how to operate the system successfully. The user guide is updated regularly as the WAS program is modified.

This guide begins with an explanation of the theory and concepts in the WAS model, with the full mathematical description given in Appendix A. This is followed by a description of the necessary hardware and software to run WAS, and the installation of the WAS software.

The remainder of the guide details the use of WAS. WAS is made up of essentially two parts: the algorithm that solves the allocation problem, and the user interface. The details of the algorithm are presented in Appendices A; the files used in the program are described in Appendix B, and the program in Appendix C. The user interface is described in Section 6.

2. WAS Theory and Concepts

The WAS model allocates the flow of water to users in each district so as to produce the greatest net benefits for all people based on the data used and the assumptions made. Associated with these flows is a system of prices (shadow values) for water in different locations. These prices and the quantities of water allocated are those that a competitive market would reach if demand considerations included both the private willingness to pay and the social value of water as reflected in social policies.

In this context, it is important to note two fundamental concepts underlying the WAS model. First, it is the scarcity of water, and not just its importance for sustaining human life, that gives water its value. Where water is very scarce, such scarcity is reflected in a private willingness to pay relatively large sums for small amounts of water. Where water is somewhat more abundant (albeit still scarce), the value of a unit of water is lower. *Where water is not scarce, it is not valuable.*

Second, water can have a social value that goes beyond its private value. For example, in a country where agriculture is socially desirable (but not necessarily privately profitable), the government may decide to subsidize water for agriculture. This subsidy reflects an excess of the social value of water over its private value. *The WAS model explicitly allows for such social values to be taken into account. Indeed, WAS enables the user to impose his or her own values and constraints on the model and then optimize net benefits subject to those constraints.* ***WAS DOES NOT MAKE WATER POLICY, BUT SERVES AS A TOOL TO GUIDE IT.***

The model is based on annual average conditions. The country is divided into districts, with data for supply, demand, and water treatment for each district incorporated into the model. In addition, data on the conveyance between each pair of districts, whether by pipeline or natural means, is used in the model. Water supply includes both fresh water and recycled water, the latter being defined as wastewater from households and industry that has been treated to a level sufficiently safe for agriculture. The fresh water supply is the average annual renewable quantity. Another potentially important supply source is desalinated seawater; this possibility may be investigated easily with the model. The costs of water extraction, transportation between districts, recycling, and desalination are taken into account and play an important role. The model considers water demand by households, industry, and agriculture. It takes as given the private demand curves for each district, augmenting and modifying these to include the social value of water as reflected in social policies.

WARNING: One must not confuse the concept of "demand" with that of "consumption." "Demand" means how much water users would want to consume if they could get it at the stated price. "Consumption" is an estimate of how much they will (or do) in fact consume given actual availability. Consumption includes supply features. Demand does not. Failure to distinguish these when collecting data will lead to major errors in the use of WAS.

It is crucial in the use of the WAS model to fully understand the meaning of net benefits and shadow values[1] of water. If you are familiar with these terms, the explanation below may not be necessary, but we encourage a review of these ideas.

[1] Shadow values are better known in the economics literature as shadow prices, but we use the term "values" here to distinguish them from the prices charged to consumers.

Net Benefits of Water: Private and Social. **Figure 1** shows the amount of water a hypothetical household would be willing to buy at various prices. Note the downward sloping curve, indicating the very valuable nature of the first few units of water while later units represent those used for purposes less essential than drinking and cooking.

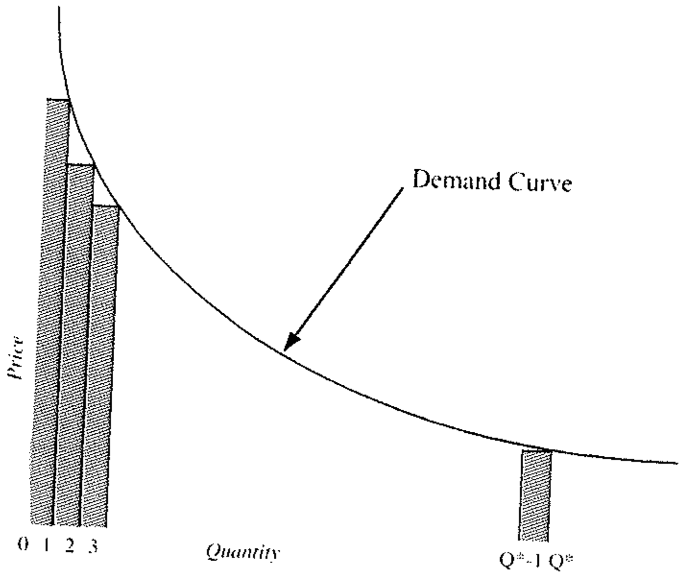

Figure 1

In **Figure 1** we consider the worth to the household of having a quantity of water (Q*). We ask how much that household would be willing to pay for the first small unit; the price is given by a point on the curve above the interval on the horizontal axis from 0 to 1. (Exactly where does not matter.) The amount to be paid (one unit times the price in question) is approximately the area of the leftmost vertical strip in **Figure 1.** Similarly, the amount to be paid for the second unit can be approximated by the area of the second-to-left vertical strip, and so on until we reach Q'. As the unit size decreases, the total amount the household would be willing to pay to get Q' approaches the area under the demand curve to the left of Q*.

Now reinterpret **Figure 1** to represent the aggregate demand curve of all households in a district. The gross (private) benefits from the water flow Q^* can then be represented as the total area under the demand curve to the left of Q^*.

To derive net benefits from Q^*, we subtract the costs of providing Q^*. This is illustrated in **Figure 2**, where the line labeled "marginal cost" shows the cost of providing an additional unit. Additional units cost more as more expensive water sources 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 between the demand curve and the marginal cost curve.

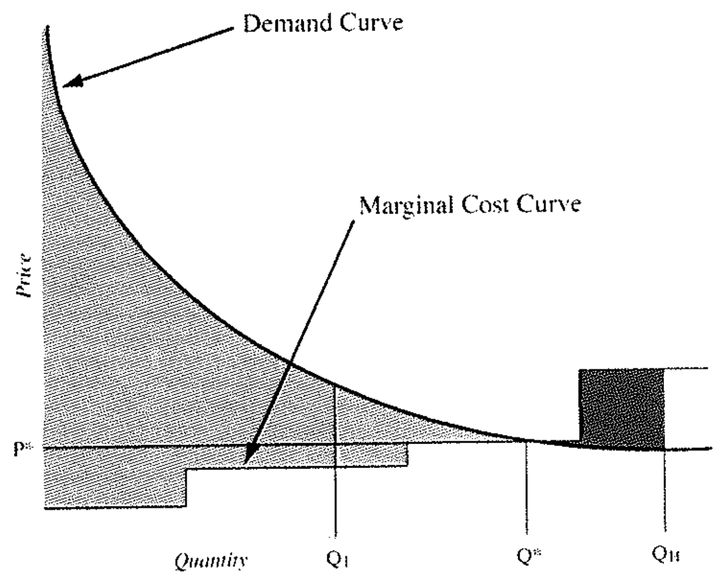

Figure 2

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^*, 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 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 cost of providing the last few units. Hence Q^* is the optimal amount of water to deliver. (Note that in **Figure 2** a price (P^*) is associated with Q^*; we return to this later.)

Consider a government policy to subsidize water for agriculture by \$0.10 per cubic meter at all quantities - an unrealistic but simple example (**Figure 3**).

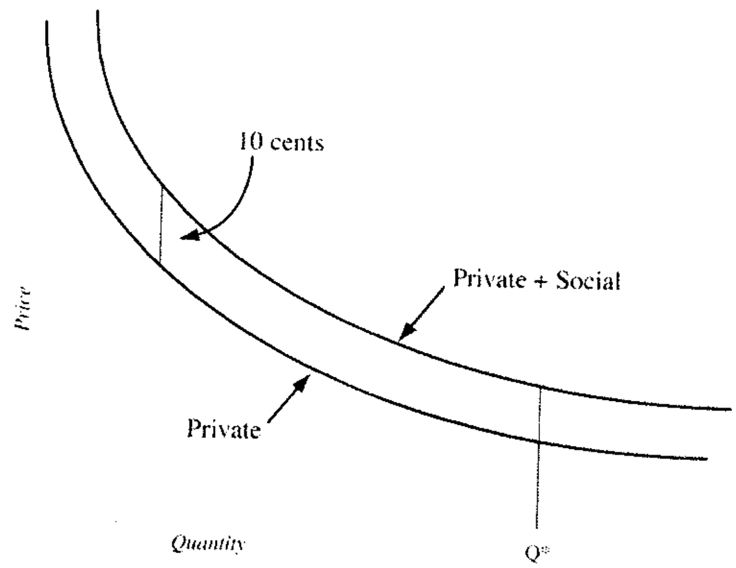

Figure 3

The lower demand curve represents the private value of water to agriculture; the upper demand curve also includes the public value of water as reflected in this policy, an additional value of $0. 10 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 above methods can be used to measure net benefits. In the model, this has been done so that a user can choose various policies and then optimize.

Shadow Values and Scarcity Rents. In competitive markets, prices measure what buyers are willing to pay for additional units of the goods in question (marginal value) and the cost of providing such additional units (marginal cost). A price higher than marginal cost signals that the unit is worth providing since the value placed by the buyer on that unit is greater than the production cost; 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. In the case of water, there are reasons for not relying on a totally competitive private market to serve such functions. One reason is that the social value of water can differ from its private value; we have shown how the model handles this issue. Secondly, typically water is not supplied privately and competitively by many sellers. Thirdly, "externalities" are associated with water use, such as the effect of pumping in one location on the availability or cost of water in another location. Such externalities do not form part of the private calculations done by buyers and sellers in a competitive market.

The model allocates water so as to maximize the net benefit obtained from it. As shown above, that net benefit consists of a measure of the total amount that buyers (consumers or nations) would be willing to pay for the water, less the costs of providing it. The maximization of net benefits is done subject to constraints, essentially concerned with water availability. For example, in each district, the amount of water consumed cannot exceed the amount produced there plus net imports into that district.

It is a general (and important) theorem that when maximization involves one or more constraints, a shadow value is associated with each constraint that indicates how much the benefit would increase if the constraint were relaxed by one unit. While the theorem applies to such things as constraints on pipeline throughputs, the central shadow values in our model are those of water itself. The shadow value of water at a given location is the amount of increased benefits to water users (in the system as a whole) that would be obtained from the cost-free availability of an additional unit of water at that location. It is also the price that buyers at that location who value the water the most would be willing to pay to obtain an additional unit of water. (In **Figure 2**, the price, P^*, would be the shadow value if Q^* were the maximum amount of water available.)

The shadow value of water in a given location does not generally equal the direct cost of producing it there. Consider a limited water source whose pumping costs are zero. If demand from that source is sufficiently high, the shadow value of that water would not be zero; the benefits to water users would be increased if the capacity of the source were greater. Equivalently, buyers would be willing to pay a positive 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 cost-free for the owner to provide a user with an additional unit even if direct costs are zero. That additional unit can be provided only by depriving some other user of the water benefit; that loss of benefit represents an opportunity cost. In other words, scarce resources have positive values and positive prices even if their direct production costs are zero. Such a positive value - the shadow value of the water in situ is called a "scarcity rent."

For zero direct costs, the shadow value of the resource involved consists entirely of the 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 it at that location (if that subtraction yields a nonnegative result). Just as in a true competitive market, a positive scarcity rent is a signal that more water from that source would be beneficial if available. Water shadow values and, accordingly, water scarcity rents depend upon the infrastructure assumed to be in place.

When water is optimally allocated, as in the model solutions, the following relationships hold. (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. Water will be produced at a given location only if the shadow value there equals or exceed the direct marginal cost. Water will be transported from location a to location b only if the shadow value at b equals the shadow value at a plus the conveyance cost. Equivalently, if water is transported from a to b, the scarcity rent of that water is the same in both locations.
- This situation is illustrated in **Figure 4**, where water in a lake (L) is conveyed to locations a, b, and c. It is assumed that the only direct costs are conveyance costs. The marginal conveyance cost from the lake to a is denoted t_{La}; similarly, the marginal conveyance cost from a to b is denoted t_{ab} and that from b to c is denoted t_{bc}, The shadow values at the four locations are denoted P_L, P_a, P_b and P_c, respectively. Examination of the diagram shows that each location connected to the lake has a shadow value consisting of the shadow value at the lake, P_L (the scarcity rent), plus the total marginal cost of conveyance from the lake to the given location.
- At each location the shadow value of water is the price at which buyers would be just willing to buy and sellers would be just willing to sell an additional unit of water.

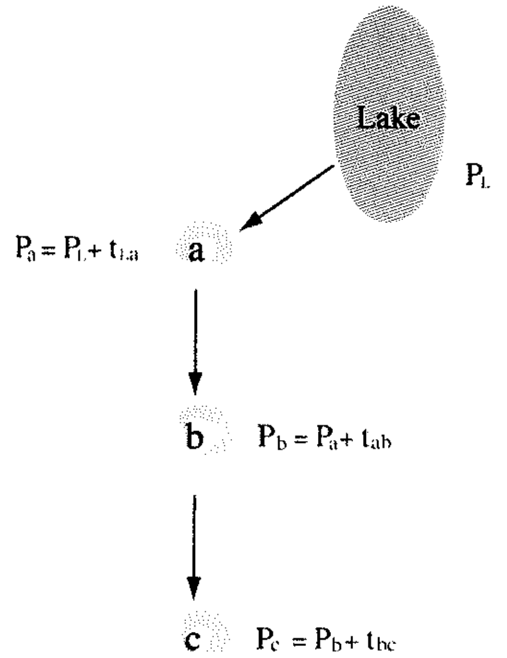

Figure 4

3. Capital Costs in WAS

WAS 3.3 handles the linked issues of (1) cost-benefit calculations for proposed new infrastructure and (2) capital costs in two alternative ways: as a lump sum or on a per-cubic-meter basis.

Dealing with Capital Costs as a Lump Sum: Direct Cost-Benefit Analysis. The recommended method for dealing with capital costs of proposed infrastructure is to make a direct comparison of benefits and costs. In this method the capital costs are not included in the data on a per cubic meter basis, but are entered in for a comparison with benefits. This may be done through the interface (see section 6.6). This method has both advantages and defects.

1. It does not require the separate calculation of per-cubic-meter capital costs, which depend on the actual quantity used, and is thus very easy to use.

2. The shadow values in the scenario with the projected infrastructure will not accurately reflect all costs involved.

3. It will not choose which projects to build from a menu of possible projects.

Expressing Capital Costs on a Per-Cubic-Meter Basis. The alternate method is to include the per-cubic-meter capital cost of the proposed infrastructure as a cost associated with the use of that infrastructure. If the new infrastructure's benefits exceed its costs (including capital costs) in the assumed steady state conditions, then the model will use the infrastructure. Otherwise it will not.

Note that the per-cubic-meter capital costs of existing infrastructure (or of infrastructure assumed to be existing at the time that the proposed new infrastructure is to be built) must NEVER be included in this way. However those capital costs are recovered in the charges made to users, they are sunk costs. Including them as use-related costs will lead the model not to use existing infrastructure fully because it will wrongly assume that it can save capital costs by so doing!

This method has both advantages and defects.

1. The per-cubic-meter capital costs of the new infrastructure will show up in the shadow values of water. Since such values are expressed in units of dollars per cubic meter, they bear a strong resemblance to prices. The inclusion of capital costs will make the values look relatively natural in terms of prices.

2. On the other hand, the shadow values are *not* the same as the prices charged to users. It is a mistake to think of them in that way. Further, since the capital costs of existing infrastructure (or infrastructure assumed to exist at the time the proposed infrastructure is to be built) must not be included (see above), the shadow values will not include them, so that they will in any case not resemble the prices charged to users.

3. The fact that the shadow values of water in each location will include the capital costs of the new project does, however, make those shadow values more accurate as measures of the value of the marginal cubic meter than are shadow values that do not include such costs. For example, if the proposed infrastructure is a conveyance line, the shadow value

of water at the terminus should properly reflect the fact that if water were delivered there by other methods, then the capital cost of the proposed infrastructure would be saved.

4. The big advantage to using the method described is that one need not test out only one proposed project or collection of proposed projects at a time. By specifying the costs of all projects under consideration and seeing which ones are used in the model solution, one can tell which of a menu of projects should be built in the presence of the others (under the assumed steady-state conditions.)

5. On the other hand, in the present state of the program, this method will not handle the cost-benefit analysis of the capacity expansion of existing infrastructure. For example, when conveyance capacity between two points is to be expanded by adding an additional line, the capital cost of the new line is not incurred when water moves over the old one. Just increasing the capacity and averaging the new and old costs on a per-cubic meter basis will therefore give the wrong result. While this can be fixed in later versions, the alternate method described above is fully capable of handling it now.

6. The method under discussion will not generate the total benefits of the new infrastructure for direct comparison with its capital costs. But it can be made to generate estimates of both the annual *net* benefits and the present discounted value of the net benefits. To do this, click on the "Cost-Benefit Calculations" button on the main menu. Then proceed as described below for the alternate method, treating the scenario with the new infrastructure as the one that includes the capital costs and inserting zero for the capital cost figure. *If you do this, be sure that you use the same interest rate and project life here as were used in generating the per-cubic-meter capital cost figure already included in the run with new infrastructure.* (Note that the "discount rate" should here be the interest rate.) The benefits calculated will be *net* of capital costs.

It should be emphasized that both the methods given are correct. If properly done, they are equivalent.

Multi-year WAS (MYWAS). The above methods, however, are superseded in the multiyear version of WAS that has now been developed but not yet applied. (A user guide for MYWAS has not yet been produced.) MYWAS optimizes the discounted present value of net benefits from water over a user-chosen time period. This permits capital costs to be entered as costs at the time that they are expected to occur. In this treatment, a menu of possible infrastructure projects is provided by the user; MYWAS then yields the optimal order in which to build (or not to build) particular projects, together with the optimal capacities and the timing of the projects.

It should also be added that MYWAS will handle the use of natural and man-made storage facilities including the management of aquifers. It can also be used to study the effects of different variations in climate.

If Jordan undertakes the updating and use of the WAS methodology, then adapting MYWAS for Jordan will be an important part of the resulting project.

4. Hardware Requirements

To run the WAS system, algorithm plus interface, requires:

- An IBM compatible PC with a Windows XP/VISTA operating system.
- GAMS (Generalized Algebraic Modeling System) software.
- At least 8 MB RAM (preferably 16 MB).
- Approximately 10 MB of free space on the hard drive.
- Additional disk space as needed for saving results.

Note: If you are planning to run scenarios fairly frequently, we recommend that you install the WAS system on the fastest machine you have.

5. Installation

To install the WAS system, please complete the following steps, noting that this procedure is different from previous versions.

1. In order to copy the WAS files to your computer, complete the following steps:

    - Insert the WAS CD-ROM
    - Double click on **WAS.msi** to launch the install.

2. You will now find WAS as an icon on the screen. Simply **double click on the WAS icon to run WAS**.

If the WAS program stops working at any time and you suspect that it is due to some of the files accidentally being deleted or altered, you should be able to rectify this by re-installing the WAS software.

6. Using the WAS program

In this section we examine and provide a general description of the different menu options, and also give some useful hints. Our discussion is based on the menus, and does not cover all the possible things you could do. We trust that once you become familiar with the options, you will have the ability to create the scenarios you are interested in, and that the model accommodates.

After completing the installation, all you have to do is double-click on the WAS_IJP icon. The first screen that appears, shown in **Figure 5**, which simply indicates that the data are available for the countries of Jordan, Palestine and Israel, and makes no assumptions about cooperation between the countries – that is left to the user to decide.

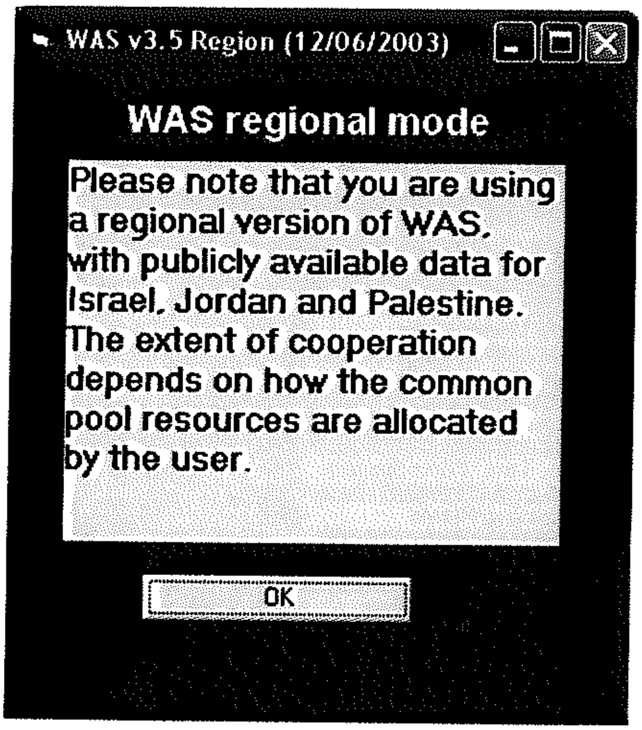

Figure 5 – Initial Screen

Once you click the OK button, the *Main Screen* appears, as shown in **Figure 6**. The *Main Screen* allows you to modify/view the data for demands, supplies, infrastructure and social policies, as well as run the model and view results. Each of these options is described below in more detail.

