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9. ABSTRACT

This dissertation develops a model for allocating water between competing users to maximize net economic returns to the basin. Water users within the basin are aggregated into sectors, with the net economic returns to each producing sector treated as sole functions of the water consumed, excluding economic returns from other resource inputs. The use of economic input-output analysis affords a method of determining sectoral changes within the net economic returns caused by modification of the final demand. Within the model, the total net monthly economic return for the entire basin is maximized through a process of static iteration, with incremental modifications being made to the final demand sector through developed distribution multipliers. An initial water allocation policy is required to determine the initial net economic return to the basin. This policy has been established through development of a simple water allocation program, incorporating arbitrary allocation criteria under water restriction conditions. To illustrate how the model operates, synthetic natural inflow and sectoral demand data have been tabulated for a natural catchment area located in the midwestern U.S.. Real economic data obtained from a literature review indicate the potential economic value of water for the described area. From operation of the model, comparative net economic returns are computed, with the resulting increases validating the optimization process.

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DISSERTATION

ECONOMIC OPTIMIZATION FOR WATER ALLOCATION SYSTEMS

Submitted by

John William Andrew

In partial fulfillment of the requirements
for the Degree of Doctor of Philosophy
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Fort Collins, Colorado
Fall 1976

ECONOMIC OPTIMIZATION FOR WATER ALLOCATION SYSTEMS

by

John William Andrew

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ABSTRACT OF DISSERTATION

ECONOMIC OPTIMIZATION FOR WATER ALLOCATION SYSTEMS

Within a fixed boundary water basin, a model has been developed to allocate water between competing users to maximize net economic returns to the basin. Water users within the basin have been aggregated into particular sectors, with the net economic returns to each producing sector sole functions of the water consumed, excluding economic returns from other resource inputs.

Any change of product output within a particular sector induces changes in production in all other sectors, and consequently, net water consumptions. The use of economic input-output analysis affords a method of determining sectoral changes within the net economic returns caused by modification of the final demand. Within the model, the total net monthly economic return for the entire basin is maximized through a process of static iteration, with incremental modifications being made to the final demand sector through developed distribution multipliers. The economic maximization process operates under the prime constraint of actual water available for consumption within the basin during the adopted time period.

An initial water allocation policy, in relation to average monthly sectoral demands, is required to determine the initial net economic return to the basin This policy has been established through the development of a simple water allocation program, incorporating arbitrary allocation criteria under water restriction conditions.

To illustrate operation of the model, synthetic natural inflow and sectoral demand data have been tabulated for a natural catchment area located in the midwestern U.S.A. From a literature review, real economic data have been derived, and though not explicit, indicates the potential economic value of water for the above area. From the model operation, comparative net economic returns between initial and optimal conditions are made, with the resulting increases validating the viability of the optimization process. During periods of water restriction, or periods of water importation, the model also offers a conceptual means of valuing water transferred out of the basin or water imported from an adjacent basin.

The high dependence of the model upon economic data, and the effects of comparatively small data variations, indicates the necessity for continuing research in the valuation of water to consumers. This dependence also elucidates the necessity for consideration of the effects of physical water constraints upon water allocation systems and the economics of such.

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LIST OF SYMBOLS

Symbol	Definition	Dimension	Units
Input-Output Symbols			
A_{ij}	Matrix of technical coefficients	--	--
A_{ij_w}	Matrix of transactions table for water consumption conditions	--	\$
a_{ij}	Technical coefficients	--	--
C_j	Column sum of x_{ij} values	--	\$
D_i	Import demands	--	\$
E_i	Transposition of E_j	--	--
E_j	Total sectoral outlay adjustment $= G_j - L_j$	--	\$
F_j	Total payments sector value	--	\$
G_j	Total sectoral outlays	--	\$
$(G_j)_w$	Total sectoral outlay for water use	--	\$
I	Identity matrix	--	--
I_j	Import payments	--	\$
$(I_j)_w$	Import payments for water use	--	\$
I_t	Level of induced investment at time t	--	\$
K_{ij}	Matrix of direct and indirect technical coefficients	--	--
k_{ij}	Capital coefficients	--	--
L_j	Depletion payments	--	\$
$(L_j)_w$	Depletion payments for water use	--	\$
P_i	Export demands	--	\$
P_{ij}	Production coefficient	--	--
R_j	Ratio of import to depletion payments $= \frac{I_j}{L_j}$	--	--

LIST OF SYMBOLS - Continued

Symbol	Definition	Dimension	Units
$S_{ij}(t)$	Produce stock at beginning of time period t	--	$
$\dot{S}_{ij}(t)$	Rate of change of produce stock	--	$/month
T_i	Total sectoral outputs	--	$
$(T_i)_w$	Total sectoral outputs for water use	--	$
U_i	Capacity coefficient	--	--
W_j	Capacity level in sector j	--	$
X_i	Output level of industry i	--	$
X_t	Output level at time t	--	$
x_{ij}	Transaction table sectoral values	--	$
$(x_{ij})_w$	Transaction table sectoral values for water use	--	$
Y_i	Total final demand = $P_i + D_i$	--	$
α	Investment coefficient	--	--
λ	Production lead time	T	secs.

Water Allocation and Economic Symbols

A	Catchment area	L^2	ft
A_1	Irrigation area	L^2	ft
B_n	Total net economic benefit for sectoral consumption	--	$
B'_n	Total net economic benefit for the basin	--	$
b_A	Net economic benefit per unit of accumulated water	$\$/L^3$	$/gallon
b_D	Net economic benefit per unit of depleted water	$\$/L^3$	$/gallon
b_E	Net economic benefit per unit of exported water	$\$/L^3$	$/gallon

LIST OF SYMBOLS - Continued

Symbol	Definition	Dimension	Units
b_I	Net economic benefit per unit of imported water	$\$/L^3$	\$/gallon
b_i	Net economic benefit per unit water consumption	$\$/L^3$	\$/gallon
L_{R_i}	River lengths	L	ft
L_i	Canal lengths	L	ft
M_1	Distribution multiplier	--	--
M_2	Final demand multiplier	--	--
MS	Maximum storage capacity of basin	L^3	gallons
P_{av}	Average annual rainfall	L	inches
Q_i	Monthly discharges between diversions	L^3	gallons
Q'_i	Total monthly consumption	L^3	gallons
q_A	Accumulated water	L^3	gallons
q_D	Depleted water	L^3	gallons
q_E	Export water outflow	L^3	gallons
q_{EB}	Minimum export flow requirements	L^3	gallons
q_I	Import water inflow	L^3	gallons
q_{L_i}	Water loss per unit length in canal	L^2	glls/ft
q_N	Natural monthly inflow	L^3	gallons
q_{R_i}	Water loss per unit length in river	L^2	glls/ft
q_T	Total inflow to basin	L^3	gallons
q_i	Diversion to user i	L^3	gallons
q'_i	Consumption by user i	L^3	gallons
q_t	Total sectoral consumption	L^3	gallons
q_{xi}	Sum of individual sectoral demands	L^3	gallons

LIST OF SYMBOLS - Continued

Symbol	Definition	Dimension	Units
RR	Restriction ratio	--	--
R_i	Return coefficients	--	--
S_i	Water storage at beginning of month i	L^3	gallons
S_{i_I}	Storage available plus imported water $= S_i + q_I$	L^3	gallons

1.00 INTRODUCTION:

With ever increasing concern being placed upon the earth's limited resources, both renewable and nonrenewable, man is slowly becoming more conscious of the term "efficiency." And in the context of resources use, efficiency can imply nothing more than extracting the maximum amount of social good from a minimum quantity of resource. For pure economic purposes, efficiency in resource use or allocation is traditionally defined as the condition in which no reallocation alternatives exist which would allow economic gains to one sector without consequent economic losses to another sector. This implies, basically, that all unambiguous possibilities for increasing net economic welfare have been considered and exhausted.

Although many resources at the present moment have very low or zero economic value, a resource takes on a positive economic value as the competition for its use between consumers increases. Resources may also increase in positive value, as the total known reserve quantity of the resource is depleted, with this being well illustrated in the market for crude oil and precious metals. The later case is applicable only to nonrenewable resources, while competition for renewable resources, and consequential increases in economic value, usually results in an increased market or production activity of the resource. Long term consumer prices of a renewable resource probably average out in line with general economic inflation of the entire economy. Competition arising in the use and allocation of renewable resources has led to continuing contention, with a key concept in the theory of resource allocation, applicable to the resolution of such contention, being the value of water used in the resource extraction, conversion to a marketable commodity, or purification of the initial or final product.

Water may be considered as a fugitive renewable resource and as with all renewable resources, may further be considered as a noneconomic social good, but only, in this case, when an abundant and consequential noncompetitive supply exists. With increasing demands and technology during the last two centuries, the resource of water has taken on an economic value arising due solely to the scarcity and the ensuing competition for its use. However, this economic value and the ensuing optimization, is complicated to a large degree by the many basic inconsistencies and socially irrational operational procedures existing within the water laws of democratic countries [25]. The basic cause of these problems may stem from the effect of private parties influence over ownership, distribution and transfer, and it is felt that major modifications to existing systems may be made to the overall social and net economic benefit of society.

The basic objective of this thesis is the development of a model to maximize net economic returns from water available within a river basin during a discrete time period. It has been assumed that no legal, political or private ownership constraints exist on the allocation of water. The net economic returns are based solely on the water resource and do not consider other resource inputs such as power, raw materials, etc. During the discrete time period, it is assumed that a fixed quantity of water is available from the basin and thus available to the water users within the basin. The minimum water requirements of each user are allocated initially, and the net economic returns are computed. If water is still available for consumption during the time period, the net economic return is arbitrarily increased; and the quantity of water required to achieve this is computed. The model continues in this operation until all the water has been allocated within the basin or maximum demand has been satisfied.

Figure 1.1 following gives the flow chart of the basic process with the considered optimization path given by the heavier connecting lines. In outlining the basic principles governing current theoretical water allocation policies, two cases of allocation systems, with and without return flows, are developed. Numerous constraints exist within a river basin upon the net economic return maximization objective, and existing techniques for their consideration are discussed together with recommendations of their influence in the initial design of planned allocation systems.

The net economic return to a particular water user is dependent upon all other water using sectors within a defined area, and the economic interdependencies may be determined through economic input-output analysis. While very much applicable to the formulation and consideration of economic transfers between sectors, input-output studies are constrained to some degree in their use, and rely upon some broad general assumptions within their formulation. These constraints and assumptions are discussed together with their validity. The economic interrelationship between water users also relies upon the water quantities consumed, and a water allocation model is necessary to distribute water to the users initially. A generalized physical water allocation model has been developed within the thesis to allocate water to the individual users under the constraints of minimum water requirements.

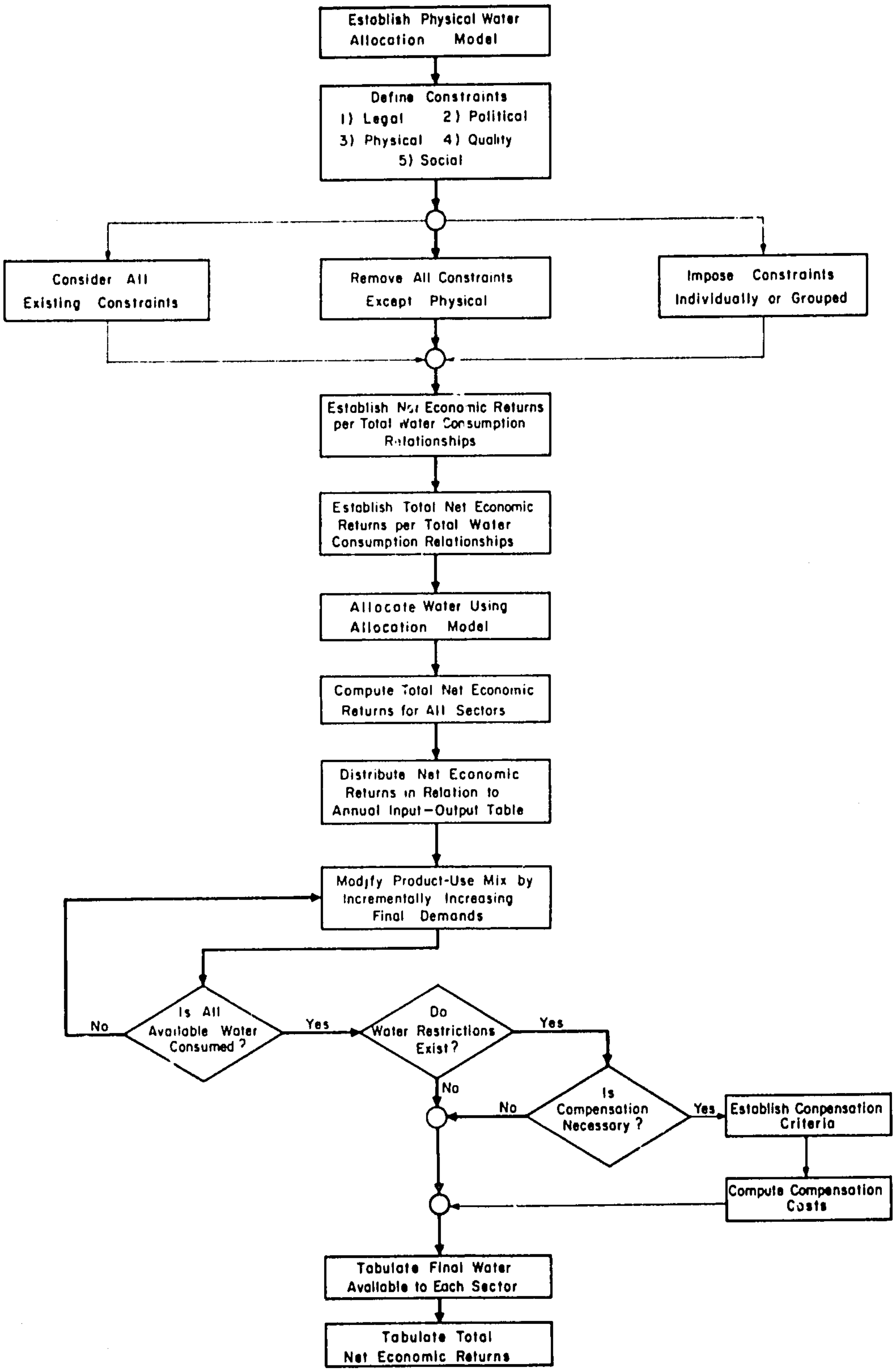

Figure 1.1 Flow Chart of the Basic Process.

An adoption of a workable water allocation model under a net economic maximization criteria requires definition of the net economic return as a function of the total water quantity used for each consuming sector. Problems associated within the derivation of these functions, and the lack of empirical data have been discussed, together with the additional complications arising between competing sectors. The types of data required, methods of data collection and the necessity of synthetic data generation have also been discussed. Data types are considered under the three major headings of economic data, climatic data, and water-consumption data. Each of these three main technical data types have been subdivided into their major subsections and their impact upon the system operation evaluated.

The economic maximization of a water allocation system requires the formulation of a logical sequence of discrete steps for either an existing or a proposed system. Using synthetic data, an example of the formulation is given together with the assumptions and simplifications necessary. The example model is operated in the following manner.

1. The physical water allocation program is employed initially to distribute water to the consuming sectors in relation to their demands and the net quantity of water available within the basin during the discrete time period.

2. From the economic demand functions, the net returns to each sector are derived.

3. The net returns to each sector are distributed throughout the input-output transactions table in relation to the average annual input-output table.

4. The table is then balanced within the import and export sectors and the total net output determined.

5. If additional water is available and not all demands have been satisfied within the basin, the final demand sector is increased within the transaction table using multipliers dependent upon the net economic benefit per unit water consumption values (b_i).

6. The transactions table is then rebalanced with the new final demand values and the new water quantities determined.

7. Iterations are continued until all demands have been met, or the total water quantity available has been allocated, to arrive at the optimal condition.

8. The final total net economic return to the basin is then compared to the average consumptive conditions for the time period.

The final chapter discusses conclusions of the entire model, and offers recommendations regarding its use in actual allocation problems. The application of the entire model and its usefulness are indicated together with recommendations regarding the data sensitivity of the model, and assumptions necessary to reduce the effect of this data orientation to a minimum.

Recommendations are also made regarding the areas in which further research should be undertaken and the nature and extent of this research. These recommendations have been made in an attempt to increase the overall operational efficiency of the entire system, and reduce costs of its operation.

2.00 THEORETICAL WATER ALLOCATION SYSTEM:

A generalized physical model of a catchment area is shown in Figure 2.1 following, in which the boundaries are defined by the physical extremities of all natural creeks and consequential topographic grade changes. Diversions for productive and consumptive uses, together with in-stream use may be represented both diagrammatically and in flow line form as individual withdrawal units, acting as complete system entities, and considered wholly independent of other catchment diversions. Although "inflow" uses, such as power generation,

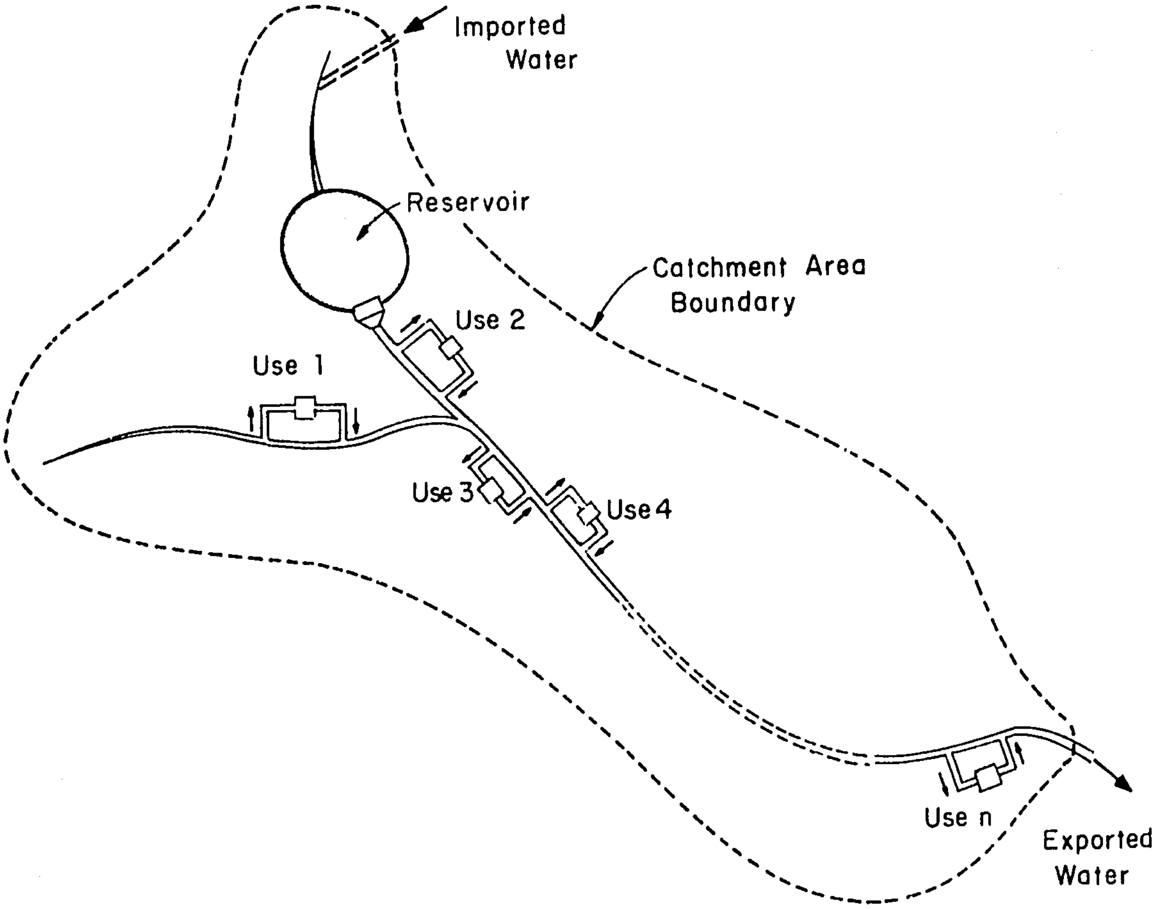

Figure 2.1 Generalized Catchment Area

recreation, fish hatcheries, etc., return a large percentage of their withdrawals to downstream users, the productivity and/or net economic return to the catchment area is a real entity, and must be considered as such in conjunction with return flows.

The diagrammatic catchment area may further be reduced to flow line form, depicting all consumptive and nonconsumptive water uses throughout the entire length of all rivers and creeks in the catchment. This flow line format is shown in Figure 2.2, and is accompanied by symbol definition and explanation. Each use is represented by an actual diversion from the river, irrespective of them being consumptive or nonconsumptive, or off river - in flow uses. All users have been

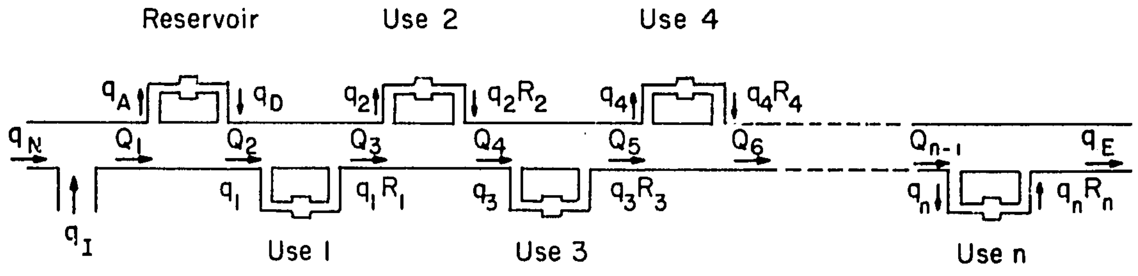

Figure 2.2 Flow Line Format for a Generalized Catchment Area

considered as giving return flow to the river, allowing full generalization for return and nonreturn flow criteria development.

The concepts of return and nonreturn flow introduce the two main water transfer criteria of dependent and independent release [7]. A dependent release water transfer implies that a user is legally bound to return to the main stream a certain percentage or a fixed amount, of his original quantity diverted, and further, that downstream users are partially or wholly dependent upon this upstream return flow. An independent release water transfer implies that there is no return flow to the stream, for consumptive water uses, and further, that downstream users are solely dependent upon the base, and natural flow of the stream. In the extreme case of physical water restrictions, there may be no base flow in the stream under the dependent release transfer criteria, while it is mandatory that a base flow exists for the independent release transfer criteria.

In Figure 2.2 the alphanumeric symbols have the following designations:

q_n = natural monthly inflow discharge (glls)
q_I = imported monthly inflow discharge (glls)
$Q_{(1 \rightarrow n)}$ = monthly discharge between diversions (glls)
q_E = exported monthly outflow discharge (glls)
q_A = monthly discharge to storage (accumulation) (glls)
q_D = monthly discharge from storage (depletion) (glls)
$q_{(1 \rightarrow n)}$ = monthly discharge to users $1 \rightarrow n$ (glls)
$R_{(1 \rightarrow n)}$ = return coefficients for the respective users.

(All R_n values must lie in the range 0.0 to 1.0).

In conjunction with the above alphanumeric symbols, the following symbols shall also be used in dependent and independent release transfer criteria:

$b_{(1\rightarrow n)}$ = net economic benefit derived from the unit water consumption on individual diversions $1 \rightarrow n$ (\$)

B_n = total net economic benefit derived from the total water consumption on all areas (\$)

b_A = net economic benefit of a unit water quantity transferred to storage (\$)

b_D = net economic benefit of unit water quantity removed from storage (\$)

b_E = net economic benefit derived from a unit of water sold to export (\$), and

b_I = net economic cost of a unit of water obtained from imports (\$).

The alpha symbol b_I may be considered as a net economic benefit within all equation developments, but with a negative sign.

2.10 Dependent Release Transfer:

The basic transfer criteria for this transfer system is developed following, using equations of continuity. As each downstream user is solely dependent upon the return flows of the immediate upstream user, then, with reference to Figure 2.2, at the first diversion (in this case the reservoir):

$$q_A = Q_1. \tag{2.1}$$

$$\text{(where in turn } Q_1 = q_N + q_I) \tag{2.2}$$

For User 1, the following equation holds

$$q_1 = Q_2 = q_D \tag{2.3}$$

For the second user,

$$q_2 = Q_3 = q_1 R_1 \tag{2.4}$$

Similarly, for the third user

$$q_3 = Q_4 = q_2 R_2 \tag{2.5}$$

Substituting $q_2 = q_1 R_1$ from equation (2.4) into (2.5) yields

$$q_3 = R_2 (q_1 R_1)$$

For the fourth user,

$$q_4 = q_3 R_3 \tag{2.6}$$

and substituting for q_3 yields

$$q_4 = R_3 (R_2 (q_1 . R_1)). \tag{2.7}$$

For the n^{th} user within the catchment the water quantity available for diversion is given by

$$q_n = R_{n-1} (R_{n-2} . R_{n-3} . R_{n-4} \cdots . R_1 q_1) \tag{2.8}$$

(Note that for manipulative ease the substitution $q_1 = q_D$ (equation (2.3)), has not been made in equation (2.8)).

