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ASSESSING THE VALUE OF  
WATER IN MINNESOTA:  
MODEL CHARACTERISTICS

by

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## ABSTRACT

The purpose of this paper will be to outline the practical considerations involved in estimating the value of water in Minnesota. The paper will include a review of previous modelling efforts, including an analysis of data requirements and data weaknesses inherent in these previous efforts. The form of the input-output and programming efforts in Minnesota study will be outlined. The data to be used in the Minnesota effort will be highlighted, along with a comparison between Minnesota's data sources and those of other studies.

Also included will be descriptions of both the structure of a large scale simulation model (IPASS) currently being used in the State of Minnesota and the anticipated structure of the water module to be attached to the IPASS system. These descriptions will follow from the theoretical discussion out of the previous paper.

## INTRODUCTION

The possibilities of water shortages in some states in recent years have prompted research interest in the area of water usage and its effect on a regional economy (Kelso et al. [5] and Cicchetti et al. [3]). The diverse effects of water resource use on regional economies arise mainly from differences in water resource endowments, interdependence among industry sectors, and industrial base characteristics.

A reduction in the supply of industrial commodities would be a probable consequence of imposing water constraints on production. This reduced supply would result in higher output prices, interregional shifts in both production and producer incomes, changes in employment and income for the labor force, and secondary impacts on communities in the region. The secondary impacts of water constraints can be important ones. The majority of counties in Minnesota depend considerably on the economic success of

certain basic industries (e.g., farming) for their prosperity. Studies ranging in scope from local to regional have been made of the direct effects of water shortages on production (Young and Gray [16] and Maeder et al. [7]). But little work has been done in assessing the direct and indirect effects on a region of water shortages on production (for one study see Henry and Bowen [4]) and in imposing controls on water availability for non-production purposes (Yaron and Olian [15]).

The specific model presented below is restricted to the analysis of water usage and alternative water allocation decisions in regard to quantity of water. The objective of this paper is to develop and describe a linear programming (LP) and interindustry (I/O) model as an integral part of a simulation model (IPASS, Olson et al. [11]), to estimate both the direct effects on an industry and the secondary effects on a regional economy of water constraints on industry production. This model will rely on earlier studies that link LP and I/O models in studying water usage and water valuation with an economy (Mann [8], McCarl and Everett [9] and Henry and Bowen [4]). The model should generate estimates of the potential effects in a regional economy that result from changes in water resources and in the aggregate level of economic activity.

In addition, the proposed model is designed to examine the effects of policy decisions regarding tradeoffs in resource conservation and economic development. Society has developed a demand for natural resource conservation itself. This demand, based on aesthetics, or ecology, or non-market uses of water (e.g. recreation), may be viewed as a final demand and entered as a requirement in the model in the same way that final demands for goods enter as required. Thus, as part of the solution to LP and I/O model the marginal cost of meeting these demands may be calculated.

The paper provides an overview of the LP and I/O methodology. This is followed by a brief presentation of data required for model implementation. Some possible scenarios and their implications that can be examined with the model are reviewed and finally discussion of limitations and applications of the suggested model are presented.

## THE ANALYTICAL FRAMEWORK

If water shortages reduced industrial production and purchases of production inputs and sales of commodities by an industry, the employment and income levels of its labor force would suffer. If household net income also declined, the reduction on household spending and saving would reduce the sales, employment and income of other industries' labor forces in the region. Hence, changes in the production conditions confronting an industry would be translated into changes in sales, employment, and incomes in the remaining sectors of the region. The interindustry effect will be proportional to the intraregional ties. That is, the interindustry effects will be greater for regions with larger, more diverse, and more complex economies. The impact on industries would be reduced to the extent that some sectors purchases and sales occur through industries outside the regional economy as imports and exports.

The LP and I/O model is based on the above considerations. Water constraints may be imposed on the LP model and the model may be solved for changes in gross output, employment, and sector income. The changes in production, labor, and income from the LP model are converted into equivalent gross output, employment, and income units in the industrial sectors of the I/O model. Hence the changes in regional gross output, employment, and income for each industry sector are taking into consideration the direct and indirect feedback relations inherent in the economic linkages of the region. This model is summarized in Fig. 1.

### The LP and I/O model assumptions

The linear programming and interindustry model has several linear homogeneity assumptions. The LP and I/O model assumes constant commodity and input prices.