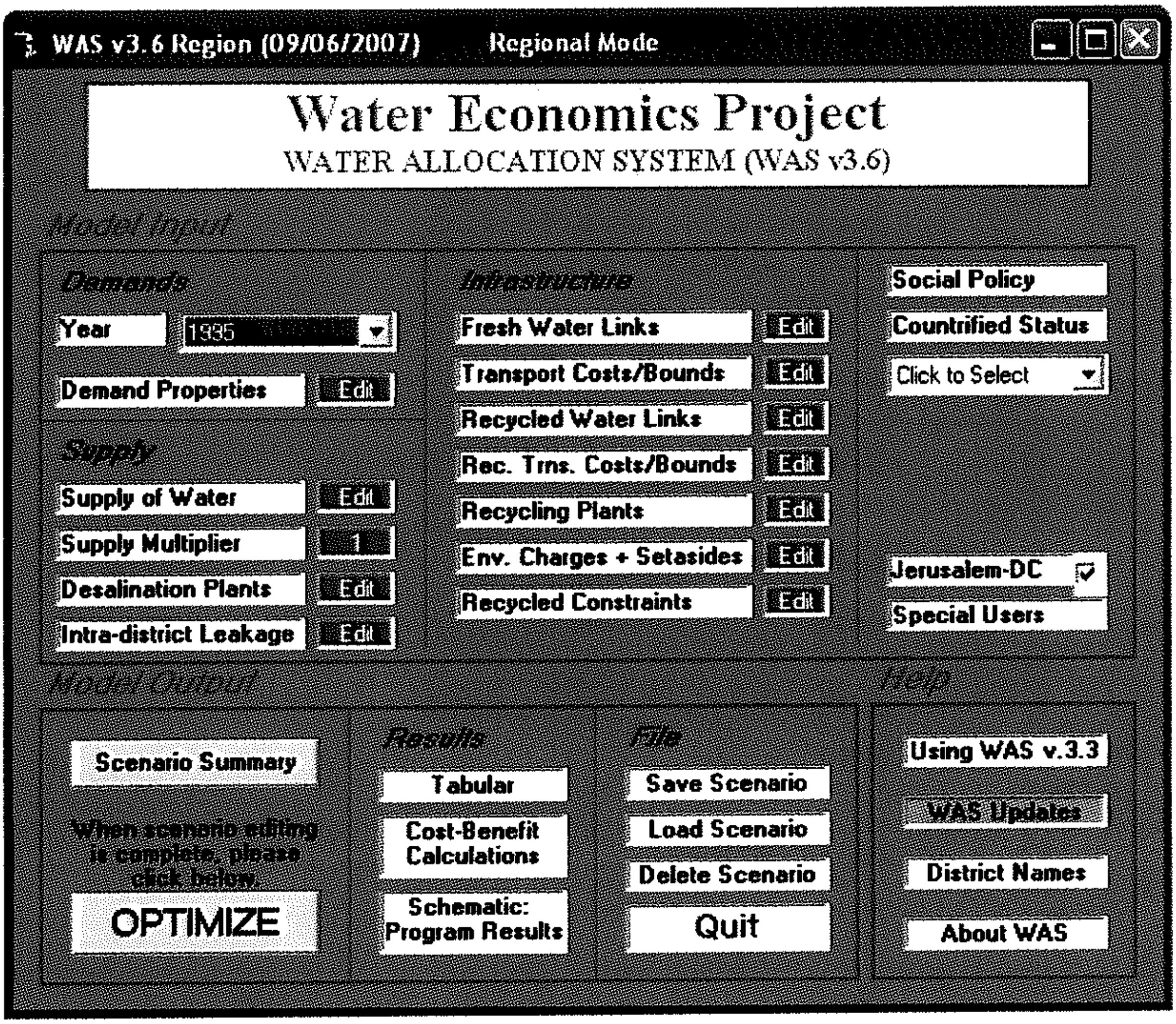

Figure 6 – Main Screen

6.1 Demands

From the *Main Screen*, the demands may be modified through clicking on one of two buttons in the *Demand Section* of the *Main Screen*. The first button, *Year*, allows the selection of the demand year, and the second allows modification of the demand elasticities, shifts of the demand curves and the population, as described below.

Scenario Year. This button allows you to choose the demands for the year for which you wish to consider. The current choices are 1995, 2010 and 2020, but of course these can be changed. Simply click on the drop-down button to select the appropriate year.

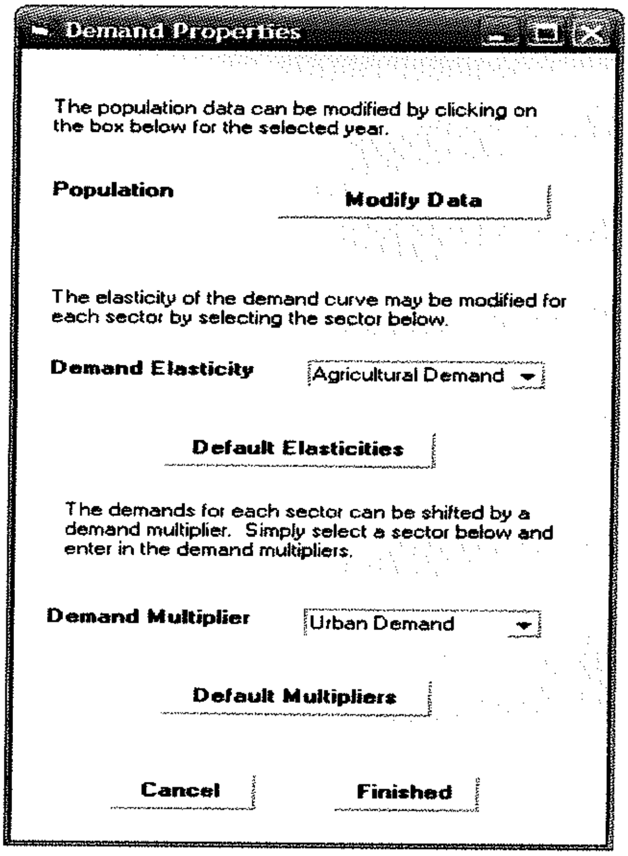

Figure 7 - Demand Properties

Demand Properties. When you click on the *Edit* button to the right of *Demand Properties* on the *Main Screen*, a new form appears, as shown in **Figure 7**. This form allows the editing of population and the demand curves. When you click on *Modify Data* to the right of the word *Population* on this form, another form appears, as shown in **Figure 8**. The population can be edited directly on this form. Once you are satisfied with the numbers, click on *Finished.* If you want to return to the default values, click on *Defaults.* If you wish to cancel any changes, click on *Cancel.* This will bring you back to the *Demand Properties* screen shown above.

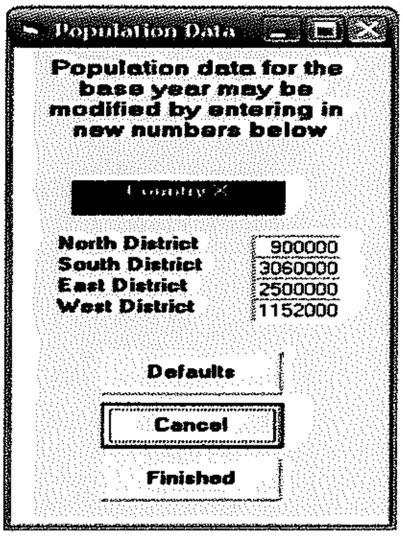

Figure 8 – Population Data

There are two features of demand curves that can be easily modified, one which affects the shape of the curve (more accurately, the elasticity of demand), and one that allows proportional changes to the curve (see Section 2 above on theory). The demands in WAS are represented by a constant elasticity function of the form $Q=MP^{-\mu}$, where Q is quantity, P is price, and M and μ are parameters. The parameter μ is the absolute value of the elasticity of demand, and measures how responsive demand is to price. The first option regarding demand curves allows the user to modify μ. Simply select the user type that you would like to view/edit from the dropdown box. The options are agricultural, urban or industrial demand. From here another screen will appear, as shown in **Figure 9**.

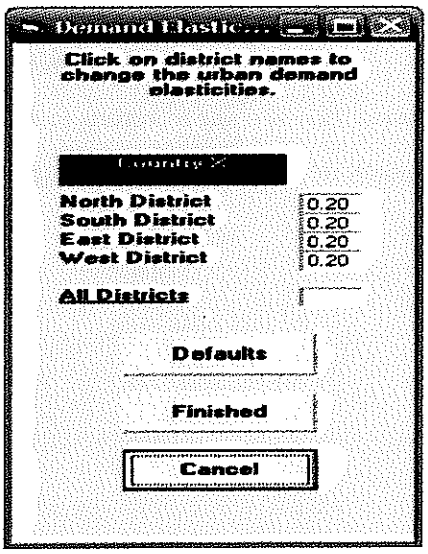

Figure 9 – Demand Elasticities

Demand elasticities can be set individually by district, or for the entire country, by clicking on the *All Districts* button. The program specifies bounds, partly according to what is reasonable, and partly for computational reasons, and will not allow input values outside of these bounds. The *Cancel*, *Defaults*, and *Finished* buttons function the same as those for population. All will return you to the *Demand Properties* screen.

The second option regarding demand curves adjusts the coefficient, M in the demand function, allowing the exploration of the effects of greater or lesser demands. Again, select the user type you would like to adjust by choosing the appropriate type from the dropdown box to the right of the *Demand Multiplier* button. A new screen will appear (shown in **Figure 10**).

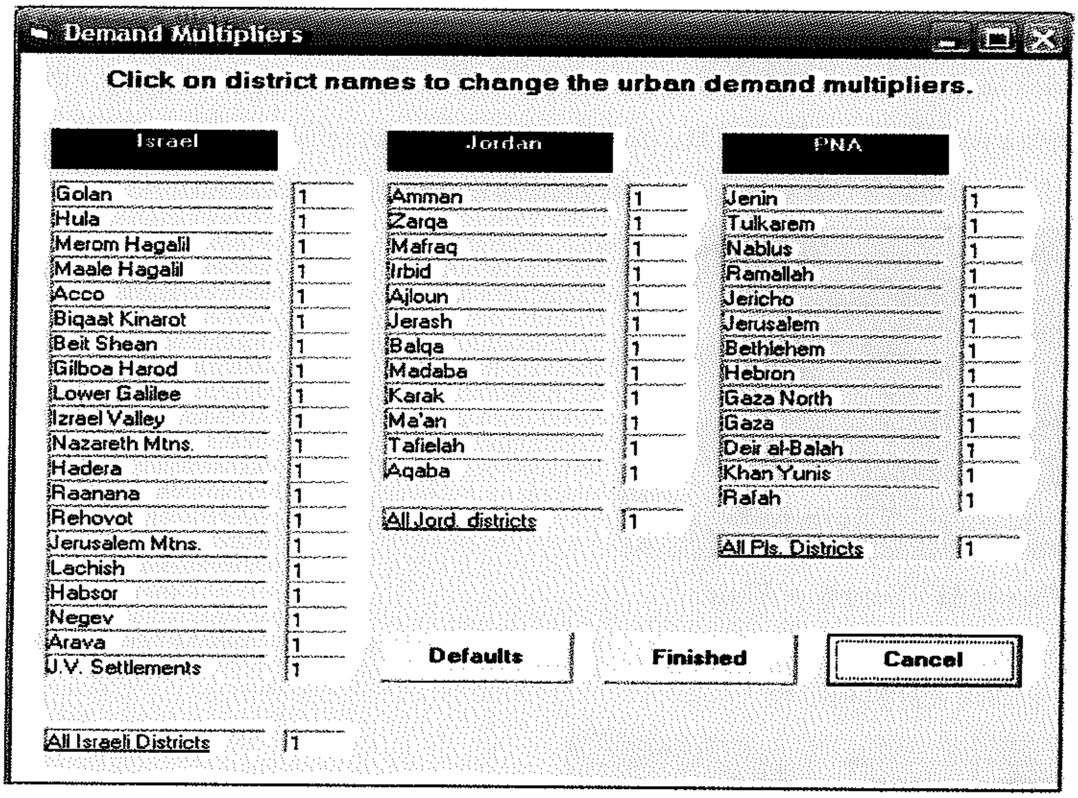

Figure 10 – Demand Multipliers

Demands can be adjusted by district or by country, by clicking on the district name or by clicking on the *All Districts* button. For example, if you wish to assume a 20% greater population in a district than that assumed in the chosen demand scenario year, you would do this by setting the value of M for that district equal to 1.2. Note that if you increase the urban demands here, you may want to revise the population estimates to be consistent. The *Cancel*, *Defaults*, and *Finished* buttons function the same as those for population and demand elasticities. All will return you to the *Demand*

Properties screen.

Once satisfied with the demand properties, click *Finished* to return to the *Main Screen*, or *Cancel* to return to the *Main Screen* without changes.

6.2 Supplies

The *Supply section* of the *Main Screen* allows you to modify the data for fresh water supply and desalination. In addition, dry and wet years can be simulated through the supply multiplier, and the leakage within a district specified. These options are described in detail below.

Supply of Water. The supply of water in WAS is represented with 'supply steps,' which are the average annual renewable quantities of water available at given prices. Up to five increments may be specified for each district. When you click on the *Edit* button to the right of *Supply of Water* on the *Main Screen*, a form appears (**Figure 11**), that allows you to select either the *Supply Step Function* or the *Common Pool* resources by clicking on the *Edit* buttons to the right.

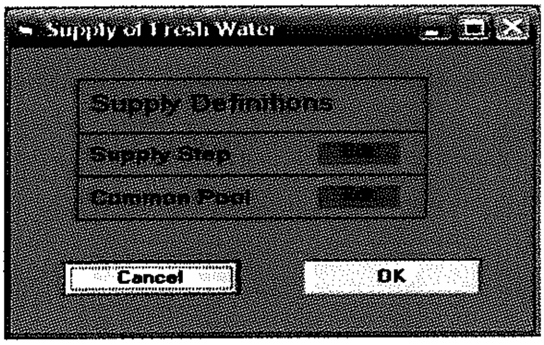

Figure 11 – Supply of Water

When you click on the *Edit* button to the right of the words *Supply Step Function,* a form appears, as shown in **Figure 12.**

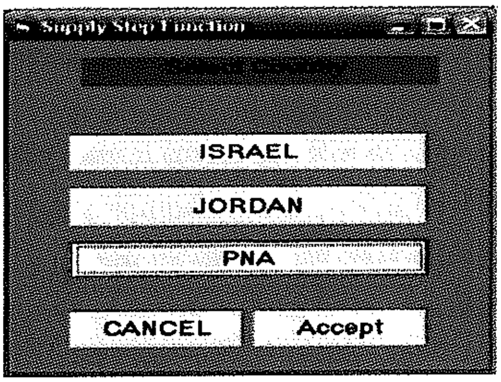

Figure 12 – Supply Step Function

(If you are running in *'Uncountrified'* mode, you will have to select which country first). Here the data for each district are displayed, up to five steps, for the annually renewable quantities at an average annual operating and maintenance cost, given in millions of cubic meters (MCM) and dollars per cubic meter, respectively. To return to the default values, simply click on the *Default Values* button. Once completed with editing, click on the *Finished* button, or select *Cancel* to exit without any changes. Both will return you to the *Selection of Supply Editing* screen.

In doing a countrified run, supply steps are used to show water ownership. If you wish to look at a regional run (with data supplied by you), then you should specify supply steps in physical terms and use the common-pool facility to restrict the total that can be drawn by two or more parties.

Common Pool. If you click on the *Edit* button to the right of the words *Common Pool* on the *Selection of Supply Editing* screen, a new screen appears, as shown in **Figure 13**.

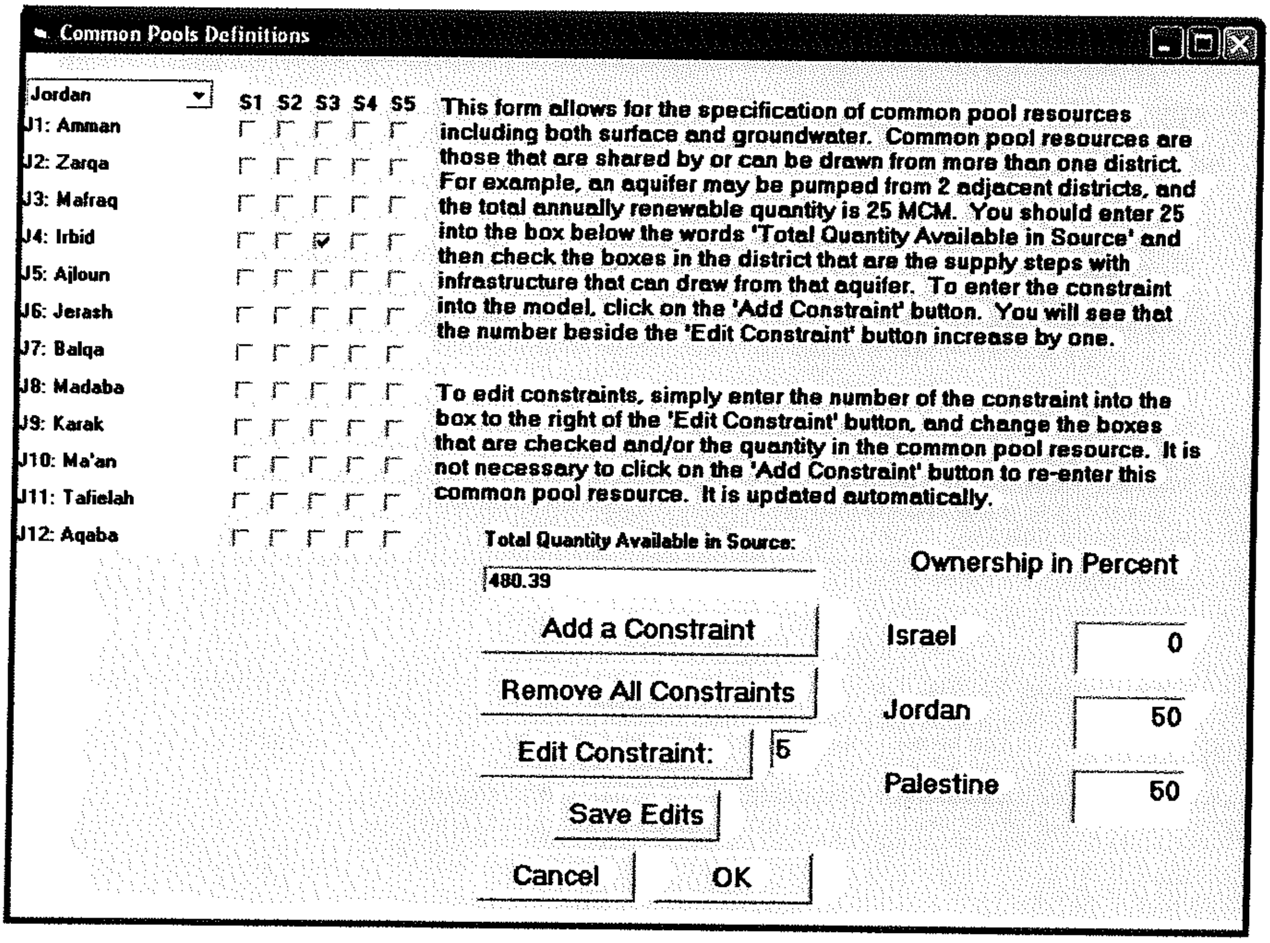

Figure 13 – Common Pool Definitions

This screen allows for the specification of common pool resources including groundwater and surface water. Common pool resources are those that are shared by or can be drawn from more than one district. For example, an aquifer or river may be withdrawn from two or more districts, and the total annually renewable quantity is 25 MCM. You would enter 25 in the box under the words *Total Quantity Available in Source*, and then check the boxes of the steps associated with that aquifer or river. To enter this into the model, click on *Add a Constraint*. You will see the number to the right of the *Edit Constraint* button increase by one, and the screen will clear of checks and numbers for the entry of another common pool resource.

To edit constraints, simply enter the number of the constraint into the box to the right of the *Edit Constraint* button. The associated constraint will appear, and additional boxes may be checked or checked boxes removed, and the quantity may be modified as well. It is not necessary to click on the *Add Constraint* button to re-enter this constraint. It is updated automatically. To remove all constraints, click on *Remove Constraints*. Note that this will remove all constraints, and not just the one currently in view. Clicking on the *Cancel* button will return you to the *Selection of Supply Editing* screen without any of the changes made, and the *OK* button will return you to the same screen, but with the modifications saved.

From the *Selection of Supply Editing* screen, clicking on *OK* will return you to the *Main Screen*, and *Cancel* will return you to the *Main Screen* without changes to the data.

Supply Multiplier. Supply multipliers can be specified for drought and wet year scenarios. Simply edit the value to the right of the words *Supply Multiplier* on the *Main Screen*. The specified value multiplies all naturally occurring water supplies. The default value is 1, representing an average year.

Desalination Plants. Desalination plants may be added or removed by clicking on the *Edit* button to the right of the words *Desalination Plants* on the *Main Screen*. A new screen will appear that allows the choice of locations for desalination plants (shown in **Figure 14**).

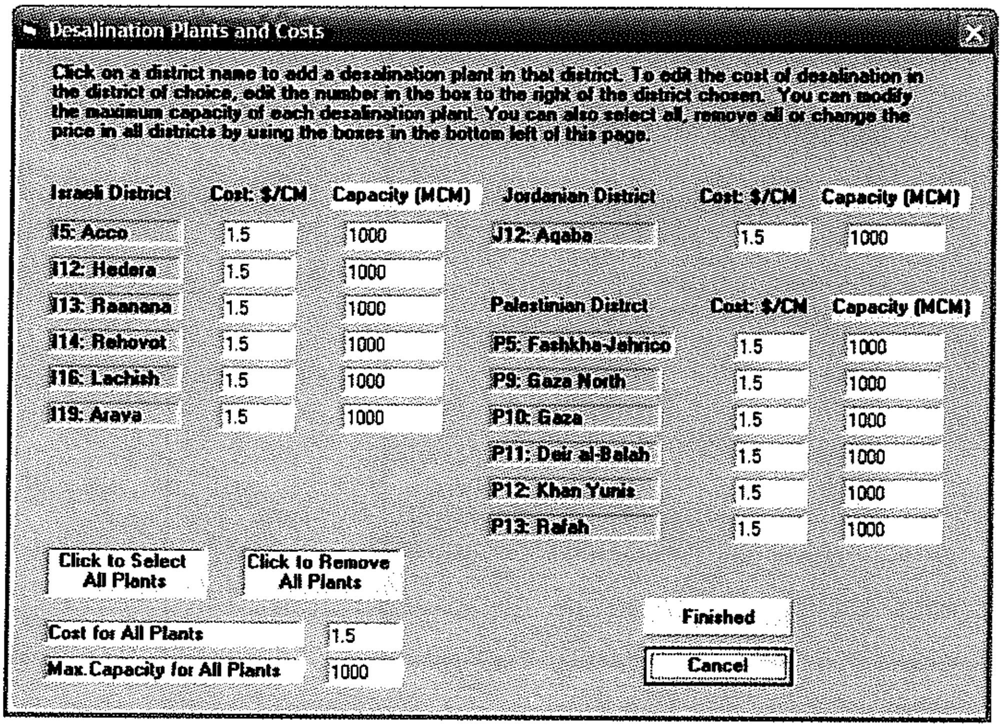

Figure 14 – Desalination Plant Infrastructure

Given the variability of desalination costs, the cost of desalination can be set here (typical values from the literature are roughly $0.55m³). The default assumption is unlimited capacity for user-specified desalination plants (i.e. 1000 MCM), however limited capacities may be specified. Program results can then be used to determine how large a capacity will be needed in a particular scenario.

Leakage. The intra-district leakage may be viewed/edited by clicking on the *Edit* button to the right of the word *Leakage* on the *Main Screen*. The *Intra-district Leakage* screen appears, as illustrated in **Figure 15**.

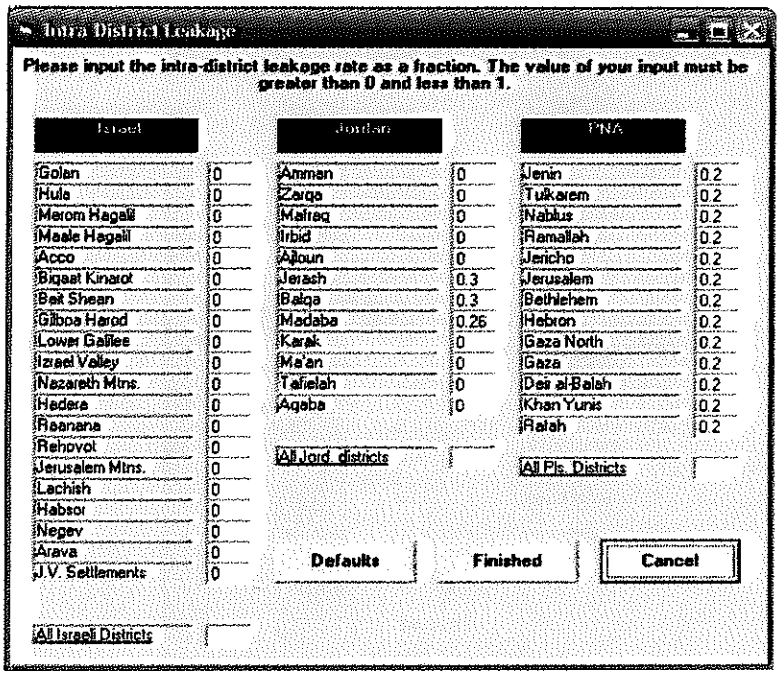

Figure 15 – Leakage

The data may be viewed or edited by clicking on a district name, or by clicking on the *All Districts* button to view/edit the entire country's data. The values entered are fractions, and therefore must be between zero and one. Note that leakage here refers to physical leakage, and not to unmetered usage (which brings benefits). Clicking on the *Defaults* button will restore the default values. Clicking on *Cancel* will return you to the *Main Screen* without any changes, and clicking on the *Finished* button will save the modifications and return you to the *Main Screen* as well.