For Users 1 through n, the total net economic benefit derived by any particular individual user is given by $b_i q_i$. Thus for a total of n users, the total net economic benefit derived from the total water usage on all areas is given by

$$B_n = b_i q_i + b_2 q_2 + b_3 q_3 + \ldots + b_n q_n . \tag{2.9}$$

Substituting q_i values in the above equation yields

$$B_n = b_1q_1 + b_2(q_1R_1) + b_3(R_2(q_1R_1)) + \ldots$$
$$+ b_n(R_{n-1}(R_{n-2}.R_{n-3}. \ldots .(q_1R_1))). \quad (2.10)$$

If it is assumed that a constant efficiency of use exists between all users, then the percentage of return flow for all users (R_i) will be constant,

$$\text{i.e., } R_1 = R_2 = R_3 = R_n. \quad (2.11)$$

Substituting $R = R_i$ into equation (2.10) gives the following:

$$B_n = b_1q_1 + b_2q_1R + b_3q_1R^2 + \ldots + b_nq_1R^{n-1}. \quad (2.12)$$

Thus

$$\frac{B_n}{q_1} = b_1 + b_2R + b_3R^2 + \ldots + b_nR^{n-1}. \quad (2.13)$$

Note should be made that under a purely hypothetical equitable transfer criteria, the net benefit per unit of water derived by all users would be constant. Under this condition,

$$b_1 = b_2 = b_3 = b_n = b.$$

Substituting $b = b_i$ into equation (2.13) yields

$$\frac{B_n}{q_1} = b + bR + bR^2 + \ldots + bR^{n-1}. \quad (2.14)$$

Thus

$$\frac{B_n}{bq_1} = 1 + R + R^2 + \ldots + R^{n-1}. \quad (2.15)$$

Equation (2.15) is equivalent to the expression

$$\frac{B_n}{bq_1} = \frac{1 - R^n}{1 - R}. \quad (2.16)$$

and indicates the general expression for dependent water transfer between all users within a catchment area under the assumptions of constant return coefficients and constant net benefits per unit of water. Although the first assumption does have some validity in the real world, the second assumption is purely hypothetical, and the total economic benefit for n diversions on a river may be expressed rationally as

$$\frac{B_n}{q_1} = \sum_{i}^{n} b_n (R)^{n-1} \qquad (2.17)$$

$i = 1 \rightarrow n.$

For this case of dependent release transfer the nonlinear maximization objective function may be stated as:

$$\text{maximize } \frac{B_n}{q_1} = \sum_{i}^{n} b_n (R)^{n-1} \qquad (2.18)$$

$i = 1, 2, 3, \ldots, n$

under the constraints of

$$0 < R \leq 1 \qquad (2.19)$$

and

$$b_i \geq 0 \qquad (2.20)$$

2.20 Independent Release Transfer:

An independent release transfer relies upon the basic implication that a variable base flow exists between users within the river and that downstream users are not dependent upon upstream return flows [7]. Referring again to Figure 2.2, and using the same method of derivation described previously, the following independent release transfer criteria may be developed.

For diversion at the reservoir,

$$Q_1 = q_N + q_I, \tag{2.20}$$

while for reservoir depletion, the returning flow is given by

$$Q_2 = Q_1 - q_A + q_D \tag{2.21}$$

which is the available river flow that User 1 may draw upon. For User 2, the available water quantity is

$$Q_3 = Q_2 - q_1R_1. \tag{2.22}$$

Similarly for User 3,

$$Q_4 = Q_3 - q_2R_2. \tag{2.23}$$

Substituting equation (2.22) into (2.23) yields

$$Q_4 = Q_2 - q_1R_1 - q_2R_2, \tag{2.24}$$

and in general, for the n^{th} diversion,

$$Q_{n-1} = Q_n - q_{n-2}.R_{n-2}. \tag{2.25}$$

The net economic benefit derived by User 1 is $b_1(q_1 - q_1R_1)$; by User 2, $b_2(q_2 - q_2R_2)$; and for the n^{th} user, $b_n(q_n - q_nR_n)$. The total net economic benefit derived from water usage on all individual diversions is thus given by

$$B_n = b_1(q_1 - q_1R_1) + b_2(q_2 - q_2R_2) + b_3(q_3 - q_3R_3) + \ldots + b_n(q_n - q_nR_n). \tag{2.26}$$

Again, if it assumed that the return flow percentage for all users is constant, i.e., $R_1 = R_2 = R_3 = R_n = R$, then equation (2.26) reduces to

$$B_n = b_1q_1(1 - R) + b_2q_2(1 - R) + b_3q_3(1 - R) + \ldots + b_nq_n(1 - R). \tag{2.27}$$

If the purely hypothetical equitable transfer criteria of constant net economic benefit per unit of water, derived by all users, is adopted then

$$b_1 = b_2 = b_3 = b_n.$$

Substituting $b = b_i$, into equation (2.27) yields

$$B_n = bq_1(1 - R) + bq_2(1 - R) + bq_3(1 - R) + \ldots + bq_n(1 - R) \qquad (2.28)$$

$$B_n = b(1 - R)(q_1 + q_2 + q_3 + \ldots + q_n) \qquad (2.29)$$

From equations (2.22), (2.23) and similar equations developed for each user, then,

$$q_1 = \frac{Q_2 - Q_3}{R_1} \qquad (2.30)$$

$$q_2 = \frac{Q_3 - Q_4}{R_2} \qquad (2.31)$$

and in general,

$$q_n = \frac{Q_{n-1} - Q_n}{R_n} \qquad (2.32)$$

Substituting these equations into equation (2.29) gives,

$$B_n = b(1 - R)\left[\frac{Q_2 - Q_3}{R_1} + \frac{Q_3 - Q_4}{R} + \ldots + \frac{Q_{n-1} - Q_n}{R}\right] \qquad (2.33)$$

$$\therefore B_n = \frac{b}{R}(1 - R)(Q_2 - Q_n). \qquad (2.34)$$

Note should be made that this expression does not include any net economic benefit arising from reservoir accumulation or depletion. However, with reservoir changes, the final equation would be identical except that Q_2 would be equivalent to Q_1. As for the case of dependent water transfer, the assumption that $R_1 = R_2 = \ldots R$ may be rationally valid, though a constant net economic return between all users is hypothetical and very much unreal under existing operational practices.

From equation (2.26) the objective function for maximization of the total net economic benefit derived from water usage on all individual diversions for the case of independent survey is linear, and may be expressed as

$$\text{maximize } B_n = \sum_i^n b_i q_i (1 - R_i) \qquad (2.35)$$

$$\text{subject to } 0.0 < R_i \leq 1.0 \qquad (2.36)$$

$$Q_i + R_i q_i > 0.0 \qquad (2.37)$$

and

$$\sum_i^n q_i (1 - R_i) = Q_2 - Q_n \qquad (2.38)$$

where

$i = 1, 2, 3, \ldots, n.$

For both the dependent and independent transfer equations developed, it has been assumed that discrete time periods are being considered. The input-output analysis following requires the use of such discrete time periods and analysis must be carried out for each time period considered. However, optimization is conducted during these discrete time periods through static iteration to achieve optimal net economic benefits (b_i) for all sectors within the catchment area, under the constraints of physical water quantities available. As will be discussed later, the greatest problem arising within any optimal allocation system is the determination of the b_i values and the correlation of b_i to q_i values. From the literature survey, conducted it appears that a great deal of research has been carried out along these lines, especially in the demand areas of recreation, domestic and social consumption, though results have been questionable.

2.21 Independent Release Transfer, Including Losses:

The foregoing equation derivations have not considered canal and river losses between and within diversions. Although total net economic optimization in the following analysis relies upon net physical water quantities delivered to the user, the following derivation for an independent release transfer including canal and river losses, is relevant to the consideration of water quantity allocations. It is possible from the resulting equations to determine the gross economic loss due to canal losses under the assumption that an average b_i value is computed for all water consumers. However, as optimization of $b_i q_i$ values is the prime concern of this analysis, inclusion of variable loss rate values within the system would give rise to a further extremely complex iterative procedure. As a result of this, the $b_i q_i$ values computed during the input-output and allocation iterative process rely upon net q_i values delivered to the point of use.

Considering a section of the flow line format depicted in Figure 2.2, the following figure will be used to illustrate the development of canal loss minimization equations. Within Figure 2.3, the following alphanumeric symbols are added.

L_{R_1} = river length between nodes A and B (ft; m)

L_{R_2} = river length between nodes B and C (ft; m)

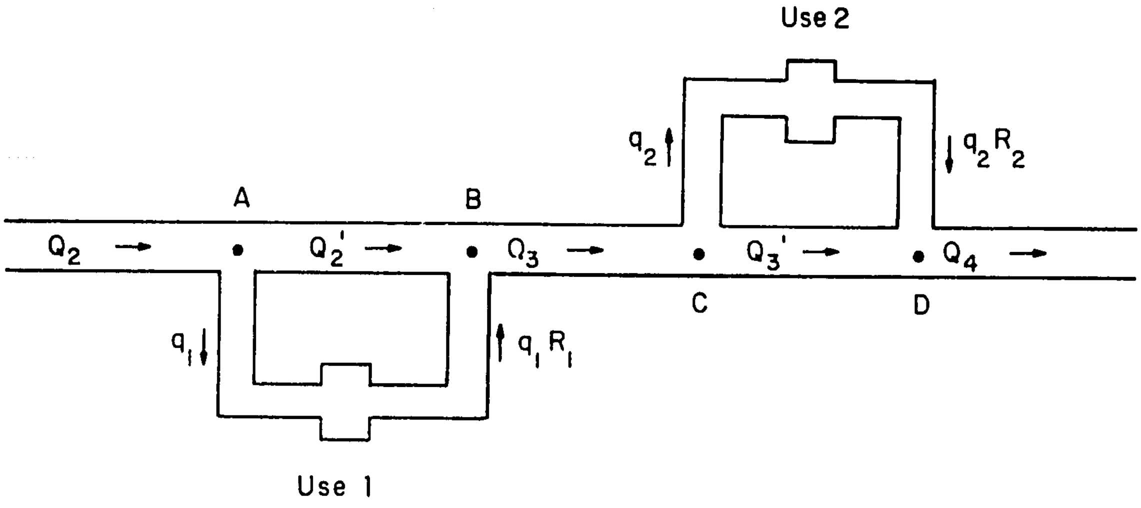

Figure 2.3 Flow Line Format Section

L_{R_3} = river length between nodes C and D (ft; m)

L_1 = canal length between node A, use 1, and node B (ft)

L_2 = canal length between node C, use 2, and node D (ft)

q_{R_1} = water loss per unit length in L_{R_1} (cfs/ft)

q_{R_2} = water loss per unit length in L_{R_2} (cfs/ft)

q_{R_3} = water loss per unit length in L_{R_3} (cfs/ft)

q_{L_1} = water loss per unit length in L_1 (cfs/ft)

q_{L_2} = water loss per unit length in L_2 (cfs/ft)

For User 1, the returned water quantity to the river is $(q_1R_1 - L_1 \cdot q_{L_1})$, and similarly for User 2, $(q_2R_2 - L_2 \cdot q_{L_2})$. Consideration of actual flows at each node yields the following. At node A:

$$Q_2 = Q_2' + q_1. \tag{2.39}$$

At node B:

$$Q_3 = Q_2' + (q_1R_1 - L_1 \cdot q_{L_1}) - L_{R_1} \cdot q_{R_1}. \tag{2.40}$$

Substituting for Q_2' from equation (2.39) yields:

$$Q_3 = Q_2 - q_1 + (q_1R_1 - L_1 \cdot q_{L_1}) - L_{R_1} \cdot q_{R_1}. \tag{2.41}$$

At node C:

$$Q_3 = Q_3' + q_2. \tag{2.42}$$

At node D:

$$Q_4 = Q_3' + (q_2R_2 - L_2 \cdot q_{L_2}) - L_{R_2} \cdot q_{R_2}). \tag{2.43}$$

Substituting for Q_3' from equation (2.42) yields:

$$Q_4 = Q_3 - q_2 + (q_2R_2 - L_2 \cdot q_{L_2}) - L_{R_2} q_{R_2}. \tag{2.44}$$

Substituting for Q_3 from equation (2.41) yields:

$$Q_4 = Q_2 - q_1 + (q_1R_1 - L_1 \cdot q_{L_1}) - L_{R_1} \cdot q_{R_1} - q_2 + (q_2R_2 - L_2 q_{L_2}) - L_{R_2} q_{R_2}. \tag{2.45}$$

$$\therefore Q_4 = Q_2 - q_1(1 - R_1) - q_2(1 - R_2) - (L_1 q_{L_1} + L_2 q_{L_2}) - (L_{R_1} q_{R_1} + L_{R_2} q_{R_2}).$$

Generalizing, for an enclosed distribution system,

$$q_E = q_T - \sum_1^n q_i(1 - R_i) - \sum_1^n L_i q_{L_i} - \sum_1^n L_{R_i} \cdot q_{R_i} \tag{2.46}$$

where $i = 1, 2, \ldots, n$

q_E = exported outflow discharge (glls)

q_T = inflow discharge to the entire catchment (glls)

If the distribution loss per unit length is assumed constant for the entire network, and is thus designated by q_L, then equation (2.46) reduces to

$$q_E = q_T - \sum_1^n q_i(1 - R_i) - (q_L \sum_1^n (L_i + L_{R_i})). \tag{2.47}$$

For small catchment areas, where variation in soil and vegetal conditions are relatively small, and canals are unlined the previous assumption may be held valid.

Within a purely physical distribution system incorporating canal and river losses, the objective function for the problem becomes;

$$\text{maximize } (q_E) = q_T - \sum_1^n q_i(1 - R_i) - q_L \sum_1^n (L_i + L_{R_i}) \tag{2.48}$$

under the constraints of;

$$\sum_1^n (L_i + L_{R_i}) \geq 0 \tag{2.49}$$

and

$$\sum_1^n q_i(1 - R_i) \geq 0. \tag{2.50}$$

For a continuous time function, the generalized objective function may be defined as previously, though with the use of time superscripts. Equation (2.47) may thus be rewritten as;

$$q_E^{(t)} = q_T^{(t-2)} - \sum_1^n [q_i(1 - R_i)]^{(t-1)} - q_L \sum_1^n (L_i + L_{R_i})^{(t-2)} \tag{2.51}$$

where superscript t = flow condition at time t;

$t-1$ = flow condition at time $(t-1)$ which allows for travel time from the previous node to the next point of demand

$t-2$ = flow condition at $(t-2)$ which allows for travel time from the point of demand to the outlet node.

From this basic generalization, a complex set of linear equations may be established for any size network within a catchment area. If an average net economic return per unit of water (b) is derived for the entire catchment area, then the net economic maximization function for the area may be written as

$$\text{maximize } B_n = b[q_E + q_T - \sum_1^n q_i(1 - R_i) - q_L \sum_1^n (L_i + L_{R_i})] \qquad (2.52)$$

subject to similar constraints.

A more detailed discussion of the use of continuous time functions within water allocation systems may be found in references [22] and [23].

3.00 CONSTRAINT CONDITIONS:

Constraints may be classically defined as restrictions, naturally placed upon a maximizing condition. They may also define the area, or boundaries, in which a system is confined and must operate within. Constraining conditions exist upon the use of all renewable and non-renewable resources, and the different types of constraints have a large variation in the severity of confinement. This variation in effect also defines the degree of difficulty with which they may be removed from, or modified within, the system.

The major classifications considered within the text of this thesis are those constraints associated with the legal, political, physical, quality and social conditions affecting the optimal allocation and use of water. Subsections of each of these classifications are discussed following, including the effects of the individual constraints, the comparative effect of each, and methods for reducing, or eliminating, their effect upon water allocation systems.

3.10 Legal Constraints:

By far the most hampering water allocation constraints existing in the western world are those associated with the legal aspects of water ownership and control. In these societies there exists both public and private control of natural watershed, collection and allocation systems. The most predominant legal constraints arise in the form of the riparian doctrine, prior-appropriation doctrine and the doctrine of minimum consumption.

Though more applicable to the public sector, both private and public management authorities use the riparian doctrine as the basic water allocation legality. This doctrine allows either a free flow of water from a natural surface source adjoining the user's property, or a fixed volume of water available per discrete time period as a function of the length of frontage to the property. This doctrine does not consider the use to which the water will be put, or the economics relating to its actual use, yet has very strong legal backing in many American states and many other countries.

The second most revered legal implication in water allocation is that associated with the "appropriation" doctrine. This doctrine implies a water use priority system with users holding the older rights to water use having preference over later applications [25]. Again this doctrine does not consider the use, or economic allocation, of the water and may be far removed from an optimal allocation criteria. Due to existing operational methods, both of the above doctrines induce severe legal complications with regard to new water use applications and transfers.

Several types of private water control authorities exist in the western society. Although these private authorities are normally operational on small river basin areas, and are thus not affected to any significant degree by interbasin water transfers, similar constraints on the water use efficiency exist within the current allocation policies and organizational systems. It is normal practice for a private water authority to conduct the business of water collection and allocation as a public company, with a fixed number of shares available for the area capable of being supplied, and a fixed quantity of water (during average annual flow conditions) attached to each share. Net economic maximization is more prone to exist under this system than for the riparian or prior-appropriation doctrines, though this method of allocation may in fact be part of the legal implications associated with the appropriation doctrine. The willingness to buy shares from a private water allocation authority, and the consequent ability to transfer water between shareholders indicates, to a significant effect, the comparative unit benefits to be derived from water units within competing consuming sectors. However, these comparative unit benefits are normally quoted on an intra-basin basis, and may be no indication of comparative net economic benefits per water unit between basins.

In many countries, water is considered as a gross social resource, and its collection, distribution, management and all general operations are handled by a central national body, such as a state or federal governing agency. Although these bodies possibly have the greatest opportunity to attain net physical and economic optimization of water allocation, they also are hampered by certain social constraints.

The doctrine of minimum consumption may imply two main water use legalities. In association with the prior-appropriation doctrine, minimum annual consumption values may be placed upon the consumer, and if these values are not exceeded, the water rights may be transferred to another user. Alternatively the doctrine may be activated during periods of water restrictions, during which time users consuming the lowest quantities are restricted (partially or fully, depending upon physical water quantities available) initially. Both of these implications again bear little, if any, relevance to economic returns, and do not differentiate between the types of goods, or services produced.

For all of the above constraints, economic maximization may only be obtained by their complete removal, though allocation optimization may exist under application of any of them. Allocation of supplies in relation to demand and economic return may then be carried out through an unbiased water administrative body, as is the case within this thesis. Further specific reading on legal constraints may be found in references 25, 35 and 41.

3.20 Political Constraints:

Under existing democratic conditions, land masses are divided into political areas that normally govern the resources of that particular area. These subdivisions often give rise to distribution and use contention due solely to the self-interest of the people within the area. Contention may exist between state government bodies, state and federal governments, and differing federal government bodies.

State government constraints are normally localized and are highly correlative with the legal constraints discussed previously. If contention continues between these bodies, the problems may become a federal issue, which consequently induces further nonproductive social costs for all water consumers. This is particularly evident in European countries where a river may serve as a boundary between countries. For all of these cases, problem delineation must include consideration of overall use aspirations, groups and areas affected, the allocation of costs and benefits, and the conflict, or cooperation, existing within international relations [14]

Removal of, or a reduction in, these constraints normally reverts to the problem of legal issues, and complete optimization of a water allocation system may only be achieved, again, through the establishment of an individual water allocation authority for a particular river basin.

3.30 Physical Constraints:

These types of constraints normally constitute the largest part of all problems existing within an operative or planned water allocation system. However, many of the constraints classified within this subsection are readily handled rationally by allocation authorities, and in general do not induce severe costs, arising from contention, to consumers.

Of all individual constraints acting on a water allocation system, the singular most severe constraint is that of an absolute water shortage. This constraint implies that, under any allocation system, a sufficient water supply is not available to satisfy the total demand within the system. Although not prevalent at present in the U.S.A., absolute water shortage conditions serve as the prime constraint in many of the nations around the world. It is also common occurrence to find economic water shortages serving as constraints where sufficient water supply is available, but severe competition exists for its use. This type of shortage, especially within continental U.S.A., has induced many hours of research in an attempt to maximize economic returns between competing users, though as explained previously, the objectives are hampered to a large extent by the existing legal and political constraints.

A further physical constraint, strongly interwoven with legal issues, is that of minimum flow criteria. This criteria requires that a minimum discharge be retained within natural river systems for the preservation of aquatic life, navigation, and the satisfaction of downstream demands. This criteria is becoming far more prevalent in the Western World due to an upsurge in environmental concern, though has always been operative regarding downstream demands for consumptive use. At present, very little interaction between basins exists regarding the optimal release of water for downstream consumption.

Physical constraints may also be found within the pure geography and topography of the basin. Geologic, climatic and existing development factors serve as constraints in the initial design and operation of distribution systems. However, exact definition of their effect, and constraining severity may be evaluated rationally, with their final effect reflected in the overall cost of development and operation. The growth of urban development may impinge upon the allocation efficiency, causing rerouting of water lines and continuous changes in the supply costs to individual sectors. Again, these constraints may be reflected in the economics of the system, and numerous techniques are available for minimizing costs of water distribution pipe networks.

3.40 Quality Constraints:

Water quality considerations may be considered as physical constraints upon allocation and economic optimization, though they have recently acquired entity consideration due to environmental concern. Quality constraints may be physical, chemical, organic or inorganic material, or radioactivity, and evaluation of their effect may again be conducted economically. Normal evaluative practices involve the determination of costs associated with the purification of water, or the reduction in benefits to producers for varying degree of quality reduction.

Compared to the legal and political constraint conditions, quality constraints do not affect allocation optimization severely, and it is normal for the costs associated with water purification to be considered within the overall operation and maintenance costs of the allocation system. Numerous references are available for the determination of purification costs to each sector, though less has been researched regarding reduction in producer benefits in relation to water quality.

3.50 Social Constraints:

Social constraints, as considered within this thesis, revolve around the contention existing in water demands and valuation for consumption within schools, hospitals, and general public uses. They may also include water use for esthetic values, such as park areas, landscaping, etc., and as such, may also be encompassed within the bounds of environmental considerations. Within this definition, water use and protection of natural flora and fauna is also included. For all of these uses, the basic constraints arise more from the problem of economic evaluation than from consideration of demand and allocation objectives.

Constraints may also arise in the evaluation of an optimal size of urban centralization in relation to the gross water quantity available. Large cities within relatively small basin areas may cause severe constraints on the economic objective of the area when considered in competition with other sectors. This is particularly prevalent when water restrictions exist. Social constraints in general do not induce severe allocation problems in comparison to those previously discussed, though the major problem with their consideration arises in the economic evaluation and establishment of production functions relative to other consuming sectors.

4.00 INPUT-OUTPUT ANALYSIS:

4.10 General Considerations:

The application of programming techniques to water resource systems for project development, operation, and river basin management has become well-grounded and continues to increase in their acceptance and use. To a large extent, however, most programming techniques have been applied to particular projects or management systems without regard for the integrated relationship the project may have to the economy of a region as a whole. Nor have project plans or management schemes usually considered the phasing of various investments within the area under consideration relating to the particular pattern of growth that is anticipated.

Due primarily to population increases and to a lesser extent, increases in economic efficiencies, it is not possible to satisfactorily consider an economic area within a partial equilibrium setting. However, within this partial equilibrium setting, the questions of development, scale of development or river basin management can be viewed as those in which the planning agent can take a comparative development approach and maximize the present value of production on the basis of consumer demand, physical input quantity constraints, and a revealed social rate of interest. For project development, the projects yielding the highest present value may then be selected for construction. This comparative development or management approach is only valid however, if the marginal value of all products is equal to the price of all relevant commodities and services necessary for that production.

Input-output analysis revolves around the dependencies existing between various producing and consuming sectors within any particular defined region. The system is designed to reveal these interdependencies among the various industries of the economy, and the relations of these industries as sellers to the final consumers. In doing so, the system becomes a format expressing general economic equilibrium within the defined region. Although the defined region is purely arbitrary and no constraints exist upon its boundaries, most input-output studies have been conducted on an intra-regional or inter-regional basis, with the boundaries being defined by major production sectors or geographic areas. Irrespective of the geographic size or the degree of disaggregation to be considered, all input-output studies revolve around the basic formulation of a transactions table that depicts the actual gross dollar amounts of transactions between the producing and consuming sectors. By modifying this economic network of transactions, it is possible to reach an optimal economic condition for the defined area.

However, as the input-output programming technique of analysis for water resource systems is a static technique, any economic optimization within the allocation system can only be made through comparative analysis of a number of static balances, while remaining within all geographic, physical quantity and economic constraints. This comparative analysis may be obtained by modifying the "water use mix" between competing users within the region and consequently inducing changes within the total gross output. Changes in the "water use mix" basically implies reallocation of physical water quantities from one competing sector to another, and this reallocation will consequently cause a change in the net economic benefit values (b_i) of affected users. An excellent introduction to input-output analysis may be found in reference [31].

4.20 Static Input-Output Analysis:

Due to the complex nature of input-output analysis, a detailed discussion of the tabulations and method of operation is justified. Table 4.1 following illustrates the generalized format of the basic transactions table, with the alphanumeric symbols defined in detail following. It should be stressed that the higher degree of disaggregation possible in the basic transactions table (that is, by having the most detailed breakdown of users and sectors) allows a far more accurate compilation of the total gross output from the region. Consequently, the highest degree of disaggregation should be sought in construction of this basic table. Unfortunately, data constraints will play a very important role in the degree of disaggregation within any formulation.

The basic transactions table is made up of two main sectors, namely the producing sector and the purchasing sector, and these sectors together with their subsectors, will be considered separately as follows.

4.21 The Producing Sector:

This sector consists of the Use (or processing) Sector and the Payments Sector. The Use Sector contains the industries and production facets of society that, in this particular case, use water for the production of goods and services, and are included within the area or river basin under consideration.

The Payments Sector consists of all elements and materials that are used by the use sector during the predefined production period.

		OUTPUTS INPUTS		PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	x_{11}	x_{12}	x_{13}	–	–	–	x_{17}	P_1	D_1	T_1
		INDUST'L	x_{2j}	x_{21}						│			T_2
		DOM'	x_{3j}	x_{31}						│			T_3
		COMM'	x_{4j}	│						│			
		POWER	x_{5j}	│						│			
		REC'N	x_{6j}	│						│			
		SOCIAL	x_{7j}	x_{71}	x_{72}	– –		– – –		x_{77}	P_7	D_7	T_7
	PAYMENTS	IMPORTS	I_j	I_1	I_2					I_7	I_8	I_9	$\sum I_j$
		DEPLET'N	L_j	L_1	L_2					L_7	L_8	L_9	$\sum L_j$
TOTAL OUTLAY			G_j	G_1	G_2					G_7	G_8	G_9	$\sum G_j$

Table 4.1 Generalized Format of the Transactions Table.

The Imports row in this tabulation lists the economic costs from the affiliated water consumption of each use. This indicates that User 1, reading down from the purchasing sector, imported a certain quantity of goods valued to that user at I_1 dollars. The Depletion row implies the using up of previously accumulated stocks, and in terms of water produced goods, lists the economic costs born by each user for water used that was stored in a previous period. Thus User 1 used up water that has a total value of L_1 dollars during the covered period.

In considering a table orientated around pure commercial transactions, the payments sector may also include depreciation allowances, payments to governments, and payments to households, allowing further disaggregation within the table.