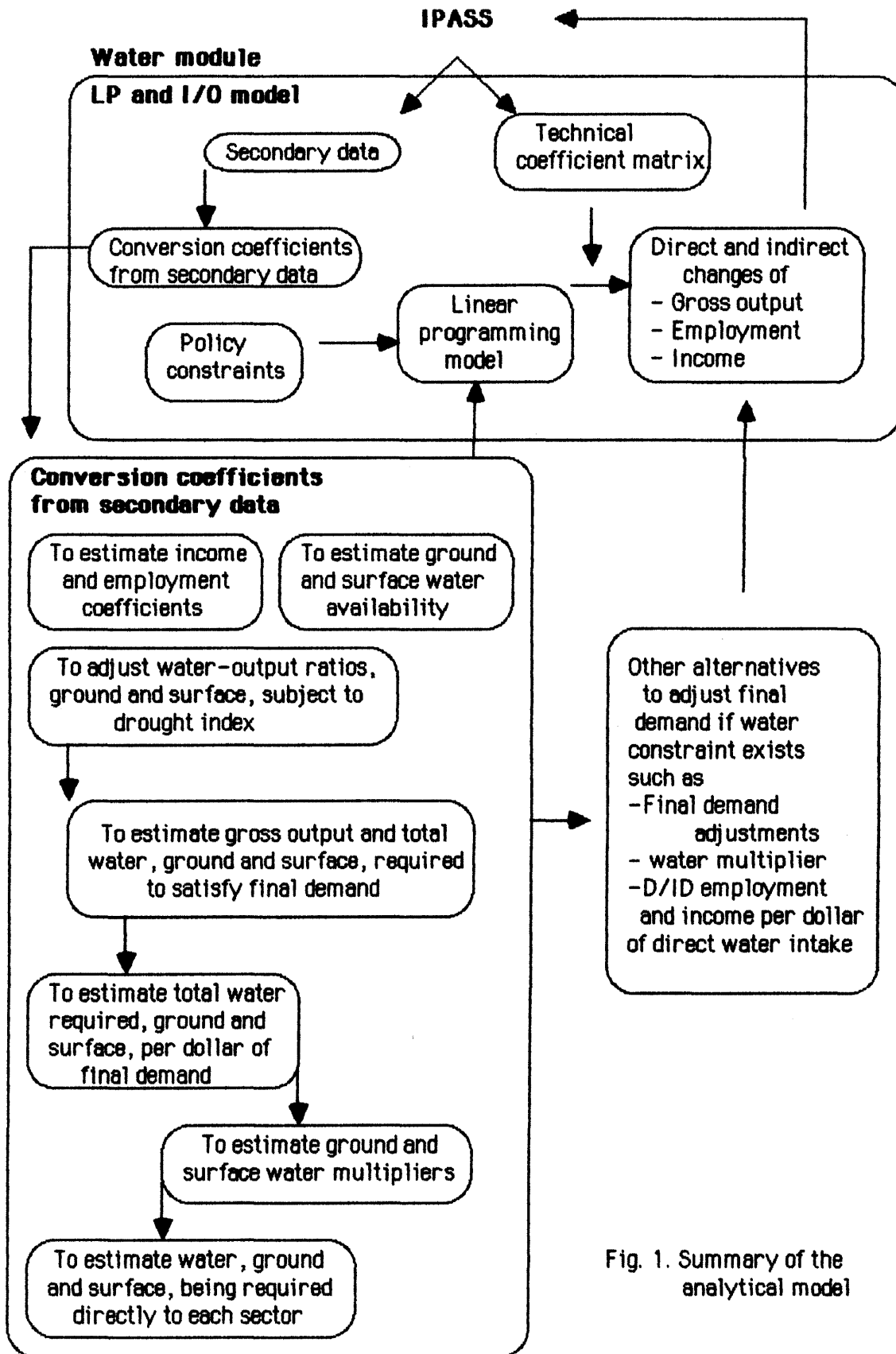


Fig. 1. Summary of the analytical model

However, water shortage effects could lead to changes in the prices of industrial commodities. Another characteristic with the LP and I/O model is that the model is not closed with respect to the household sector, so that the inverted Leontief matrix does not contain the induced effects of changes in household incomes. However, These omissions will not cause the estimates of employment and income changes to be understated. IPASS contains calculations offsetting to an undetermined extent the tendency to understate the employment and income effects. The I/O formulation in general does not allow substitution. The inputs used by a sector are a linear homogenous function of the activity level of that sector. Internal economies and diseconomies are absent. The economy is assumed not to have alternative production techniques which might be less water intensive, allow substitution of one water source for another, or permit substitution of labor for water. At best, these assumptions are valid only in the short run.