6.3 Infrastructure

The options in the *Infrastructure Section* of the *Main Screen* allow the modification/viewing of the conveyance connections or links, both for fresh and recycled water, and the cost, capacity and leakage of those links. In addition this section allows the editing of recycling plants, and their capacities and costs, and limits on the quantity of recycled water that may be used in a given district. The costs of water treatment and the costs of safe environmental disposal may be specified in this section. Finally quantities of water that may be setaside for any reason may be specified. Each option is described in detail below.

Freshwater Links. You can specify the existence or removal of freshwater links between any two districts by clicking on the *Edit* button to the right of the words *Freshwater Links* on the *Main Screen.* A new screen appears, as illustrated in **Figure 16.**

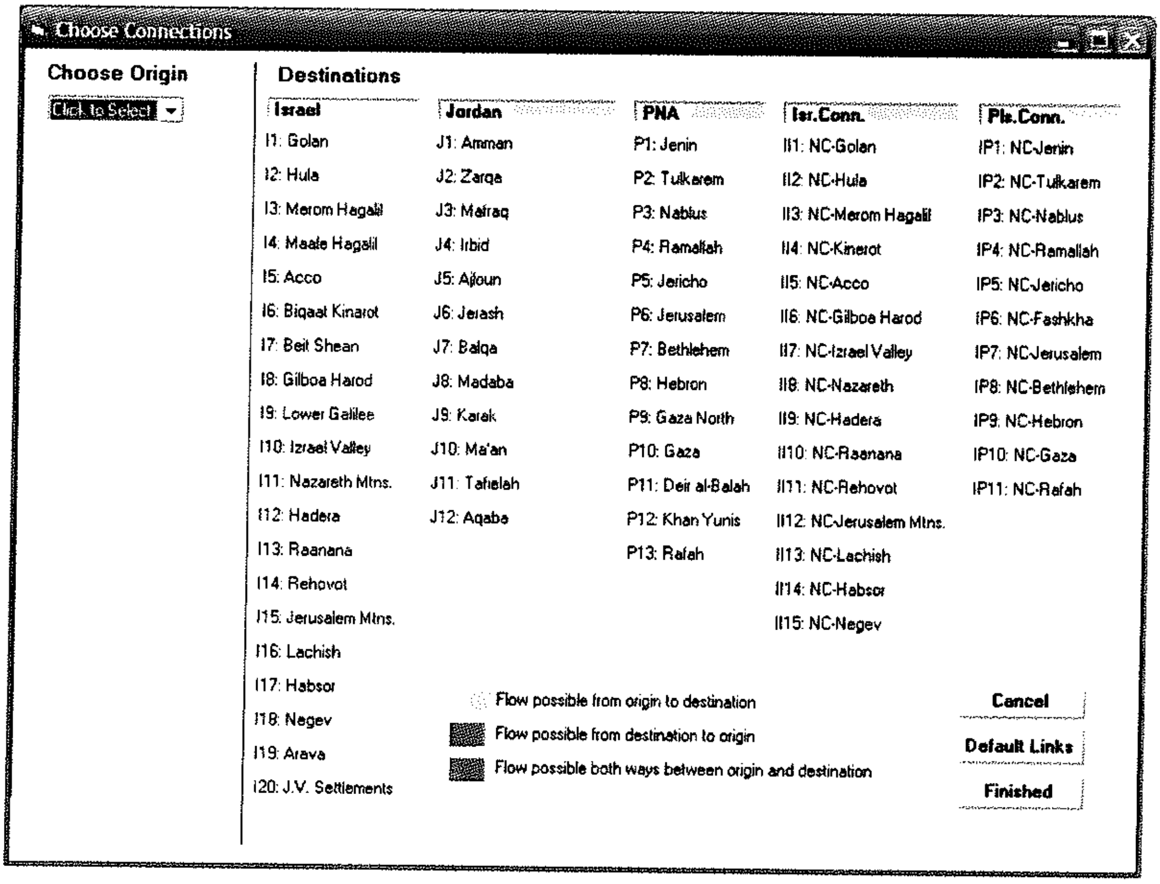

Figure 16 – Freshwater Links

The direction of flow is color-coded: yellow indicates flow from the originating district to the destination district, green indicates the reverse, and pink indicates the ability of flow in both directions.

To use this option, proceed as follows: Click on the dropdown box below the words *Choose Origin* and select an origin list. Then click on the origin you want. The color code now tells you what links are in place. To change a link, click on the destination until you get the color you want. If you add a link, you will be asked to specify transport costs (in dollars per cubic meter), leakage (as a fraction of the flow) and capacity (in MCM per year), as shown in **Figure 17.**

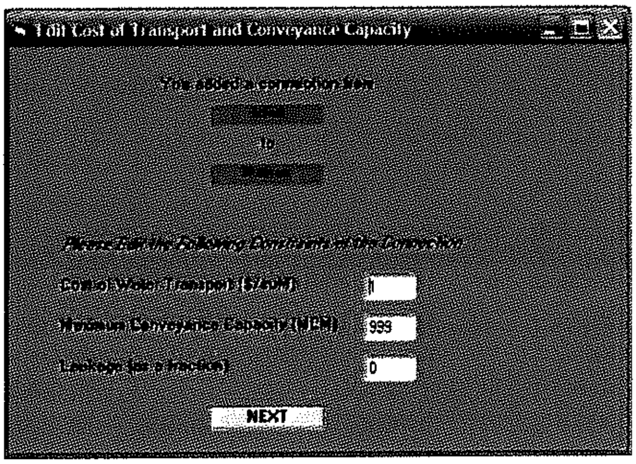

Figure 17 – Cost of Transport and Conveyance Capacity

You can re-establish the default links by clicking on the *Default Links* button. If you want to save changes, click on the *Finished* button, otherwise click on *Cancel.* Both will return you to the *Main Screen.*

Transport Costs/Bounds. This option allows the user to alter the cost of transport (**not** including capital costs) between any two districts, as well as any capacity limits. Click on the *Edit* button to the right of the words *Transport Costs/Bounds* on the *Main Screen* and you will see the screen shown in **Figure 18**. <u>Note that you can only edit links already existing in this screen</u>.

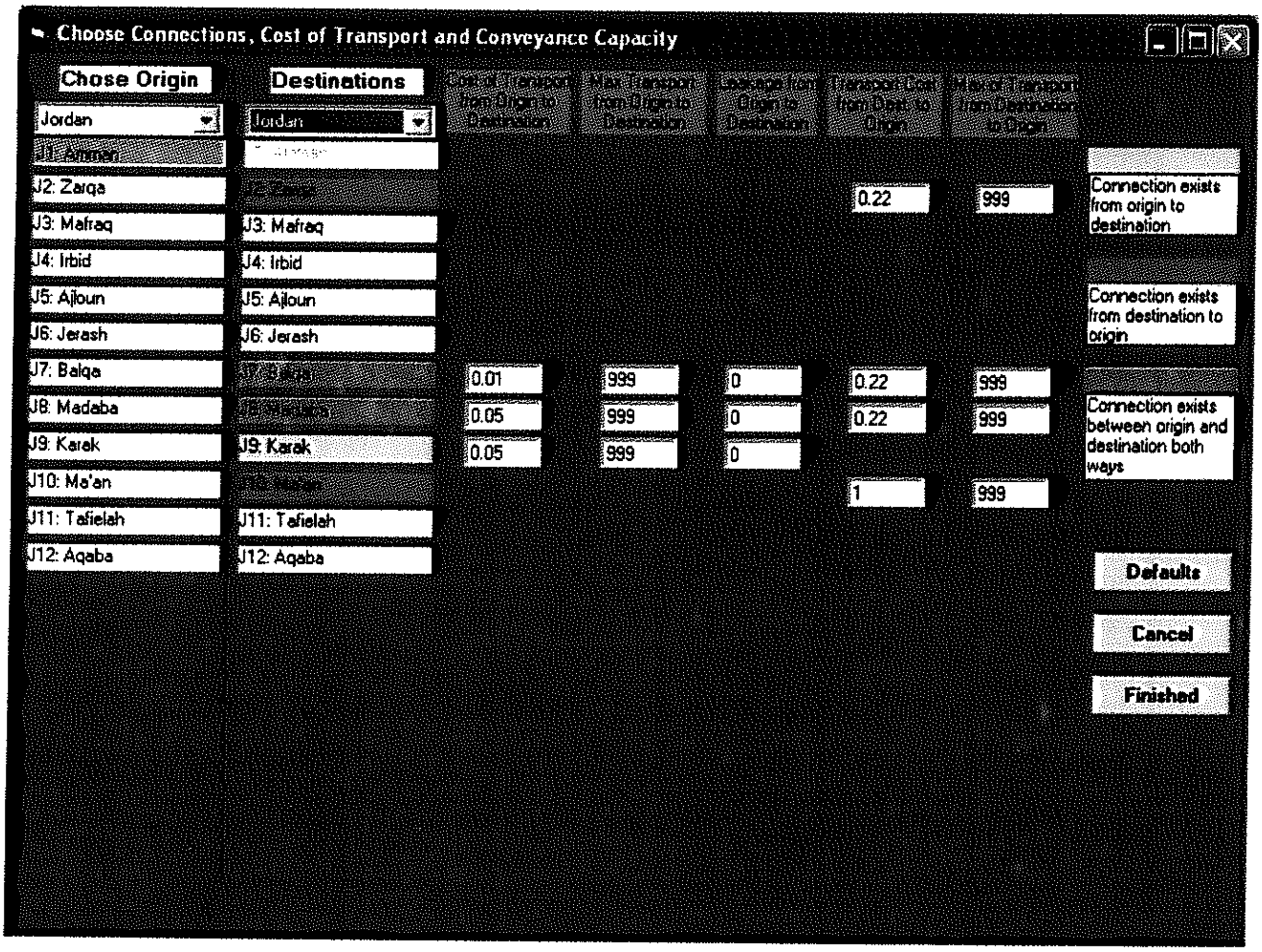

Figure 18 – Connections, Cost of Transport and Conveyance Capacity

The procedure for editing/viewing the data is similar to those of the links. Click on the dropdown button under the words *Choose Origin*, and click on the origin you want. Then click on the dropdown button under the word *Destination* and click on the destination you want. If there is a link to or from the origin district, boxes will appear with values, as illustrated in the figure. Simply enter the data you wish, and click on *Finish*, which will return you to the *Main Screen*. The *Defaults* button will re-establish the default links, and the *Cancel* button will return you to the *Main Screen* with no changes made to the connections.

Recycled Water Links. You can specify the existence or removal of recycling links between any two districts. The direction of flow is color-coded, as with the freshwater menu: yellow indicates flow from the originating district to the destination district, green indicates the reverse, and pink indicates the ability of flow in both directions. To edit, click on the *Edit* button to the right of the words *Recycled Water Links*. This will bring up a screen as illustrated in **Figure 19**. Use of this option is identical to the use of the freshwater links option described above.

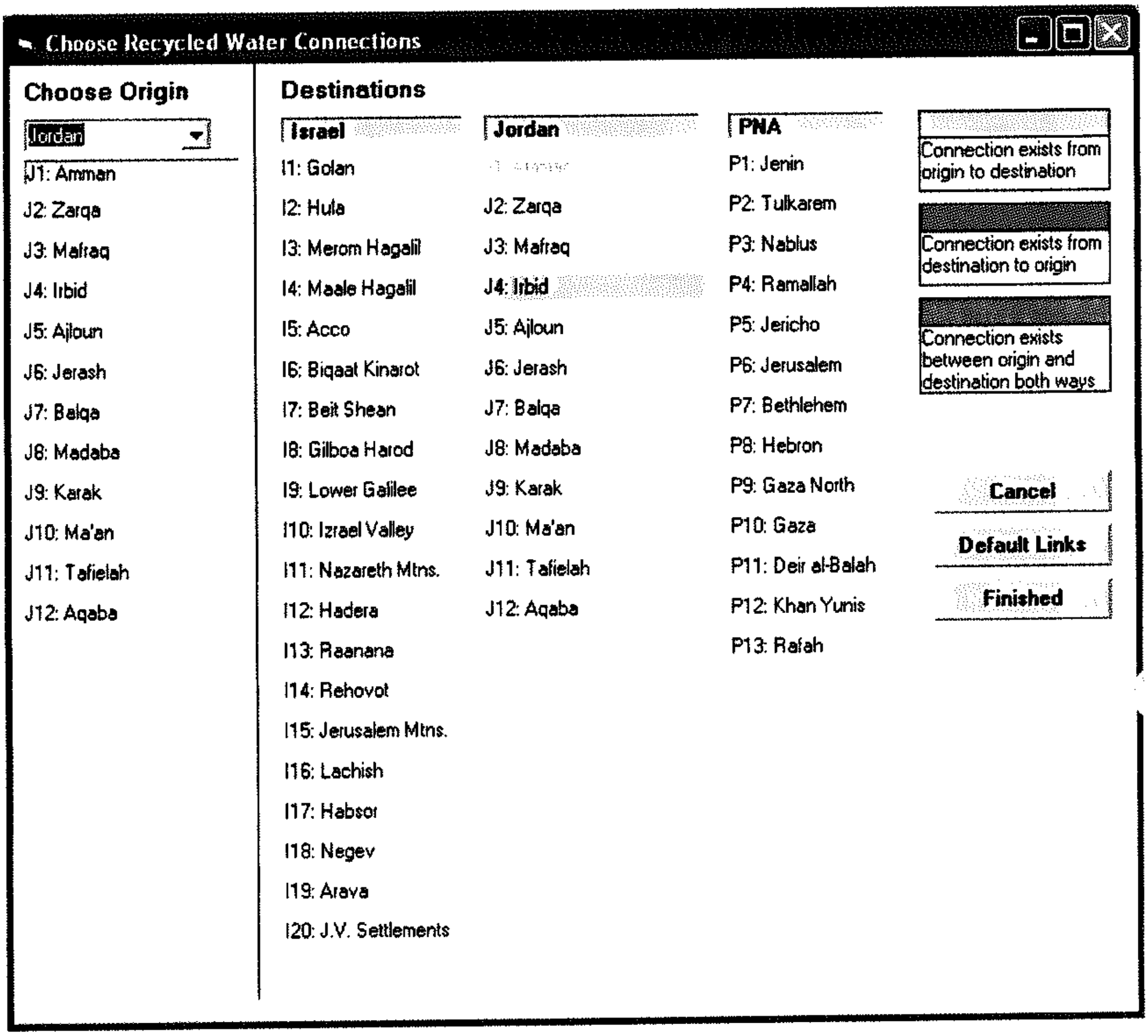

Figure 19 – Recycled Water Connections

Recycled Water Transport Costs/Bounds: This option allows you to alter the non-capital cost of recycled water transport between any two districts, as well as any capacity limits. Only links already existing can be modified in this menu option. To edit, click on the *Edit* button to the right of the words *Rec. Trns. Costs/Bounds*. The screen shown in **Figure 20** will appear. Use of this option is identical to the use of the freshwater transport costs/bounds screen option described above.

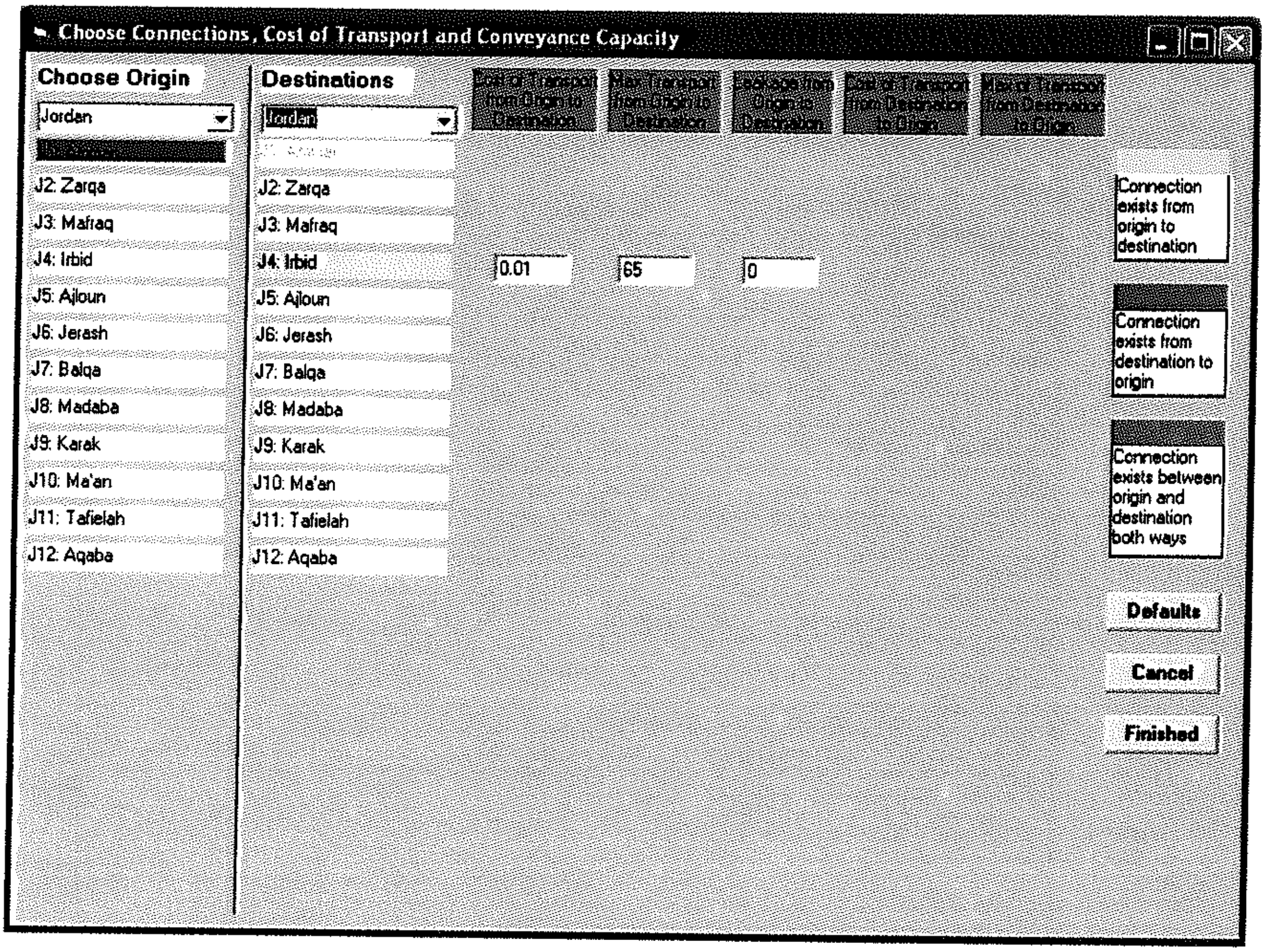

Figure 20 - Recycled Water Transport Costs/Bounds

Recycling Plants: Recycling plant locations, the associated percentage of the household and industry fresh water consumption that can be recycled and the cost per cubic meter for retreatment are specified with this option, which can be activated by clicking on the *Edit* button to the right of the words *Recycling Plants* on the *Main Screen.* This brings up a screen as illustrated in **Figure 21.**

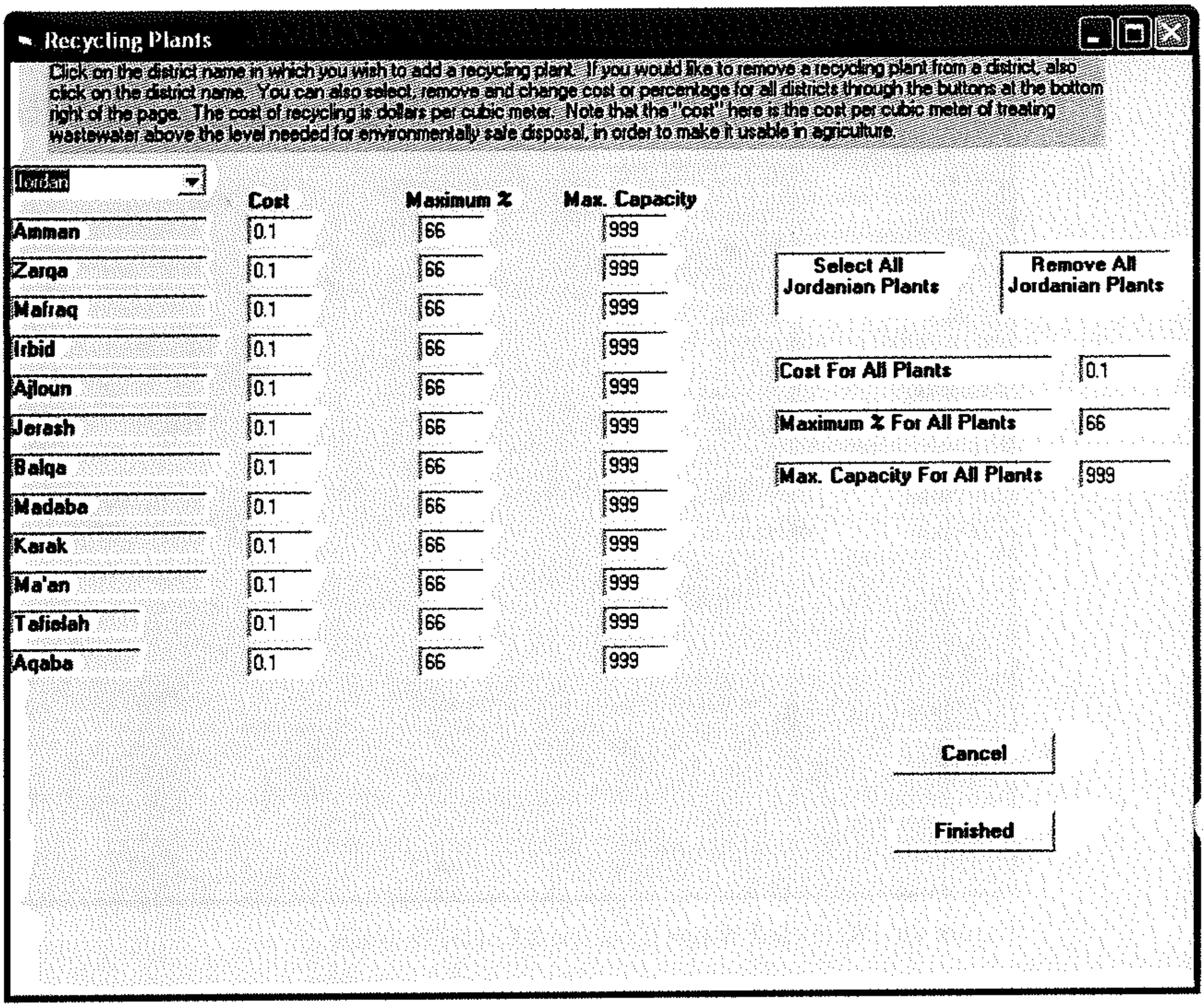

Figure 21 – Recycling Plants

Note that the current program assumes that water is recycled only from urban and industrial uses and is used only in agriculture. The recycling cost specified in this option is the cost of additional treatment to make wastewater suitable for use in agriculture above the cost required to make its disposal environmentally safe. The latter cost (which is specified in the *Environmental Costs section* below) is treated as an effluent cost.