4.22 The Purchasing Sector:

This sector consists again of the Use (or processing) Sector together with the Final Demand Sector. The Use Sector consists of the same industries and production facets as the column of the producing sector. Values within the Use Sector indicate the amount of purchases from one industry by another, and the amount of sales from one industry to another. Thus the x_{23} entry indicates the economic value of goods purchased by User 3 (at the top of the table) that were produced by User 2 (on the left-hand side of the table). The actual numerical value is in dollars, and indicates the net economic value of the sale of produce from User 2 to User 3. This transaction will indicate a certain percentage of the net total water quantity diverted from the allocation system to User 2.

The Final Demand Sector is a completely autonomous sector, and the sector in which induced changes are transmitted throughout the rest of the table. Columns in this sector usually consist of gross inventory accumulation (the amounts of additions to inventories held by each of the users in the left-hand side of the table), exports (the value of exports produced by each user), government purchases (purchases made by all levels of government), and gross private capital formation. In Table 4.1, gross inventory accumulation, government purchases, and gross private capital formation are aggregated within the accumulation column. However, should individual areas warrant disaggregation, only further minor computations are necessary within the input-output operational analysis.

In addition to the producing and purchasing sectors, the final additions of all sectors are also entered. The total gross outlays give the total value of inputs to each of the users in each column, while the total gross outputs give the row additions of the total production of each user, together with the outputs from the payments sector. From these two totals, it may be seen that the input-output table is essentially a system of double entry bookkeeping, with each industry in the Use (or processing) Sector giving the receipts of sales that are paid out for goods and services purchased from other industries or sectors. After considering appropriate inventory changes, the total gross output of each industry in the Use Sector is equal to the total outlays made by that industry. Thus, within the Use Sector, the row additions culminating in the total gross outputs column, are identical to the column additions in the total gross outlays row.

Note should be made that the final addition of the total gross output column (or similarly, the total gross outlay row) is a double counted value measuring all transactions within the table, and is thus not equivalent to the gross areal product or the gross product of total net water consumption. Within the basic input-output transactions table, some goods will enter into more than one transaction, and the value of these goods must be counted each time a different transaction takes place. However, by maximizing the total gross outputs (or total gross outlays), consequential maximization occurs within the sectors of the table under prevailing constraint conditions. The maximization objective within the input-output analysis normally revolves around increasing the final demand columns in an attempt to increase exports, or accumulate the maximum economic amount of goods produced within the area during the time period considered. Changes in the final demand automatically induce changes within the Use Sector, implying modification of the product use mix.

The entire transaction table may be expressed in matrix form, and the entire operation of maximization conducted in this format as follows. For any particular Use Sector, the static balance equation for total gross output is given by

$$T_i = (x_{i1} + x_{i2} + x_{i3} + \dots + x_{in}) + P_i + D_i . \tag{4.1}$$

Designating Y_i as the total final demand, then

$$Y_i = P_i + D_i . \tag{4.2}$$

Substituting equation (4.2) into (4.1) yields

$$T_i = (\sum_1^n x_{ij}) = Y_i . \tag{4.3}$$

This equation may be expressed in matrix form for the entire transactions table as:

$$|T_i|_C = [x_{ij}] + |Y_i|_C \tag{4.4}$$

where $[x_{ij}]$ represents the following matrix.

$$[x_{ij}] = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{ij} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & & & \vdots \\ x_{i1} & & \cdots & x_{ij} \end{bmatrix} \tag{4.5}$$

The values $|T_i|_C$ and $|Y_i|_C$ thus become column vectors of total gross output and total final demand respectively.

To determine the quantity of inputs required by each user to produce one dollar's worth of produce, the depletion values in the payments sector are subtracted from the total gross outlay values to give adjusted total gross outlay (or similarly, adjusted total gross output). Each column entry in the Use Sector is then divided by the respective adjusted total gross outlay value for that use. The resulting values are known as technical coefficients, designated by a_{ij}, and the computations may be expressed in the form

$$a_{ij} = \frac{x_{ij}}{E_j} \tag{4.6}$$

where

$$E_j = G_j - L_j \, . \tag{4.7}$$

In matrix format, the technical coefficients are given by:

$$[A_{ij}] = \left[\frac{x_{ij}}{|E_j|_R} \right] \tag{4.8}$$

or

$$[A_{ij}] = \begin{bmatrix} \frac{x_{11}}{E_1} & \frac{x_{12}}{E_2} & \cdots & \frac{x_{1j}}{E_j} \\ \frac{x_{21}}{E_1} & \frac{x_{22}}{E_2} & \cdots & \frac{x_{2j}}{E_j} \\ \vdots & & & \vdots \\ \frac{x_{i1}}{E_1} & & \cdots & \frac{x_{ij}}{E_j} \end{bmatrix} \qquad (4.9)$$

This matrix indicates the direct purchases per dollar of output for each user, and does not consider the indirect effects of allied sectors. Equation (4.8) may be rewritten as

$$[x_{ij}] = [A_{ij}]|E_j|_R \qquad (4.10)$$

Rearranging equation (4.4), and substituting $|E_i|_C$, the adjusted total gross output, for $|T_i|_C$, yields

$$|Y_i|_C = |E_i|_C - [x_{ij}] \qquad (4.11)$$

Since both $|E_j|_R$ and $|E_i|_C$ are numerically equivalent, though in transposed form, the substitution $|E_i|_C = |E_j|_R = |E_i|$ is possible. Thus, equation (4.11) becomes

$$|Y_i|_C = |E_i| - [x_{ij}] . \qquad (4.12)$$

Substituting equation (4.10) into (4.12) yields

$$|Y_i|_C = |E_i| - [A_{ij}]|E_i| . \qquad (4.13)$$

Equation (4.13) is the basic matrix formulation for the direct coefficients table. To convert these direct coefficients to take account of both the direct and indirect purchases or sales in the use sector, the technical coefficients table is inverted in the following manner. Rearranging equation (4.13), and considering the relationship in pure matrix notation yields

$$[E_i] - [A_{ij}][E_i] = |Y_i|_C \; . \tag{4.14}$$

Thus

$$[E_i][I-A_{ij}] = |Y_i|_C \tag{4.15}$$

where I is an identity matrix, of the same size as $[A_{ij}]$. Using matrix inversion techniques, the following equation for adjusted total gross outlay (or output) results.

$$[E_i] = |Y_i|_C \, [(I-A_{ij})^{-1}] \; . \tag{4.16}$$

The $[I-A_{ij}]^{-1}$ matrix is known as the direct and indirect technical coefficients table, and may be used directly, in conjunction with modified demand values, to obtain a new basic transactions table in the following manner [31].

If we assume that a new final demand value $|Y_i'|_C$ (which may consist of either new P_i or D_i values, or both) is to be fed into the tabulation to determine a new basic transaction table, it is necessary to adjust this new final demand with regard to depletion values within the payment sector, that were subtracted from the total gross outlays and outputs in the initial computations. This adjustment is carried out by initially summing the column of the initial final demand values. This summation may be designated by

$$H_i = \sum |Y_i|_C \quad . \tag{4.17}$$

The initial depletion values are also summed within the use sector, and may be designated by

$$M_j = \sum |L_j|_R \quad . \tag{4.18}$$

From these two summations, the new final demand $(|Y_i'|_C)$ is adjusted using the following expression to yield the adjusted new final demand, $|Y_i'|_C'$

$$|Y_i'|_C = |Y_i'|_C [1 - \frac{M_j}{H_i}] . \tag{4.19}$$

Designating the direct and indirect technical coefficients matrix by $|K_{ij}|$, then the new direct and indirect technical coefficients matrix is given by

$$[K_{ij}]' = |Y_i'|_C' [K_{ij}] \tag{4.20}$$

which in expanded form may be written as

$$[(I-A_{ij})']^{-1} = |Y_i'|_C' [(I-A_{ij})]^{-1} \quad . \tag{4.21}$$

The resulting $|K_{ij}|'$ matrix is then transposed to return the matrix to respective row-column matrix format of the original transactions table. Thus, the new direct and indirect technical coefficients matrix is given by

$$[|K_{ij}|']^T = [|Y_i'|_C' [(I-A_{ij})]^{-1}]^T . \tag{4.22}$$

The columns of this transposed matrix are then summed to give the row vector of adjusted total gross outputs, given by $|T_i'|_R$. Thus

$$|T_i'|_R = \Sigma[[K_{ij}]']^T . \tag{4.23}$$

These adjusted total gross output values are then multiplied by the original matrix of direct technical coefficients, $[A_{ij}]$ to give the matrix of projected use (or processing) sector values, $[x_{ij}']$. That is,

$$[x_{ij}'] = |T_i'|_R [A_{ij}] . \tag{4.24}$$

Once these basic transaction values have been determined, they may be inserted into the overall input-output table to allow computation of the new export and accumulation values within the payments sector. This is necessary to ensure that the new total gross outlay row vector is equivalent to the new total gross output column derived from the new final demand values and the new use sector values.

The new total gross output is computed by summing the rows of the new use sector values $[x_{ij}']$, and including the respective new P_i' and D_i' values. The resulting total gross output, represented by T_i', may be expressed as

$$|T_i'|_C = x_{ij}' + P_i' + D_i' . \tag{4.25}$$

which is then transposed to a row vector yielding

$$|T_i'|_R^T = |T_i'|_C . \tag{4.26}$$

The individual use sector values are also summed, columnwise, and the resulting vector, $|C_j'|_R$, may be expressed as

$$|C_j'|_R = \sum |x_{ij}'|_C . \tag{4.27}$$

From equations (4.26) and (4.27), the total value of the payments sector, designated by $|F_j'|_R$, may be computed using the expression

$$|F_j'|_R = |T_i'|_R^T - |C_j'|_R . \tag{4.28}$$

These new total payment sector values must then be disaggregated into the respective new imports and depletion values. Decisions regarding this disaggregation will be entirely dependent upon policy decisions of the areal management body, and for purposes of the tabulation here being considered, it is assumed that the original import/depletion ratio, $\frac{I_j}{L_j}$, remains constant during the optimization process. From equation (4.28) the new import and depletion values are given by the expression

$$|I_j'|_R + |L_j'|_R = |F_j'|_R . \tag{4.29}$$

From the original import and depletion values, a row vector of the individual ratios, given by $|R_j|_R$, is computed, and may be expressed as:

$$|R_j|_R = \frac{|I_j|_R}{|L_j|_R} = \frac{|I_j'|_R}{|L_j'|_R} . \tag{4.30}$$

Equations (4.29) and (4.30) may now be considered as simultaneous equations to solve for the new import and depletion values I_j' and L_j'. These may then be substituted into the new input-output table to complete it. If new final demand values are to be considered, then the entire process is repeated, computing a new direct and indirect technical coefficients table from the previous basic transactions table.

Specific note should be made that the entire analysis discussed above is static within itself, in that no allowances have been made within the table for the time variation of demand, supply, accumulation or depletion values. The analysis is further constrained, as mentioned previously, by the degree of desired disaggregation. For the purposes of this thesis, the industrial sector encompasses all industrial sectors within the area of consideration, and it may be necessary, for in situ application, to break these down into the actual producing industries. Aggregation may be accomplished by totalling the net amount of produce worth of all the industries, and computing the average net economic return per unit of water. This method may also be used for all other producing sectors, though disaggregation will be a necessity for large-scale projects.

Under pure economic considerations, changes in final demand are induced by policy changes, or normal stabilization of economic transactions within an area, over long periods of time [32]. The static input-output model has been used by state bodies primarily on an annual basis, with new final demand data being extracted at the end of fiscal year transactions, from actual state economic data collected. Thus, the input-output data tabulated is of past economic nature, though the tabulations have been used extensively to determine variations within the use sector after considering trend changes in, and forecasting from, final demands. By forecasting from final demand variations, and the induced production changes within the use sector, the analysis takes on a time sensitive approach to the utilization of resources available to the area, and in doing so, the static process takes on dynamic attributes [2, 3]. Numerous methods have been formulated for the mathematical conversion of the static input-output analysis to a dynamic process. The most economically and mathematically valid formulations are considered, in precise form, in the following subsection, together with their relevance, application, constraints and general acceptance.

4.30 Dynamic Input-Output Analysis:

For the primary determination of the flows of goods and services, among mutually interrelated sectors, the static input-output model serves adequately for structural economic analysis. However, due to its very definition, the method is restrained from the point of view of determining changes between intersectoral activity over extended time periods. These modifications are necessary due to adjustment, within the economic system, of price changes. Changes in commodity prices will be induced to a large extent by changes in the value of basic resources, especially water. Actual value changes of these basic resources arise due to the willingness of various sectors to pay higher or lower prices for the commodity, and is a direct result of actual demand changes.

In contrast to static analysis, the term "dynamic" basically implies the inclusion of a time parameter within the input-output process, and provides a time sensitive approach to economic forecasting and planning decisions with regard to the utilization of resources in both the public and private sectors in pure economic theory. Investment, or capital formation, is considered in terms of the actual and potential outputs and capacities of a sector or a defined enclosed system [3]. The concept of time lags is normally introduced through the consideration of production occurring ahead of the demand, and the resulting stockpiling. This stock-flow relationship forms the backbone of the dynamic input-output model, and a number of different major premises. The basic concepts of the main methods, together with their pros and cons and applicability are considered briefly following.

4.31 Leontief Dynamic Model:

In an attempt to explain investment within each sector of an input-output study, Leontief introduced the concept of a crude acceleration principle that reflects the fact that any change in output over a period of time, or from one discrete time period to another, influences the net investment as the addition to capital stock during that period of time [2, 9]. This investment, known as "induced investment" reflects directly recent changes in output, and is contrast to the theoretical concept of "autonomous investment."

The Leontief dynamic input-output model reflects a continuous analysis, with the general formulation expressed as follows:

$$X_i - \sum_{j=1}^{n} x_{ij} - \sum_{j=1}^{n} \dot{S}_{ij}(t) = Y_i \qquad (4.31)$$

where X_i = output level of industry i

x_{ij} = sales of produce from industry i to industry j

$S_{ij}(t)$ = capital stock of produce i held by industry j at the beginning of time period t

$\dot{S}_{ij}(t) = \frac{d}{dt}(S_{ij}(t))$ = rate of change of the above stock (investment)

Y_i = total final demand

and $S_i(t) = \sum_{j=1}^{n} S_{ij}(t)$ = the total capital stock of good i available for the economy at the beginning of the time period t.

Incorporating capital coefficients, k_{ij}, indicating the stock of industry i used per unit of produce output of industry j over time period t, the structural stock flow relationships are given by

$$S_{ij} = k_{ij}. \tag{4.32}$$

Differentiating the above with respect to time, and substituting into equation (4.31) leads to:

$$X_i - \sum_{j=1}^{n} p_{ij} X_j - \sum_{j=1}^{n} k_{ij} \dot{X}_j = Y_i \tag{4.33}$$

which allows the formation of a system of n linear differential equations with constant production coefficients, p_{ij}, and constant capital coefficients k_{ij}. Solution of these equations is undertaken following the formation of a set of closed form homogeneous linear differential equations by shifting the households output section (included within the payments and final demand sectors) to the left-hand side of equation (4.33).

This model, however, assumes the existence of a unique pattern of capital accumulation, and consequently does not allow a choice between alternative production patterns. Nor does the model allow disinvestment of capital through the basic assumption of irreversibility. As time is considered continuous, rather than divided into discrete intervals, the final demand is thus an instantaneous rate of flow, and the net capital formation is the rate of increase of flow. This is represented by the defined expression $\dot{S}_i(t) = \frac{d}{dt}(S_i(t))$.

4.32 Dorfman Dynamic Model:

In order to apply the Leontief dynamic model to actual numerical data, it is necessary to consider discrete time periods rather than a continuous time series. Working with differences, in preference to differential equations, permits analysis in terms of flows per discrete time period rather than an instantaneous flow rate, and provides a great deal more relevance to economic planning in general.

Difference equations are introduced through the concept of the accelerator principle again, but using period analysis in preference to continuous time series analysis. The basic expression of this principle, in linear terms and without time lags in the period analysis is given by

$$I_t = I[(X_t - X_{t-1})] = \alpha(X_t - X_{t-1}), \tag{4.34}$$

where I_t = the level of induced investment at time t

X_t = output level of the industry at time t

X_{t-1} = output level of the industry at time $t-1$

α = investment coefficient, a positive constant

Considering a single period time lag, the expression may be restated as:

$$I_t = I[(X_{t-1} - X_{t-2})] = \alpha(X_{t-1} - X_{t-2}), \tag{4.35}$$

where X_{t-1} and X_{t-2} are the total outputs of industry X at time periods $(t-1)$ and $(t-2)$ respectively.

Using this discrete formulation of the accelerator principle, the dynamic input-output model may be modified from the continuous counterpart case as follows.

$$X_i(t) - \sum_{j=1}^{n} p_{ij} X_j(t) - \Delta S_i(t) = Y_i(t) \qquad (4.36)$$

where $\Delta S_i(t) = S_i(t) - S_i(t-1)$ (4.37)

$$= \sum_{j=1}^{n} k_{ij} (X_j(t) - X_j(t-1)) \qquad (4.38)$$

$$\geq 0 .$$

Expressing this formulation in matrix terms, equation (4.36) becomes

$$[I-P]X_{(t)} - K[X_{(t)}-X_{(t-1)}] = Y_{(t)} \qquad (4.39)$$

where $P = [p_{ij}]$

$K = [k_{ij}]$.

From the above formulation, the total output of industry i in period t, $X_i(t)$, can be used for consumption in that time period. Also, the value $Y_i(t)$ indicates the final demand during the period, and the net addition to the stock of capital good in industry i is given by

$$S_i(t) - S_i(t-1) = \sum_{j=1}^{n} k_{ij} (X_j(t)-X_j(t-1)) . \qquad (4.41)$$

It should be noted that, unlike flow coefficients, the capital coefficients (k_{ij}) and production coefficients (p_{ij}) depend entirely on the time interval being used and are not necessarily held constant. The major difference between the Leontief and Dorfman dynamic models is that relationships in the later model are expressed in terms of inequalities rather than equalities. As a consequence of this, the

Dorfman model leads to a linear programming formulation which provides for the possibility of excess capital stock in various time periods. Optimal economic development may, in fact, call for the provision of capital ahead of the time of production demand. Thus, equation (4.36) may be restated as

$$X_i(t) \geq \sum_{j=1}^{n} p_{ij} \, X_j(t) + \Delta S_i(t) + Y_i(t) \tag{4.42}$$

and

$$S_i(t) \geq \sum_{j=1}^{n} k_{ij} \, X_j(t) \tag{4.43}$$

where $S_i \geq 0$

$X_i \geq 0.$

In matrix notation, these two equations may be written as

$$[X] \geq P[X] + [\Delta S] + [Y] \tag{4.44}$$

and

$$[S] \geq k[X]. \tag{4.45}$$

The inequality sign in equations (4.44) and (4.45) is only relevant if the output of an industry becomes so large that the entire operation becomes economically wasteful.

The formulation of the Dorfman dynamic model set of inequality equations necessitates the use of an optimization procedure to differentiate between the alternatives of production and allocation of available capital resources in time. By considering one single time period an optimal solution may be determined based on the initially available capital stocks, for the particular time period. This solution may then be used as the initial condition for solution of optimal distribution within the second time period, and the process repeated until all time periods designated have been considered.

4.33 Chenery-Clark Dynamic Model:

Although the Leontief and Dorfman dynamic input-output models constitute the presently most widely used methods [9], the Chenery-Clark model warrants brief discussion due to the inbuilt provision of storing produce (or equivalent economic value) ahead of demand. This model is thus designed to analyze the accumulation of fixed capital in a regional or areal economy where the level of productive capacity of each sector, defined by W_j, is considered. In preference to capital coefficients, (k_{ij}), as used in the Leontief and Dorfman models that relate purely to outputs from each sector, the coefficients in this model relate to capacities, and are defined as the marginal stock capacity ratio for commodity i in sector j. This may be written as

$$k'_{ij} = \frac{S_{ij}}{W_j} \tag{4.46}$$

where S_{ij} is the stock of commodity i required to produce a level of capacity W in sector j. Separating the imports subsector from the payments sector, the model takes the following form:

$$I_j(t) + X_i(t) = \sum_{j=1}^{n} P_{ij}\, X_j(t) + \sum_{j=1}^{n} k'_{ij}\, \Delta W_j(t) + Y_i(t) \tag{4.47}$$

where $I_j(t)$ = import sector values at time t

and $\Delta W_j(t)$ = change in productive capacity at time t.

The investment demand segment, $k'_{ij}\, \Delta W_j(t)$ may be disaggregated as follows.

$$k'_{ij}\, \Delta W_j(t) = k'_{ij}\, (W_j(t)-W_j(t-1)) \tag{4.48}$$

$$= k'_{ij}\,(W_j(t+\lambda)-W_j(t+\lambda-1)) \tag{4.49}$$

$$= \Delta S_{ij}(t) \tag{4.50}$$

where λ = the lead time.

The building ahead of demand attribute induces the use of an unused capacity term, $U_i(t)$, during time period t, and may be defined as follows:

$$U_i(t) = W_i(t) - X_j(t)\ . \tag{4.51}$$

From this expression, it follows that

$$\Delta U_i(t) = U_i(t) - U_i(t-1) \tag{4.52}$$

which implies the model's capacity to build up excess capacity in the earlier periods in order to reduce the amount of investment in the latter periods.

Due to the model formulation containing four unknowns (X, Y, ΔW, and U) for each time period, specification of final demands, as in the static model, leaves the timing of the investments in earlier or later periods of the planning time span, open. This model is very similar to Leontief's if no excess capacity is assumed in advance. Note should be made that it is necessary to make additional assumptions regarding the anticipated future capacities if allowances are made for excess capacity initially. This would further induce the necessity of obtaining and including additional data if results from the model were to be used for forecasting purposes.

4.40 Adopted Input-Output Analysis:

Selection of an input-output model is highly dependent upon the objective to be optimized, and alternative formulations of the value to be maximized may be conceived with reference to this objective. Variations within the objective function depend upon the ultimate use of the model; whether it is to be used for economic forecasting; an efficient capital accumulation program; a detailed analysis of certain sectors of the economy with respect to investment and resource utilization; or the efficient allocation of resources with respect to time and space. Alternative objective functions may be formulated to maximize the growth of productive capacities for a whole planning period, maximizing total gross outputs, or maximizing any desired combination of stock and outputs. The dynamic model may be employed for optimization purposes in terms of capital output coefficients as in most of the models, or in terms of capital capacity coefficients similar to the Chenery-Clark model.

Within this study, the optimization objective is to allocate a fixed quantity of water to all water users within a defined river basin area to maximize the net economic return through the export and capital accumulation sections of the final demand sector. As discussed in Chapter 2.00, when considering dependent or independent release criteria, it is necessary to adopt discrete time periods for optimization, and the same time periods will be used in conducting the input-output analysis. Optimization is conducted during these discrete time periods through static iteration to achieve maximum net economic benefits ($b_i q_i'$) for all sectors within the catchment area, under the constraints of social demands and physical water quantities available. The actual physical water quantities diverted to each user (q_i), will serve initially as the prime constraints, and optimization of the net economic returns is conducted in relation to this prime constraint.

As mentioned previously, severe difficulties arise in the formulation of the net economic benefits versus net quantity of water used relationship for each water consuming sector, and the following two chapters will discuss these relationships, and their formulations, at length. It is also necessary to establish policy decisions regarding the breakdown of the final demands desired; that is, which users should be allocated more water to increase the total gross output of the entire input-output table, and these decisions will be a direct function of the b_i-q_i relationship. Whereas pure dynamic input-output analysis relies upon the use of accumulating excess capital stock, and programming formulations are combined with these models to maximize this accumulation, the economic optimization following is basically static for planning purposes, though maximization is reached through iteration of the product-use mix under physical water quantity constraints primarily.

For the input-output method adopted, Figure 4.1 following gives the flow chart for the entire operation as discussed in section 4.20. The computer program for this flow chart is given in Appendix A-1.

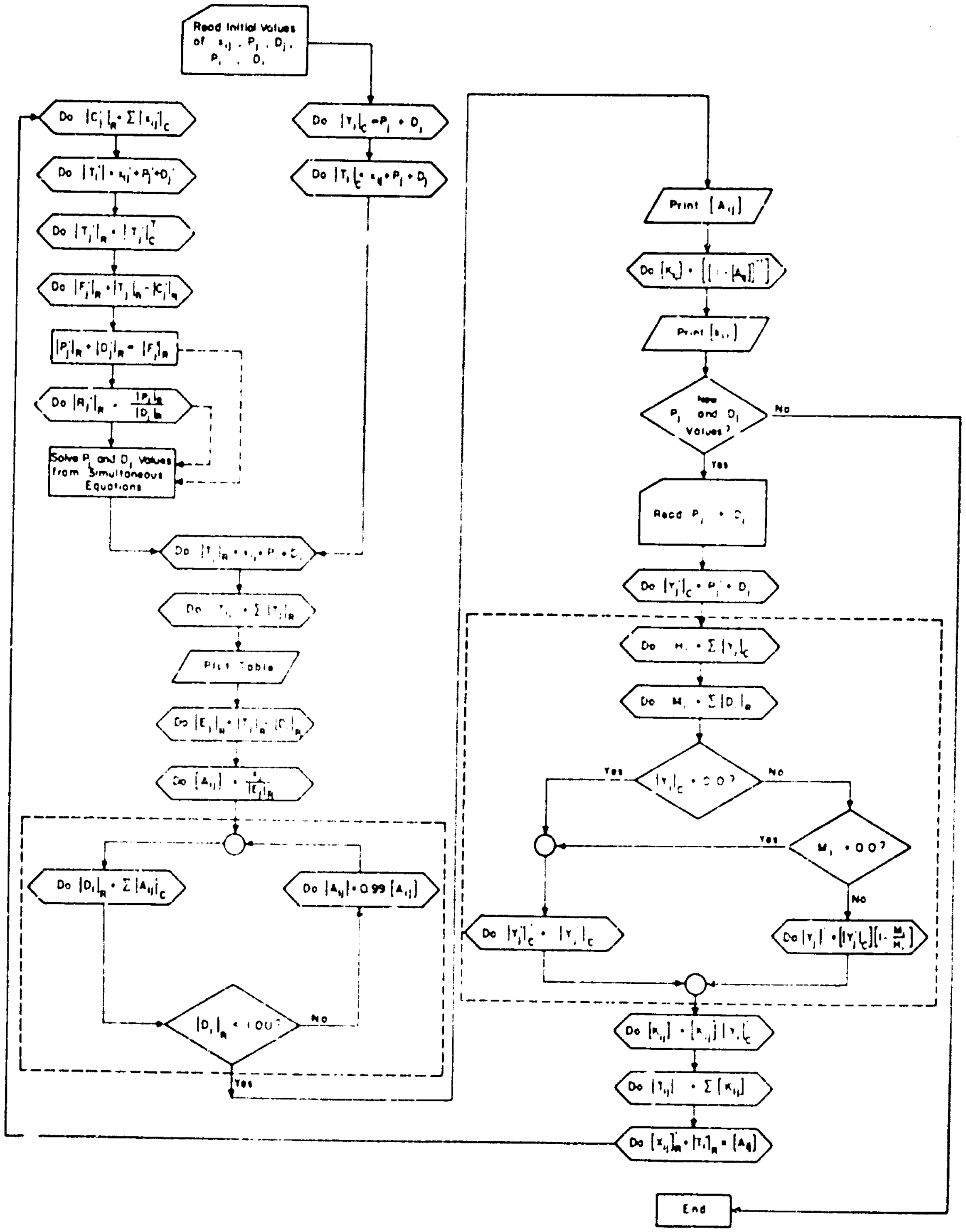

Figure 4.1 Flow Chart for the Input - Output Program.