#### The LP and I/O model

The integrated LP and I/O model is shown in schematic and in matrix form in Table I. A detailed description of LP and I/O models can be found in Chenery and Clark [2], Miernyk [10], Richardson [12], McCarl and Everett [9], and Schluter and Dyer [13]. The plus sign indicates that the output production by a sector draws upon that constraint while a negative sign indicates that the sector's production contributes to an easing of a particular constraint.

The components of the model may be described in general terms as follows. A technical coefficient matrix  $A$  that describes production technologies available in the region. A set of direct water requirements per dollar of output for the given production processes. It is assumed that for each production process the quantity of water needed to produce a unit of output is given by a linear relation. Different water sources are included to reflect the different options available for water supply. In particular those

sources include ground water and surface water. Total water supply may represent, besides groundwater and surface water, interbasin transfers of water. The supply of different water sources in a given process may be allowed for by expressing them as multiples of the total output of the sector. Regional water supply constraints require that the quantity of water entering or used in economic production from all sources must be no more than the total quantity of water available.

Table I. A schematic representation of the LP and I/O model

Row description	Industry gross outputs 1.....n	Matrix notation equations	RHS constraint	
Objective function	1.....n	<b>X</b>	max	
Production constraints		<b>(I - A) X - Y</b>	<b>= 0</b>	(1)
Final demand constraints		<b>Y</b>	<b>≤ Y*</b>	(2)
		<b>Y<sub>i</sub> - Y<sub>0</sub></b>	<b>= 0</b>	(3)
Resource constraints				
Water ground and surface	+.....+	<b>H<sub>1</sub>X + H<sub>2</sub>Y<sub>0</sub> + H<sub>3</sub>R<sub>1</sub> + R<sub>2</sub></b>	<b>≤ H<sub>0</sub></b>	(4)
Final demand		<b>R<sub>2</sub></b>	<b>≥ H*</b>	(5)
Labor	+.....+	<b>LX</b>	<b>≤ E</b>	(6)
Capital	+.....+			

The capabilities of water bodies to meet specified demands for recreation and fisheries/wildlife support are assumed to imply maximum permissible levels for consumptive use. These water demands are specified exogenously and enter the model through specific bounds in consumptive parameters use by the region. A data set of variables of interest such as sector output, final demand levels, employment, income, and value added.

In this paper, gross output is maximized. However, other criterion functions such

as employment and income may be selected. The first resource restriction states that total sector output equals the sum of its uses as intermediate products by other sectors plus final demand by the exogenous sectors,  $X=AX+Y$ . The exogenous sectors are personal consumption expenditures (PCE), gross private capital formation, net change in business inventory, net exports, and Federal, State, and local government purchases. The second restriction limits the level of total exogenous final demands,  $Y$ , to a specified upper limit,  $Y^*$ . The third resource restriction ensures that total final demand accepted by the economy,  $Y_0$  equals the sum of its parts,  $Y_i$ . The fourth restriction limits water use from production, final demand excluding household, and recreation and fisheries/wildlife support to no more than that available from ground and surface water,  $H_0$ .  $H_{1,2,3}$  are matrices of water requirements per dollar of output, per dollar of final demand, and per dollar of PCE (for recreation and fisheries/wildlife support), respectively, for ground and surface water.  $R_1$  is total personal consumption expenditures.  $R_2$  is a matrix of water levels for fisheries and wildlife support. The fifth restriction limits the use of water, ground and surface, for fisheries and wildlife support to no less than a minimum quantity,  $H^*$ . Finally, the sixth restriction simply accumulates employment, gross outputs, income, and value added.

A solution of LP and I/O model will determine the combination of production activities that will maximize gross output, employment, or income subject to the regional resource constraints needed to produce a specified amount of the final product. Most important it will be possible to determine the quantities of water used and the assigned value of water. However, the possibly negative effects on economic production caused by water availability are not the only way in which water resources affect society. As mentioned before, society has developed a demand for natural resource conservation as a good. If this demand, expressed as quantity of water, enters final demand as a requirement, then the LP and I/O model will estimate the effects of increasing or reducing these water levels and the marginal costs of meeting these

demands.

### Data requirements

The water model requires data on both water supply and on water demand. The supply acts as constraints to the model while demand relates water input to industrial output for the various sectors of the economy.

These are two separate sources of water that can be input into an economy, ground water and surface water (lakes and rivers). Many studies lump all water together and ignore the source, however this results in misstatements of water available for certain industries. For example, agriculture is highly dependent on surface water for irrigation while the cost of pumping groundwater prohibits its extensive use in irrigation. Therefore even if there is plentiful groundwater agriculture might face a water constraint due to limited surface water.