To edit, simply click on a district name. If there is no plant, one will appear, with default values of costs, maximum percentage of water than can be recycled from the wastewater of urban and industrial users in that district, and the capacity of the plant. To remove a plant, click on the district name where these boxes appear, and the plant will be removed. You can put plants in all districts by clicking on the *Select All Plants* button. Similarly, you can remove all plants by clicking on the *Remove All Plants* button. To return to the *Main Screen*, click on *Finished* if you would like to save your edits, otherwise click on *Cancel*.

Environmental Charges and Setasides. The costs of treating water to an environmentally safe level, or alternatively, the cost of environmental damage can be specified by clicking on the *Edit* button to the right of the words *Env. Charges + Setasides*. A screen will appear, shown in **Figure 22**.

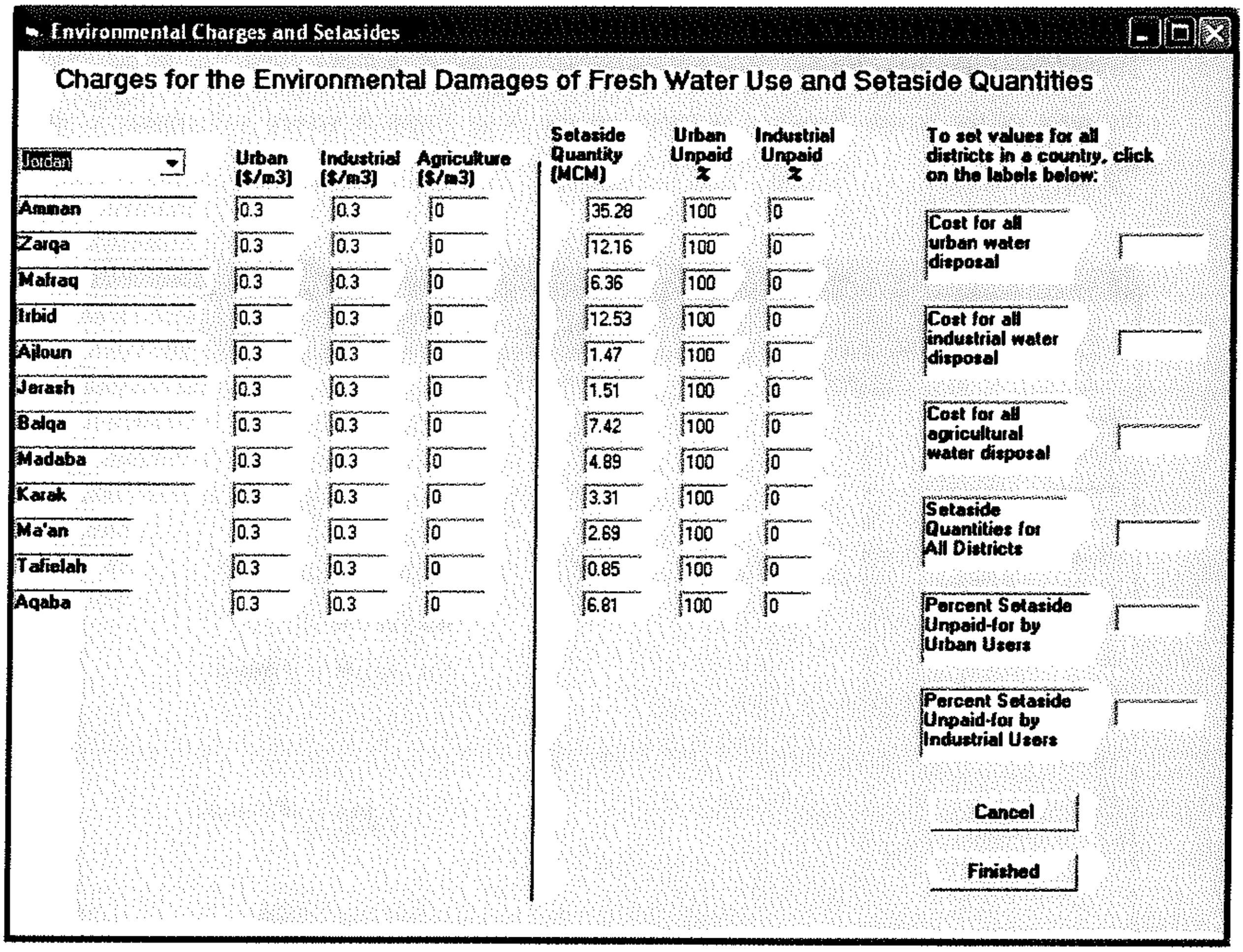

Figure 22 – Environmental Charges and Setasides

This screen also allows the specification of setasides, which may be for purposes of aquifer recharge, parks, or other public uses. The environmental charges are in units of dollars per cubic meter. The setasides are in MCM per year. The setasides are assumed to be costless for the intended use. Costs and quantities may be specified by district by clicking on the appropriate district, or for the entire country by clicking on the boxes labeled with *All Districts*, and entering a number in the boxes that will appear to the right. To save changes and return to the *Main Screen*, click on *Finished*, otherwise click on *Cancel* to return to the *Main Screen* with the original values intact.

Recycled Constraints. The general assumption in WAS is that recycled water and fresh water are perfect substitutes at the same price. This ignores possible added benefits (nutrients) from recycled water as well as possible added costs. Such costs could occur either in the form of reduced yields (because of salinity, for instance) or because equipment to use recycled water is more costly to the farmer. In addition, the treatment of the two water types as exactly equivalent may produce the result that there will be districts using only recycled water despite the environmental consequences. To address these possibilities, recycled water use can be modified by clicking on the *Edit* button to the right of the words *Recycled Constraints* on the *Main Screen*. A screen will appear as illustrated in **Figure 23.**

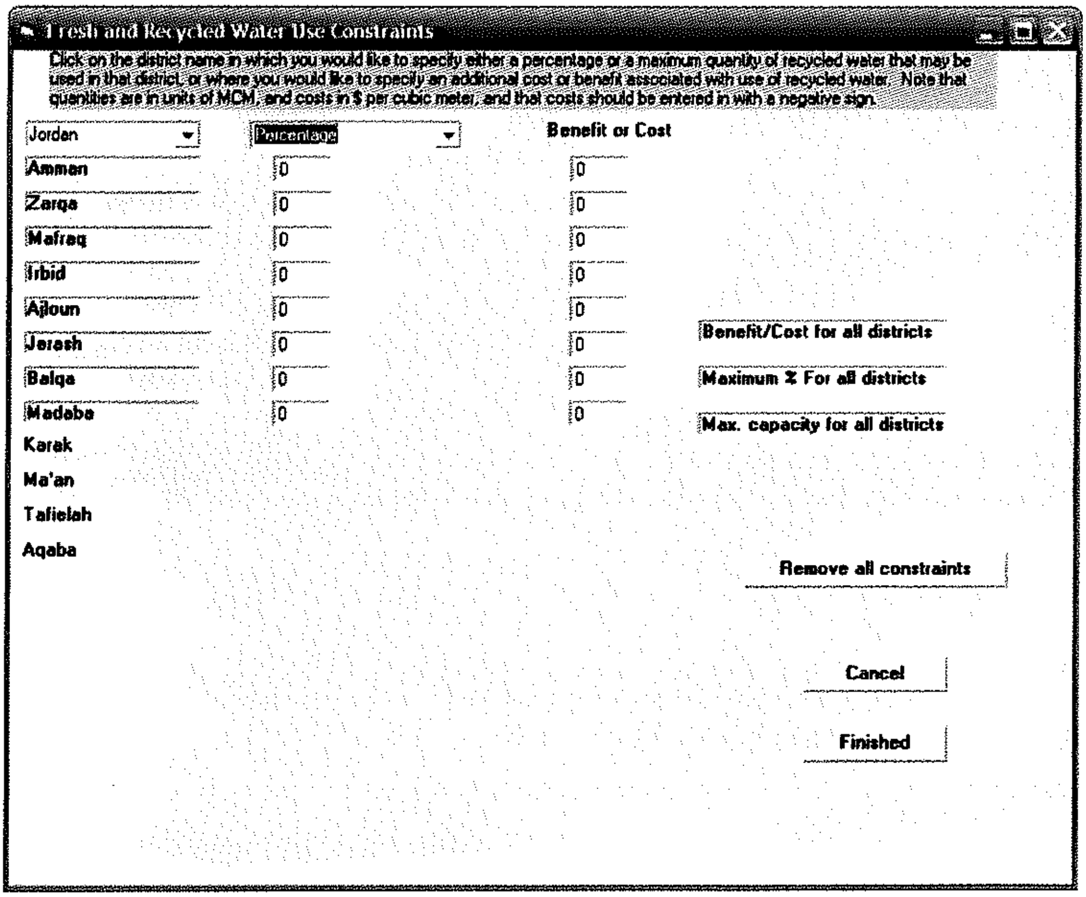

Figure 23 – Fresh and Recycled Water Use Constraints

For any district, an upper bound can be imposed on the amount of recycled water that can be used either absolutely or relative to the total water used. This can be done by clicking on the district you would like to limit recycled water use, and then selecting from the dropdown button either a *Quantity* or *Percentage*.

The additional costs or benefits associated with the use of recycled water for any district may be specified by clicking on the appropriate district and entering a number in the column labeled *Benefit or Cost*. The units are in US dollars per cubic meter. A positive value indicates a cost; a negative value indicates a benefit. The value entered will be multiplied by the amount of recycled water used in that district and subtracted from the objective function. This amounts to assuming that the two types of water are perfect substitutes when the price of fresh water equals the price of recycled water plus the value entered. The farmer chooses the water type with the lower price.

To save changes and return to the *Main Screen*, click on *Finished*, otherwise click on *Cancel* to return to the *Main Screen* with the original values intact.

6.4 Social Policies

This set of options allows the testing of implications of various social policies. The policy tools may be used separately, or in combination, however, you cannot specify more than one policy tool in the same sector for any given district.

To select a price policy tool, click on the dropdown box that says *Select Policy* on the *Main Screen* found below the words *Social Policies*. Choose the type of user for which you would like to set up a price policy (either urban, industrial or agricultural users). You will see a screen appear (see **Figure 24**) that asks you to select one of three policy tools. Each is described below in more detail.

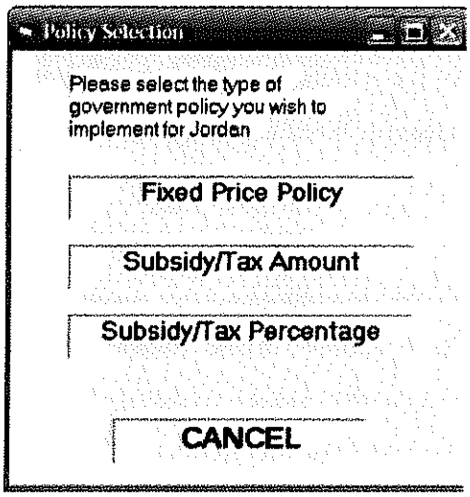

Figure 24 – Social Policy Selection

Fixed Price Policy: A fixed price policy is a system in which the user specifies a set of prices at which consumers must purchase each quantity of water. It is possible to specify different systems of fixed prices for different districts, different demand sectors, and different water qualities.

You will first see a warning screen when you select this policy (shown in **Figure 25**).

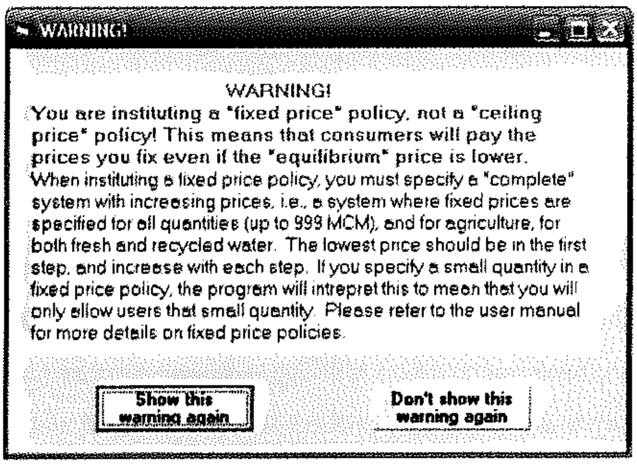

Figure 25 – Warning Screen

If you select agricultural users, you will see an additional screen, shown in **Figure 26**, which asks whether you wish to set a policy for recycled or fresh water.

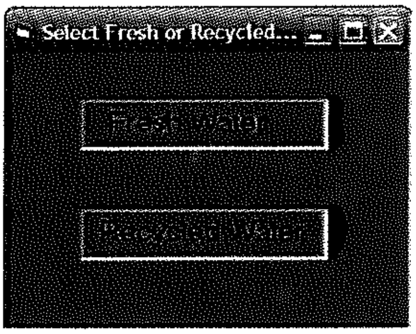

Figure 26 – Fresh or Recycled Water

Simply click on the appropriate water type. The screen shown in **Figure 27** then appears.

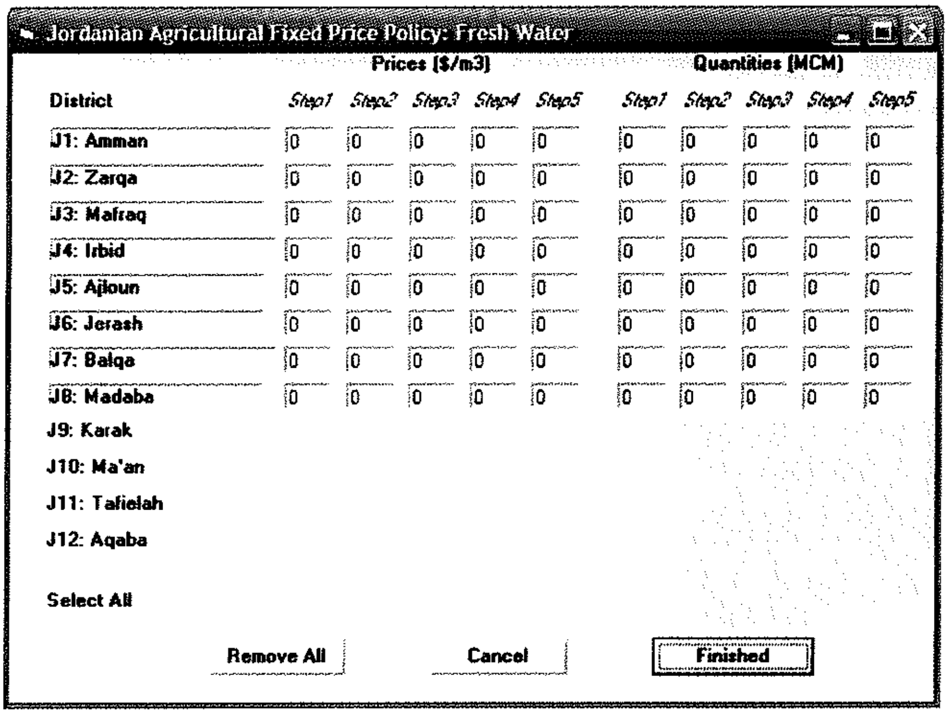

Figure 27 – Fixed Price Policy

The user is allowed to specify up to 5 different "steps" for each district, demand sector, and water type. There are, however, two rules that must be obeyed in defining a fixed-price policy:

1. Prices must increase as quantities do. You cannot have later water quantities purchased at lower prices than earlier quantities.
2. The system of fixed prices must be "complete". This means:

a. Prices must be specified for all water quantities. Hence the last "step" must extend to 999 MCM. Otherwise, the lower quantity will be taken as an upper bound on the quantity available to that consumer.
b. If a fixed-price policy is imposed for either water type and the demand sector in question can use both water types (This effectively means agriculture in WAS 3.3.), then you must also specify a fixed-price policy for the other water type. For example, you cannot set prices for fresh water and say that users can buy recycled water at whatever its price turns out to be. If you set prices only for fresh water for agriculture, then agriculture in that district will not be able to consume any recycled water.

For example (see **Figure 28** for illustrations of these):

a) Enter \$0.10 and \$0.20 for prices in the first two steps, and 5 and 999 million cubic meters (MCM) as the corresponding quantities in the first two steps. Then water users will pay \$0.10 per cubic meter for the first 5 MCM and \$0.20 for all additional water.
b) Enter \$0.10 and \$0.20 for prices in the first two steps, and 5 and 10 MCM as the corresponding quantities in the first two steps. Then water users will pay \$0.10 per cubic meter for the first 5 MCM and \$0.20 the next 10 MCM, and <u>will receive no additional water</u>.
c) Enter a price policy for agriculture for fresh water only, say \$0.10 for 999 MCM. The users will pay \$0.10 for any amount of fresh water they use, but will not be allowed to consume any recycled water.

The reason for such restrictions is that the model will take the fixed-price policies you specify, offer them, in effect, to the demand sector in question, and deliver the water quantities that then maximize that demand sector's consumer surplus. To do this, the prices at which that sector can buy must be known in advance rather than depending on the outcome of the total WAS optimization procedure.

There is another matter that should always be borne in mind while setting fixed-price policies: the model operates at the level of the district, *not* that of the individual consumer. But actual fixed-price policies are invariably set at the individual level. You must translate these to the district level for use in the model. The easiest way to do this is to assume that all consumers in the relevant demand sector will consume the same amount of water and multiply the size of the steps for the individual consumers by the number of consumers in the district. For example, if the first step of the policy allows each farmer to buy 1000 m^3 of fresh water at $0.10 per cubic meter, and there are 5000 farms in the district, then you might specify that the first step at the district level is 5 MCM of fresh water available at $.10 per cubic meter. (Of course, the assumption that all farms will consume the same amount of water may not be a good one; in that case, some other method of aggregating to the district level should be developed.)

Note that the model will treat a fixed-price policy as a commitment by the government to supply water according to a certain price schedule. An example is given in **Figure 28**, where, it is assumed, only one water quality (i.e. fresh water) can be consumed by the demand sector in question, and the user specifies four different steps. The prices corresponding to the steps are denoted by $P_1, \ldots, P_4$, respectively, and the shadow value of water is denoted by P_0.

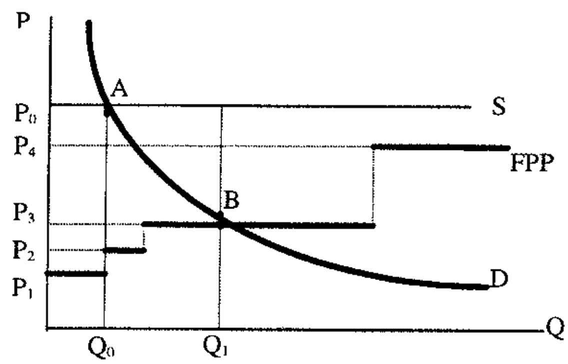

Figure 28

In this case, the consumers will choose to buy quantity Q_1 at price P_3 (instead of buying quantity Q_0 at price P_0, which they would have done in the absence of a fixed-price policy).

Note that the model calculates the quantity to be delivered to consumers as independent of the shadow value of water in the district (which can only be known after the full optimization has been performed). This leads to two possibilities that may not have been intended by the user.

1. The collection of fixed price policies may be infeasible in the sense that it is impossible to deliver to all the consumers involved the amounts they would demand given those policies (and given the infrastructure and other conditions that have been assumed). In this case, the program will show an infeasible result by a shadow value of \$999/m^3, which is indicated on the schematic results with the word INFEASIBLE. The user must then rethink the fixed-price policies involved.

2. The user may intend to subsidize the consumers involved but have created a situation in which the shadow value of water in their district is actually *lower* than the fixed price at which they buy their last m^3, so that they are being taxed. (Of course, such water taxes can also be intentional.) You will know if you have imposed a tax by comparing the shadow values of water against the prices paid by the consumers.

Subsidy/Tax Amount: If you select this policy tool, the screen shown in **Figure 29** will appear. To set the policy for a single district, simply click on the district name and enter the subsidy in dollars per cubic meter. To set the policy for all districts, click on *Select All Districts* and enter in the subsidy, again in dollars per cubic meter. Click on *Finished* or *Cancel* to return to the *Main Screen.*

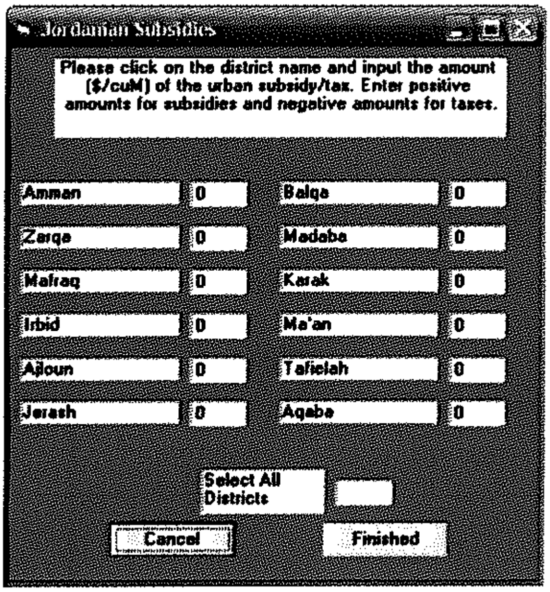

Figure 29 – Subsidy / Tax Amount

Subsidy/Tax Percentage: This option (the screen is shown in **Figure 30**) allows you to incorporate a percentage subsidy or tax for agriculture, urban and/or industry for any district. Subsidies are entered positively, and taxes negatively. Please note that you can enter a general subsidy rate for all the districts in the entity by clicking on *Select All Districts* and entering the rate in the box next to it. Click on *Finished* or *Cancel* to return to the *Main Screen.*

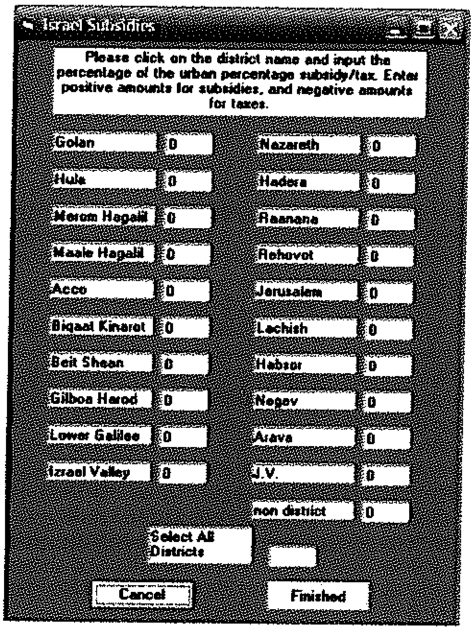

Figure 30 - Subsidy / Tax Percentage

Special Users. There may be issues of impacts on particular water users (e.g., agriculture) that are not taken into account in the demand curve for those users. (For example, long-run effects may not be included in the demand curves.) Although this may be addressed through subsidies, you may think that it is inappropriate to deal with this by means of a subsidy, making the government (as it were) pay for the model's mistake. The alternative is to add a term to the objective function that provides a penalty (per cubic meter) if the users in question receive less than some stated amount of water. To incorporate these costs to special users, click on *Special Users* on the *Main Screen.* The screen shown in **Figure 31** appears. To specify the minimum quantity below which a user suffers an impact, click on the district or *Select All* for all districts, and enter in the quantity (in MCM) and the losses in dollars per cubic meter for the appropriate user. Click on *Finished* when the data are complete, or click on *Cancel* to return to the *Main Screen* with no changes made to the data.