5.00 WATER VALUATION AND ALLOCATION MODEL:

5.10 General Considerations:

Economic optimization, or maximization of efficiency, is traditionally defined as the allocation, or use of resources to producers and consumers in such an allocation pattern that no reallocation alternatives exist which would allow net economic gains to some users, without accompanying losses to others. This basically implies that all unambiguous allocation possibilities for increasing economic welfare within an area have been exhausted, and that all resources available to the area have been consumed or used. However, this definition requires that between the users, the actual rate of product substitution (satisfactorily substituting one alternative product for another) is equal to the rate of substitution that these products are actually consumed at. The definition also requires that the rate of factor substitution within production (changes within actual production items) is equal to the rate at which these factors will be substituted within the consuming sector [15]. In summary, economic efficiency implies simultaneous satisfaction between the producers and the consumers.

However, economic efficiency in the real world is a rather theoretical condition implying a completely static relationship between the production and consuming sectors. The properly functioning, though theoretical, competitive price system adopted in democratic countries throughout the world, allocates resources initially to consuming sectors that yield the greatest net economic return for the minimum amount of resource use. However, certain social constraints are placed upon this system due to necessary consuming sectors that have no, or very low, economic returns from any amount of resource use. These sectors are well exemplified by the recreational, domestic and social use sectors of a water allocation system. In some instances, where actual resource quantity constraints exist, it may be necessary to introduce the concept of compensation. Compensation side payments provide an excellent conceptual method of ranking alternative methods in an attempt to satisfy a given objective. The concept further allows a convenient introduction to the additional concept of willingness to pay which acts as an indicator of value.

The willingness by a consumer to pay for produce reflects the willingness to forego other consumption, and in terms of public projects, the net willingness to pay becomes the difference between the aggregate willingness of all concerned sectors to pay for a particular alternative and the aggregate willingness to pay to do without the project entirely [11]. Note should also be made that the term "value" in the context of this study is taken as the economic amount that a perfectly rational user of a publicly supplied good is willing to pay for that good. The competitive, complementary and supplementary relationships among producers and consumer will greatly affect the actual numerical value of these publicly supplied goods, and only through a socially and economically just allocation system can optimization of resource use be obtained.

For the purposes of this study the entire catchment, or river basin, area being considered is assumed to contain seven main producing and water-using sectors. These are irrigation, industrial use, domestic use, commercial use, power generation, recreation use and social use. The latter use has been included to consider such water consuming sectors as educational institutions, hospitals, street cleaning, public lawns and garden watering, and any other use not directly affiliated with one of the other sectors, but uses that are social necessities or mutually desirable. For each of these sectors, literature has been investigated in an attempt to determine the actual value and marginal value that water has. For these seven aggregated sectors, the specific river diversion model, together with transfer criteria development are developed briefly in the following section. The optimization functions thus developed shall be used within the physical water allocation model and the input-output analysis as the objective functions for net economic return maximization.

5.20 Specific River Diversion Model:

The diagrammatic catchment illustrated in Figure 2.1 is again used as the generalized model of catchment area, and with the seven use sectors adopted is shown in Figure 5.1 following. For this catchment area, the specific flow line format is also given in Figure 5.2, with the specific alphanumeric designations as defined in Chapter 2.00, included. Both the dependent and independent release transfer cases will be considered and the respective objective functions developed. Explicit note should be made that the model under consideration is highly aggregated purely for the sake of descriptive ease, though conversion to a higher degree of disaggregation necessitates only a greater degree of data collection and computation time.

5.21 Dependent Release Transfer:

As discussed in Section 2.10, the dependent release transfer criteria implies that each downstream water user is dependent upon the return flows of the immediate upstream user. For

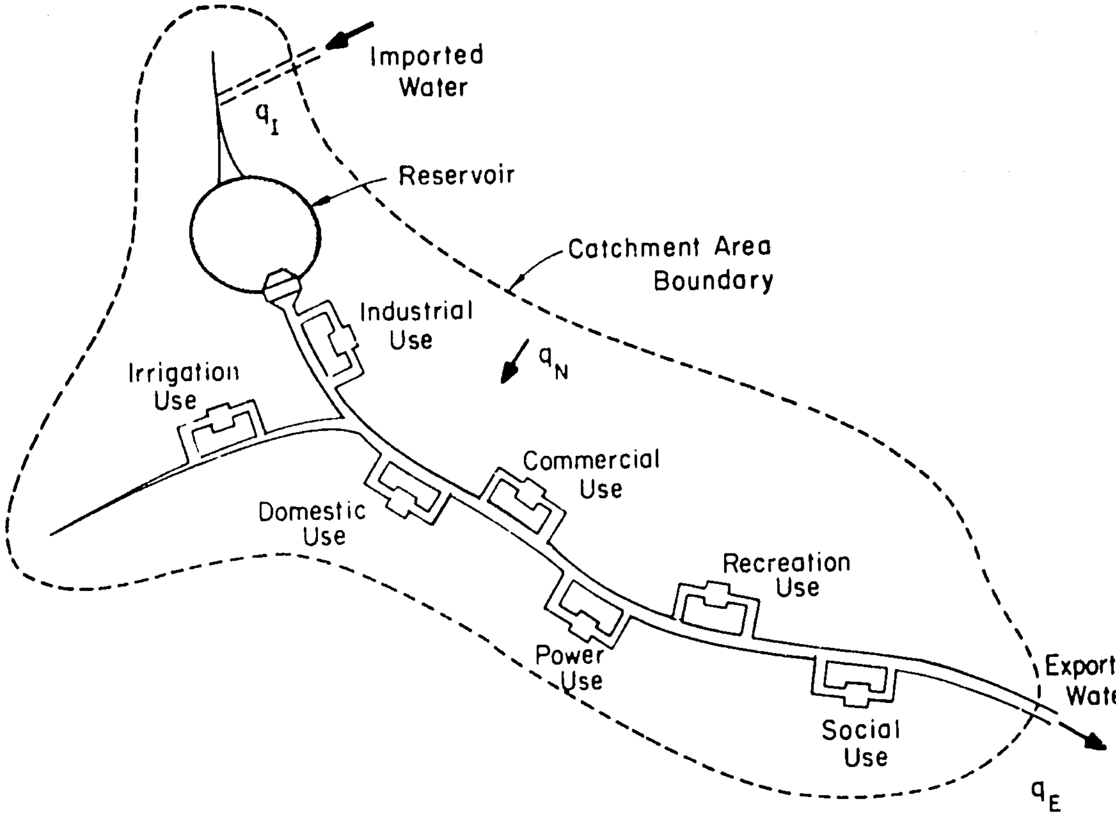

Figure 5.1 Specific Catchment Area Und·r Consideration

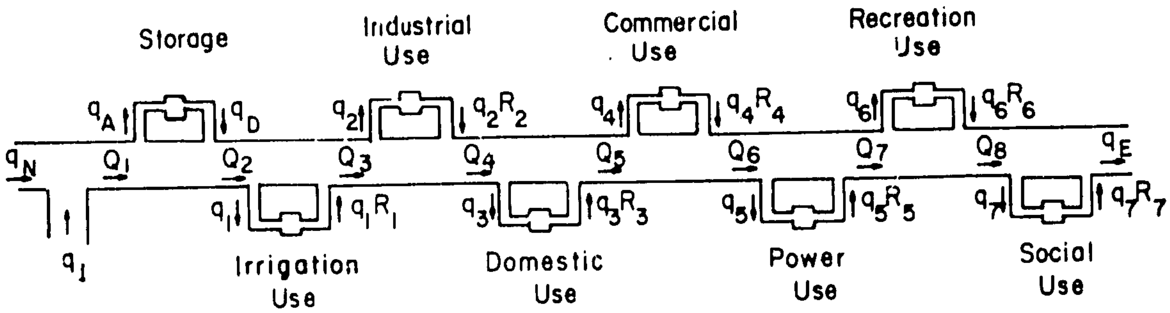

Figure 5.2 Flow Line Format for Specific Catchment Area Considered

the seven sectors considered, the total net economic benefit, excluding imports, exports, accumulation and depletion, may be expressed generally as

$$B_n = \sum_i^n b_i q_i \qquad (5.1)$$

$$i = 1 \rightarrow 7 \, .$$

Including imports, exports, accumulation and depletion, equation (5.1) expands to the following expression

$$B_n' = \sum_i^n b_i q_i + b_A q_A + b_D q_D + b_E q_E + b_I q_I \, . \qquad (5.2)$$

During a discrete time period, any of the last four terms within the expression may be removed independently or grouped. Depending upon accumulation, depletion or static total water quantity conditions existing within the storage facilities of the system, the $b_a q_a$ and $b_d q_d$ terms will not occur together during a discrete time period.

From the theoretical expression given in equation (2.10), equation (5.2) expands to the following expression:

$$\begin{aligned} B_n' = b_1 q_1 &+ b_2 (q_1 R_1) + b_3 (R_2 (q_1 R_1) + b_4 (R_3 (R_2 q_1 R_1) + b_5 (R_4 (R_3 R_2 q_1 R_1)) \\ &+ b_6 (R_5 (R_4 R_3 R_2 q_1 R_1) + b_7 (R_6 (R_5 R_4 R_3 R_2 q_1 R_1)) + b_a q_a + b_d q_d \\ &+ b_E q_E + b_I q_I \, . \qquad (5.3) \end{aligned}$$

For the seven sectors considered, this expression becomes the maximization objective function for the entire allocation system under the dependent release transfer criteria. The constraint conditions for the system may be written as:

$$0 \leq R_i \leq 1 \qquad (5.4)$$

$$Q_i + R_i q_i > 0 \qquad (5.5)$$

and

$$\sum_{i}^{n} q_i(1 - R_i) - q_N + q_I - q_E - q_A + q_D \ . \tag{5.6}$$

Expanding constraint condition equation (5.6) yields, for the seven sectors

$$q_1(1 - R_1) + q_2(1 - R_2) + q_3(1 - R_3) + q_4(1 - R_4) + q_5(1 - R_5) + \\ + q_6(1 - R_6) + q_7(1 - R_7) = q_N + q_I - q_E - q_A + q_D . \tag{5.7}$$

For the purely theoretical condition of constant return coefficients, the objective function may be rewritten as

$$B'_n = q_1[b_1 + b_2R + b_3R^2 + b_4R^3 + b_5R^4 + b_6R^5 + b_7R^6] \\ + b_Aq_A \ b_Dq_D + b_Eq_E + b_Iq_I . \tag{5.8}$$

with the constraint conditions varying accordingly and $R = R_i$. If all of the sectors within the catchment area were irrigation, the above assumption that $R = R_i$ may be valid, but for the diverse sectors under consideration, the assumption is purely hypothetical.

The entire concept of downstream users being completely dependent upon upstream return flows, is also rather hypothetical under both the major existing water law doctrines of riparian rights and prior-appropriation. Due to the physical constraint of water losses occurring within the allocation system, a base flow, dependent upon physical conditions of both natural and man-made conveyance structures, is required, and the independent release transfer criteria following is a far more realistic optimization base.

5.22 Independent Release Transfer:

For the water allocation system where downstream users are not solely dependent upon the return flows of the upstream users, the resulting programming problem is linear, and the total net economic benefit for the seven sectors, excluding imports, exports, accumulation and depletion, is given by equation (2.35) as

$$B_n = \sum_i^n b_i q_i (1 - R_i) \tag{2.35}$$

$$i = 1 \rightarrow 7 .$$

Including the import, export, accumulation and depletion terms, and expanding for the seven sectors, yields:

$$B'_n = b_1 q_1 (1 - R_1) + b_2 q_2 (1 - R_2) + b_3 q_3 (1 - R_3) + b_4 q_4 (1 - R_4)$$

$$b_5 q_5 (1 - R_5) + b_6 q_6 (1 - R_6) + b_7 R_7 (1 - R_7) + b_A q_A + b_D q_D + b_E q_E + b_I q_I \tag{5.9}$$

in which any of the nonconsumptive use terms may again be removed from the expression during a discrete time period. As with the dependent release transfer, the $b_A q_A$ and $b_D q_D$ terms will not appear together during a discrete time period.

Equation (5.9) is the maximization objective function for the entire catchment area under an independent release transfer operational system. This system operates under the following general constraints.

$$0 \leq R_i \leq 1 \tag{5.10}$$

$$Q_i + R_i q_i > 0 \tag{5.11}$$

and

$$\sum_i^n q_i (1 - R_i) = q_N + q_I - q_E - q_A + q_D \tag{5.12}$$

Expanding equation (5.12) yields,

$$q_1(1 - R_1) + q_2(1 - R_2) + q_3(1 - R_3) + q_4(1 - R_4) + q_5(1 - R_5)$$
$$+ q_6(1 - R_6) + q_7(1 - R_7) = q_N + q_I - q_E - q_A + q_D. \quad (5.13)$$

Again, if the hypothetical condition of constant return coefficients exist within the system, the objective function of equation (5.9) reduces to:

$$B'_n = (1 - R)(b_1q_1 + b_2q_2 + b_3q_3 + b_4q_4 + b_5q_5 + b_6q_6 + b_7q_7)$$
$$+ b_Aq_A + b_Dq_D + b_EQ_E + b_IQ_I. \quad (5.14)$$

where

$R = R_i$.

However, constant return coefficients shall not be considered within the context of this study due to the diverse sector aggregation, and equations (5.9) to (5.12) shall be used as the maximization objective function and constraint conditions for net economic return optimization.

The two major constraints that exist within the entire operation of the objective function are the physical water quantities available to each user, q_i, and the net economic benefits capable of being derived from this water use, b_i. As the actual b_i values are directly dependent upon the q_i values, it is necessary to determine water valuations, from empirical estimates, on the quantities of water available to each user, and what these users are willing to pay for varying water quantities. The following subsection considers the alternative methods of valuing water for the sectors considered, from both empirical estimation methods and theoretical concepts.

5.30 The Economic Value of Water:

Within any particular water consuming sector, the possibility exists of either a physical (or absolute) or an economic water shortage. An absolute water shortage, though it may be temporary in nature, may further induce accompanying economic shortages due to the fact that, irrespective of absolute quantity limits, more water will become available at a higher price if time is allowed for the development and construction of new storage, conveyance and treatment structures. However, due to the fugitive, renewable resource nature of water, the prime problems involving water allocation are centered around the conflict that develops from user competition and the resulting economic scarcity.

An idealistic and properly functioning competitive price system will allocate water to those sectors that yield the highest net economic return per unit quantity of water. The competitive price system is hampered to a large degree by the flexibility of the resource and the property rights upon which this system depends. Due to the overlapping and consequently ill-defined market institutions which could serve as allocation authorities, it is necessary to base water resource development plans or reallocation decisions primarily on estimated or synthetic market prices [41]. Numerous methods have been postulated and derived for the economic valuation of water though the following four alternative procedures summarized from reference [41], are considered within the literature as the most feasible methods.

5.31 Valuation by Water Transaction Observation:

The simplest form of this type of transaction is the pure exchange of water for money. However this exchange normally takes place in the form of rental between sectors, though usually on a temporary basis due to the legal implications of water ownership. Due to the highly seasonal orientation of water rental transactions, the resulting water values must be considered as short term estimates, and bear very little correlation to long term values. The historical connection between land and water particularly, may allow valuation on the long term basis by observation of these group resource transactions. However, often within these transactions, value distortion may occur due to the uncertainty of resource supply, and the possibility of speculation of use transfer on behalf of the buyer.

A further, though insignificant example of the exchange of water for money, is the sale of bottled distilled and natural spring water. These transactions however must be considered as pure luxury commodity purchases and do not form any real part of water value determination.

A further common example of the exchange of water for money is the concept of an administered price for unit quantities, or time orientated quantities of water. This method is well illustrated with public water supplies for domestic use where metering is used to private property and users. However, the actual method is highly dependent upon the methods of data collection and any associated socio-economic value judgments imposed by the allocating authority. For these reasons, this administered price concept only provides crude valuations on short term marginal value. Constant unit price changes add further weight to the short term qualities of this valuation.

Administered water prices have not, in the past, reflected comparative net economic water values with other use sectors. Within the irrigation sector, this method has been used, though in a majority of cases there is a high degree of speculative purchase under assumptions of areal rezoning. Values arrived at from this method for the domestic sector, have normally been derived through consideration of distribution, maintenance, and overall operation.

5.32 Value Estimated from Demand Functions:

Value estimates using demand functions involve the basic estimation of the quantity demand, and for water these demand curves may be estimated by the derived or observed price-quantity relationships. With many of the use sectors, problems of demand curve derivation are complicated by the nonconsumptive use of water and its nature as an intermediary good. However, it is possible and realistic to make demand curve estimation through estimation of reduction in marginal value, that is, through the imposition of extreme quantity constraints, the willingness to pay may be computed and the resulting correlation extended to the realistic operational range, within fixed probability boundaries.

Demand functions may be distorted to a large degree in certain sectors due to public intervention in the form of price controls, subsidies, and basic financial assistance in general. The major problem arising with the application of demand functions is the quantity of data collection associated with their derivation and the lack of available data generally. This lack of data has given to pseudo demand functions for consumer goods that do not include water as a variable parameter of production. However demand functions are considered the most reliable method of water value estimation and are used mainly for specific sector application. Within the application of demand functions it may be necessary initially to generate data synthetically, apply the functions to the maximization technique and continuously modify the functions to align with current market conditions and any distortions occurring due to subsidization.

5.33 Valuation through Residual Imputation:

This method of valuation involves the concept of allocating portions of the total value of output to each resource used within the producing sector. The method assumes that water is the unknown quantity within production, and that prices may be levied to all other resources used. It further assumes that marginal productivity exists with all other resources and that the production is at the optimum level. Problems arise is actual residual imputation methods due to the disaggregation of the output into the various resource uses, and the possibility of variable parameter omission within the imputation equations.

Residual imputation is affected to a large extent by the induced problems of price subsidies and controls, and conflicting valuation may arise due to the possibility of multiple resource imputation, which is well exemplified within the valuation of recreational water. In general, if the final product may be disaggregated into the percentages of each basic resource used, than residual imputation may be used to determine the value of water used within production. This method is very much applicable to the commercial and industrial sectors, though its use within other sectors is highly contentious.

5.34 Valuation by Alternative Cost:

The alternative cost concept basically implies the use of the same activities within producing sectors to obtain the same end product by using substantially different means. Valuation using this method has been used extensively in the comparative analysis of public versus private development and also between competing private development schemes. By determining alternative costs of production or of distribution system development, the willingness to pay for water, or any other resource, is determined within the necessity of demand function estimation. However the method is purely static, and is not applicable under expanding or depleting demand conditions. Under these static conditions the method is complicated to a large degree by the interdependencies existing between sectors. This problem may be eradicated using dynamic evaluation through the use of incremental and stochastic time series.

This method has been used as a water valuation technique within all sectors, though it is most applicable to sectors that have public development alternatives such as recreation and some commercial production areas.

In summary, the most realistic methods of determining the economic value of water are through demand functions and through consideration of alternative cost. Observation of actual water sale transactions does give the value of water from the point of what consumers are willing to pay, though in many instances the price is highly distorted due to subsidization and buyer speculation. Valuation through residual imputation requires the application of major assumptions that within themselves may be unrealistic in most cases. For economic optimization within a proposed allocation system, especially applicable to developing countries, the use of demand functions gives the most accurate value estimated, though the development of the $b_i - q_i$ relationships will involve a highly expensive data gathering study. This is particulary prevalent within established allocation systems, and due to this data expense, water values have normally been quoted as single unit values in the past.

In the following subsection, the value of water for the seven sectors considered will be estimated using demand functions derived from unit values computed for the central western area of the United States, together with alternative cost methods where considered rationally applicable. However, it should be stressed that water values should be determined for the individual basin under consideration, either from empirical estimates or derived from anticipated use patterns. Values quoted in the following subsection are given as illustrative examples to be used within the entire hypothetical economic optimization model. Specific note should be made that through the use of demand functions, it is not assumed that constant returns to scale are applicable, though for some sectors constant returns to scale will occur above certain use levels.

5.40 Net Benefit - Water Quantity Relationships:

For each of the seven sectors considered, hypothetical $b_i - q_i$ relationships and $b_i q_i - q_i$ relationships are discussed in the following subsections. These relationships give the general form of the demand functions anticipated for each sector, though actual numerical values will depend upon the country and area under consideration. Actual demand function estimates must be made with relation to geographic evaluation, temporal variability, actual soil capabilities and site productivities in general and the economic scales of both adjacent area and the entire country.

5.41 Irrigation Water Value:

The physical productivity of irrigation water is highly dependent upon the effects of the natural physical conditions; water and land management; nutrient additions; type of crop being irrigated; the effects of technological change over time, and the effect of the time of the year of production [5]. The latter effect can only be considered within an economic optimization process through a sequential or multistage decision making process. This process may include benefit (or failure) - cost analysis [5], sequential linear programming or dynamic programming. Although problems do arise when determining the economic value of water on a microscale due to the determination of actual consumptive use, withdrawal quantities versus actual consumption quantities, and the induced complications of return flow consideration, the net quantities of water referred to in this paper refer to the quantities of water delivered to the farm minus return flow.

Valuing irrigation water has normally been carried out in the past by pricing inputs and outputs and the evaluation of intermediate products. However this method may be distorted due to the occurrence of market failure, public intervention, or unemployment. For any particular crop however, and assuming a constant management technique for all irrigation water users, the actual crop response will be directly dependent upon the quantity of water applied and all other parameters, such as timing, fertilizers, climatic conditions, etc., [4,24].

The generalized $b_i - q_i$ relationship will, for any crop, take on the form illustrated in Figure 5.3, with an anticipated decline in the net economic benefits occurring with over irrigation causing flooding and overland scour.

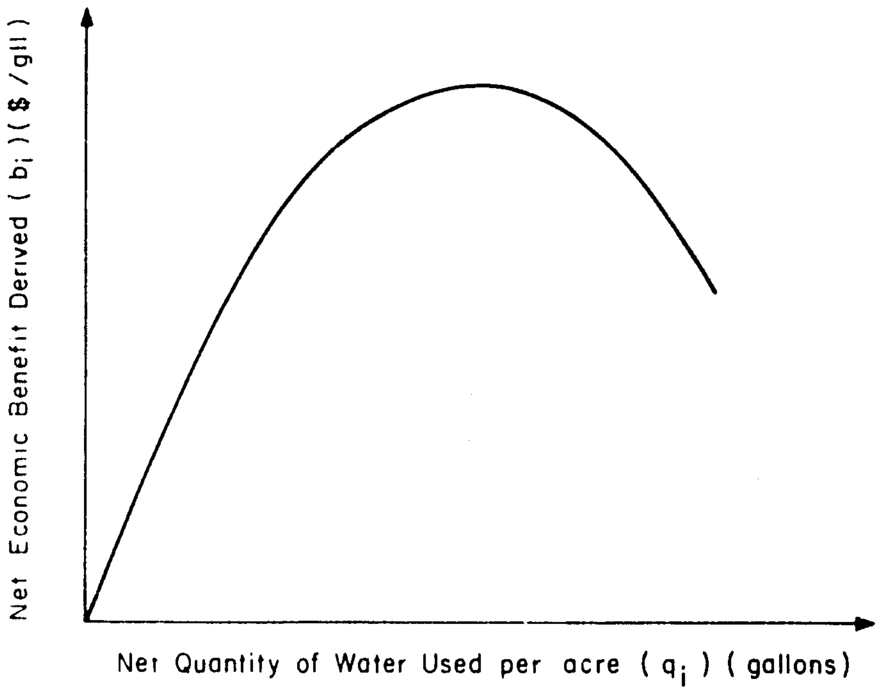

Figure 5.3 $b_i - q_i$ Relationship for Irrigation Water.

In Figure 5.3, the net economic benefit derived represents the actual net profit returned to the user (and consequently the entire area under consideration) after all operating, produce and material costs have been deducted. Thus any point on the curve represents the marginal value of the water for the specific quantity allocated. From this relationship, the following total net economic benefit relationship (Figure 5.4) may be computed.

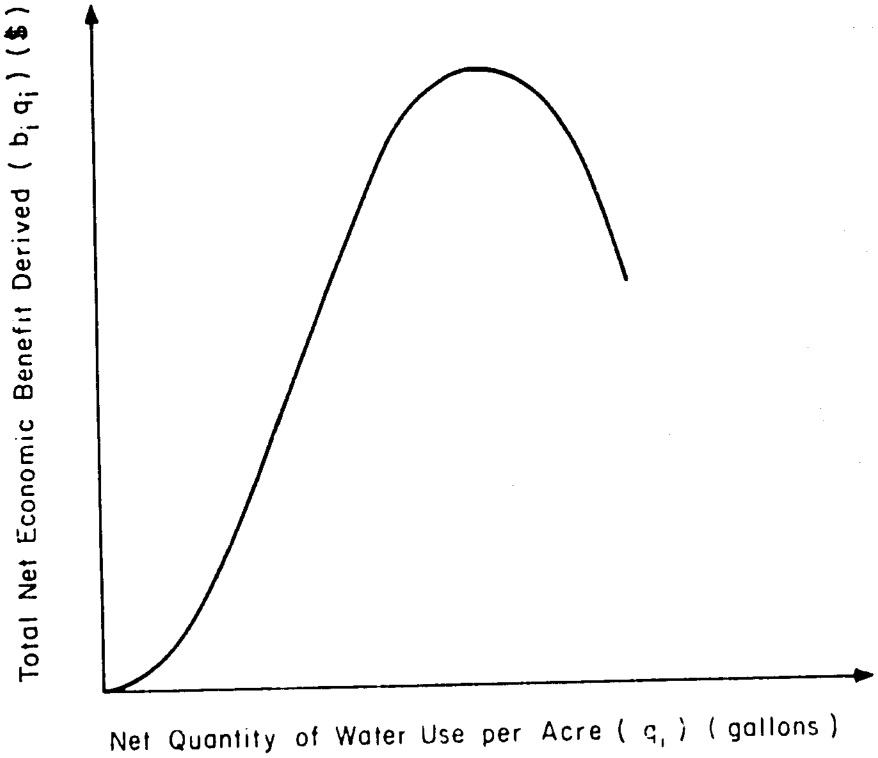

Figure 5.4 $b_i q_i - q_i$ Relationship for Irrigation Water.