The proposed model separates out the two sources of water supply. Surface water in rivers is measured by average annual in-stream flow while water available from lakes will be based on current legal limits for withdrawal. Quantifying the supply of ground water is harder than surface water. In the state of Minnesota, groundwater could be essentially considered limitless over the short run with the only constraint being the willingness to pay for pumping from deeper aquifers. Since the current model design assumes constant input prices, water supply cannot be dependent on price. For the current model it is assumed that ground water supply will be equal to the average recharge rate of ground water. For the very long run this is the true groundwater supply [14].

Previous studies have used several measures in estimating water requirements for various sectors in the economy. The two most common measures are water withdrawal or intake, and water consumption. Water intake is a measure of the quantity that must

flow through a region in order to support the region's economy. Unfortunately withdrawal actually overstates this water need in areas of any size; this is because water that is withdrawn, used, and discharged by one plant may be used by another industry further downstream. For some major water users (agriculture) it has been assumed that most water withdrawn is consumed (Bradley and Gardner [1]), however this is an unrealistic assumption for other water uses (utilities).

The measure of water consumption on the other hand eliminates double counting of water used. Consumption is defined as the difference between water withdrawal and water discharge over a given time period. However while withdrawal overstates water needs, consumption understates actual water needs. Utilities withdraw larger amount of water from the system at any moment for cooling but their consumptive use is essentially zero since all is returned. Information on this instantaneous withdrawal or "consumption" is difficult to acquire although attempts have been made.

Because both of the common measures of water demand have their shortcomings and advantages, it was decided that for modelling needs runs would be made using both consumption and withdrawal demand. Results from both sets of data would provide a range in which the true water needs of the economy would fall. Scenario development would provide high and low estimates of the impact of water constraints on the economy.

Water demand not only must be measured by consumption and withdrawal rates but it must be separated by source of the water, ground water, or surface water, to correspond with water supply measures. Fortunately the Minnesota Department of Natural Resources (DNR) has an excellent data base regarding water withdrawal and discharge, by industrial sector, including water quantity and water sources. This data from the base year (1982) will be used in estimating water input/product output ratios for all sectors of the economy and also for estimating normal ground water to surface water use ratios for the major water using industries.

### Some water allocation schemes

The objective function should be maximized first under the assumption that no water shortages are present (the baseline run) and then again for a series of policy runs, each of which should assume a different set of water shortages. Since the technical coefficient matrix and water requirements will be assumed to remain invariant, the change in the objective function should be an estimate of the changes in gross outputs. Aggregate economic activity, as evidenced by changes in the employment and income indicators, will, in some extent, be reduced or increased proportional to the employment and income ratios.

To illustrate the types of scenarios that may be treated using the model, several possible simulations are presented. Specific simulations of water restriction, ground and/or surface, are no allocation, allocation to specific production sectors, final demand water restrictions, expanded production, and alternative objective functions. A no allocation scenario allows all industrial sectors to compete freely for the reduced supply of water. Allocation to specific production sectors is accomplished by zeroing water requirements per dollar of output for these sectors and subtracting their base level utilization from the total water available for allocation. Water available for final demands is reduced to estimate impacts of shortages of water sources, which is particularly important for household water demands for wildlife/recreation/ecology objectives. Another possibility to limit water availability for production is to assume that water demands for environmental quality/ecology/wildlife must be met.

Some preliminary analysis may suggest that allocation schemes providing certain sectors enough water to satisfy their final demands would affect sector activity levels. Aggregate output effects are less than proportionate to the water restriction because intermediate product demands at all levels are lessened as economic activity is reduced. The ranking of sectors by the extent of output reduction is considerably altered when

different sectors are constrained. These results may indicate that providing a particular production sector with adequate quantities of one input is not very helpful if necessary quantities of other inputs are unobtainable. Thus, while individual sector effects from a water shortage may be significant, a rationale for a specific water allocation may be more political than economic. In the longer run, interdependence among sectors is so great that the needed allocation for one sector depends heavily on the level of activity that is possible in the sectors directly bearing the shortfall in water.

Alternative objective functions may assume the same water shortages and water allocation as above but the objective is to maximize a different function such as employment and income ( Bradley and Gardner [1] ). A critical question to be asked is what effects the choice of a regional objective has on optimal water allocations. The alternative objectives that can be maximized are employment, private and/or public, income, and total value added. These objectives may approximate a variety of interests affected by an water shortage: employment, net production, part of government tax revenues, and capital earnings. Solutions maximizing gross output and value added should be very similar, with several exceptions, since there is generally high correlation between them.