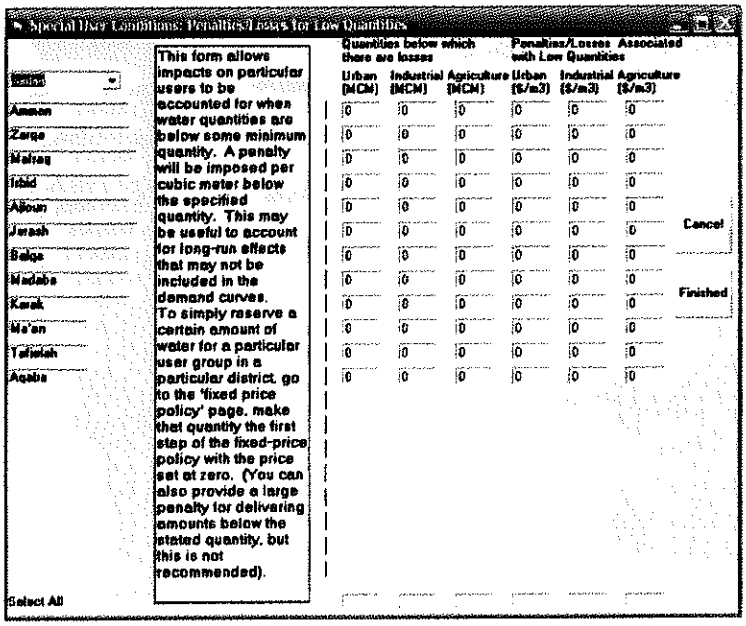

Figure 31 – Special User Conditions

6.5 Optimizing the Model

Scenario Summary. This allows the use to review the options selected, as shown in **Figure 32,** including any descriptive text, and can be viewed at any time, before or after optimization.

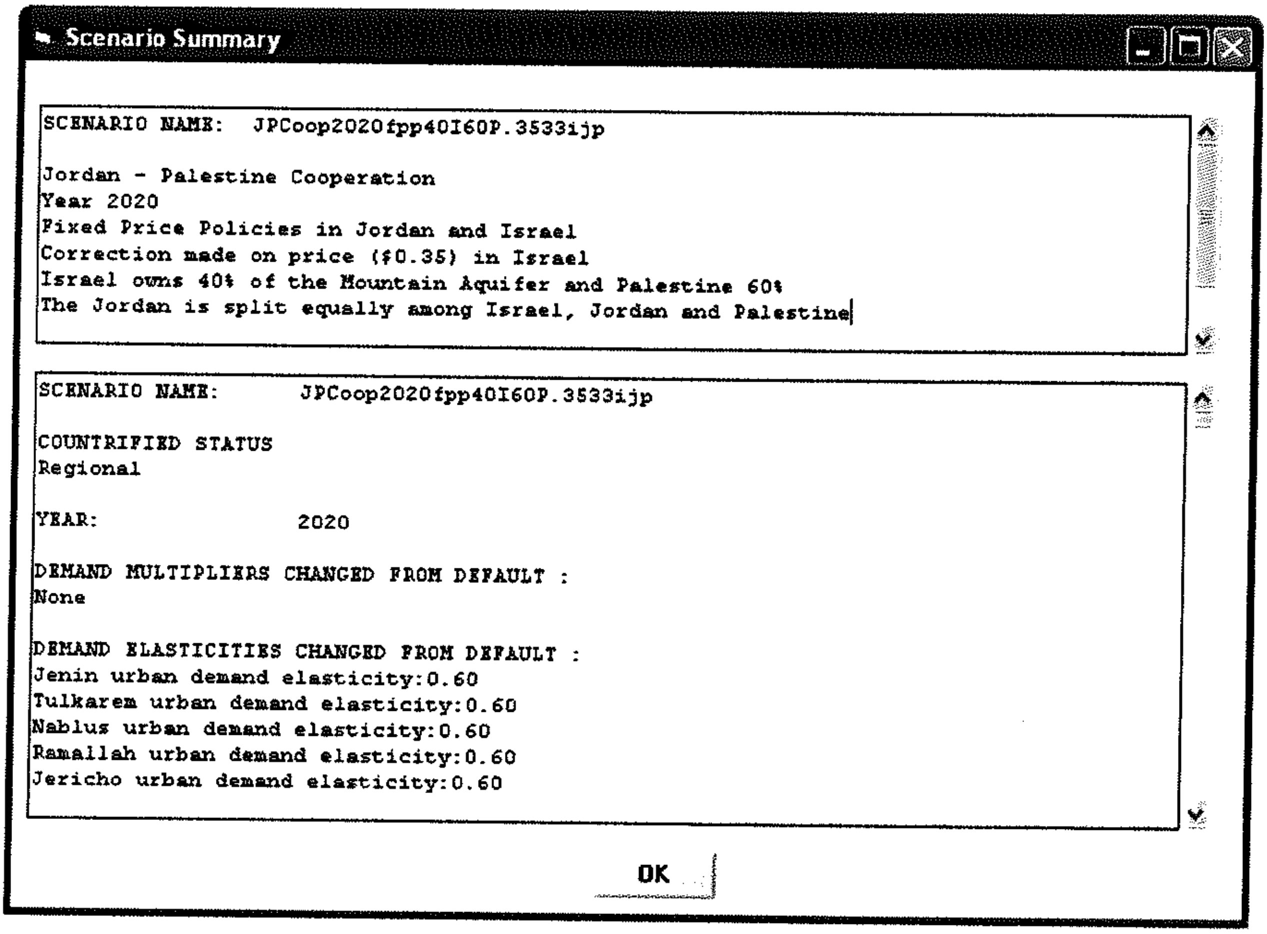

Figure 32 – Scenario Summary

Optimize. When you have completed the input for the scenario, click on *Optimize* on the *Main Screen*. This calls up the GAMS optimization package to generate a non-linear optimization program using the MINOS algorithm. You must choose a scenario name (up to 20 characters with no spaces), and will be prompted to write any length of descriptive text for the run at this point, as illustrated in **Figure 33**.

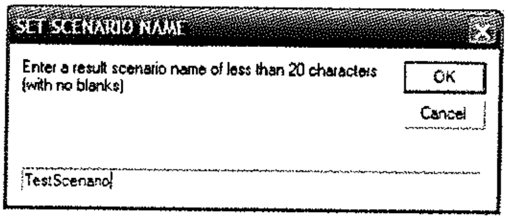

Figure 33 – Scenario Name

You will then see the program optimizing (see **Figure 34**).

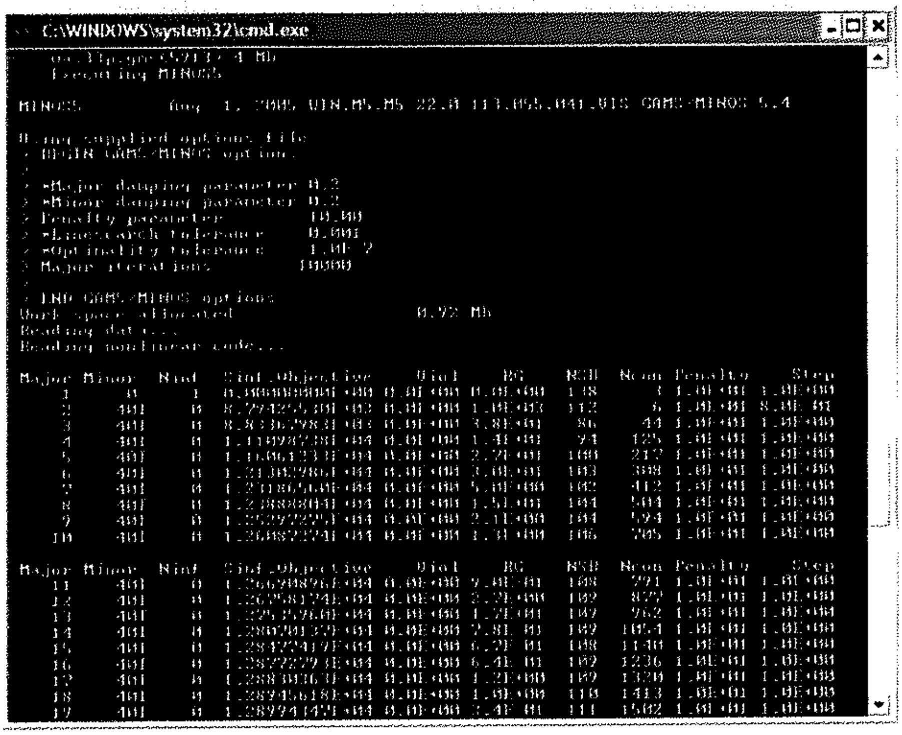

Figure 34 – Optimization Program Execution

When the optimization is complete, you will be notified (see **Figure 35**). You can now review the results of the optimization.

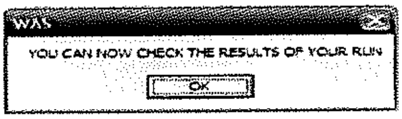

Figure 35 – Optimization Complete

6.6 Viewing Results

The system presents the results in the form of tables and schematics, reflecting the last scenario optimized or loaded.

Tabular. The tabular results include eight different tables, as well as the scenario summary page. One example is shown in **Figure 36.** These tables include information on the shadow values, the prices of water for each of the users in each district, quantities produced, consumed and transported, as well as the social welfare results. Results for the use of desalination plants can be found at the bottom of the eighth screen, titled, *Scenario Data.*

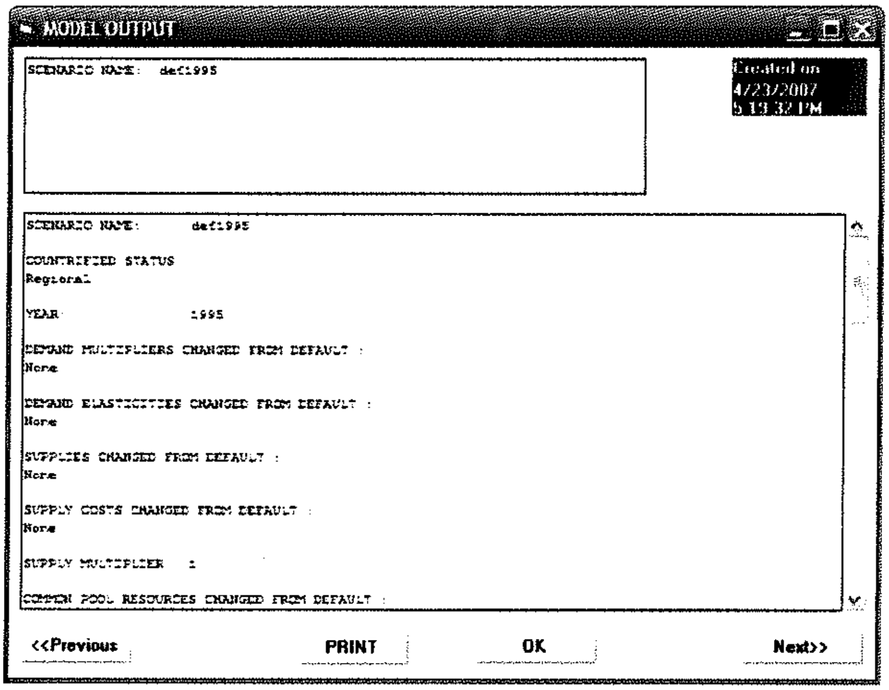

Figure 36 – Tabular Output

To view the tables, simply click on *Next* or *Previous*. In addition, there is an option to print all the tables. To return to the *Main Screen*, click on *OK*.

Schematic—Program Results. This provides a schematic with the results displayed spatially (see **Figure 37**).

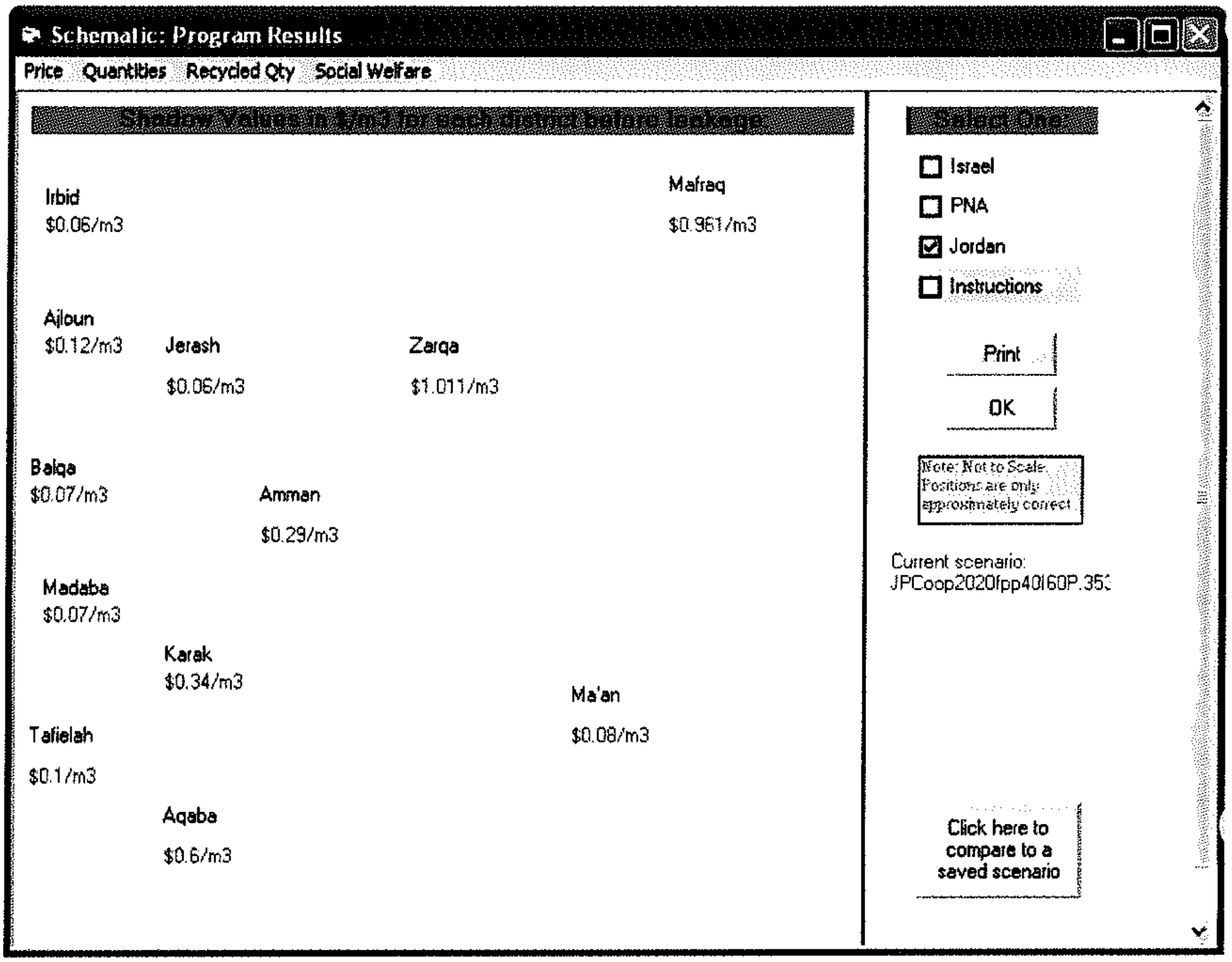

Figure 37 – Model Schematic

You can choose to see the results regarding the prices, and quantities of water, as well as the social welfare. To select the results for any of these, choose from the menu bar at the top of the screen (i.e. Price, Quantities, Recycled Quantities or Social Welfare). After selecting an item the new information will appear, as shown in **Figure 38**.

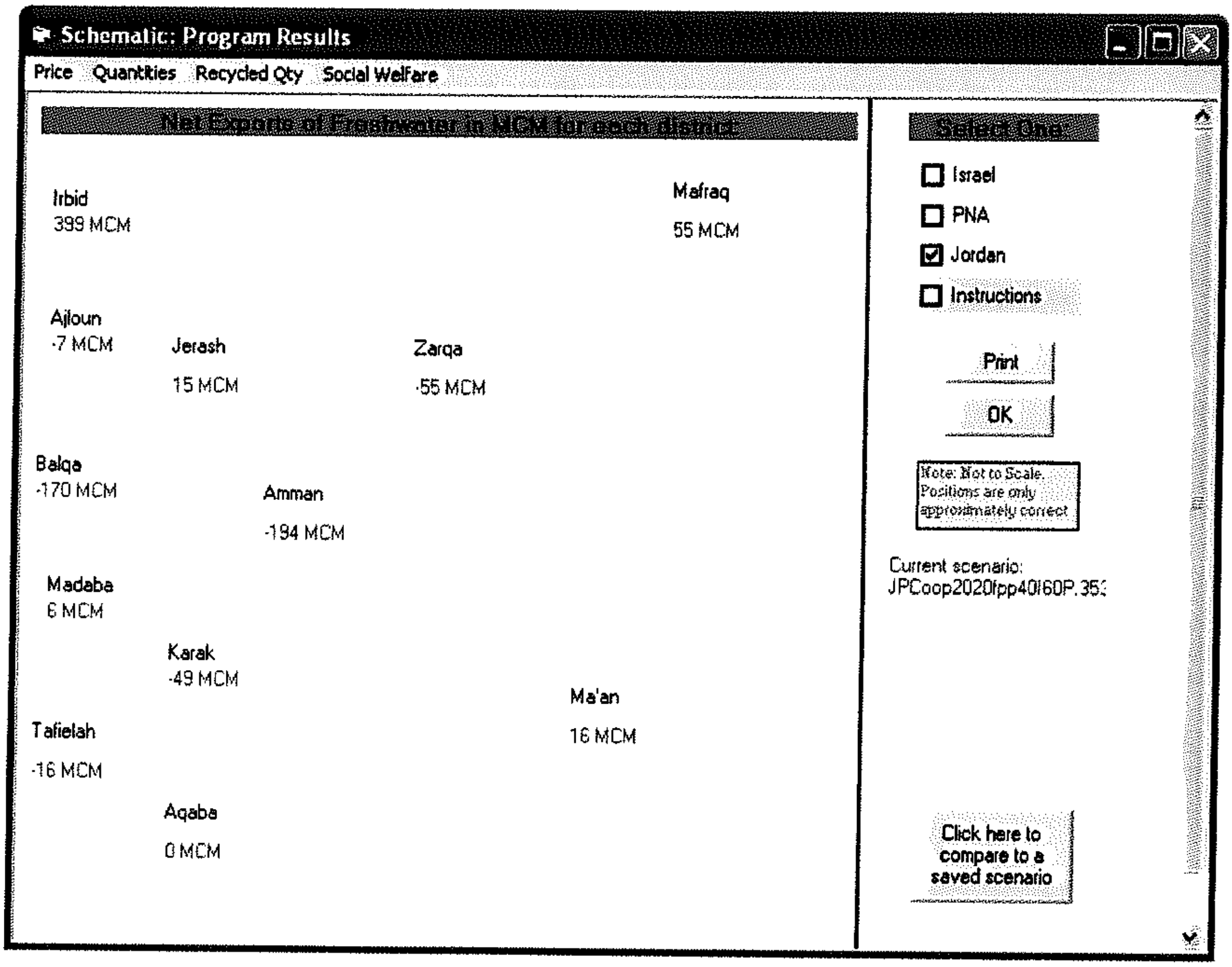

Figure 38 – Net Export of Freshwater

If you see the word <u>INFEASIBLE</u> on the shadow value screen, this is an indication that the specified demands exceed the annual renewable quantity available to a district. You must investigate the source for this error.

NOTE: You can also compare the results from the current run with those from a saved scenario by clicking on *Click here to compare to a saved scenario.*

Cost-Benefit Analysis. This screen allows for a direct comparison of benefits and costs. To do this, run two scenarios. The first scenario should not include the proposed infrastructure; the second should differ from it only in the inclusion of that infrastructure. (Note: This method is not restricted to the evaluation of a particular infrastructure project. It can be used to evaluate collections of infrastructure, the imposition of a particular policy, or any other proposed change. The case of an infrastructure project is used only as the leading example.)

Save each of the scenarios.

Click on the *Cost-Benefit Calculations* button on the *Main screen*. You will see the screen illustrated in **Figure 39**. Select the two scenarios by clicking on the appropriate buttons for the runs with and without infrastructure (and/or policies).

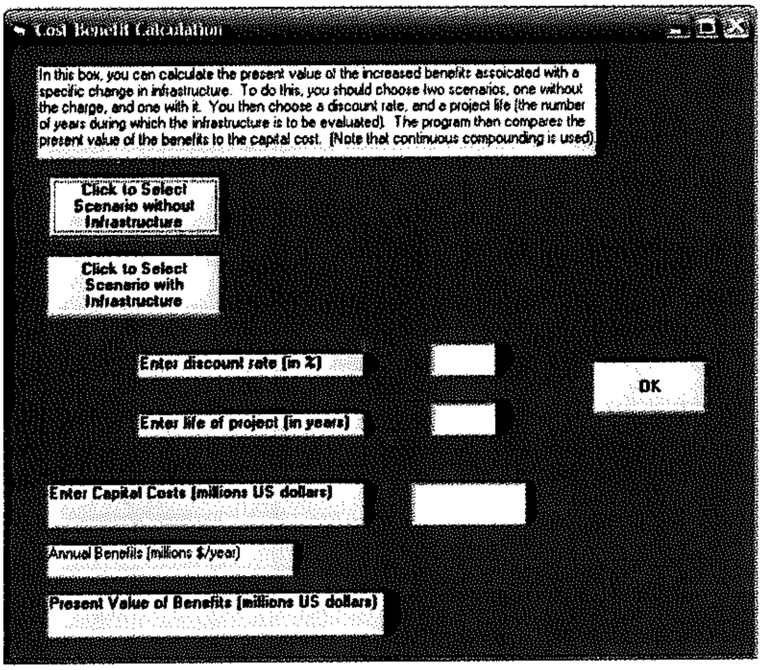

Figure 39 – Cost-Benefit Calculation

Enter the project life (the number of years that the new infrastructure will last or the number of years that a particular change will be in effect). It is not necessary to be very accurate concerning long lives if a non-trivial discount rate is used.

Enter the discount rate (the rate at which you discount future years). In many cases, this will be the same as the interest rate paid on borrowings to finance the project, but this need not always be so.

Enter the capital costs of the project as a lump sum.

The model will now calculate both the annual and the total discounted net benefits of the project. The benefits can then be directly compared to the capital costs. If the benefits exceed the costs, the infrastructure/policies are worth further investigation.

In addition, this can be used to evaluate the costs and benefits associated with a price policy or setaside, not only with the districts directly affected, but the entire system-wide effects.

6.7 File Maintenance

Save Scenario. This is used to save the results currently generated (after optimizing). Simply click on the words *Save Scenario* from the *Main Screen.* The name chosen before running the optimization is used as a default to create a subdirectory to "**c:\was33**" which then will contain copies of the results. You may modify the name at this point. You will then be asked to write some descriptive text that will assist you in knowing what the run contains (see **Figure 40**, which is helpful when you wish to load results.