5.42 Industrial Water Value:

The actual consumptive use of industrial water is complicated to a large degree by the recycling that is conducted within the industries, arising from the fact that eighty percent of water used in industry is primarily for cooling purposes only. Literature surveys [39, 41] reveal that approximately ninety percent of all industrial water is consumed by the five main sectors of food production, pulp and paper production, chemical industries, petroleum production and primary metal extraction. Empirical estimates reveal the value of water has been derived using the actual cost of water intake to each industry, though the value added, alternative cost and residual imputation approaches have also been used depending on the industry under consideration.

If water restrictions were applied to an industry, then the willingness to pay for additional water supplies would increase significantly (or the industry would cease to operate) to the point where additional water supplies would be wasted and passed through the operation without any economic benefit being derived. Thus, the marginal value of the water reaches zero as soon as the demand under full production conditions is reached. From these considerations, the $b_i - q_i$ relationship takes on the generalized form as shown in Figure 5.5. This figure is applicable to industries that do, or do not, use recycled water within their production, though for the recycling case the curve would be significantly steeper and the marginal value would approach zero with lower net unit water quantity values.

From the generalized format in Figure 5.5, the total net economic benefit relationship may be derived, and its general format is shown in Figure 5.6 following. Note should be made that the upper portion of this curve may be a straight line if the marginal value of production has reached zero.

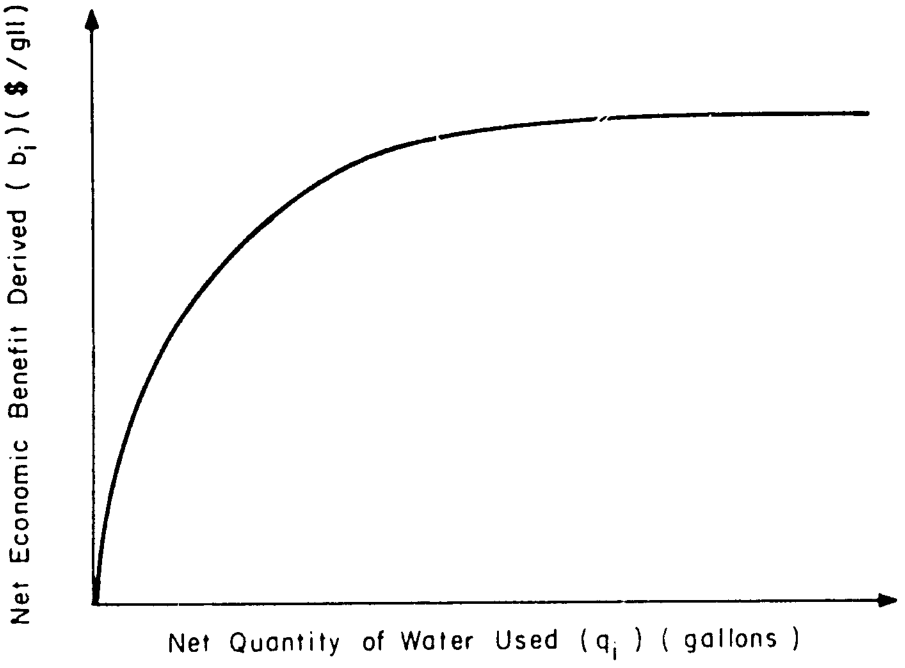

Figure 5.5 $b_i - q_i$ Relationship for Industrial Water.

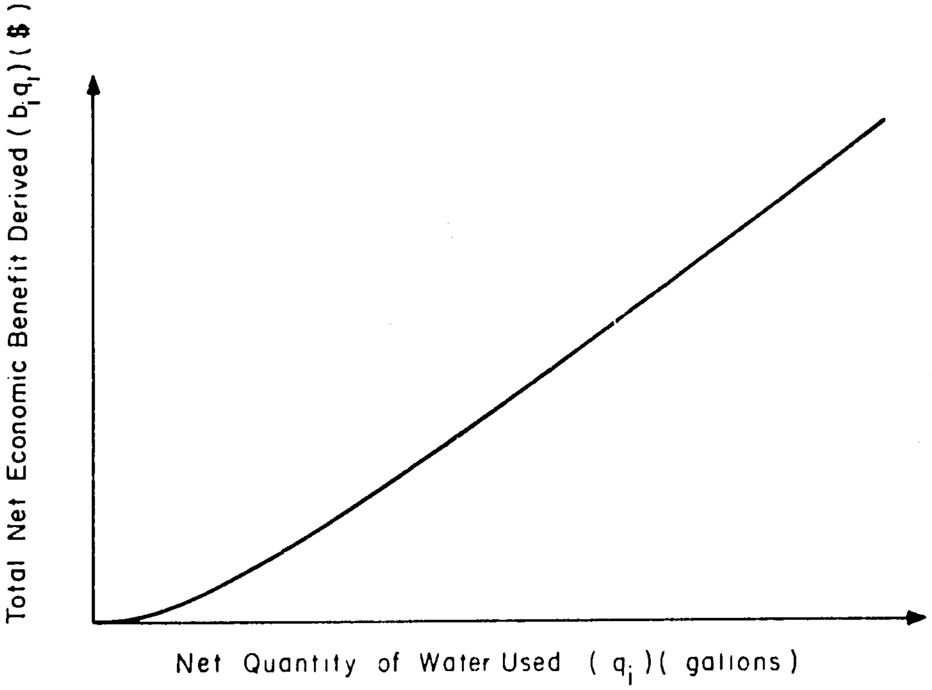

Figure 5.6 $b_i q_i - q_i$ Relationship for Industrial Water.

5.43 Domestic Water Value:

Domestic water supply in the context of this paper refers solely to residential development in the form of private homes, domestic apartments and residential estates. For both municipal and domestic water supplies, water consumption and the rate of such, is not generally very responsive to the unit price or actual domestic incomes. This is due primarily to the necessity of water to sustain life, though the quantities involved are comparatively low compared to the other sectors. With private home water use, the greatest portion of consumption is used in the tendering of lawns and gardens which induces comparative consumption problems between high-rise dwelling type residents and private home residents. In both cases, if the water is nonmetered the marginal price (and marginal value) is zero [41]. For metered domestic water, a positive marginal value is apparent, though if a constant unit price is applied to this metered water then the marginal price is again zero. In the following $b_i - q_i$ relationships it has been assumed that for all domestic uses, the water is metered.

Due to the difficulties encountered in determining a user's willingness to pay for water, the customary procedure for estimating benefits of public water supplies is through an alternative cost procedure. The value of water is thus defined as the cost of supplying all dwellings within the basin, or area, under consideration through the least expensive distribution system alternative. This approach adequately handles the cost involved in the construction, operation and maintenance of the distribution system but does not allow for value comparisons between other sectors, and consequently does not allow economic optimization within the defined area. As a consequence of this, it is necessary to use demand curves and the price elasticity of demand to determine the individual user's willingness to pay. As with the $b_i - q_i$ relationships established for all of the sectors here considered, determination of the price elasticity of demand will involve a great deal of data collection, and an expensive assessment of all current empirical data.

The general format for the demand curves for domestic water are given in Figure 5.7 following. In Figure 5.7 the net willingness to

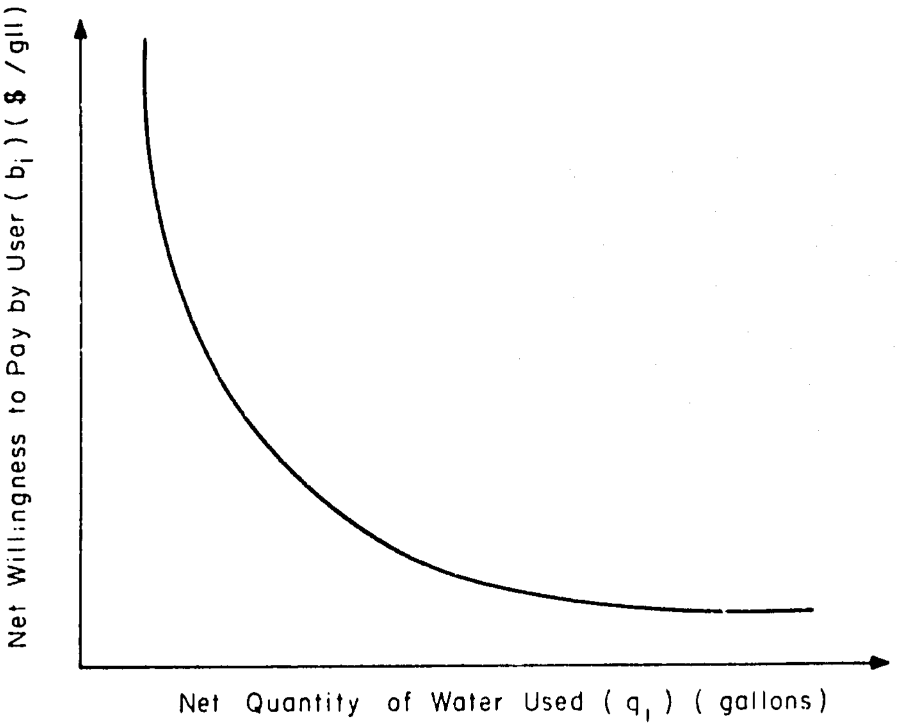

Figure 5.7 $b_i - q_i$ Relationship for Domestic Water.

pay for water indicates the actual economic return to the allocating authority, and consequently may be classified as the net economic benefit derived within the entire area. Also, the net quantity of water used must be specified within a fixed time period, as is the case with all other sector users.

From Figure 5.7, the generalized form of the $b_i q_i - q_i$ relationship may be derived and is shown in Figure 5.8 following. If water restrictions are imposed upon the domestic sector at any time, the $b_i - q_i$ curve will be shifted to the right of the ordinates: that is, the willingness to pay shall increase for the same net quantity of water used. This will induce very high $b_i q_i$ values for relatively small q_i values.

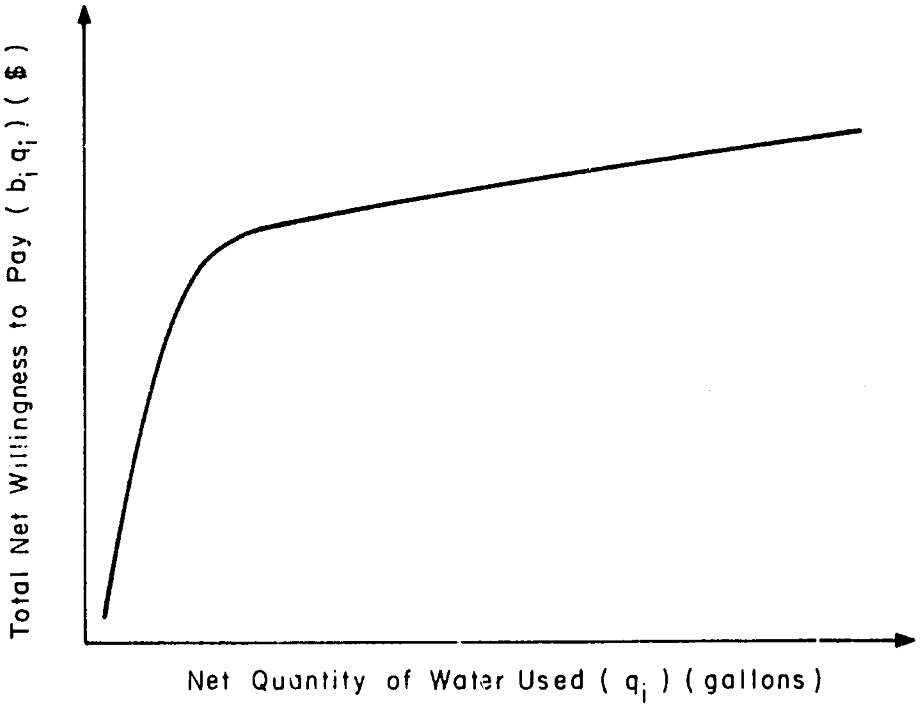

Figure 5.8 $b_i q_i - q_i$ Relationship for Domestic Water.

5.44 Commercial Water Value:

Within the context of this paper the commercial sector is aggregated to include all commercial distribution businesses, water releases for purification and navigational use. However, these individual uses may be broken down into three respective subsectors if large activity of these industries occurs within the area. In general, the commercial distribution and retailing section of the sector shall contribute the greatest percentage of economic return to an area of uses aggregated above. The $b_i - q_i$ relationship for this sector will be similar to the industrial sector, with a characteristic zero marginal value occurring as the supply quantity increases.

Estimates for the value of purification of water have normally been made through estimation of the damages caused by the pollution, though difficulties do arise in the determination of actual damages. The economic value of the water may also be made from the treatment costs involved in purifying the water to established drinking or general reuse specifications. In conjunction with these treatment costs, the alternative cost approach may also be used if competing projects of alternatives are available within the basin. The actual economic values derived for water purification are comparatively low compared to other sectors, and the marginal values are correspondingly low.

The method of water valuation for navigation has normally involved the alternative cost approach in which the capital, operation and maintenance costs incurred by a public or private agency in transporting goods through rivers is compared to the freight costs associated with alternative methods [41]. No major problems arise in the valuation of water for navigation purposes other than the valuation of the relatively high minimum flow requirement necessary and the corresponding valuation of this water that may be held out of productive use.

For this aggregated sector the $b_i - q_i$ relationship takes on the generalized form shown in Figure 5.9 following. As for industrial

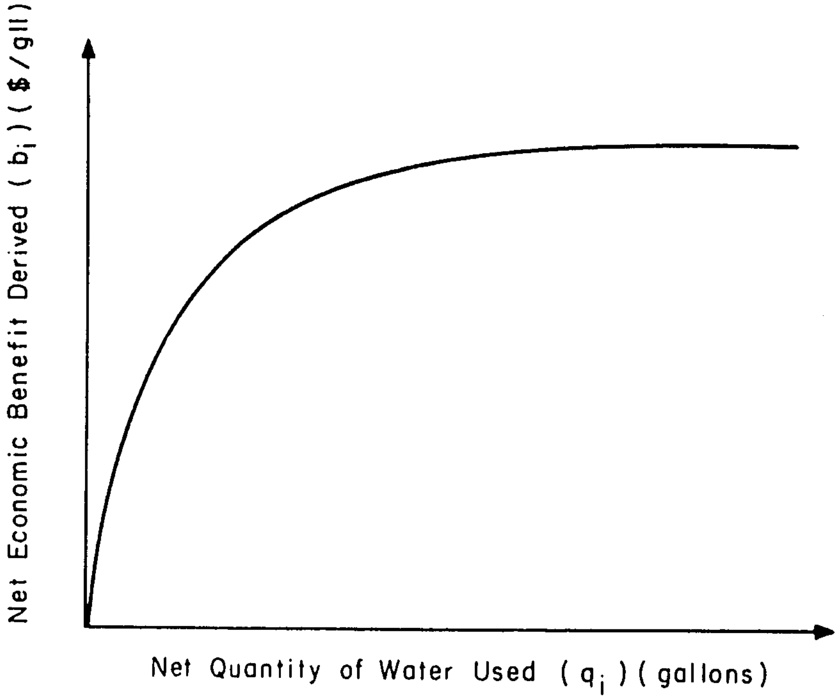

Figure 5.9 $b_i - q_i$ Relationship for Commercial Water.

consumption the net economic value derived will approach a zero marginal value as the net quantity of water used increases.

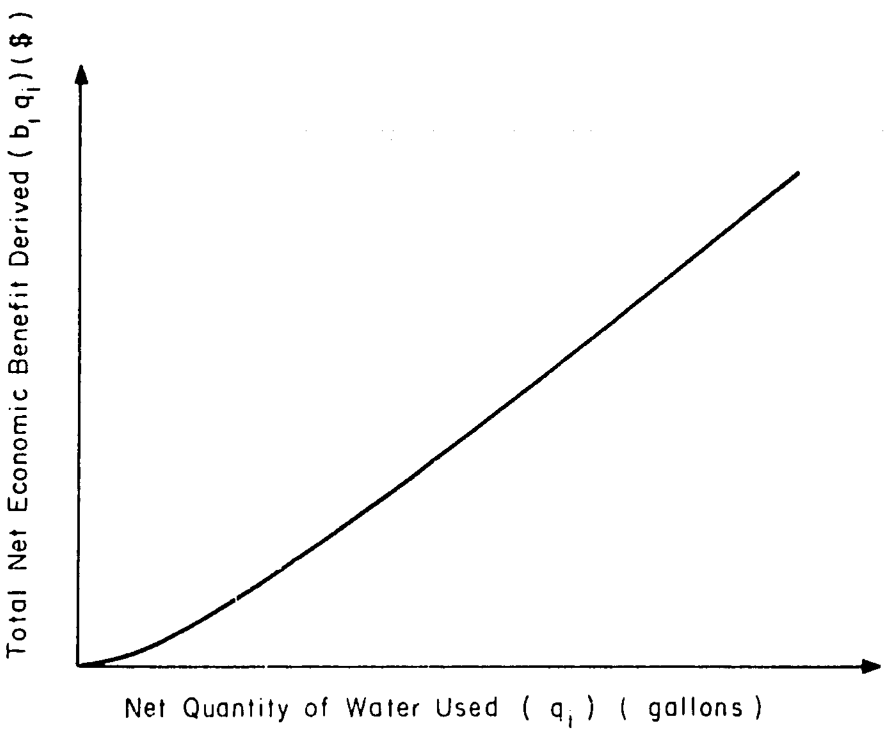

Figure 5.10 $b_i q_i - q_i$ Relationship for Commercial Water.

5.45 Hydroelectric Power Generation Water Value:

Due to the comparatively low consumptive use of hydroelectric plants, the resulting economic returns per unit of consumed water are exceptionally high. However due to the complimentary or supplementary nature of all water passing through the power stations the economic value of all water used is low. Valuation is also complicated through consideration of short term and long term operational policies, as hydroelectric plants are taking on the role of peak load boosting rather than constant, base load, supply sources [41]. Variation within the operational policies between peak and base load generation also induce two sets of actual values, and in the economic optimization example following it will be assumed that hydroelectric power generation is being used for both base and peak load supply and on a long term basis. Empirical estimates reveal that large variations in economic value from one region of the United States to another, and actual economic forecasting within a specific basic must be unique to that area, considering all possible alternatives of power sources.

Past empirical estimates of the value of water have normally been made through a combination of residual imputation and the alternative cost methods. For existing hydroelectric stations, a reduction of the power output has been hypothetically induced, and cost estimates of producing this reduced quantity of electricity by alternative means have been computed. For continuous incremental reductions, the marginal water value may be determined by supplementing this power deficiency with continuous incremental power increases from alternative sources. As mentioned previously, this method is complicated due to the peak and base load considerations, and further complicated if peak load operation is conducted through pumped storage regulation in which water is pumped back into the storage, during off peak power demands, for peak load generation.

Figure 5.11 following illustrates the hypothetical $b_i - q_i$ relationship for long run, base and peak load hydroelectric power generation. Once full power demand is satisfied within the area, the marginal value of water passing through the station is zero, and under

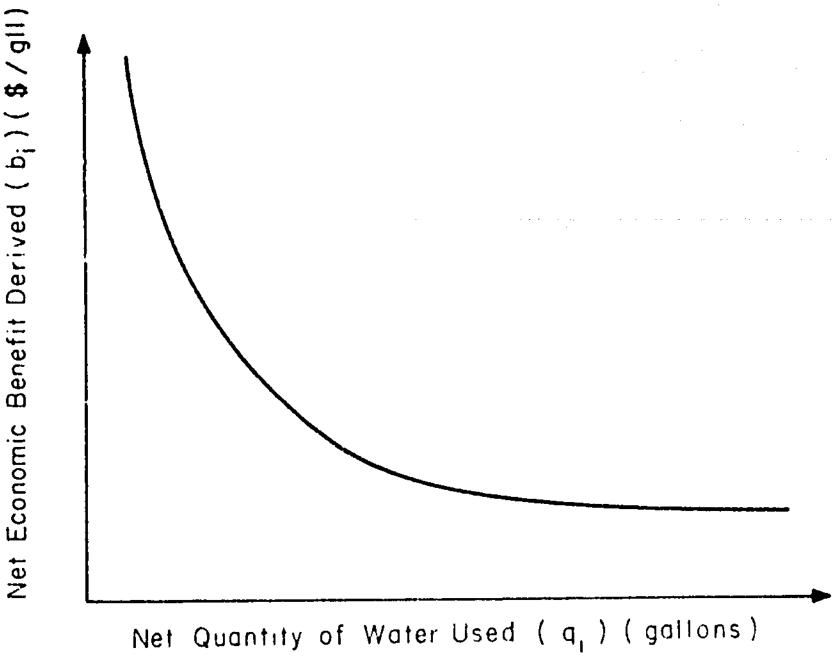

Figure 5.11 $b_i - q_i$ Relationship for Hydroelectric Power Generation Water.

the extreme conditions of physical water restrictions the net unit economic value will increase considerably. From Figure 5.11 the $b_i q_i - q_i$ relationship takes on the following general format.

5.46 Recreational Water Value:

For the purposes of this thesis the term "recreation" includes all activities associated with water use for pleasure and the use of water for wildlife habitat and fishing, though the latter two may also be classified within the industrial or commercial sectors. Since recreation is a nonproductive water use, it is necessary to use synthetic imputation techniques in the derivation of economic values. The actual consumptive use of water for recreation is also complicated

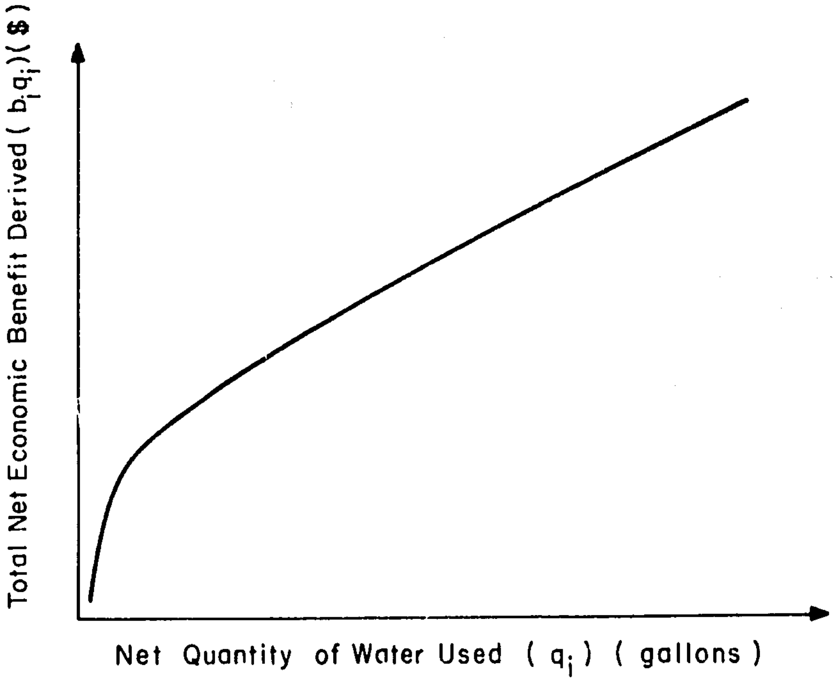

Figure 5.12 b_i q_i Relationship for Hydroelectric Power Generation Water.

due to problems of complimentary or supplementary, though numerous methods are available for overcoming this problem [37, 41]. Recreational water values are highly variable due to the actual water use, the areal location, water quality, the volume and surface area of the water, the actual flow rate in natural streams and the method used in valuation. Generalized numerical values for recreational water use are empirically impossible and specific areal values may also be unrealistic in application due to the relatively minute quantity and quality of literature available.

Estimates may be made however by considering the total expenditure of participants at recreational facilities; by comparing the market value of private resorts and public facilities; by equating the cost of facilities to the benefits generated; by considering indirect value added in the form of fees, licenses, etc., or by equating recreational time with manpower output hours within the gross national product. The overriding concept witin all these methods is the individual's willingness to pay for recreation opportunity in preference to going without it, and as such the $b_i - q_i$ relationship will take on a generalized form similar to the domestic sector. However, the net economic return to a distribution authority will increase in relation to the quantity of water available to a use saturation point where the marginal value approaches zero. The hypothetical form of the $b_i - q_i$ relationship is given in Figure 5.13 following and indicates an approach

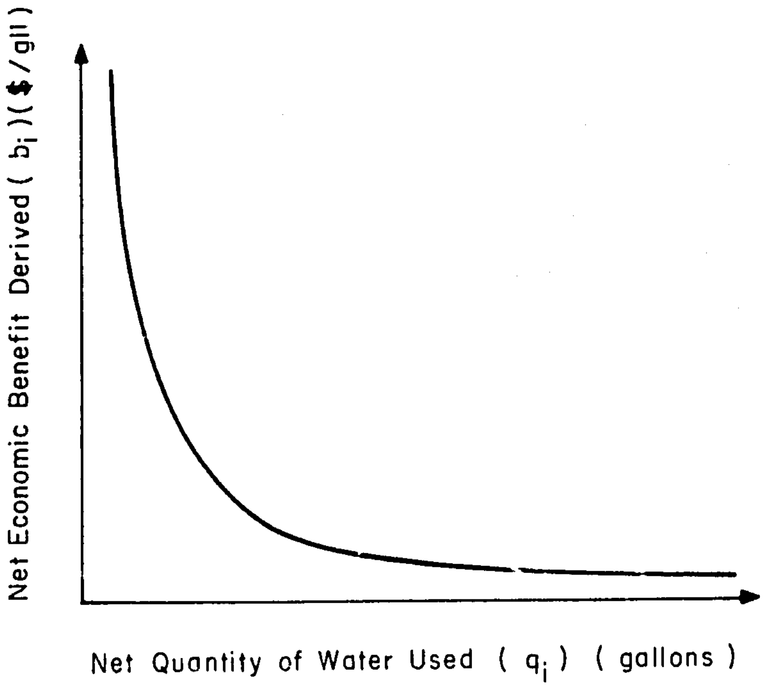

Figure 5.13 $b_i - q_i$ Relationship for Recreational Water.

to zero marginal value as the quantity of water available for use increases. Due to participants from outside the area, the marginal value will not reach exactly zero, though this will be highly seasonally orientated and also dependent upon complimentary demands. From Figure 5.13, the $b_iq_i - q_i$ relationship for recreational water may be derived and is shown in Figure 5.14 following.