Using employment as the criterion function will produce some differences from other solutions. The tendency is to encourage increased production levels in the relatively labor intensive industries such as manufacturing. However, there are other effects to objective function choice which are not initially evident. For example, maximizing employment puts the most people to work but may also produce the lowest level of PCE of all the objectives. This would suggest that jobs created by this objective function are likely to be in relatively low wage industries, producing employment income which adds little to aggregate PCE, and hence, aggregate economic activity.

The rationale for choice of an objective function is unclear. The information obtained from alternative solutions with a single objective may provide additional

information to policymakers on magnitudes of employment and income results as there do appear to be important differences in results depending upon choice of objective. Another approach, discussed below, is simultaneous consideration of several objectives through use of multiple-goal objective functions.

The choice of criterion function is also significant in determining shortages in the final demand market. Final demands for various sectors are restricted differently. In any shortage, some final demands must go unmet. Which ones depend on the type of shortage, its severity, and the objective being optimized. For any specific situation being examined, a sector would be more severely affected than the economy as a whole. Sector's employment declines would be greater and sector's gross income declines would show even greater disparity. Water allocations to a production sector may indicate that for specific shortages, alternate schemes to alleviate their impacts may produce similar results for the economy in the aggregate, but the impacts on individual sectors may be different. For some sectors, the results may emphasize the direction and relative magnitudes of tradeoffs that should be considered by policymakers in selecting one or more economic goals for emphasis over others.

Another useful output from the model is the shadow price or dual multipliers (Schluter and Dyer [13]). These indicate the values of additional units of the limited resources, or, in  $1/0$ , of increased final demand levels. For water, they could be particularly useful in deriving an allocation scheme of limited water sources to various uses, one which would be consistent with a specified regional objective, such as maximizing employment or gross output. These values often are highly specific to the type of water shortage and the type of allocation scheme assumed. The model is formulated in such a way as to separate impacts of various water schemes on shadow prices. The model determines which of the final demands go unmet in a shortage situation, and hence assigns shadow values to decreased final demands and capacities. By the formulation of the equation sets (1) and (2), values originating in final demand can

be separated from those originating in intermediate product uses.

## SUMMARY AND CONCLUSIONS

In this paper a general equilibrium approach to the economic evaluation of water in an economic system was described. This study demonstrates a LP and I/O model that maximizes gross output when water supply shortages are considered. While the emphasis of the paper was on methodology, empirical estimates can be easily obtained.

The economic significance of the model and the results which may be derived through its use are on two levels, the industry sector level and the regional water resource development level. Regarding the industry sector, use of the model points to the optimal water use policy, and where for the purposes of this paper the decision options available to an industry are restricted to water quantity decisions only. Regarding the regional level, the model and the empirical estimates that can be easily obtained may be useful in the analysis of water resource development where water quantity is the only variable being taken into consideration.

Many additional extensions could be made of the basic model. Modifications and extensions being suggested below would enhance the capability of the model for providing additional detail and for extending the range of questions which might be addressed.

The LP and I/O model being described in this paper can be extended to include other water resource concerns such as water supply-demand interactions, water pricing, water allocation among alternative users, welfare criteria, and water quality. Water quality has gained increasing attention in recent years due to the gradual process of pollution and quality deterioration of some major natural sources of water supply and to the technological possibilities for improving water quality by different treatments (Yaron and Olian [15]). With minor modifications the model can be applied to analyses of situations in which, beyond the possibility to vary water quality and quantity,

adjustments can be made in the production/substitutions effects among production factors. For this type of LP and I/O model to be valid it is essential that the input-output coefficients describing each production activity be fixed. But a problem of increasing importance, particularly in regard to water use, is that the changes in resource quality are causing substantial changes in the production efficiency of processes using these resources as inputs. Consequently, the technical coefficients describing these processes are not fixed but must be written as functions of input quality parameters.

Multiple objective programming (Lee [6]), basically involves setting goals, for example a specific level of gross output, or employment, and then optimizing over the deviations from these goals. Such analysis would appear to provide useful information to policymakers for analyses associated with water restrictions.

In addition to the positive aspects of water shortages on production, distributional concerns could be interpreted broadly in this paper as relating to decision-makers' interests in pursuing normative questions of implications for income distribution effects of water shortages. The results could be examined with respect to factors such as water shortages' impacts on different industrial sectors, employment preferences of the labor force, and total labor supply.

In general, the use of I/O enhances the analyses of water shortages and that, even with the inherent limiting assumptions and data base, constrained I/O models provide additional information and flexibility for consideration in policy analyses.

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