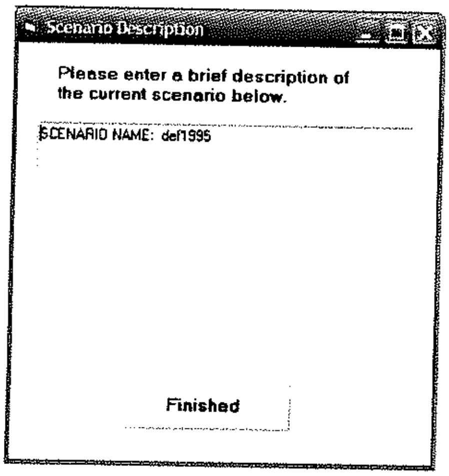

Figure 40– Scenario Description

Load Scenario. To see the results from an existing scenario, click on the words *Load Scenario* on the *Main Screen.* You will see a list of saved scenarios. When you click on the name of a scenario, you will see the descriptive text that you wrote when you saved the run, as described above. The schematics and tables are then updated with the loaded scenario.

Delete Scenario. To delete existing saved scenarios, click on the words *Delete Scenario* on the *Main Screen.* You will see a list of the scenarios saved on the computer currently being used. Simply click on the scenario you would like to delete and click on *Delete.* You will be asked to confirm that you would like to delete the selected scenario. Click on *Yes* or *No*, as appropriate.

Click to Quit. When you've finally had enough!

6.8 Help

The user can obtain help from the Visual Basic form by clicking on the white boxes to the left of where data are entered, such as the words *Year, Demand Properties, Supply of Water, Recycled Constraints,* etc.. Additional help is provided as described below.

User Guide. This guide, on-line (not yet implemented).

WAS Updates. When you click on this button, a screen appears, as illustrated in **Figure 41** which describes the changes made to the program over the past year.

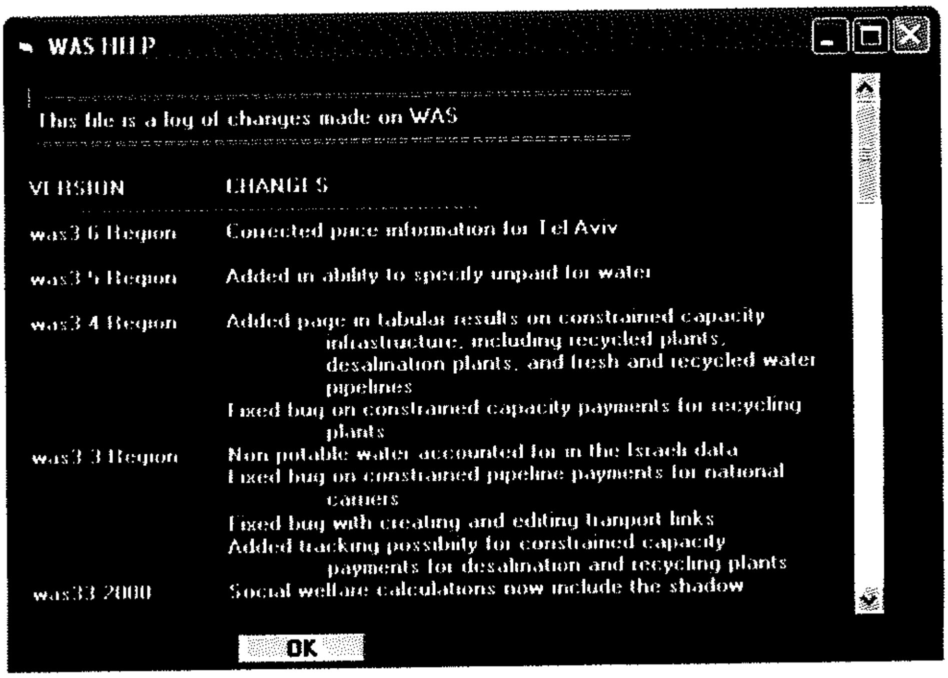

Figure 41– WAS Updates

District Names. Displays the names of the districts

About WAS. This button provides information on whom to contact with comments or questions. See section 7 of this document for this information as well.

7.0 Contacts

Please try to explore the options that WAS provides and please report any problems/ bugs/suggestions/comments/ compliments(?) you may have to the Central Team so that any program faults can be corrected as soon as possible.

There are bound to be problems as with all new releases - please let us know as soon as possible if (or when!) you find any. Please send us your views/suggestions/corrections or other updated costs, links, capacities, supplies, demands, scenarios, etc., as soon as possible. Please email us at:

a.huber-lee@cgiar.org or ffisher@mit.edu

Harvard Middle East Water Project

WAS

VE RI TAS

Harvard University, ISEPME
Delft Hydraulics Institute
Al Azhar University Water Research Center
PMU - Palestinian Management Unit
ROID Development & Engineering
Technion Water Research Institute

Facilitated by the Government of the Netherlands

The Water Allocation System (WAS)

Volume I

Version 3.2

Developed by the

Palestinian, Jordanian, Israeli and Central Teams
of
The Harvard Middle East Water Project

September 1997

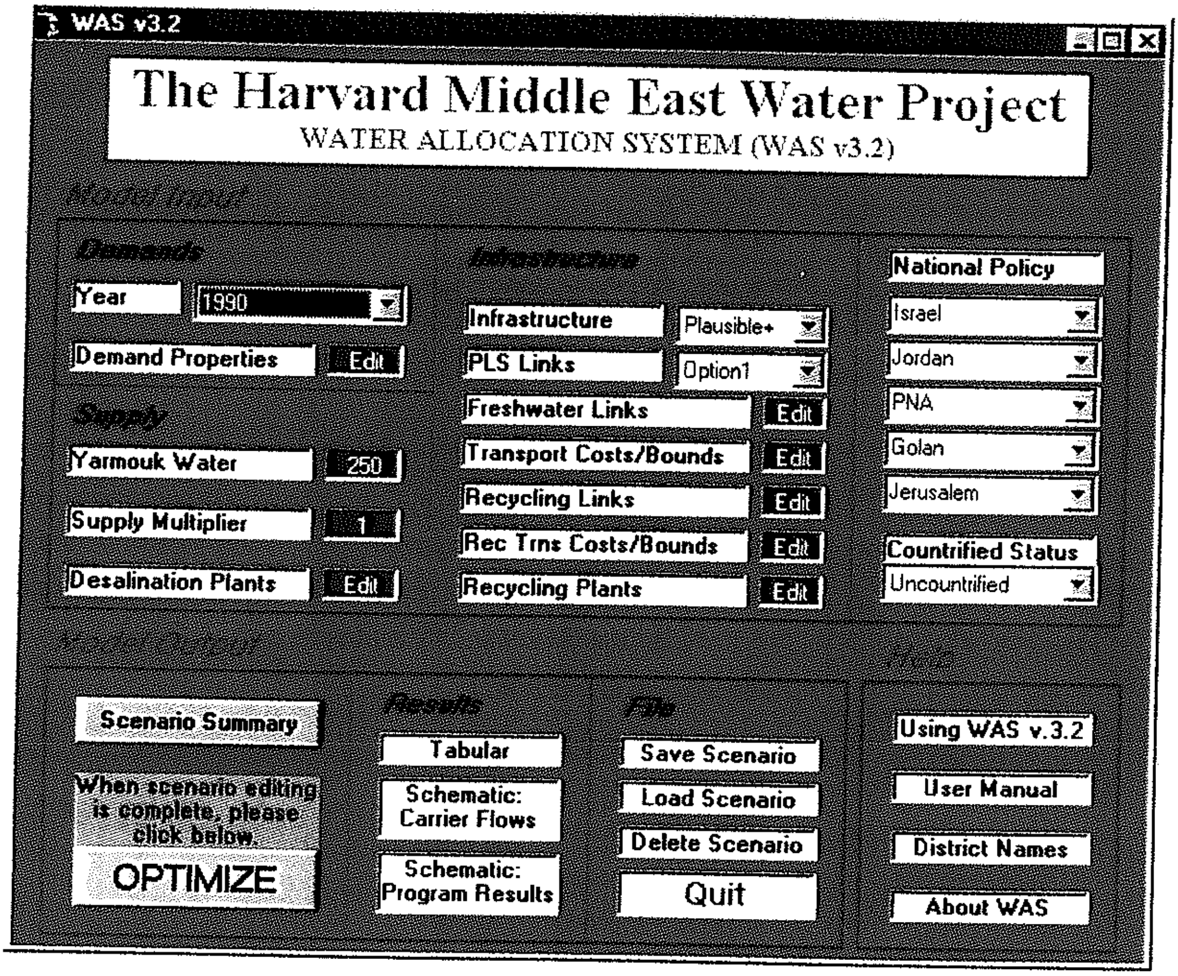
WAS v3.2
The Harvard Middle East Water Project
WATER ALLOCATION SYSTEM (WAS v3.2)
Demands
Year
1990
Demand Properties
Edit
Supply
Yarmouk Water
250
Supply Multiplier
1
Desalination Plants
Edit
Infrastructure
Infrastructure
Plausible+
PLS Links
Option1
Freshwater Links
Edit
Transport Costs/Bounds
Edit
Recycling Links
Edit
Rec Trns Costs/Bounds
Edit
Recycling Plants
Edit
National Policy
Israel
Jordan
PNA
Golan
Jerusalem
Countrified Status
Uncountrified
Scenario Summary
When scenario editing is complete, please click below.
OPTIMIZE
Results
Tabular
Schematic: Carrier Flows
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Table of Contents

1. Introduction

This user manual explains the installation and execution of the Water Allocation System (WAS) model, version 3.2, developed by the Harvard Middle East Water Project Team. It also provides useful hints on how to operate the system successfully. The user manual will be updated regularly as the WAS program is modified.

This manual assumes some knowledge of computers in general. It is also assumed the reader is familiar with the theory behind the model, however, a summary is given in Appendix A to this user manual.

WAS is made up of essentially two parts: the algorithm that solves the allocation problem, and the user interface. The main innovation of WAS 3.2 (over previous versions) is the improved user interface. The user can now run (almost) any scenario, without having to interact with the DOS code or environment.

2. Hardware Requirements

To run the WAS system, algorithm plus interface, requires:

- An IBM compatible PC with a Windows 95 operating system, preferably with a Pentium chip.
- GAMS (Generalized Algebraic Modeling System) software.
- At least 8 MB RAM (preferably 16 MB).
- Approximately 10 MB of free space on the hard drive.
- Additional disk space as needed for saving results.

Note: If you are planning to run scenarios fairly frequently, we recommend that you install the WAS system on the fastest machine you have.

3. Installation

To install the WAS system, please complete the following steps, noting that this procedure is different from previous versions.

1. In order to copy the WAS files to your computer, complete the following steps:
   - Go to the **MS-DOS prompt**, which is found under Programs.
   - Insert the WAS_32 disk in drive **a:**
   - At the C:\ prompt type:

   a:\wassetup <enter>

   - Type **exit** at the MSDOS prompt to return to Windows 95.

2. Using a text editor (such as the Notepad program found under Programs and Accessories), modify the path statement in the **autoexec.bat** file to include **c:\was_32** and reboot. The path statement will look similar to the following, depending on what other software is installed on your machine:

   - **set PATH=c:\windows;c:\windows\system;c:\was_32;c:\gams;**

     Note: the path statement has a limit on the length of the string it can read, you should make sure that the statement was not truncated. To check this, type **path**, after you reboot the computer. You should see both the gams386 and was_32 directories.

3. In order to create an icon for WAS v3.2:

   - Click on **START**, select **Settings**, then the **Taskbar**.
   - Under the **Taskbar**, select **Start Menu**, then **Add**.
   - Select **BROWSE** and go to the **WAS_32 subdirectory**.
   - Choose **was_32.exe**, which is associated with an **icon of faucet with running water.**
   - Then hit **Next**, and place the shortcut in the **Programs folder.**
   - Hit **Next** again, then **Finish** and **OK.**

4. You will now find WAS_32 under START, and Programs. Simply **double click on the WAS_32 icon to run WAS.**

5. If the WAS program stops working at any time and you suspect that it is due to some of the files accidentally being deleted or altered, you should be able to rectify this by re-installing the WAS software.

4. File Description

In the installation process you copied two sets of files. The first consists of the WAS program files which will be described below in more detail. GAMS files as described in the GAMS user manual; GAMS solves the allocation problem. Second, there are files for the Windows interface, which are programmed in Visual Basic and compiled into an executable file. These files support the execution of the program.

The files at the heart of the system are located in the **\was_32** directory, which contains the following:

- **was_32.exe** – The Visual Basic executable file. It defines the user interface, and works only in a Windows environment.
- **was_32.gms** -- The allocation program written in GAMS code. This optimization program solves the water allocation problem using MINOS as the non-linear

solver[1]. The general theory is described in Appendix A to this manual. It is not critical to understand the GAMS code in detail. As you become a more advanced user, however, you may want to browse this file and with the help of the GAMS user manual get a better understanding of how the program works. The program is structured to read external files during execution - these external files (for demand, supply, etc.) are selected or created by the Visual Basic interface just prior to optimization.

- ***.lst** – The output directly from the GAMS program. This file is difficult to interpret, therefore the results are read from output files generated to be read into the Visual Basic interface.
- ***.inc** -- Files to be read by GAMS as part of the WAS program. There are various inputs you can define before running the program, in particular through using the Visual Basic interface. The was_32.gms file gets these different files by including different input files (for example dem.inc has the demand relevant for the defined inputs). The *.inc files are of two types: first, those that are read directly by was.gms; and second, those containing information which is copied into the first type when relevant. For example: when the demands for 2010 with the PNA Middle1 scenario are selected, the file dem2010b.inc is copied to dem.inc (where it is subsequently read by was.gms).
- ***.frm; *.frx** -- Visual Basic files that generate the forms viewed in the interface.
- **was.ot*; was.scn; was.sc*** -- Files containing the results of the run in a more readable form than was_32.lst. These files include the values of important decision variables and some post-processing of these values. Normally, you would access these through the interface.

5. Running the WAS program

After completing the installation, all you have to do is enter Windows and double-click on the WAS_32 icon. In what follows we describe in some detail how to work from here.

6. The Interface

In this section we examine and provide a general description of the different menu options, and also give some useful hints. Our discussion is based on the menus, and does not cover all the possible things you could do. We trust that once you become familiar with the options, you will have the ability to create the scenarios you are interested in, and that the model accommodates.

Note that most of the description given below can be found through the WAS interface by clicking on the buttons on the left side of the options, as exemplified in **Figure 1**.

---

[1] For more details, see GAMS Release 2.25: A User's Guide. A. Brooke, D. Kendrick and A. Meeraus. GAMS Development Corporation, Washington, DC. 1996.

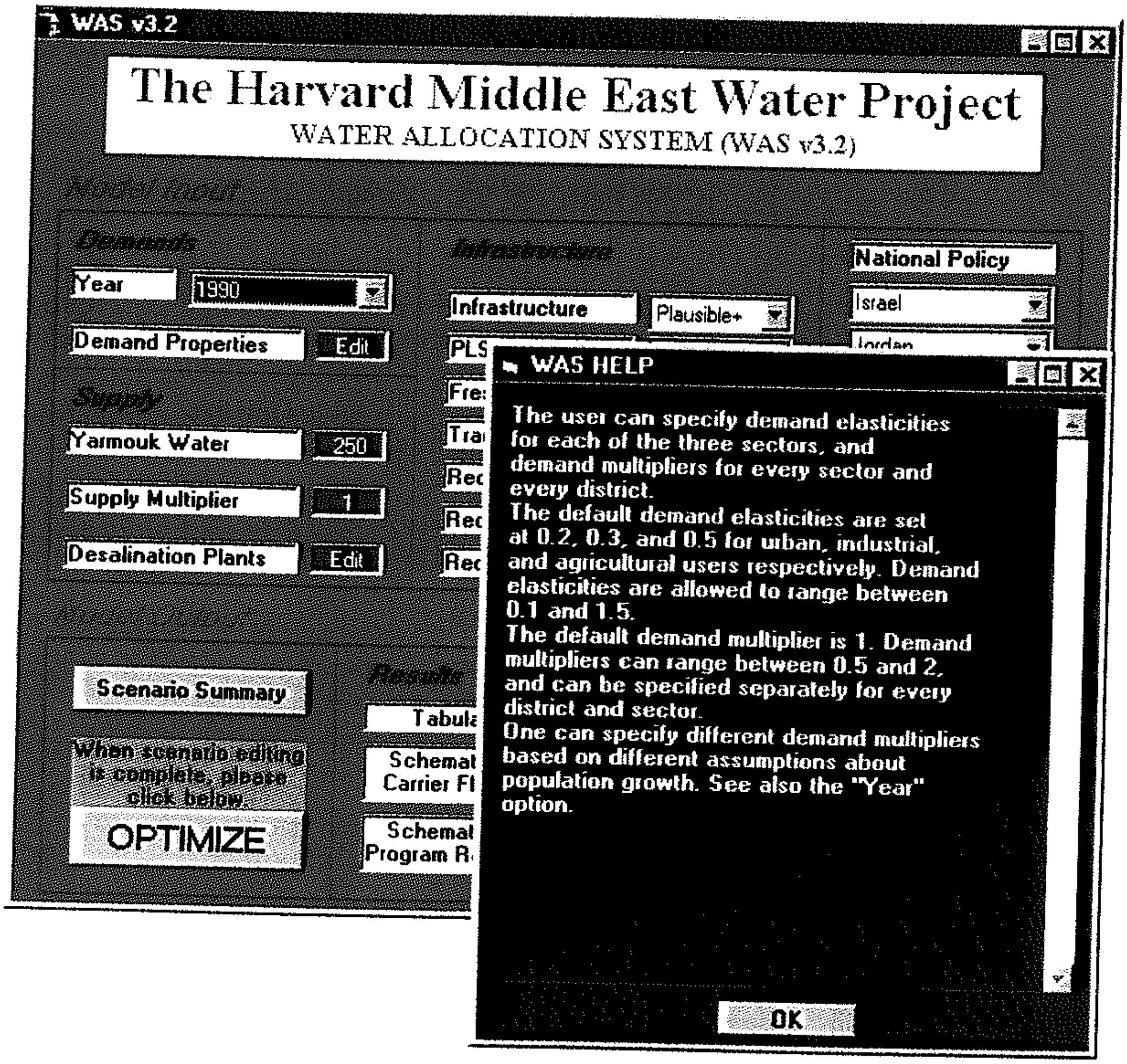

Figure 1: Help in WAS 3.2

6.1 Demands

Scenario Year: This allows you to choose the demands for the year for which you wish to consider. The current choices are 1990 (to be updated to 1996), 2010 and 2020, with the last two having three scenarios each for low, middle and high PNA growth scenarios. They also have a suffix (1 or 2) corresponding to different distribution patterns of Palestinian returnees (1 if they are proportionally distributed to the current population in each of the districts, and 2 if half the returnees are assumed to be in the Jericho region, with the rest distributed over the other districts as in option 1).

Demand Modification: There are two features of demand curves that can be easily modified, one which affects the shape of the curve (more accurately, the elasticity of demand), and one that allows proportional changes to the curve (**Figure 2**). The demands in WAS 3.2 are represented by a constant elasticity function of the form $Q=MP^{-\mu}$, where Q is quantity, P is price, and M and μ are parameters. The parameter μ is the absolute value of the elasticity of demand, and measures how responsive demand is to price. The first option allows the user to modify μ. The program specifies bounds, partly according to what is reasonable, and partly for computational reasons, and will not allow input values outside of these bounds.

The second option (shown in **Figure 3**) adjusts the coefficient, M in the demand function, allowing the exploration of the effects of greater or lesser demands. For example, if you wish to assume a 20% greater population in a district than that assumed in the chosen demand scenario year, you would do this by setting the value of M for that district equal to 1.2.

6.2 Supplies

Yarmouk from Syria: The annual flow of the Yarmouk south of Syria into the modeled region is taken as an adjustable parameter. It can range from 10 MCM to 500 MCM. The default value is 250 MCM.

Supply State: Supply multipliers can be specified for drought and wet year scenarios. The value selected by the user multiplies all naturally occurring water supplies.

Desalination Plants: This allows the choice of locations for desalination plants (shown in **Figure 4**). Given the variability of desalination costs, the cost of desalination can be set here (typical values from the literature range from $\$0.8/m^3$ to $\$1.5/m^3$). The default assumption is unlimited capacity for user-specified desalination plants. Program results can then be used to determine how large a capacity will be needed in a particular scenario.