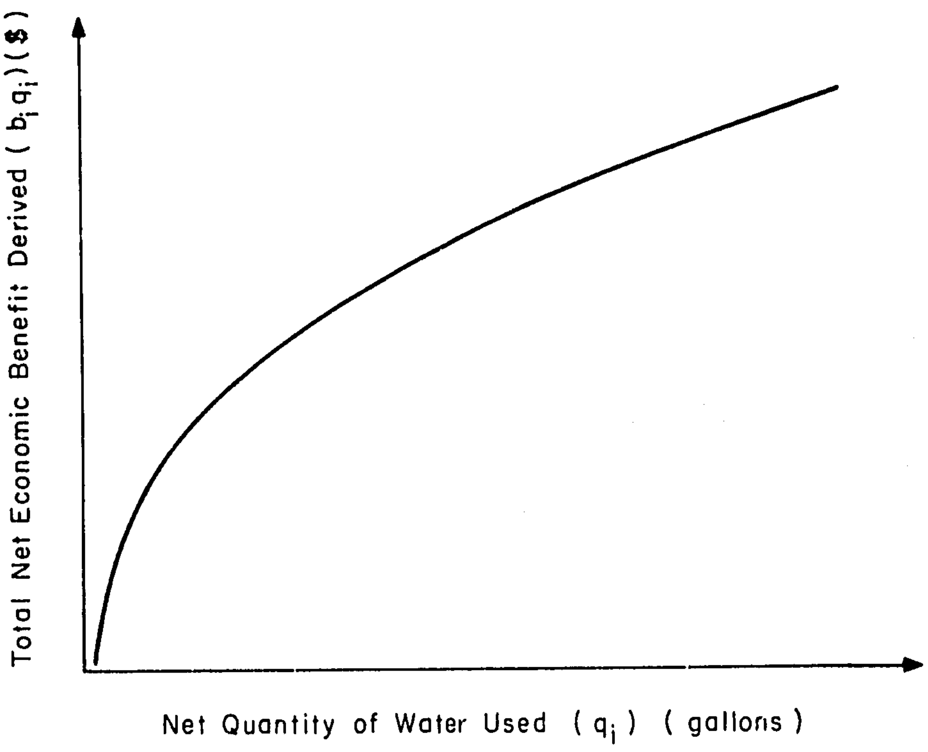

Figure 5.14 $b_i q_i - q_i$ Relationship for Recreational Water.

5.47 Social Water Value:

This sector has been considered as an entity due to the specialized nature of some facets of water use within an enclosed area. These facets include schools, hospitals, public park water use, water and sewerage treatment plant consumption, street cleaning water use and general civic water use. Though some of these subsectors may be considered within the domestic sector, the private individual's willingness to pay is not as high as it is for "in-house" residential use. An exception to this is the willingness to pay for water within hospitals, though no specific literature has been found dealing with this use. It is envisaged that within this particular subsector, the willingness to pay will increase rapidly with diminishing available water quantities.

As with the domestic sector, actual water withdrawals and consumption to satisfy this demand are comparatively low compared to the industrial and irrigation sectors, and actual water use determination may be complicated due to recycling. The high seasonal variation of use requires the time span of consideration to be a minimum and preferably no greater than a month. The economic value of water may again be determined through demand curves, and depending on the areal definition and the degree of water use anticipated from each subsector, it may be necessary to disaggregate the sector and consider separate demand curves. In the generalized $b_i - q_i$ relationship of Figure 5.15 following, the net willingness to pay indicates the actual net economic return to the distribution authority, and as such may be classified as the net economic benefit derived within the area.

With the imposition of water restrictions the previous curve will be shifted to the right, indicating an increase in the willingness to pay for the same water quantities. These higher b_i values will again induce higher $b_i q_i$ values.

In summary, the previous demand function curves illustrate the general form of the economic value of water in the seven main sectors

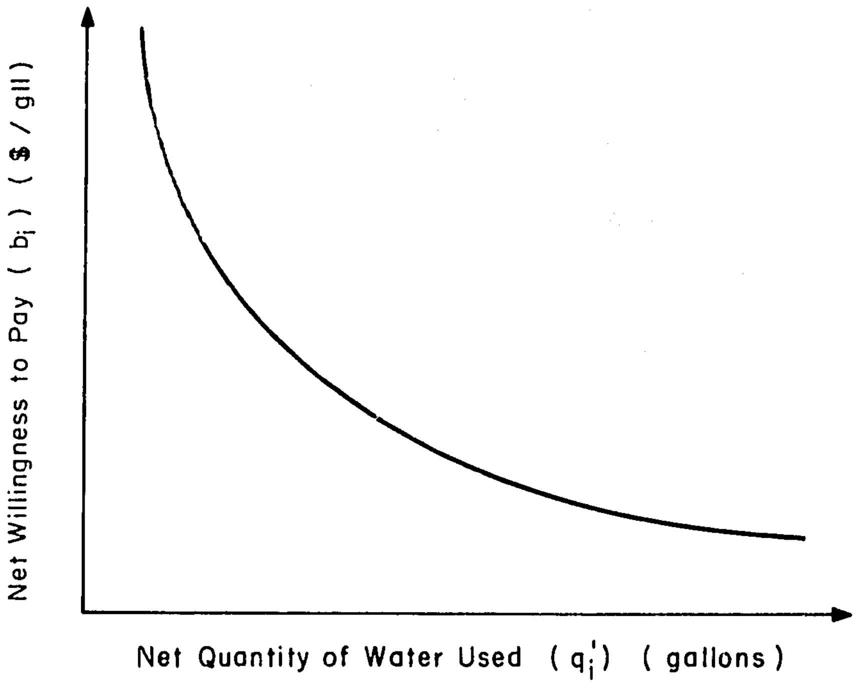

Figure 5.15 $b_i - q_i$ Relationship for Social Water Use.

considered in this paper. The extensive data requirements necessary to construct the $b_i - q_i$ relationships given are discussed in the following chapter, together with suggested methods of collection and collation. The previous curves have been drawn from literature surveys within the specific sectors, especially within the mid ranges of consumption, and author estimates and extrapolation used for the extreme value ranges. Specific note should be stressed regarding the high degree of aggregation used within each sector, and for any specific area under consideration, disaggregation into the anticipated prominent water uses may be necessary.

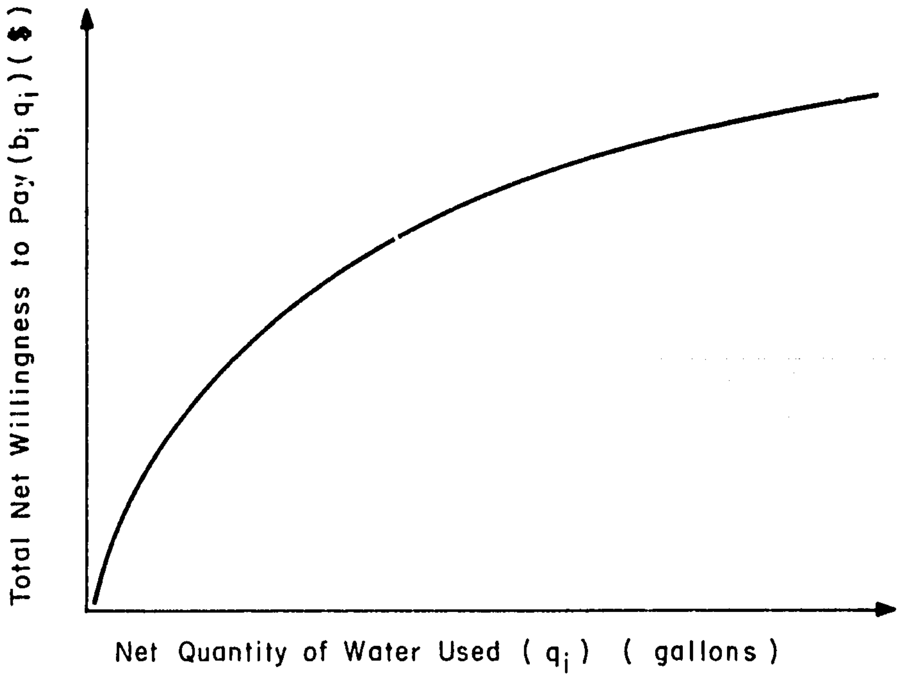

Figure 5.16 $b_i q_i - q_i$ Relationship for Social Water Use.

The foregoing curves represent the economic value of the use sector solely, and do not include secondary and pecuniary costs or benefits associated with the water use. A great deal of care should be taken during the valuation process that complimentary of use is considered within the appropriate sectors and that only consumptive use is apportioned to the value. Major discrepancies in the value of water will also arise between the comparisons of national valuation, regional valuation and private valuation from empirical estimates due to the inclusion of other resources within the accounting method. The variations in the time span of planning will also distort the true value of water within the sectors.

Complexities also arise with the valuation of water transferred from another basin, and the concepts of "on stream" or "off stream" use. However, these complexities may be reduced to a minimum through comparative cost and benefit analysis between basins, and exact qualitative definition of consumptive use.

In the following economic optimization example, the numerical values used in the compilation of the $b_i - q_i$ relationships have been extracted from the literature of data published for the mid-west area of the United States. For all of the curves it has been necessary to estimate or extrapolate the upper and lower bounds from extreme value empirical data from other areas. The numerically valued curves are, to a large degree, hypothetical, though their general shape is considered representative of the economic value of water within each sector. Consequently, a great deal of caution should be used in direct extraction of data from these curves.

5.50 Water Allocation Model:

The following water allocation model is a highly simplified dynamic water storage program incorporated within this paper to determine actual physical quantities available to consumer sectors, export flow, and storage accumulation or depletion. Any particular model available may be used in conjunction with the input-output analysis, and the degree of complexity of the model will depend upon the time increments adopted, data available, and overall required accuracy of the entire optimization.

The primary objective of this model is to allocate physical water quantities to the catchment demands from available storage supplies, imported water and natural runoff from the basin. The program has been designed to operate on a monthly basis, with initial demand satisfaction coming from available storage at the beginning of each month, and half the average monthly natural inflow. If the storage of the beginning of any one month plus half the average monthly natural inflow is insufficient to satisfy the demands, then the possibility of imported water is considered.

An arbitrary base flow requirement has been imposed for each month, and in context of the input-output program this is considered as water available for export. If imported water is not available for consumption the model considers the degree of restriction that must be imposed amd then establishes an allocation policy under restricted conditions. At the end of each month, simplified storage behavior computations are carried out to determine storage quantities and export water available for the following month.

The basic data requirements for the model are discussed in detail in the following chapter though initial mention of data to discuss the models operation is given briefly following. Normal hydraulic data in the form of net runoff to the entire system is required. As with any water resource system design, empirical data are normally the most accurate, though it may be necessary to synthetically generate data of monthly inflow and average monthly rainfall. Estimates of the full diversion requirements and minimum diversion requirements of the consumers are also necessary, together with the average annual or monthly return flow coefficients of each sector. The monthly timing of consumer requirements is also required, though the model assumes that total diversion is undertaken at the beginning of each month.

For periods of restriction it is also necessary to have data of the availability and timing of imported water, on a monthly basis, together with the minimum base flow requirement passing through the catchment and eventually considered as exported water. To commence operation of the program the initial storage available at month one must be known together with the maximum storage capacity within the catchment.

The allocation model may be divided into three main sections: data read in, allocation and storage computation. Having read in the initial average monthly total diversion requirements (q_i) together with the return coefficients of each sector (R_i), the initial net monthly consumptions of each sector (q_i') are computed from the expression

$$q_i' = q_i(1 - R_i). \tag{5.15}$$

The average net inflow to storage for the month (q_N), the maximum storage capacity (MS), the volume held in storage at the beginning of month one (S_i), the minimum base export flow requirement for the month (q_{EB}), and the imported water available during the month (q_I) are then read in. From these data, the total monthly consumption by all sectors (q_t), including the minimum base export flow requirement is computed from the equation

$$q_t = \sum_{i=0}^{n} q_i' + q_{EB}. \tag{5.16}$$

This total monthly consumption is then compared to the initial water quantity available ($S_i + \frac{1}{2}(q_N)$) and if $S_i + \frac{1}{2}(q_N) > q_t$ then all demands are satisfied for the month and the storage available for the next month computed from the expression

$$S_i = S_i + q_N - q_t + q_I \tag{5.17}$$

where

$$q_I = 0.0.$$

As it is possible that spill from the reservoir may occur, the new S_i value is compared to the maximum storage capacity (M_s) and if $S_i \geq M_s$, then the actual export flow available (q_E) is computed from the equation

$$q_E = (S_i - MS) + q_{EB}, \tag{5.18}$$

and the storage available for the next month's use is a maximum. If S_i is less than zero, the export flow available is equal to the base export flow requirement and storage available for the next month is zero. If S_i is greater than zero, but less than the maximum storage capacity, the export flow available is again equal to the base export flow requirement and the available storage remains the same.

The above computations do not require the imposition of restrictions, however if the storage held cannot meet the monthly requirements, it is necessary to rely upon imported water if available. Water thus available, denoted by S_{iI}, is given by

$$S_{iI} = S_i + q_I \tag{5.19}$$

If S_{iI} is greater than q_t, then total demand satisfaction is achieved, and the storage computations are carried out. For the case where $S_{iI} < q_t$, restrictions must be imposed upon the sectors, either equally or under an allocation restriction criteria established by the operating authority. The model given here allocates water initially to the domestic, power and social sectors so that their total demands are satisfied. The sum of these three demands, denoted by q_{xi}, is given by the equation,

$$q_{xi} = q_3' + q_5' + q_7' \tag{5.20}$$

where q_3', q_5' and q_7' represent the net monthly consumptions of the domestic, power and social sectors respectively.

However the available storage, now including imported water, may still not satisfy total demand satisfaction of these three sectors, and under these conditions it has been assumed that these sectors are restricted equally. This is achieved by computing a restriction ratio, denoted by RR, and expressed in the form

$$RR = \frac{S_{iI}}{q_{xi}} . \tag{5.21}$$

Using this ratio, the actual net diversions to these three sectors are given by the expressions

$$q_{3R}' = RR(q_3') \tag{5.22}$$

$$q_{5R}' = RR(q_5') \tag{5.23}$$

and

$$q_{7R}' = RR(q_7'), \tag{5.24}$$

and there is zero water available to all other sectors. As far as the western United States is concerned this is a purely hypothetical and highly improbable condition at the present moment.

If the domestic, power and social demands may be fully met, yet insufficient storage is available to satisfy the four remaining demands, the actual water available to these four sectors, designated by S_{iI}', is computed from the expression

$$S_{iI}' = S_{iI} - q_{xi} . \tag{5.25}$$

The total monthly demand within these four sectors (q_{x2}') is computed from the equation

$$q'_{x2} = q'_1 + q'_2 + q'_4 + q'_6, \tag{5.26}$$

and the restriction ratio computed from the expression

$$RR = \frac{S'_{iI}}{q'_{x2}}. \tag{5.27}$$

From this expression, the actual water quantities available are given by:

$$q'_{1R} = RR(q'_1) \tag{5.28}$$

$$q'_{2R} = RR(q'_2) \tag{5.29}$$

$$q'_{4R} = RR(q'_4) \tag{5.30}$$

and

$$q'_{6R} = RR(q'_6) \tag{5.31}$$

After allocating the available water to the sectors, the storage computations are carried as described previously, and the value of q'_i, q_n, q_E, Q_I, and S_i are printed. The program then returns to the data entry point and reads the next month's values of q_i, R_i, q_{EB}, Q_I and q_n for continuation.

Under the above restriction conditions, an allocation policy that is a function of the net economic returns may be advantageous if a compensation criteria is to be used for sectors that receive no water. If the water supply is sufficient to supply all sectors, but in reduced quantities, a minimum water supply criteria for each sector is required. The initial sectoral b_i values for this minimum water supply may then be read into the allocation program and the maximum amount of water available to the sector with the highest b_i value, under the minimum requirement constraints of other sectors, is allocated. Water is then allocated to the sector with the next highest

b_i value and the allocation repeated until all requirements are met, or all available water has been allocated.

This method basically implies a weighted allocation system, that is dependent upon the net economic returns from each sector, and constrained by the minimum water supply requirements of each sector.

From this allocation model, the initial values of q'_i are printed for each sector under all constraining conditions. These values are then used, in conjunction with the $b_i - q'_i$ and $b_i q'_i - q'_i$ relationships to determine the net economic returns from each sector. The b_i values are then read into the input-output analysis to compute the gross economic return of the area.

The flow chart for the above water allocation program is given in Figure 5.17 following, with the resulting computer program and program output given in Appendices B-1 and B-2 respectively.

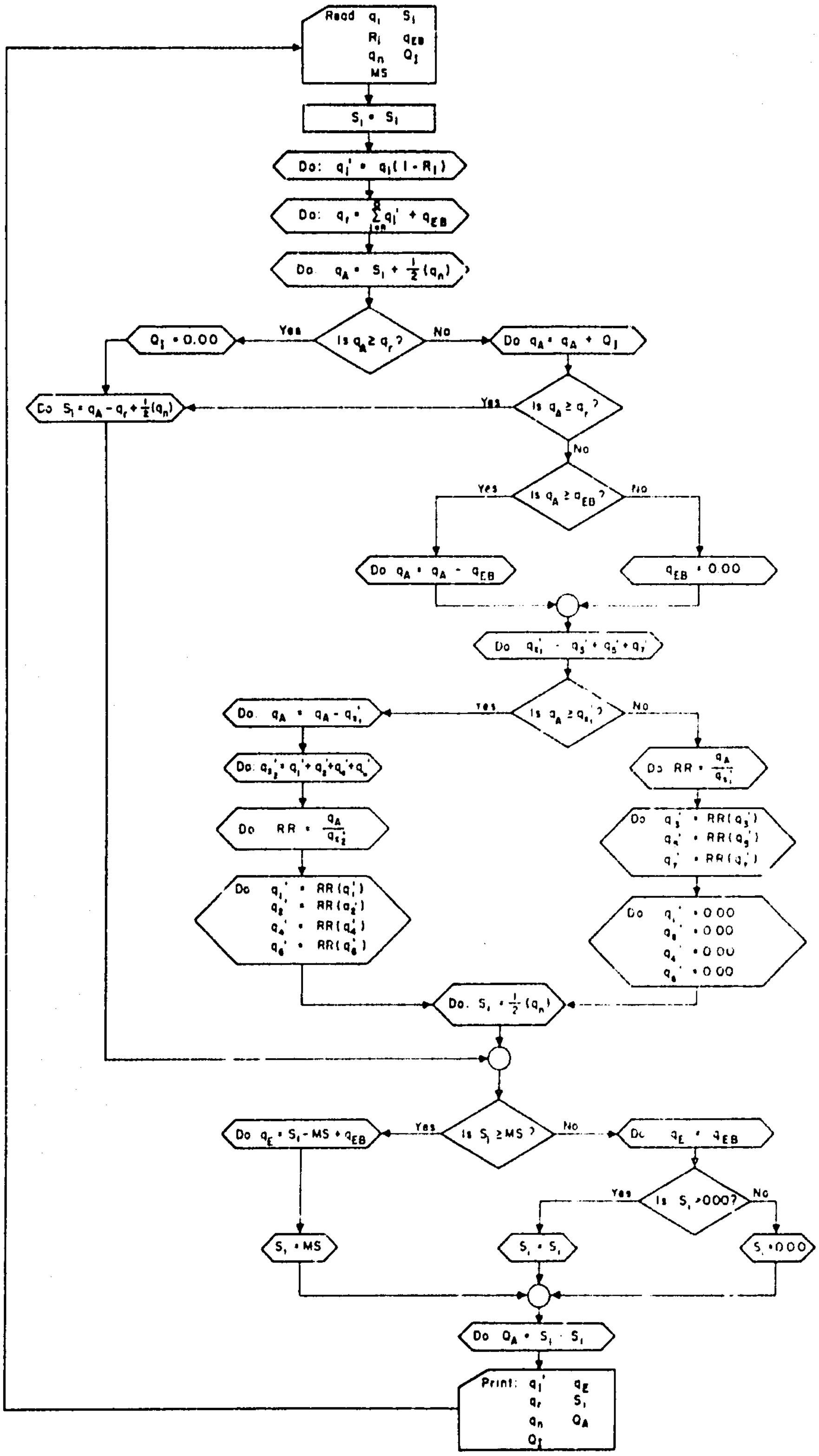

Figure 5.17 Flow Chart for the Water Allocation Model.

6.00 DATA REQUIREMENTS AND ACQUISITION:

6.10 General:

As with most water resource feasibility studies and preliminary design considerations, the major expense associated with the following optimization method occurs in data collection, evaluation, tabulation or synthetic generation. However, the basic requirement for the successful operation of this method is realistic and accurate data, irrespective of whether the data is empirical or generated. Data requirements for this model may be considered under three main interrelated sections; namely, hydrologic and hydraulic data, water consumption data and economic data. The later two data sections are highly dependent upon the hydrology of the catchment area, and it is suggested that data pertaining to this section be collected and evaluated first.

The above three sections will be considered following as separate systems, and actual descriptions of data requirements included for each section, together with suggested methods of acquisition. A flow chart of the total data requirements is given in Figure 6.1 following, though note should be made that this chart is by no means comprehensive as far as overall water resource planning for a basin is concerned. As will be mentioned within each section, the probability of collecting sufficient empirical data to satisfy the needs of the model is very low, and the generation of synthetic data, especially hydrologic data may be a necessity.

6.20 Hydrologic and Hydraulic Data:

Initial data collection requires a complete physical assessment of natural water conditions within the catchment. This implies

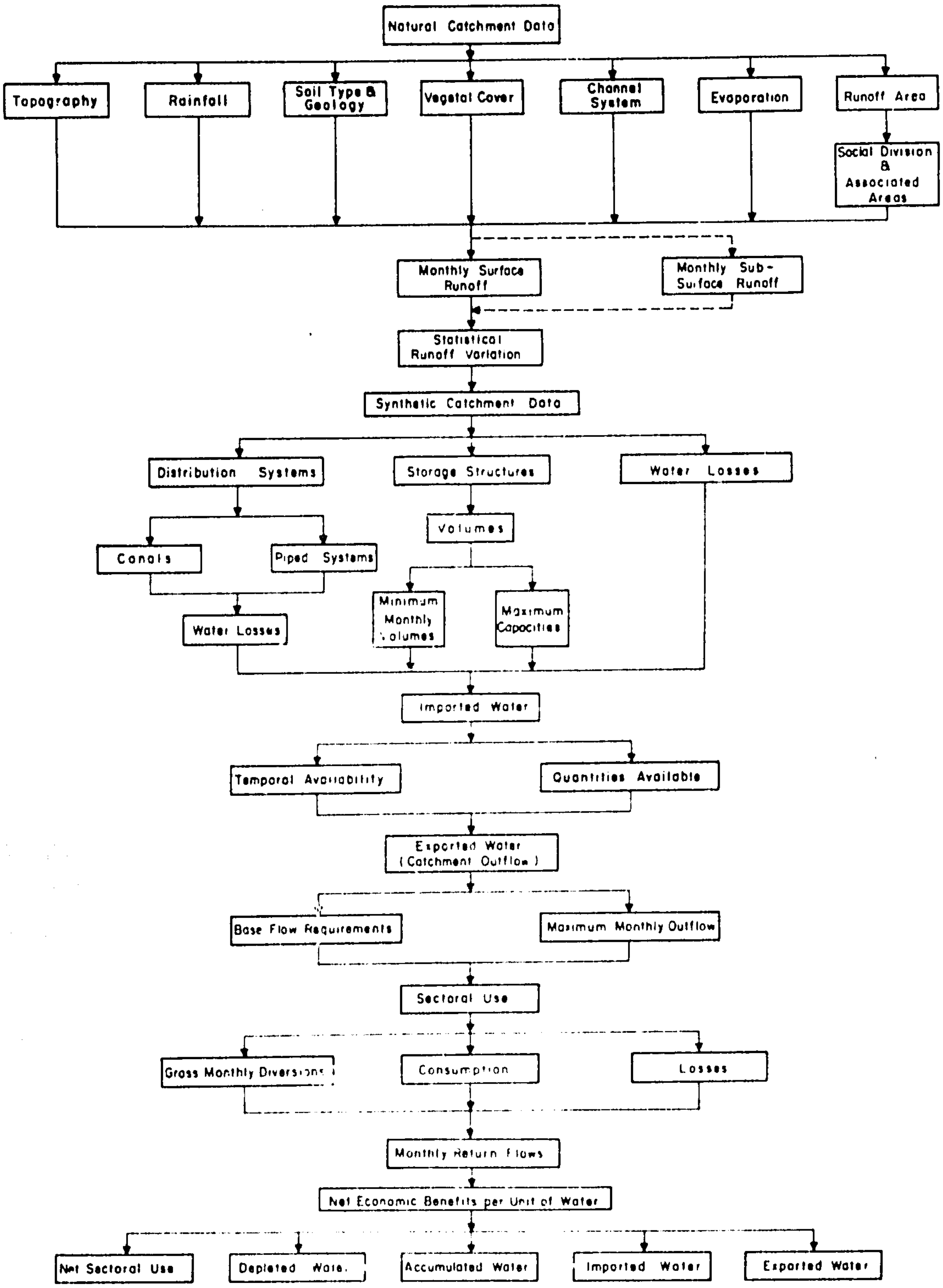

Figure 6.1 Flow Chart of Data Requirements.

both on-surface and potential-surface water, with data collected on a predetermined time basis. As shown in Figure 6.1 these requirements include rainfall, evaporation, catchment topography and vegetal cover, soil types and geology, actual physical size of the catchment and the channel runoff system. The two most important parameters in this section are rainfall and evaporation, and numerous manual and automatic gauges are available to collect such data. The spatial and temporal distribution of these two parameters highly affects the monthly runoff cycles, loss rates within the sectors, the occurrence of any temporal water restrictions. Consequently, these data should be accurate and of sufficient duration to allow complete model operation for the entire time span of planning. Numerous synthetic methods are available to determine accurately these data from adjacent basins, over long time periods, and these methods are satisfactory for the generation of runoff that is both spatially and temporally orientated.

Surface runoff data in defined natural channels may also be collected through conventional stream gaging methods and numerous manual and automatic devices are available. These data, for the purposes of this model operation, should also be collected on a total monthly discharge basis, together with the maximum and minimum flows recorded during each month. Although not discussed, nor incorporated within the model operation, groundwater flows should also be recorded or determined if extensive use is made of groundwater within any of the sectors. For purposes of projecting anticipated monthly runoffs, a full statistical analysis of past empirical or generated data should be made to determine anticipated minimum and maximum flows together with their probabilities. Such analysis allows predetermination of flood and restricted flow operation procedures and assists in the formulation of restriction and consequential compensation criteria.

From data collected for the individual channels within the basin, it is then possible to establish a complete inflow-outflow water balance under natural conditions on a monthly time basis. This balance is particularly important in determining natural outflows to downstream basins, and assists in determining what quantitative and temporal distribution of imported water is required. Natural catchment outflow conditions are also particularly important for the definition of downstream water allocation and any legal litigation developing from upstream allocation

For either developed or developing catchment areas, it is also necessary to map all existing hydraulic structures and assess their affect upon the natural runoff conditions. The storage capacities of all reservoirs must be determined together with the minimum storage capacities required for recreational or social use. Any existing distribution network should also be mapped together with the flow capacities of this network. The loss rates within the distribution system, including evaporation and seepage, should be recorded or estimated to assist in the computation of net water use in the various sectors. These loss rates are applicable to both open and closed distribution systems. Potential or existing supplies of imported water should also be determined together with the types of structures existing and their respective losses. If water importation exists, the quantitative and temporal availability of the water must be known, together with the actual input location to the catchment.

6.30 Water Consumption Data:

Following a breakdown of the entire basin into the various sectoral uses, it is necessary to determine the quantitative and temporal water consumption requirements of each sector. Depending upon the degree of accuracy required within the entire model, it may be necessary, or advantageous, to disaggregate the individual sectors into subsectoral use areas. This would be particularly important for larger water resource systems and areas that contain large, high density population areas.

For each of the sectors considered, the minimum and average water requirements during the selected time base should be determined, together with major seasonal changes in consumption. This will involve a more thorough study of all existing water consumption data within the area, including basins other than the one under consideration. Basic data may be obtained for the social and domestic sectors by considering the gross quantities of water passing through operational water treatment plants within, or adjacent to, the catchment area. Data may be expressed initially in terms of gross diversion per capita per month, or gross diversion per unit land area per month, and following inclusion of anticipated losses, may be expressed in actual gross consumption per month. Estimates for recreational use must be made in relation to the total anticipated use, in terms of per capita, and the minimum gross monthly water quantities necessary to sustain recreational activity.

Power generation water demands may be obtained from direct measurement of water passing into the plant and outgoing water. Losses associated with power generation are, on a percentage total use basis, very small and the consumptive use of the power sector is very small. However, minimum storage capacities are required for power generation and competition for this water may exist from other sectors, especially during periods of mild restriction. During these times, water consumption may be considered as the total water quantity held in storage during a particular time period under the proviso that in the following time period, water so stored is transferred to export flow. This is also applicable for the case of pumped storage power generation in which water is pumped back into storage during periods of low power consumption.

Industrial and commercial water consumption data may be collected through the consideration of inflows and outflows to the sectors to determine the monthly return coefficients. Again, data may be obtained through direct measurement comparative analysis of similar sectors in adjacent areas, or through rational estimation by considering the individual industrial or commercial activity. As mentioned in the previous chapter, the prime use of industrial water is for cooling purposes, and consumption will thus be highly dependent upon seasonal variations. As for the other sectors these data should be expressed in net consumption per month in acre feet or gallons.

Of all the sectors, the most significant monthly and seasonal water consumption variations will occur in the irrigation sector. For an existing irrigation system, data may be collected by considering an inflow-outflow water balance for each particular irrigation activity, which allows determination of the return coefficients for each crop. This study may be conducted as part of the loss rate analysis carried out in conjunction with the total catchment input-output water balance, and for the purposes of this study, on a monthly basis. It is to be expected that within the irrigation sector, a high degree of variation will occur in the return coefficients from one time period to the next. For developing catchment areas, where very little irrigation activity is pursued, comparative analysis from adjacent catchments may be necessary for compiling realistic gross diversion and return coefficient data. Reliable estimates may also be determined through consideration of the climatic conditions, topography, geology, and soil conditions of the area and applying empirical equations to determine the water requirements of the particular crops [40]. The resulting data indicates the net consumptive requirements and it is then necessary to compute or estimate anticipated monthly loss rates and consequential gross diversions to determine monthly return coefficients. As with all other sectors this data should be expressed in acre feet or gallons per month, and the probabilities of monthly variation should be determined for each crop type.

6.40 Economic Data:

The basic economic data requirements revolve around data for input to the basic transactions table of the input-output analysis, and the valuation of net water benefits to the individual sectors for development of the $b_i - q_i'$ and $b_i q_i' - q_i'$ relationships. Data for establishing the average annual transactions table necessitates the valuation of all goods and services produced and purchased by the individual sectors. These data may be collected by approaching each sector as an entity initially to determine the net worth of produce bought and sold. Through the consideration of raw material inputs, sector operational costs, and the sale prices of the finished goods, the net sectoral economic values may be determined.

Normal method for data collection within the industrial, commercial, power generation and irrigation sectors may be applied. However for the social, domestic and recreational sectors of an area as considered in this paper, severe problems may arise in the determination of production values, and many of the entries within the transaction table may appear as zero for these three sectors. However, by considering these sectors solely as purchasing sectors, data may be collected of the goods transferred from the producing sectors. It is normally far more applicable in pure economic input-output analysis to consider these sectors as a payments group within the producing sector. However, they must be considered in this paper within the main context of the transaction table due to their dependence upon water.

Data for the power generation sector may be obtained from the actual sales of power both within and outside the catchment area. For pumped power generation systems, power purchases will also be indicated from the power producing sector, indicating transfer of the same commodity within a particular sector. Actual numeric data may be obtained from existing generating plants through the basic accounting system. For catchment areas under development, it is necessary to estimate the power demands, both intra and interbasin, power generation capacity to be designed for, and total costs of installation, operation and maintenance of the plant over its design life. From these data, changes to be levied against users may be determined and the monthly production and purchasing values computed. As with the irrigation sector, large monthly variations of data will occur witin the power generation sector.

Specific note should be made of methods available for data collection within the recreation sector. As discussed in Chapter 5.00, the "producing" ability of any recreational activity may be measured most accurately through the consumer's "willingness to pay." The actual net revenue produced by a recreational facility may be classified as the producing facet of that sector. Difficulties arise using this type of assessment however in the fields of wild stream fishing, game hunting, etc., though some indication of the production may be estimated through income from licenses, permits, etc. The sale or leasing of land rights for campgrounds, lake marinas and other commercial resorts also gives an indication of the recreational value, and together with the net income received from these resorts, reliable data estimates for recreational production may be made.

Within the final demand and payments sector of the transaction table it is also necessary to determine the economic value of goods produced and bought for the annual input-output budgeting of the entire area. As the economic maximization objective is to maximize the total gross output within the transactions table, the final demand sector will be held as the prime variable, and the export and accumulation values will be changed manually in relation to outputs from the water allocation model.

Valuation of imported water may be made through the actual costs incurred in buying and transporting the water into the distribution system. For developing countries, without any existing import system, this value must be computed from the physical costs of constructing the importation system, while for existing systems, valuation may be made through empirical data of actual buying, operation and maintenance costs incurred. Comparative costs of adjacent systems may again be used to assist in net economic water valuations.

In the computation of net economic values per unit water quantity for all sectors, a great deal of reliance must be placed in the physical hydraulic data and the costs associated with such. It is to be anticipated that complications regarding the interarea transfer of goods will be encountered, though actual valuations should be accounted for in the basic transaction table of goods purchased and produced.

To establish the net benefit - water quantity relationships it is necessary in most cases to determine the gross incomes of each sector together with the gross water diversions. These data may be collected by observation of existing transactions within a developed catchment area, or comparative value assignments from adjacent areas. For undeveloped or developing areas, it will be necessary to use comparative analysis in conjunction with theoretical estimates determined from climatic, soil, hydrologic, hydraulic, and anticipated growth pattern data. Data must be collected from each sector considered as an entity as discussed in length in the previous chapter. In many cases, it may be necessary to estimate or collect from empirical data, only the extreme values for the $b_i - q_i'$ relationships and determine intermediate values through interpolation. However, for all sectors, the determination of the marginal values is crucial and in most cases will necessitate consideration of empirical and theoretical data.

Particular care should be exercised in the formation of the $b_i - q_i'$ relationships under temporal consideration. Monthly water quantity use variations may induce large variations in the net economic benefits derived per month, and is recommended that, for the irrigation, power generation and recreation sectors particularly, individual monthly $b_i - q_i'$ relationships be established.

6.50 Conclusions:

Throughout the previous chapters it has been stressed that the following optimization method requires practically all facets of physical and economic data associated with the production of goods within a catchment area. It should also be stressed that the major cost of operating this model will be associated with data collection and evaluation.

The overall accuracy of operation of the model throughout the maximization process will be dependent solely upon the reliability and precision of the data, and final results should indicate the reliability of the maximization in relation to data precision. A great deal of care should be taken in the collection and evaluation of the data and monthly modifications may be necessary within the economic and water use evaluations especially where comparative or estimated data are used. This will be particularly prevalent in the case of a developing country, where it is recommended that model operation be conducted on a monthly sequential basis until validation of data is achieved.

7.00 SYSTEM OPERATION:

In the following section, a logical sequence of discrete steps for the economic and allocation optimization of an existing water allocation system is formulated. Following the theoretical formulation, synthetic data have been adopted for the water basin discussed in Chapter 5.00. Synthetic data have been used within the example due to the large comparative cost of real data collection in relation to the model operation. However, economic data used have been derived from references reporting real costs, though are specific in their nature due to derivation from continental U.S.A. sources. Detailed operational procedures for the month of September are given in section 7.20.

7.10 Operational Theory:

The following sequential subsections list the entire operational format for the maximization procedure.

7.11 Determine general catchment data. Basic catchment area parameters in the form of area, average monthly rainfall, average monthly runoff, distribution losses, and storage capacities are determined initially. A complete accounting of the surface water movements within the catchment area, together with imported and exported flows, is required. All catchment data requirements are given in the flow chart form of Figure 6.1 previously.

7.12 Determine average monthly sectoral demands and consumptions.

7.13 Compute the initial sectoral consumptions in relation to the average monthly water available through the use of a water allocation model.

7.14 Establish the demand functions (b_i - q_i' relationships). For each sector, and from such, compile the b_iq_i' - q_i' relationships.

7.15 From the above step, determine the b_i and b_iq_i' values for total demand satisfaction consumptions.

7.16 Compile the average annual input-output table from either historical sources, or estimates on the proposed gross production values within the catchment area.

7.17 Establish the initial transactions table of net production arising solely due to water use, for average monthly water consumption conditions. This table, designated by $[A_{ij}]_w$, is compiled through the following manipulations:

i) Sum the rows of the average annual input-output table within the consuming sector (excluding exports and accumulation). If any particular sector has zero demand for water during a month, the respective annual sectoral value is assigned as zero, and the resulting matrix reduced accordingly. This summation may be expressed as

$$|T_i'|_C = \sum |x_{ij}|_R \, . \qquad (7.1)$$

ii) It is initially assumed that a value of \$1.00 x 10^3 is assigned to both the exports and accumulation columns. These values are subtracted from the b_iq_i' values to give a new net economic return for each sector designated by

$$|b_iq_i'| = |b_iq_i' - 2.00| \, . \qquad (7.2)$$

The resulting values may be expressed as a column vector given by

$$|B_i|_C = |b_i q_i'|_R . \qquad (7.3)$$

iii) Compute a distribution multiplier (M_1) from the ratio:

$$M_1 = \frac{|b_i q_i'|_R}{\Sigma |x_{ij}|_R} = \frac{|B_i|_C}{|T_i'|_C} . \qquad (7.4)$$

iv) Multiply each row in the average annual input-output table (excluding exports and accumulation) by the respective M_1 values to give the initial distribution of produce between sectors for average monthly water consumption conditions.

The initial table is completed with the following steps:

v) For each row in the exports and accumulation columns an initial value of unity has been assigned.

vi) Sum each row of the entire input-output table to give the total gross output of produce for the month arising solely from water consumption, and excluding all other resource inputs. The resulting column vector, designated by $|(T_i)_w|_C$, may be expressed as

$$|(T_i)_w|_C = \Sigma M_1 (x_{ij}) + Y_i . \qquad (7.5)$$

vii) Transpose $|(T_i)_w|_C$ to the row vector $|(G_j)_w|_R$, where $|(G_j)_w|_R = [|(T_i)_w|_C]^T$, and enter in the total gross outlay row.

viii) Complete balancing the table by computing the payments sector from the expression

$$|(I_j + L_j)_w|_R = |(G_j)_w|_R - \sum|(x_{ij})_w|_C , \qquad (7.6)$$

and adopt $|(I_j)_w|_R = |(L_j)_w|_R$. Negative values from this calculation may be induced in the payments sector, which are initially neglected during the iteration process.

The resulting table gives the initial input-output table of net produce transactions between sectors arising solely from the water resource.

7.18 Compute incremental changes in the final demand sector through the use of a second multiplier, M_2 . These multipliers may be established as follows:

i) Sum the unit net economic returns for the particular month, for all sectors, designated by $\sum_{i=1}^{i=n} b_i$.

ii) Compute the M_2 multiplier for each sector from the expression

$$M_2 = \frac{b_i}{\sum_{i=1}^{i=n} b_i} . \qquad (7.7)$$

iii) Incremental charges in final demand are then made through use of the expression

$$(\Delta Y_i)_w = 2[aM_2 + 1.00] \qquad (7.8)$$

where the variable "a" is incremented in values of $10 x 10^3 initially, then $1.00 x 10^3, $0.10 x 10^3 and finally $0.01 x 10^3.

7.19 Feed in the initial values of $(\Delta Y_i)_w$ with a = \$10 x 10^3 and determine the new transactions table of b_iq_i' values through use of the input-output program.

7.110 The row summation within the resulting table gives the total output of each sector for the new final demand values. These are the new b_iq_i' values.

7.111 From the $b_iq_i' - q_i'$ relationships, determine the actual water consumption, q_i', for each sector.

7.112 Sum the resulting q_i' values for each sector, $(\sum_{i=0}^{i=n} q_i')$, and compare the resulting value with the actual water available for consumption determined initially from the water allocation program.

7.113 If the water available for consumption is greater or less than the actual water quantity consumed, $(\Delta Y_i)_w$ is modified incrementally, and iteration continued until $\sum_{i=0}^{i=n} q_i' = Q_i'$.

7.20 <u>Operational Example</u>:

7.21 General Catchment Data:

i) Catchment area: A = 1400 square miles = 896 x 10^3 acres.

ii) Average annual rainfall over catchment: P_{av} = 12.00 inches.

iii) Average annual runoff from the catchment (considered within the allocation model as natural inflow):

q_N (annual) = 2.98 inches = 72.50 x 10^3 gallons for the entire catchment area. The average monthly distributions of rainfall and runoff are given in Table 7.1 following.

iv) Maximum storage capacity within the catchment area:

MS = 18.00 x 10^3 gallons.

MONTH		Average Monthly Precipitation (inches)	Average Monthly Runoff (inches)	Average Monthly Natural Inflow (glls x 10^3)
		P	q_n	q_n
1	Jan	0.65	0.22	5.35
2	Feb	0.65	0.23	5.60
3	Mar	0.83	0.29	7.06
4	Apr	1.20	0.40	9.73
5	May	1.66	0.43	10.46
6	Jun	1.85	0.39	9.49
7	Jul	1.38	0.18	4.38
8	Aug	0.92	0.12	2.91
9	Sep	0.83	0.14	3.40
10	Oct	0.83	0.21	5.12
11	Nov	0.83	0.25	6.08
12	Dec	0.37	0.12	2.92
TOTAL ANNUAL		12.00	2.98	72.50

Table 7.1 Average Monthly Rainfalls and Runoffs.

7.22 Water Movement Data:

Within any defined catchment area water movement may be considered under the three main sections of water inputs to the system, gross deliveries and net consumption by the sectors, and water outputs (or exports) from the system. These three main sections are considered individually in the following subsections.

7.221 Water Inputs to the System.

Primary inputs to the allocation system considered here are natural monthly inflow (q_N), water diverted (or imported) from an adjacent catchment area (q_I), and water used from storage within the area, referred to here as depletion water (q_D). Water inputs are considered separately as follows:

i) Natural Inflow.

This input to the system consists of natural precipitation and the adopted average monthly natural inflows are given in Table 7.1 previously.

ii) Imported Water.

A maximum monthly value of 2.0×10^3 gallons has been adopted as the water available from adjacent catchment areas. As the purchase of this water presents an economic loss to the allocating authority within the considered catchment area, the water allocation program only considers the availability of imported water if all storages have been depleted and restrictions need to be imposed upon the consuming sectors. If restrictions are imposed to any degree, then the maximum monthly amount available is imported.

iii) Depletion Water.

The third water input to the system is available from storages within the catchment. This water is accumulated during periods in which natural inflow exceeds consumed and required export quantities. The amount of depletion water available is solely dependent upon the quantity of water held in storage at the end of the previous month, with a maximum amount of 18×10^3 gallons available in any one month.

7.222 Gross Deliveries and Net Sectoral Consumptions.

Gross deliveries (or diversions) to the sectors are denoted by q_i, whereas the actual net consumptions are given by q_i'. The relationship between these two quantities, as discussed in Chapters 2.00 and 5.00 may be written as

$$q_i' = q_i(1 - R_i), \tag{5.15}$$

where R_i values are the respective return coefficients. For each of the seven sectors, the following subsections give the average monthly gross diversions required.

i) Irrigation Sector.

Irrigation area: A = 27,000 acres = 42.19 square miles.

Irrigation season: 6 months, May to October inclusive.

Average annual irrigation requirement (gross diversion to irrigation areas): 5 acre feet per year. The average gross monthly diversions, in gallons x 10^9, are given in Table 7.2 following.

ii) Industrial Sector.

Total number of industries within the catchment area: 200. Average monthly diversion per industry (assumed constant for each month): 3 x 10^6 gallons.

iii) Domestic Sector.

Catchment area population served by the domestic water supply system: 100,000 people. Range of average daily diversion requirements per person: 42 to 125 gallons. Average monthly discharge is based upon 30 days per month, and the gross requirements for each month are given in Table 7.2.

iv) Commercial Sector.

Total number of commercial businesses: 1500. Average monthly requirement per business: 0.3 x 10^6 glls. (assumed constant for each month).

v) Power Generation Sector.

Total number of hydroelectric plants: 5. Range of average monthly diversion requirements per plant: 0.020 x 10^9 to 0.052 x 10^9 gallons. Average monthly discharge is based upon 30 days per month, and the gross monthly requirements are given in Table 7.2.

vi) Recreation Sector.

Total number of recreational uses: 50. Range of average monthly diversion requirements per recreational area: 0.40 x 10^6 to 30.00 x 10^6 gallons, with the monthly allocation requirements given in Table 7.2.

vii) Social Sector:

Total number of social sectors serviced: 100. Range of average monthly diversion requirements for all sectors: 0.17×10^9 to 0.20×10^9 gallons.

In Table 7.2, the average gross monthly requirements (q_i) for all sectors are given together with the average monthly consumptions (q_i'). For simplicity, the return coefficients for each sector have been assumed constant throughout the year, though for the irrigation, domestic and social sectors especially, large variations may occur between the summer and winter seasons.

7.223 Water Outputs from the System.

Downstream demands for water originating within the catchment are considered as water outputs from the allocation system. If the storage at the end of the month under consideration is greater than the storage at the end of the previous month, the accumulated water is held out of productive use during the month, and as such, is also considered as a monthly output from the system. These two water output considerations are discussed separately in the following subsections:

i) Exported Water.

Under existing water law, most catchment areas are required to pass a certain amount of water to areas downstream, either on a daily, monthly, or annual basis. It has been assumed here that a minimum monthly export base flow requirement (q_{EB}) of 3.0×10^9 gallons is imposed upon the catchment area. Thus, the actual monthly export flow (q_E) is under the constraint that $q_E \geq 3.0 \times 10^9$ gallons, and in any month may constitute a portion of the storage depletion (q_D) from the catchment.

MONTH		SECTOR														TOTAL MONTHLY	
		IRRIG'N		INDUST'L		DOM'		COMM'		POWER		REC'N		SOCIAL			
		$R_1 = 0.20$		$R_2 = 0.05$		$R_3 = 0.35$		$R_4 = 0.20$		$R_5 = 0.20$		$R_6 = 0.80$		$R_7 = 0.30$		Σ_{qi}	Σ_{qi}'
		q_1	q_1'	q_2	q_2'	q_3	q_3'	q_4	q_4'	q_5	q_5'	q_6	q_6'	q_7	q_7'		
1	Jan	0.00	0.00	0.60	0.57	0.13	0.08	0.45	0.36	0.26	0.026	0.02	0.004	0.17	0.12	1.63	1.160
2	Feb	0.00	0.00	0.60	0.57	0.13	0.08	0.45	0.36	0.26	0.026	0.02	0.004	0.17	0.12	1.63	1.160
3	Mar	0.00	0.00	0.60	0.57	0.14	0.09	0.45	0.36	0.26	0.026	0.05	0.010	0.17	0.12	1.67	1.176
4	Apr	0.00	0.00	0.60	0.57	0.16	0.10	0.45	0.36	0.25	0.025	0.70	0.140	0.17	0.12	2.33	1.315
5	May	3.00	2.40	0.60	0.57	0.19	0.12	0.45	0.36	0.20	0.020	0.80	0.160	0.17	0.12	5.41	3.750
6	Jun	4.00	3.20	0.60	0.57	0.24	0.16	0.45	0.36	0.20	0.020	0.90	0.180	0.18	0.13	6.57	4.620
7	Jul	10.00	8.00	0.60	0.57	0.33	0.21	0.45	0.36	0.15	0.015	1.00	0.200	0.19	0.13	12.72	9.485
8	Aug	11.00	8.80	0.60	0.57	0.38	0.25	0.45	0.36	0.10	0.010	1.50	0.300	0.20	0.14	14.23	10.430
9	Sep	9.00	7.20	0.60	0.57	0.33	0.21	0.45	0.36	0.10	0.010	1.50	0.300	0.20	0.14	12.18	8.790
10	Oct	7.00	5.60	0.60	0.57	0.26	0.17	0.45	0.36	0.15	0.015	1.00	0.200	0.18	0.13	9.64	7.045
11	Nov	0.00	0.00	0.60	0.57	0.18	0.12	0.45	0.36	0.23	0.023	0.80	0.160	0.17	0.12	2.43	1.353
12	Dec	0.00	0.00	0.60	0.57	0.16	0.10	0.45	0.36	0.25	0.025	0.06	0.012	0.17	0.12	1.69	1.187
TOTAL ANNUAL		44.00	35.20	7.20	6.84	2.63	1.69	5.40	4.32	2.41	0.241	8.35	1.670	2.14	1.51	72.13	51.471

Note: All values in gallons x 10^9

Table 7.2 Average Gross Monthly Demands and Consumptions

ii) Accumulated Water.

Water accumulated during any particular month, designated by q_A, constitutes water in excess of consumptive demand that is placed in storage for use in the following months. As such, the maximum numerical value of q_A in this system is 18.0×10^9 gallons during any one month, with q_A only occurring after all internal consumptive demands have been met, together with the base export flow requirement.

7.224 Water Balance for Average Annual Conditions.

From the previous sections it is now possible to construct a tabular representation of the natural inflow, sectoral consumption and export water data under the conditions of average monthly runoff values and full demand satisfaction. Even under these conditions, without physical water restrictions, a water reallocation may be necessary to obtain economic maximization. The average annual data is presented in Table 7.3 following. Assuming that the storage availability is 3.02×10^9 gallons at the beginning of month 1 (S_i), we may compute the storage at the end of each month using the allocation program.