6.3 Infrastructure

Infrastructure Options: This allows a choice from a set of predefined scenarios (for transport of fresh and recycled water and recycling and desalination locations). These scenarios are a starting point for infrastructure assumptions and can then be modified later

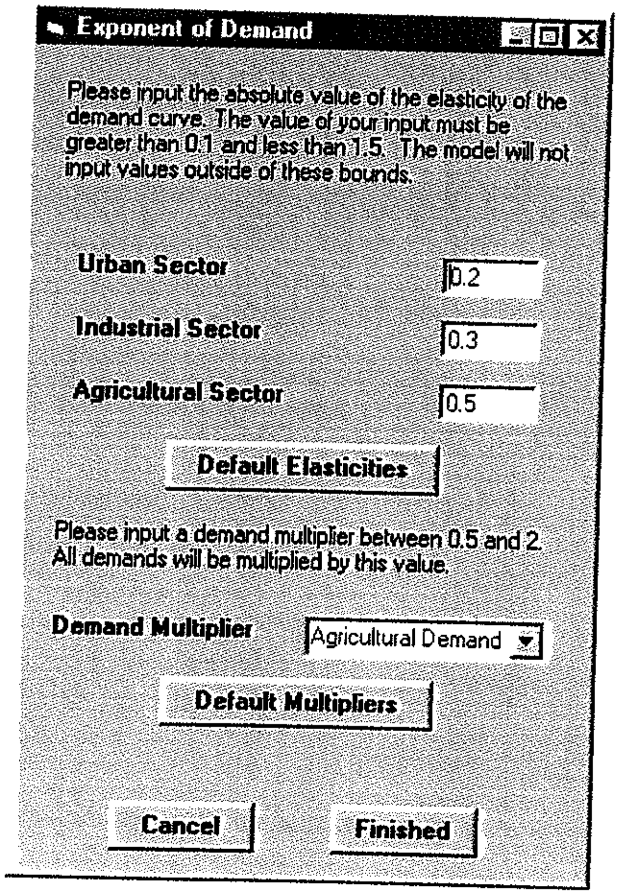

Figure 2: Modification of Demand Curves—Changing Elasticities

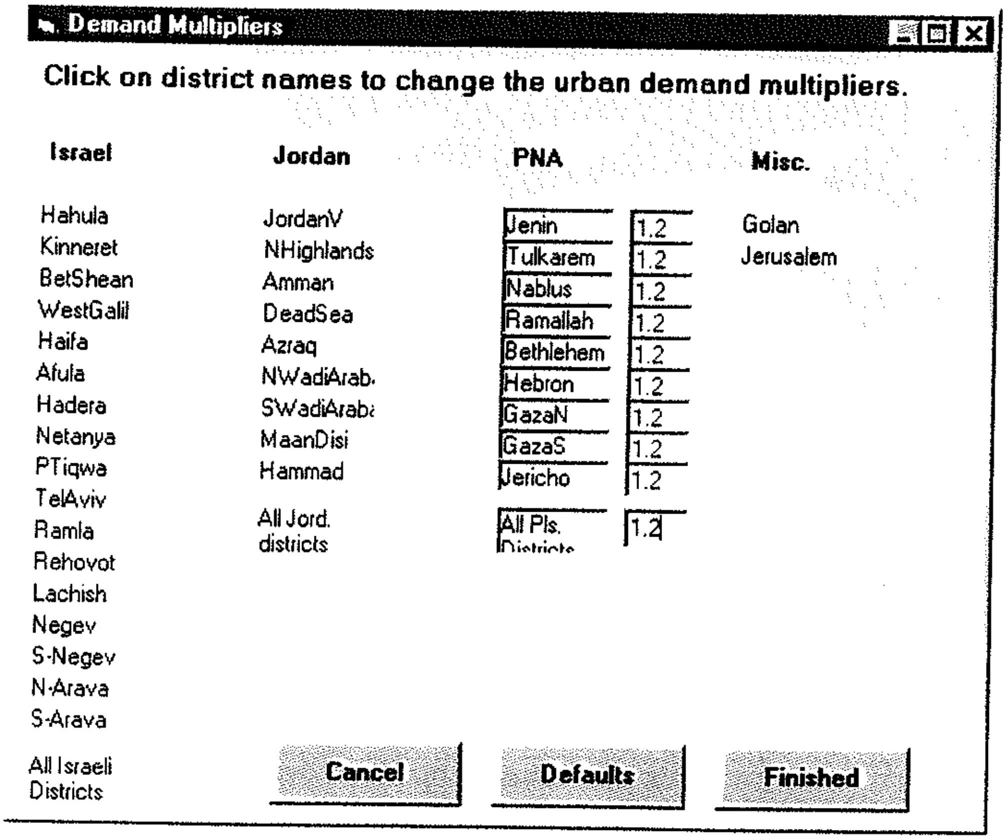

Figure 3: Modification of Demand Curves—Changing Multipliers

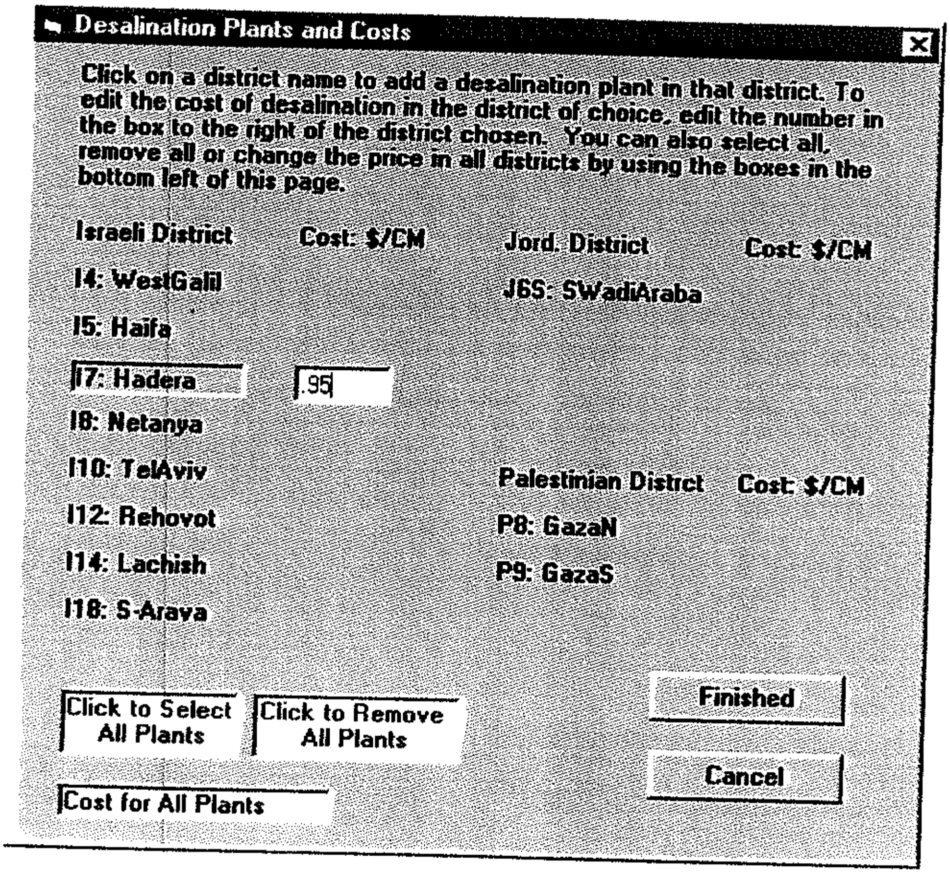

Figure 4: Adding or Modifying Desalination Plants

in the menu. The pre-defined scenarios are called "Current," "Current+," and "Plausible+" and have the following characteristics:

- Current: In the "current" scenarios, only the pipelines and recycling facilities actually in place in 1990 are assumed.
- Current+: In the "Current+" scenario, the possibility of bringing water from the Sea of Galilee to both the Jordan Valley region of Jordan and the PNA Jericho region are added. Both North and South Gaza are connected to the Israeli National Carrier by pipelines that are not capacity constrained.
- Plausible+: In the "Plausible+" scenario, capacity constraints are removed on most pipelines, and pipelines connecting the Jordan Valley and Amman to the Northern Highlands are added. Further, new recycling plants are located in Gaza with conveyance to the Negev, and also in the cities of the Northern West Bank, with conveyance to the Jericho district.

PLS Link Options: A set of predefined scenarios (for transport of fresh water on the West Bank) are given as follows:

- Option 1: (*Current connections*) In this variation, only those connections in existence in 1990 are assumed. These consist of a pipeline from Jerusalem to Bethlehem and another from Bethlehem to Hebron. The districts of the northern West Bank are not connected.
- Option 2: (West Bank Interconnected (WBI)) Here, the districts of the West Bank, except for Jericho, are assumed connected to each other and to Jerusalem, but not to any other district.
- Option 3: (WBI with Jordan River (W-J)) In this version, added to the connections of the WBI version are connections from the Jordan River (Jericho district) to three of the northern West Bank districts (Jenin, Nablus, and Ramallah).
- Option 4: (WBI with connection to the Israeli National Water Carrier (INC)) Here a connection is provided form the Nablus district to the Israeli National Carrier.
- Option 5: (WBI, W-J, INC) This final variation has all the connections already described. That is, the West Bank cities are interconnected to Jerusalem; and there are connections from the Jordan River to the northern West Bank and from the northern West Bank (Nablus) to the Israeli National Carrier.

Freshwater Links: Users can specify the existence or removal of freshwater links between any two districts. The direction of flow is color-coded, as illustrated in **Figure 5**: yellow indicates flow from the originating district to the destination district, green indicates the reverse, and pink indicates the ability of flow in both directions.

To use this option, proceed as follows: Click on "origin" and select an origin list. Then click on the origin you want. The color code now tells you what links are in place. To change a link, click on the destination until you get the color you want. If you add a link, you will be asked to specify transport costs and capacity.

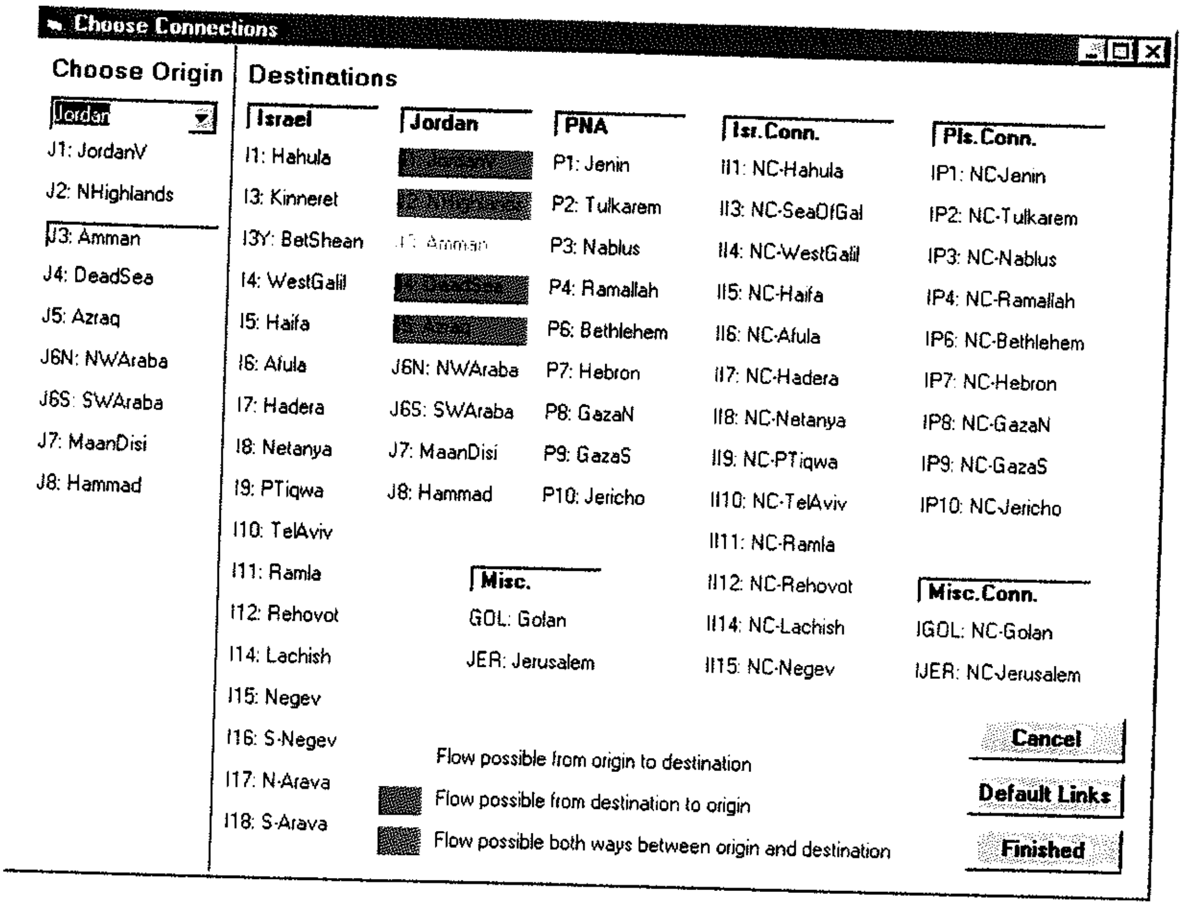

Figure 5: Adding or Deleting Conveyances between Districts

NOTE: Some of the links chosen may be overwritten by other options you specify. For example, if you choose a countrified version, you will not be able to add links between the "countrified" entity and any of the other entities.

Transport Costs/Bounds: This option allows the user to alter the cost of transport (not including capital costs) between any two districts, as well as any capacity limits (see **Figure 6**). Only links already existing can be modified in this menu option.

Recycling Links: Users can specify the existence or removal of recycling links between any two districts. The direction of flow is color-coded, as with the freshwater menu: yellow indicates flow from the originating district to the destination district, green indicates the reverse, and pink indicates the ability of flow in both directions. Use of this option is similar to the use of the freshwater links option described above.

Recycling Transport Costs/Bounds: This option allows the user to alter the non-capital cost of transport between any two districts, as well as any capacity limits. Only links already existing can be modified in this menu option.

Recycling Plants: Recycling plant locations, the associated percentage of the household and industry fresh water consumption that can be recycled and the cost per cubic meter for retreatment are specified with this option (**Figure 7**). Note that the current program assumes that water is recycled only from urban and industrial uses and is used only in agriculture. The recycling cost specified in this option is the cost of additional treatment to make wastewater suitable for use in agriculture above the cost required to make its disposal environmentally safe. The latter cost (taken as US$0.30 per cubic meter) is treated as an effluent cost.

6.4 National Policies

This set of options allows the testing of implications of various national policies.

National Policies by Country: The following three options allow for entity-specific policy tools, that can be used separately or in any combination (**Figure 8**). However, you cannot specify more than one policy tool in the same sector for any given district. The different tools are:

- **Subsidy/Tax Percentage:** To incorporate a percentage subsidy or tax for **agriculture, urban and/or industry** for any district in any of the entities considered, or any combination thereof. Subsidies are entered positively, and taxes negatively. Please note that you can enter a general subsidy rate for all the districts in the entity by selecting "All Sites" within an entity and entering the rate in the box next to it (see **Figure 9**).
- **Subsidy/Tax Amount:** Similar to above, but considers a subsidy (or tax) fixed in monetary terms, rather than a percentage.
- **Fixed Price Policy:** This option allows the specification of water quantities and prices, for up to 5 steps or intervals per district and per demand sector

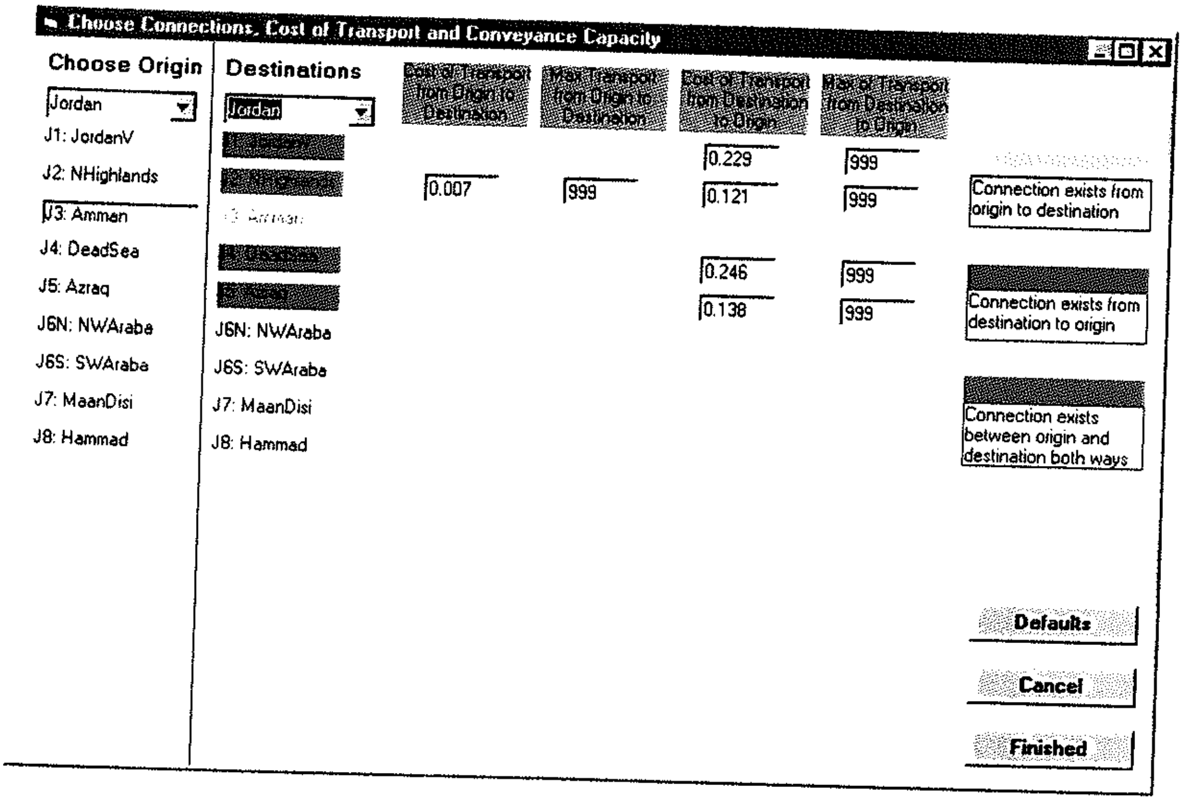

Figure 6: Modifying Costs and Capacities of Conveyances

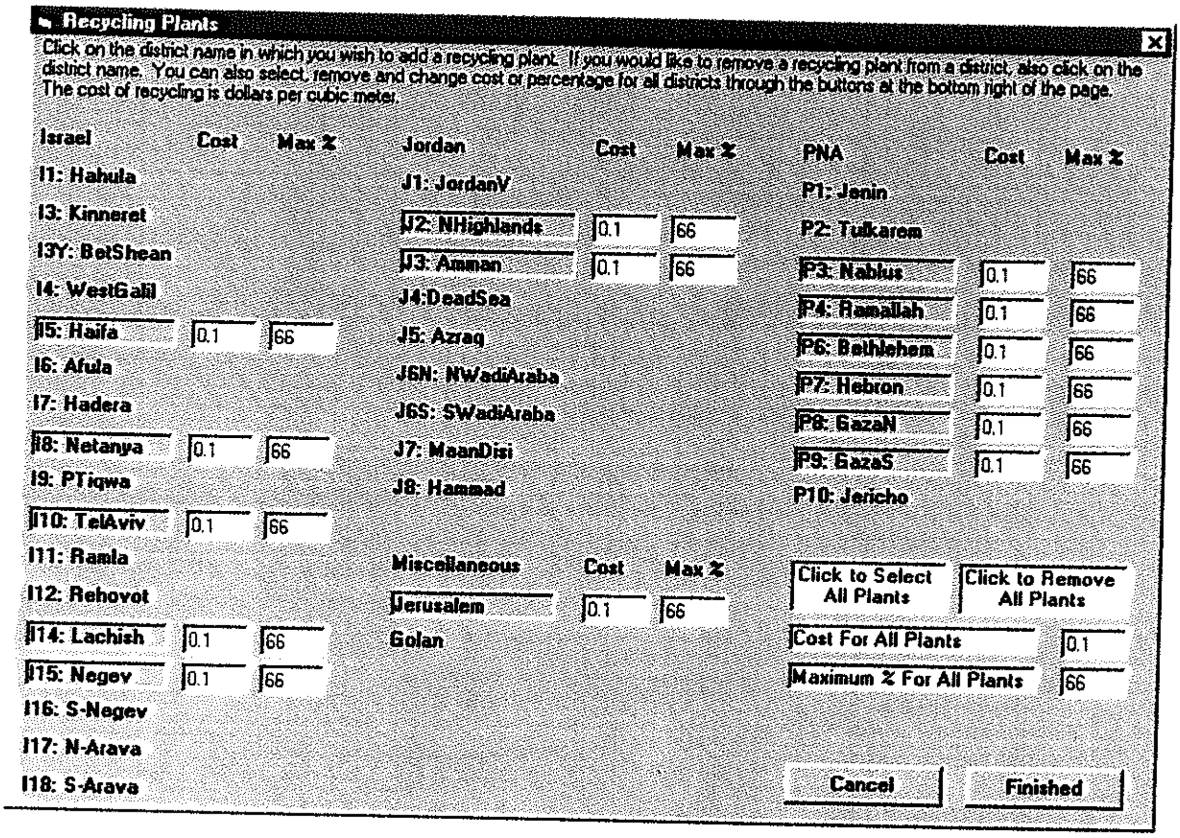

Figure 7: Adding and Modifying Recycling Plants

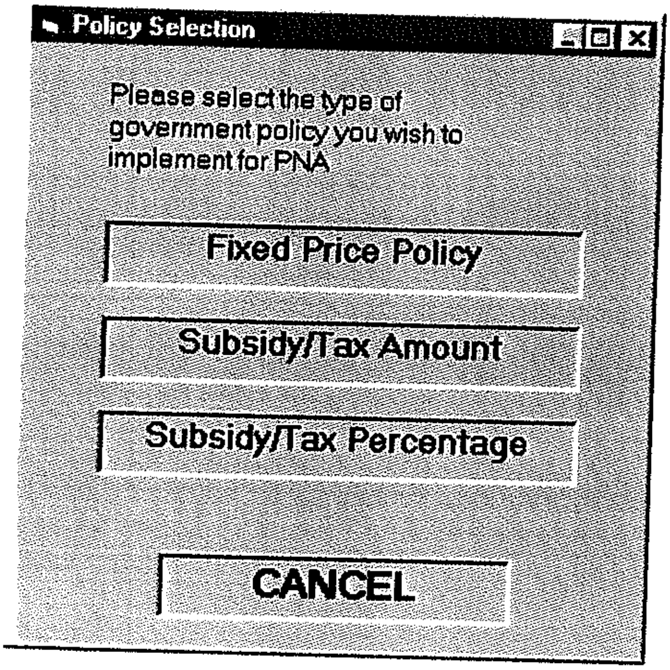

Figure 8: Selection of National Policy

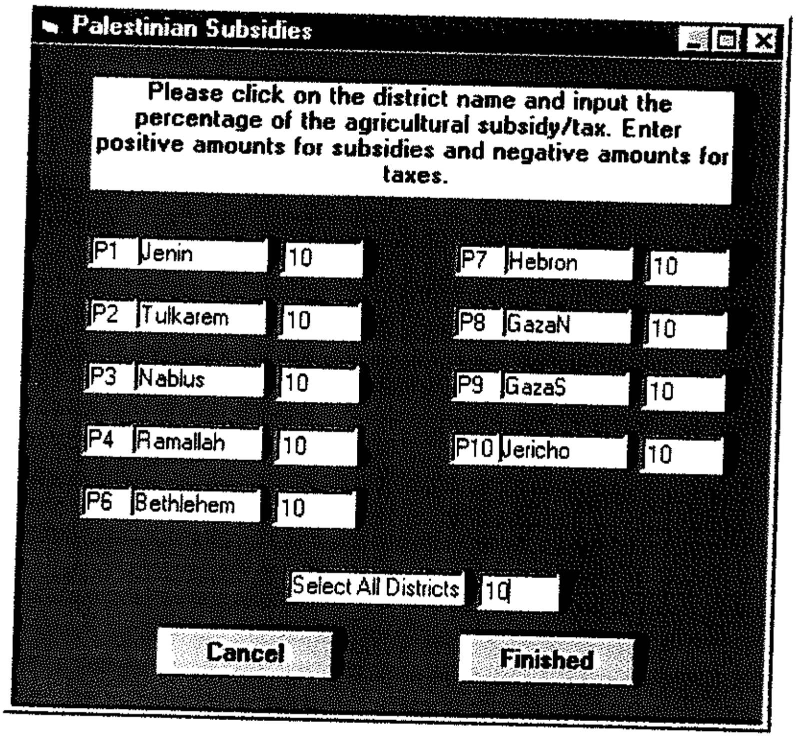

Figure 9: Setting Rates for Subsidies

- (industry, agriculture or urban). With this option you can set the prices (for up to five steps or increments) that will be paid by users. Note that the prices *must* be in ascending order, and that a quantity must be specified for each interval or step. If you want the last step (which can also be the only one) to apply for all water consumed, enter 999 as the water quantity. If you do not do this, the program will assume that users pay efficiency prices for quantities exceeding the end of the last step. For example:

  a) Enter $0.10 and $0.20 for prices in two steps and 5 and 999 million cubic meters (MCMs) as the corresponding quantities. Then water users will pay $0.10 per cubic meter for the first 5 MCMs and $0.20 for all additional water.
  b) Enter $0.10 and $0.20 for prices in two steps and 5 and 10 MCMs as the corresponding quantities. Then water users will pay $0.10 per cubic meter for the first 5 MCMs and $0.20 the next 10 MCMs, and efficiency prices for all additional water.

NOTE: The above description assumes that the fixed price policy chosen is intended to subsidize water usage— that is, to provide some or all water at prices below those that would otherwise be charged by the model (efficiency prices). You can also use the fixed-price policy option to **tax** water usage— that is, to require users to pay higher than efficiency prices. If you do this, however, you must specify a "complete" set of prices. For technical reasons, you cannot impose a high price on relatively small amounts of water and then assume that remaining quantities are purchased at a **lower** efficiency price. (This is similar to the requirement that prices for successive steps must be in ascending order.) Since you will not know the value of efficiency prices in advance, the program will later warn you if you have (usually accidentally) violated this requirement.

Countrified Option: This allows the user to specify "countrified" versions of the model, in which the water system of the chosen entity is cut off from those of the others and modeled in isolation[2]. When a countrified version is chosen, the question of how much water the particular entity has from each source becomes important (this is not the case if regional cooperation is assumed— the "uncountrified" case). Here the user making such a choice must then specify the amounts of water supplied from up to three different sources: the Sea of Galilee, the Yarmouk River, and the mountain aquifer (divided into four sub-aquifers) either as an overall constraint or for each of the subdivided mountain aquifers individually. Once the amount of water available to the chosen entity from a particular source is specified, the remaining entities have a constraint corresponding to the total amount available of the water source, less the upper limit chosen.

[2] When the countrified version is chosen for a particular entity, the model assumes the remaining two entities cooperate with each other. To examine circumstances in which there is not cooperation, you must run three countrified runs, one for each entity.

The Jordanian countrified version, shown in **Figure 10**, requires the specification of amounts available from the Sea of Galilee and the Yarmouk. Both Israel and the PNA must additionally specify the amounts available from the mountain aquifer (**Figures 11 and 12**). Note that in all three cases, the interface shows 100% of the water allocated to the countrified version selected.

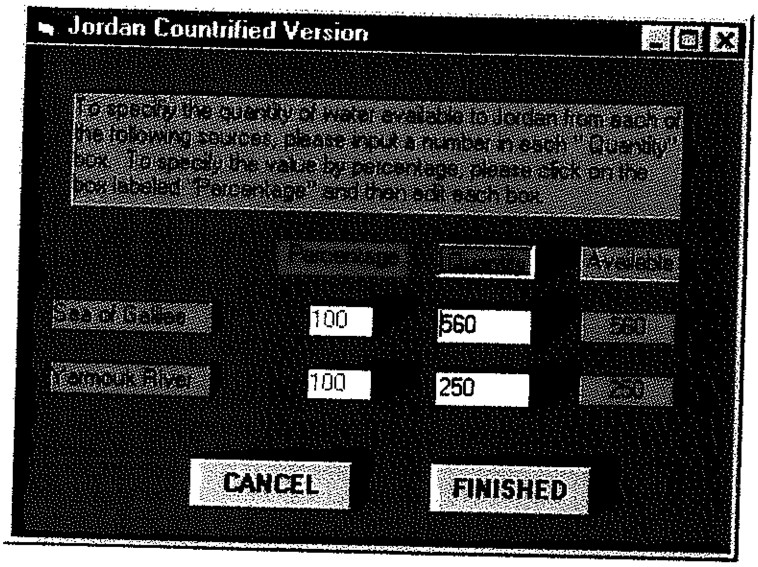

Figure 10: Jordan Countrified Box

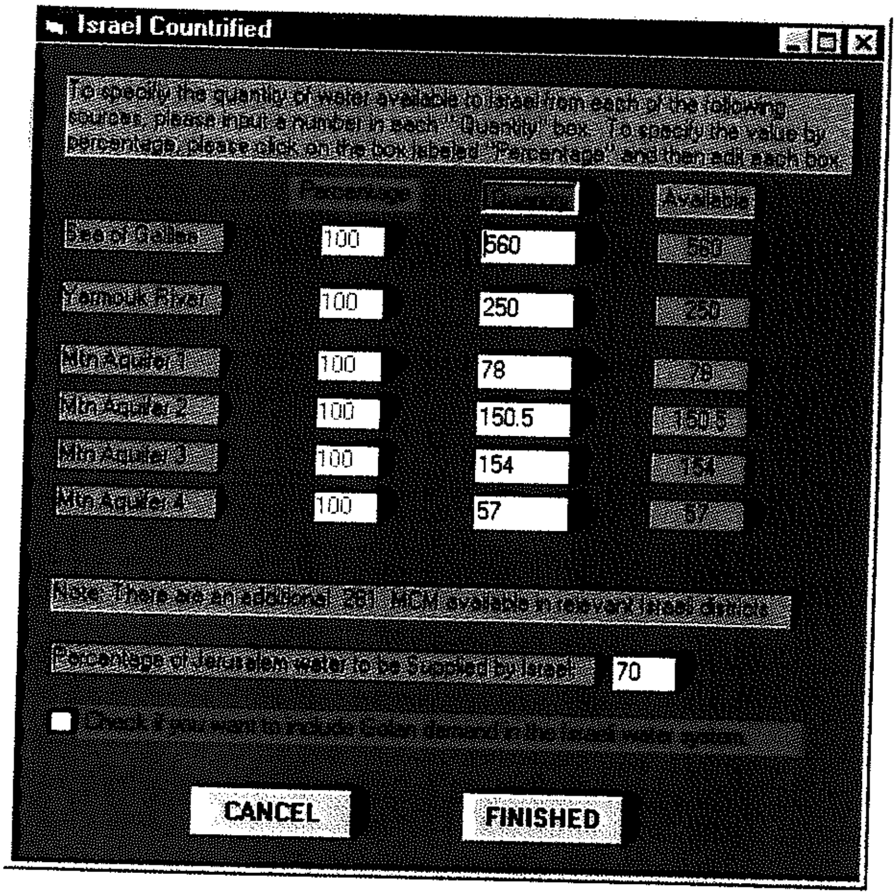

Figure 11: Israel Countrified Box

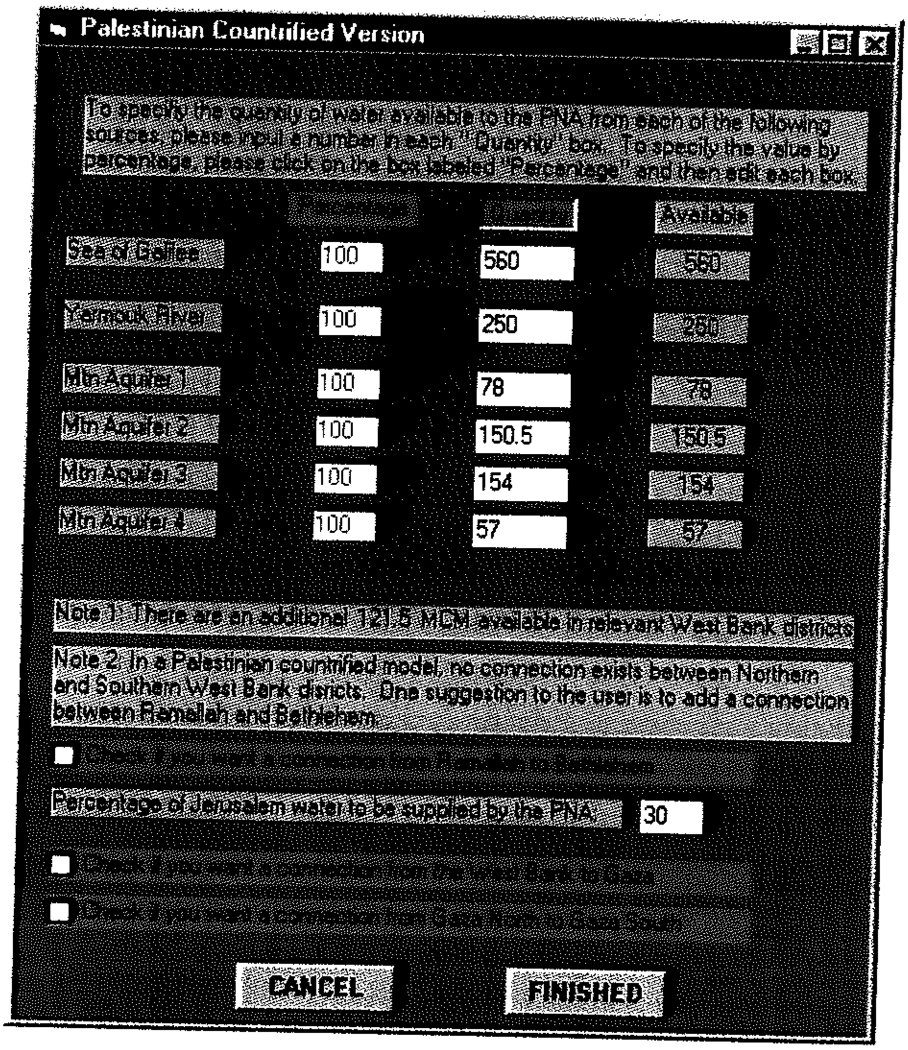

Figure 12: Palestinian Authority Countrified Box

For each entity, the capacity limit of the water source can be entered by percentage, using the scroll bar (if you check the box corresponding to "%"), or by quantity by entering the amount in the corresponding box (if you check the box corresponding to "Qty"). Note that the amount entered should not exceed the total amount of water available, as given under the column corresponding to the "Maximum Quantity available in millions cubic meters").

For the mountain aquifers, there are two options:

(i) check the overall box, to specify a constraint on the mountain aquifer water as a whole,or
(ii) specify the constraint for each of the 4 mountain aquifers.

Once all the constraints are specified, the changes will be created in the GAMS model. This choice can be canceled by clicking on the box: CANCEL, and the user will go back to the initial menu.

In addition to choosing the amounts of water available, the user of an Israeli or PNA countrified version must make further choices:

- The user must specify the percentage of water supplied to Jerusalem from either Israel, if it is the Israeli countrified version, or PNA for the PNA countrified version. This will also be the percentage of retreated water that the countrified entity can receive from Jerusalem. Note that the default percentage for the water supplied to Jerusalem in the Israeli countrified interface is 70% and 30% in the PNA countrified interface. This is based on the current percentages of Israeli and Arab populations in Jerusalem.
- The user of an Israeli countrified version can choose whether the Golan is to be included in the Israeli system.
- The user of a PNA countrified version can choose whether to provide conveyance links from Hebron to Gaza, and from Gaza North to Gaza South.

6.5 Running the Model

Scenario Summary: This allows the use to review the options selected, including any descriptive text, and can be viewed at any time, before or after optimization.

Optimize: This calls up the GAMS optimization package to generate a non-linear optimization program with about 1200 variables and 500 equations that it solves using the MINOS algorithm. The user must choose a scenario name (up to 20 characters with no spaces), and will be prompted to write any length of descriptive text for the run at this point.

6.6 Results

The system presents the results in the form of tables and schematics, reflecting the last scenario optimized or loaded.

Tabular: The tabular results include eight different tables, as well as the scenario summary page. The variables presented are described in Appendices A and B. In addition, there is an option to print all the tables.

Schematic— Carrier Flows: This shows the flow of water along the Israeli National Water Carrier, in particular the flows into and out of the carrier. This is helpful for identifying available connections to the carrier.

Schematic— Program Results: This provides a map with the results displayed spatially (at the moment you might need to stretch your imagination, but in the future we hope to have an actual map in the background). You can choose to see the results for individual political entities and regions. These maps can be presented for the same variables described in the tabular output by choosing the appropriate item in the menu.

NOTE: You can also compare the results from the current run with those from a saved scenario by clicking on "compare to saved scenario."

6.7 Files

Save Results: This is used to save the results currently generated (after optimizing). The name chosen before running the optimization is used as a default to create a subdirectory to "**c:\was_32**" which then will contain copies of the results. The user may modify the name at this point. In addition the descriptive text entered at the time of the optimization is used as a default and may be edited for additional clarity.

Load Results: Used to load the results of a scenario saved as above. The schematics and tables would now be updated with the loaded scenario.

Delete Scenarios: Lists the scenarios saved on the computer being used, and allows the user to delete any of the listed scenarios (subdirectories of "**c:\was_32**").

Click to Quit: if you've finally had enough!

6.8 Help

The user can obtain help from the Visual Basic form by clicking on the boxes to the left of where data are entered, as was shown in **Figure 1**. Additional help is provided as described below.

User Manual: This manual, on-line (not yet implemented).

District Names: Displays the names of the districts

About WAS: Provide information on whom to reach with comments or questions. See section 8 of this document for this information.

7.0 Comments

Please try to explore the options that WAS provides and please report any problems/ bugs/suggestions/comments/ compliments(?) you may have to the Harvard Development Team so that any program faults can be corrected as soon as possible.

There are bound to be problems as with all new releases - please let us know as soon as possible if (or when!) you find any. Please send us your views/suggestions/corrections or other updated costs, links, capacities, supplies, demands, scenarios, etc. as soon as possible. Please email us at::
ahuber@fas.harvard.edu. You can also send or fax them to Franklin Fisher or Annette Huber c/o Shula Gilad at:

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Appendix A

WAS Theory

Benefits, Prices, and Scarcity Rents

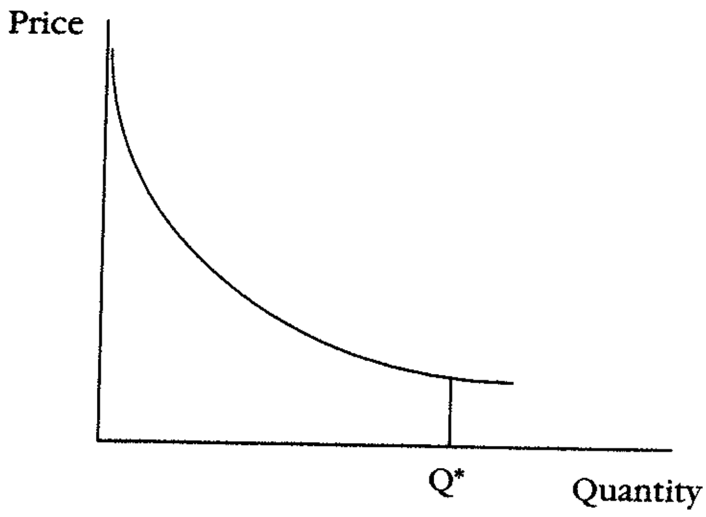
Net Benefits of Water: Private and Social

Figure 1 shows the amount of water a hypothetical household would be willing to buy at various prices. Note the downward sloping curve, indicating the very valuable nature of the first few units of water while later units represent those used for purposes less essential than drinking and cooking. In Figure 2 we consider the worth to the household of having a quantity of water (Q*). We ask how much that household would be willing to pay for the first small unit; the price is given by a point on the curve above the interval on the horizontal axis from 0 to 1. (Exactly where does not matter.) The amount to be paid (one unit times the price in question) is approximately the area of the leftmost vertical strip in Figure 2. Similarly, the amount to be paid for the second unit can be approximated by the area of the second-to-left vertical strip, and so on until we reach Q*. As the unit size decreases, the total amount the household would be willing to pay to get Q* approaches the area under the demand curve to the left of Q*.

Now reinterpret Figures 1 and 2 to represent the aggregate demand curve of all households in a district. The gross (private) benefits from the water flow Q* can then be represented as the total area under the demand curve to the left of Q*.

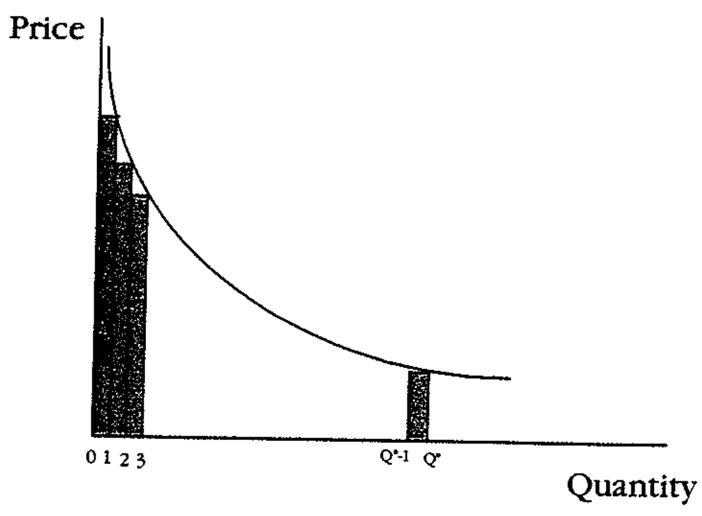
To derive net benefits from Q*, we subtract the costs of providing

FIGURE 1



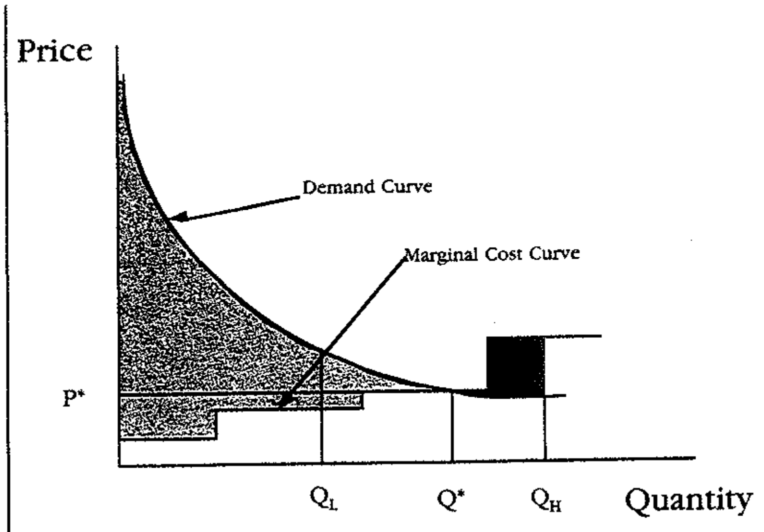
Household Demand Curve

FIGURE 2



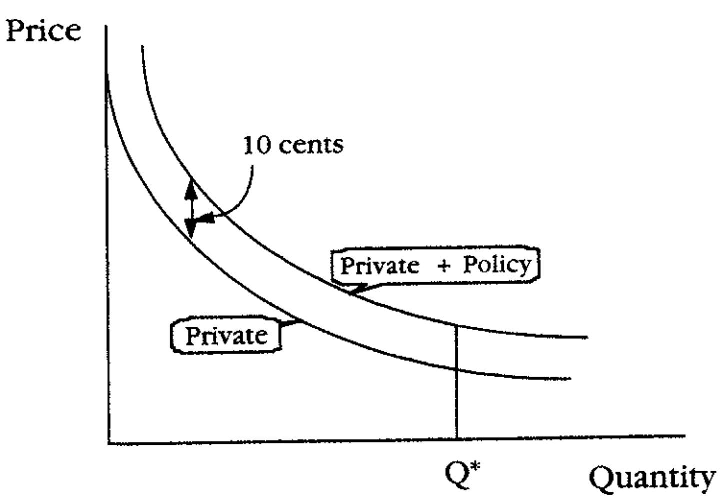
Gross Benefits from Water

FIGURE 3



Net Benefits from Water

FIGURE 4



Social Value of Water as Expressed by a Subsidy

Q*. This is illustrated in Figure 3, where the line labeled "marginal cost" shows the cost of providing an additional unit. Additional units cost more as more expensive water sources 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 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*, 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 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 cost of providing the last few units. Hence Q* is the optimal amount of water to deliver. (Note that in Figure 3 a price (P*) is associated with Q*; we return to this later.)

Consider a government policy to subsidize water for agriculture by $0.10 per cubic meter at all quantities — an unrealistic but simple example (Figure 4). The lower demand curve represents the private value of water to agriculture; the upper demand curve also includes the public value of water as reflected in this policy, an additional value of $0.10 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 above methods can be used to measure net benefits. In the model, this has been done so that a user can choose various policies and then optimize.

Shadow Prices and Scarcity Rents

In competitive markets, prices measure what buyers are willing to pay for additional units of the goods in question (marginal value) and the cost of providing such additional units (marginal cost). A price higher than marginal cost signals that the unit is worth providing since the value placed by the buyer on that unit is greater than the production cost; 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. In the case of water, there are reasons for not relying on a totally competitive private market to serve such functions. One reason is that the social value of water can differ from its private value; we have shown how the model handles this issue. Secondly, typically water is not supplied privately and competitively by many sellers. Thirdly, "externalities" are associated with water use, such as the effect of pumping in one location on the availability or cost of water in another location. Such externalities do not form part of the private calculations done by buyers and sellers in a competitive market.

The model allocates water so as to maximize the net benefit obtained from it. As shown above, that net benefit consists of a measure of the total amount that buyers (consumers or nations) would be willing to pay for the water, less the costs of providing it. The maximization of net benefits is done subject to constraints, essentially concerned with water availability. For example, in each district, the amount of water consumed cannot exceed the amount produced there plus net imports into that district.

It is a general (and important) theorem that when maximization involves one or more constraints, a shadow price is associated with each constraint that indicates how much the benefit would increase if the constraint were relaxed by one unit. While the theorem applies to such things as constraints on pipeline throughputs, the central shadow prices in our model are those of water itself. The shadow price of water at a given location is the amount of increased benefits to water users (in the system as a whole) that would be obtained from the cost-free availability of an additional unit of water at that location. It is also the price that buyers at that location who value the water the most would be willing to pay to obtain an additional unit of water. (In Figure 3, the price, P*, would be the shadow price if Q* were the maximum amount of water available.)

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

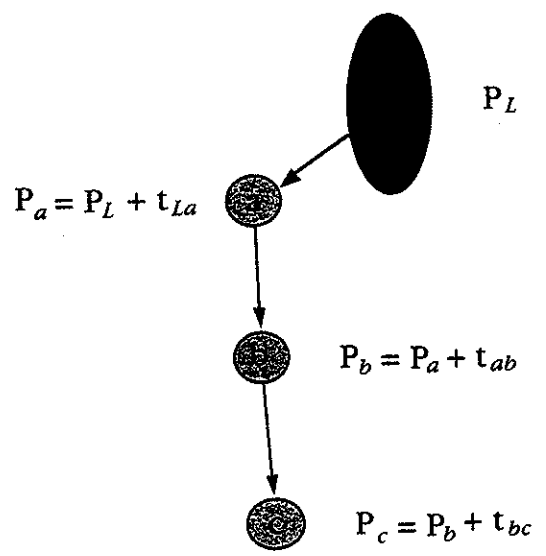
A proper view of costs accommodates this phenomenon. When demand at the source exceeds capacity, it is not cost-free for the owner to provide a user with an additional unit even if direct costs are zero. That additional unit can be provided only by depriving some other user of the water benefit; that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

For zero direct costs, the shadow price of the resource involved consists entirely of the 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 it at that location (if that subtraction yields a non-negative result). Just as in a true competitive market, a positive scarcity rent is a signal that more water from that source would be beneficial if available. Water shadow prices and, accordingly, water scarcity rents depend upon the infrastructure assumed to be in place.

When water is optimally allocated, as in the Project model solutions, the following relationships hold. (All values are per unit of water.)

- The shadow price of water used in any location equals the direct marginal cost plus the scarcity rent.
- For water *in situ*, the shadow price is the scarcity rent. Water will be produced at a given location only if the shadow price there equals or exceeds the direct marginal cost. Water will be transported from location *a* to location *b* only if the shadow price at *b* equals the shadow price at *a* plus the conveyance cost. Equivalently, if water is transported from *a* to *b*, the scarcity rent of that water is the same in both locations.
- This situation is illustrated in Figure 5, 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.
- At each location the shadow price of water is the price at which buyers would be just willing to buy and sellers would be just willing to sell an additional unit of water.

FIGURE 5



Efficient Water Allocation and Shadow Prices

Appendix B

Mathematics of the WAS Model