For month 1, the total monthly consumption and export quantity (q_t) is 4.16×10^3 gallons, and the average monthly inflow is 5.35×10^9 gallons. As the storage available is greater than the demand for the month, the storage at the end of the month is given by

$$S_i = S_i + \frac{1}{2}(q_N) - q_t + \frac{1}{2}(q_N) \qquad (6.1)$$

$$S_i = 4.21 \times 10^9 \text{ gallons.}$$

Within the allocation program it is assumed that half of the natural inflow occurs at the beginning of the month and half at the end. The

MONTH		Average Monthly Sectoral Consumption (gallons x 10^9)							Total Monthly Sectoral Consumption (glls x 10^9)	Base Export Flow Requirements (glls x 10^9)	Total Monthly Consumption (glls x 10^9)	Average Monthly Natural Inflow (glls x 10^9)
		q_1'	q_2'	q_3'	q_4'	q_5'	q_6'	q_7'	$\sum_{i=7}^{i=1} q_i'$	q_{EB}	q_r	q_n
1	Jan	0.00	0.57	0.08	0.36	0.026	0.004	0.12	1.160	3.00	4.160	5.35
2	Feb	0.00	0.57	0.08	0.36	0.026	0.004	0.12	1.160	3.00	4.160	5.60
3	Mar	0.00	0.57	0.09	0.36	0.026	0.010	0.12	1.176	3.00	4.176	7.06
4	Apr	0.00	0.57	0.10	0.36	0.025	0.140	0.12	1.315	3.00	4.315	9.73
5	May	2.40	0.57	0.12	0.36	0.020	0.160	0.12	3.750	3.00	6.750	10.46
6	Jun	3.20	0.57	0.16	0.36	0.020	0.180	0.13	4.620	3.00	7.620	9.49
7	Jul	8.00	0.57	0.21	0.36	0.015	0.200	0.13	9.485	3.00	12.485	4.38
8	Aug	8.80	0.57	0.25	0.36	0.010	0.300	0.14	10.430	3.00	13.430	2.91
9	Sep	7.20	0.57	0.21	0.36	0.010	0.300	0.14	8.790	3.00	11.790	3.40
10	Oct	5.60	0.57	0.17	0.36	0.015	0.200	0.13	7.045	3.00	10.045	5.12
11	Nov	0.00	0.57	0.12	0.36	0.023	0.160	0.12	1.353	3.00	4.353	6.08
12	Dec	0.00	0.57	0.10	0.36	0.025	0.012	0.12	1.295	3.00	4.295	2.92
TOTAL ANNUAL		35.20	6.84	1.69	4.32	0.241	1.670	1.51	51.471	36.00	87.471	72.50

Table 7.3 Average Monthly Natural Inflow, Consumption and Export Data.

above procedure is continued for each month, using the storage available at the end of the preceding month plus half the natural monthly inflow for consumption and export satisfaction. For the average annual values, Table 7.4 following tabulates the storage availability at the end of each month, and indicates storage accumulation or depletion. The complete tabulation of the monthly water balance for average monthly conditions is given in the computer printout in Appendix B-2.

7.23 Net Benefit-Water Quantity Relationships:

For each of the seven sectors, demand functions have been developed from data pertinent to the central western area of the U.S.A. These functions are, to a large extent, hypothetical due to the lack of data available. This is particularly relevant for extreme values within the functions, especially under restriction conditions. From the $b_i - q_i'$ demand functions developed, the $b_i q_i' - q_i'$ relationships have been developed for each of the sectors. From these relationships, the total net returns for each month may be obtained. Figures 7.1 through 7.14 following give the $b_i - q_i'$ and $b_i q_i' - q_i'$ relationships used within the example and Table 7.5 following these figures lists these values for each sector and month for average monthly demand conditions.

To illustrate the development of Table 7.5, example computations for month 9 are given following for each sector. Within this table the summation $\sum_{i=1}^{i=7} b_i q_i'$ for each month gives the total net economic benefit derived from consumptive water use, while the double summation $\sum_{n=1}^{n=12} \sum_{i=1}^{i=7} b_i q_i'$ gives the total annual net economic benefit derived for all sectors. Thus, for month 9 water use within the catchment area realizes a total net economic return of $499,280 to the area for average

MONTH		Storage at Beginning of Each Month (glls x 10^9)	Total Montly Consumption and Export (demand) (glls x 10^9)	Total Monthly Consumption and Export (actual) (glls x 10^9)	Average Monthly Natural Inflow (glls x 10^9)	Accumulation (glls x 10^9)	Depletion (glls x 10^9)	Actual Exported Water (glls x 10^9)	COMMENTS
		S_i	q_r	q_r	q_n	q_A	q_D	q_E	
1	Jan	4.21	4.16	4.16	5.35	1.19		3.00	
2	Feb	5.64	4.16	4.16	5.60	1.44		3.00	
3	Mar	8.53	4.18	4.18	7.06	2.88		3.00	
4	Apr	13.94	4.32	4.32	9.73	5.41		3.00	
5	May	17.65	6.75	6.75	10.46	3.71		3.00	
6	Jun	18.00	7.61	7.61	9.49	0.35		4.52	Maximum storage
7	Jul	9.89	12.49	12.49	4.38		8.11	3.00	
8	Aug	1.45	13.43	13.34	2.91		8.43	3.00	Water imported - Restrictions
9	Sep	1.70	11.79	5.15	3.40	0.25		3.00	Water imported - Restrictions
10	Oct	2.56	10.04	6.26	5.12	0.86		3.00	Water imported - Restrictions
11	Nov	4.29	4.35	4.35	6.08	1.73		3.00	
12	Dec	3.02	4.19	4.19	2.92		1.27	3.00	
TOTAL ANNUAL		$\Delta S = 0.00$	87.49	76.36	72.50	17.82	17.81	37.52	

Table 7.4 Storage Behaviour for Average Annual Values.

monthly demand and consumption values. It should be realized however, that the water allocation and net economic return may not be the optimal condition, and maximization of the total monthly economic return will be carried out in conjunction with the intersectoral product distribution through use of the basic annual input-output table.

i) Irrigation Sector.

For Month 9

Area irrigated - 27,000 acres

Gross monthly demand - 9.00×10^9 gallons

Return coefficient - $R_1 = 0.20$

Net monthly consumption - $q_1' = q_1(1 - R_1)$

$$= (9 \times 10^9)\ (0.80) \text{ gallons}$$

$$= 7.20 \times 10^9 \text{ gallons}$$

Net monthly consumption per acre $= \dfrac{7.20 \times 10^9}{27,000}$

$$= 0.267 \times 10^6 \text{ glls/acre}$$

From the $b_1 - q_1$ relationship of Figure 7.1, for $q_1' = 0.267 \times 10^6$ glls/acre, $b_1 = \$28.20$ per 10^6 gallons, and from Figure 7.2, $b_1q_1 = \$7.52$ per acre. Thus for 27,000 acres, the total net return for the month is $27,000 \times \$7.52 = \$203,000$.

ii) Industrial Sector.

For Month 9

Total number of industries - 200

Average diversion per industry - 3×10^6 gallons for month 9

(Assumed constant for each month)

Gross monthly demand - $q_2 = 200 \times 3 \times 10^6 = 600 \times 10^6$ gallons

Return coefficient - $R_2 = 0.05$

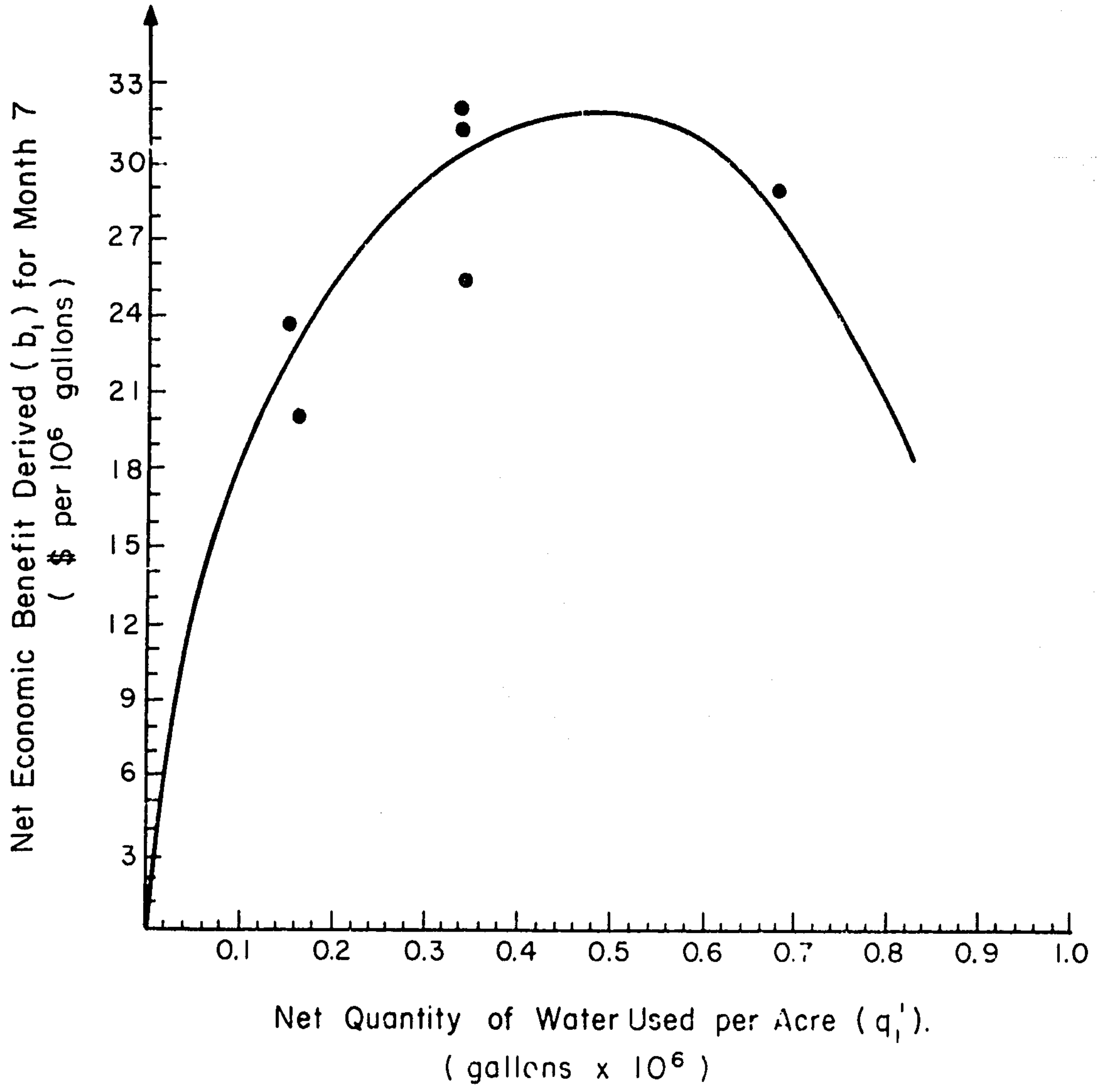

Figure 7.1 Derived $b_1 - q_1'$ Relationship for Irrigation.

(Actual Data Derived, from the References, are Given on all the $b_i - q_i'$ Relationships by the Symbol ●)

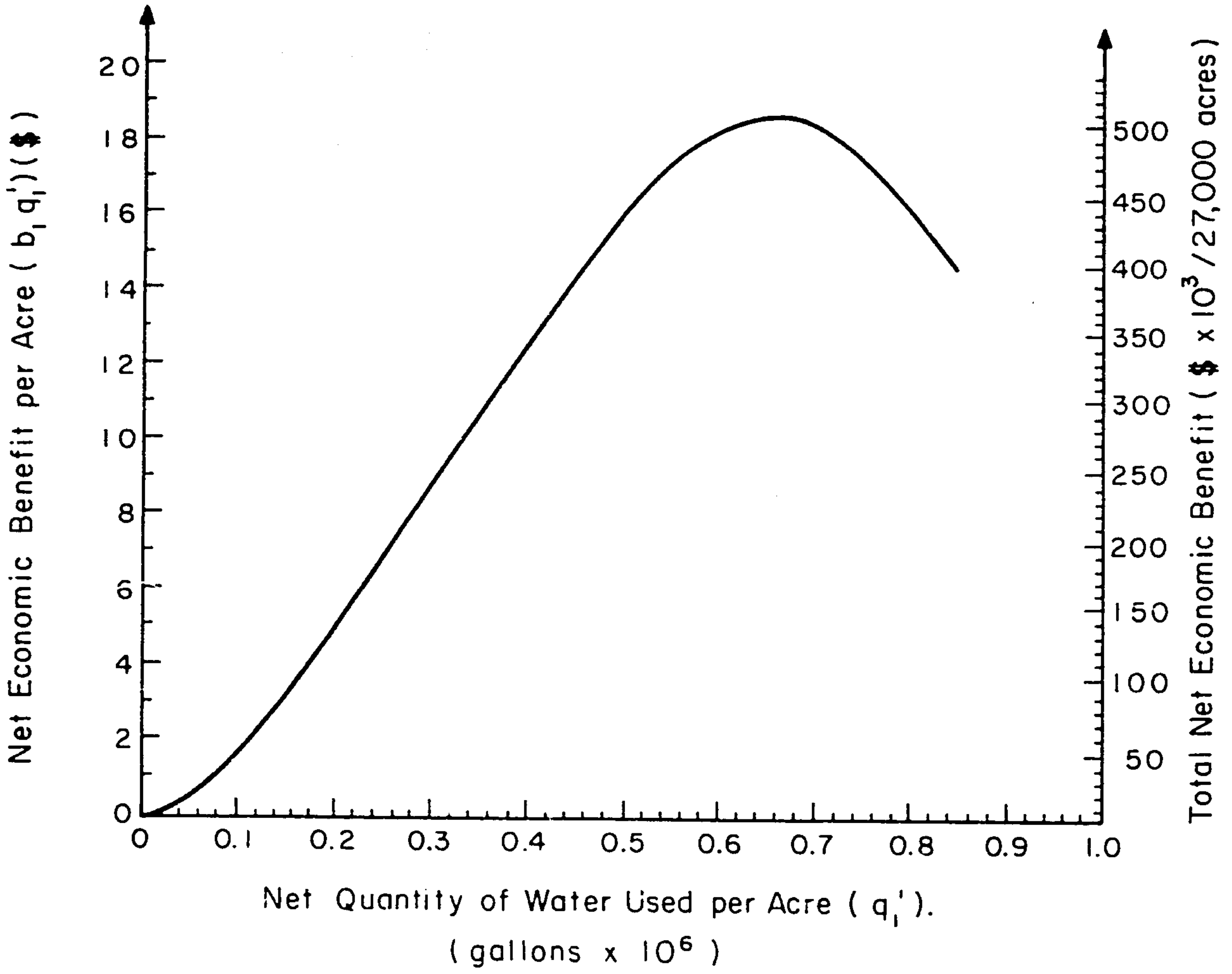

Figure 7.2 Derived $b_1 q_1' - q_1'$ Relationship for Irrigation.

Net monthly consumption - $q_2' = q_2(1 - R_2)$

$= 600\ 10^6(0.95)$

$= 570 \times 10^6$ gallons

Net monthly consumption per industry $= \frac{570}{200} \times 10^6$

$= 2.85 \times 10^6$ gallons

From the $b_2 - q_2'$ relationship of Figure 7.3, for $q_2' = 2.85 \times 10^6$ gallons, b_2 = \$160 per 10^6 gallons, and from Figure 7.4, b_2q_2' = \$456 per industry. Consequently, for 200 industries, the net economic return from the industrial sectors for the month is 200 x \$456 = \$91,200 for a total monthly consumption of 570×10^6 gallons.

iii) Domestic Sector.

For Month 9

Catchment area population served by the domestic water supply system - 100,000 people

Average daily diversion per person - 108 gallons

Gross monthly diversion - $q_3 \approx 3240$ gallons per person

Return coefficient - $R_3 = 0.35$

Net monthly consumption - $q_3' = q_3(1 - R_3)$

$= 3240\ (1 - 0.35)$

$= 2106$ gallons per person

Net monthly consumption for the entire sector

$= 2106 \times 100{,}000$ gallons

$\therefore\ q_3' = 211 \times 10^6$ gallons

Figure 7.5 gives the $b_3 - q_3'$ relationship for domestic water supply, and for a net monthly consumption of 2.11×10^3 gallons per person, the economic return to the distribution authority is given by b_3 = \$0.22 per 10^3 gallons.

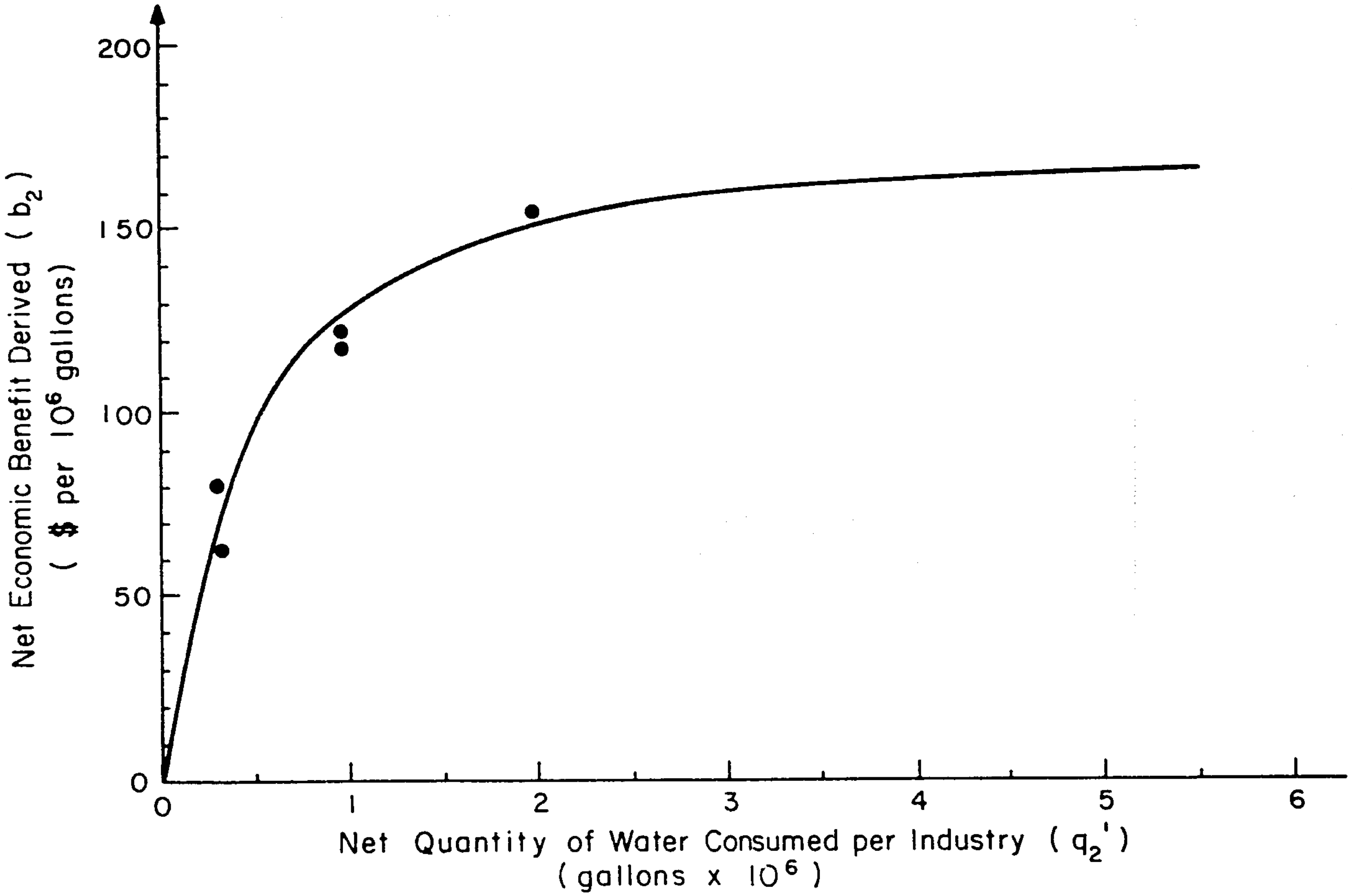

Figure 7.3 Derived $b_2 - q_2'$ Relationship for Industrial Sectors.

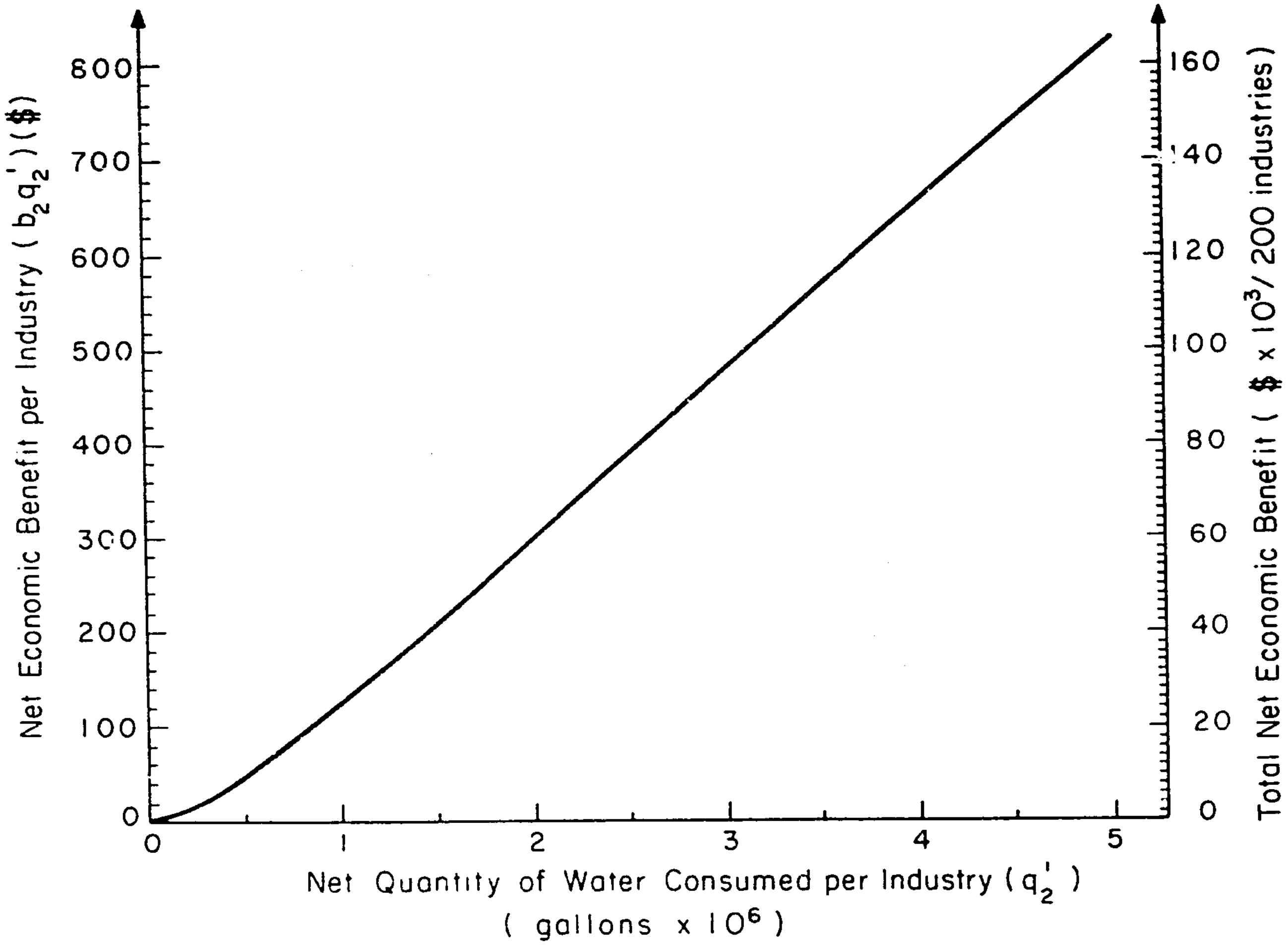

Figure 7.4 Derived $b_2 q_2' - q_2'$ Relationship for Industrial Sectors.

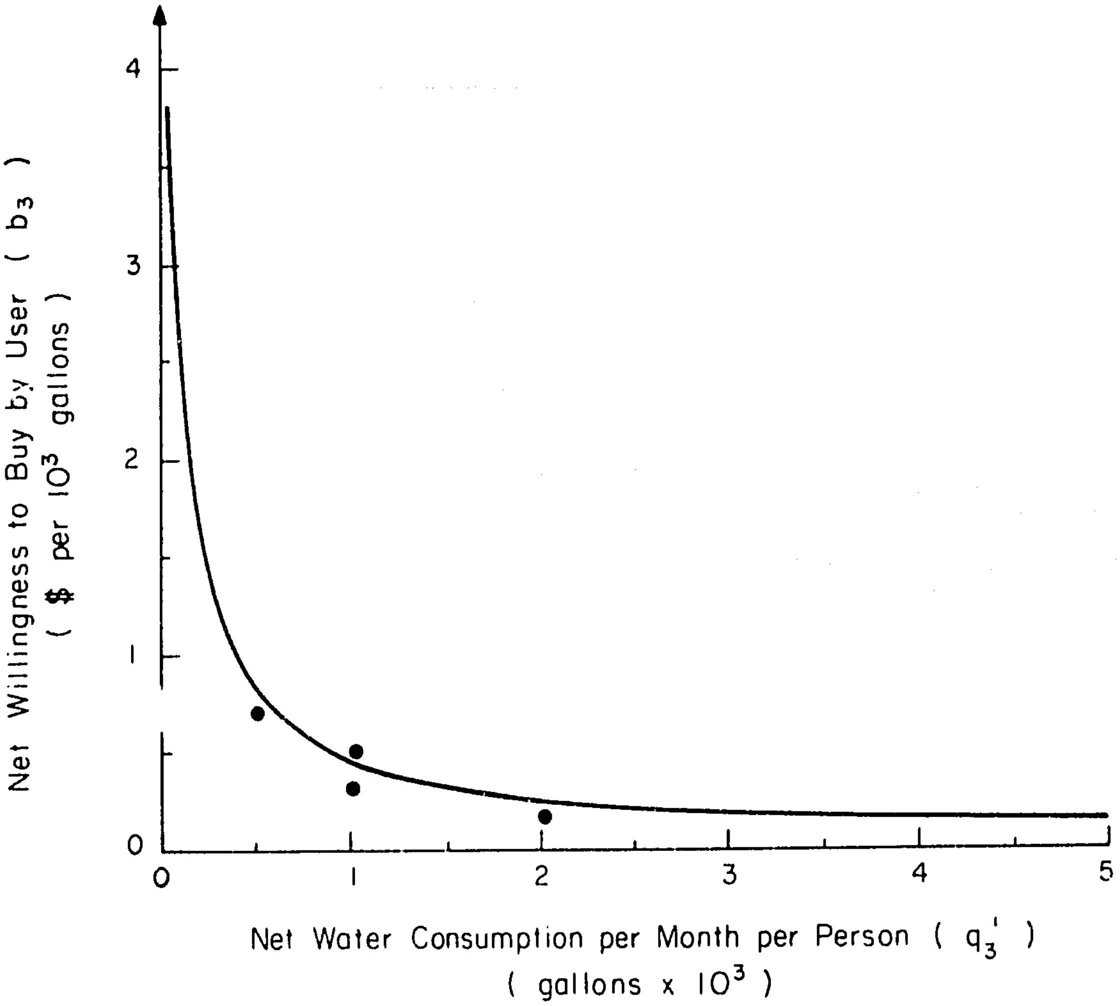

Figure 7.5 Derived $b_3 - q_3'$ Relationship for Domestic Sectors.

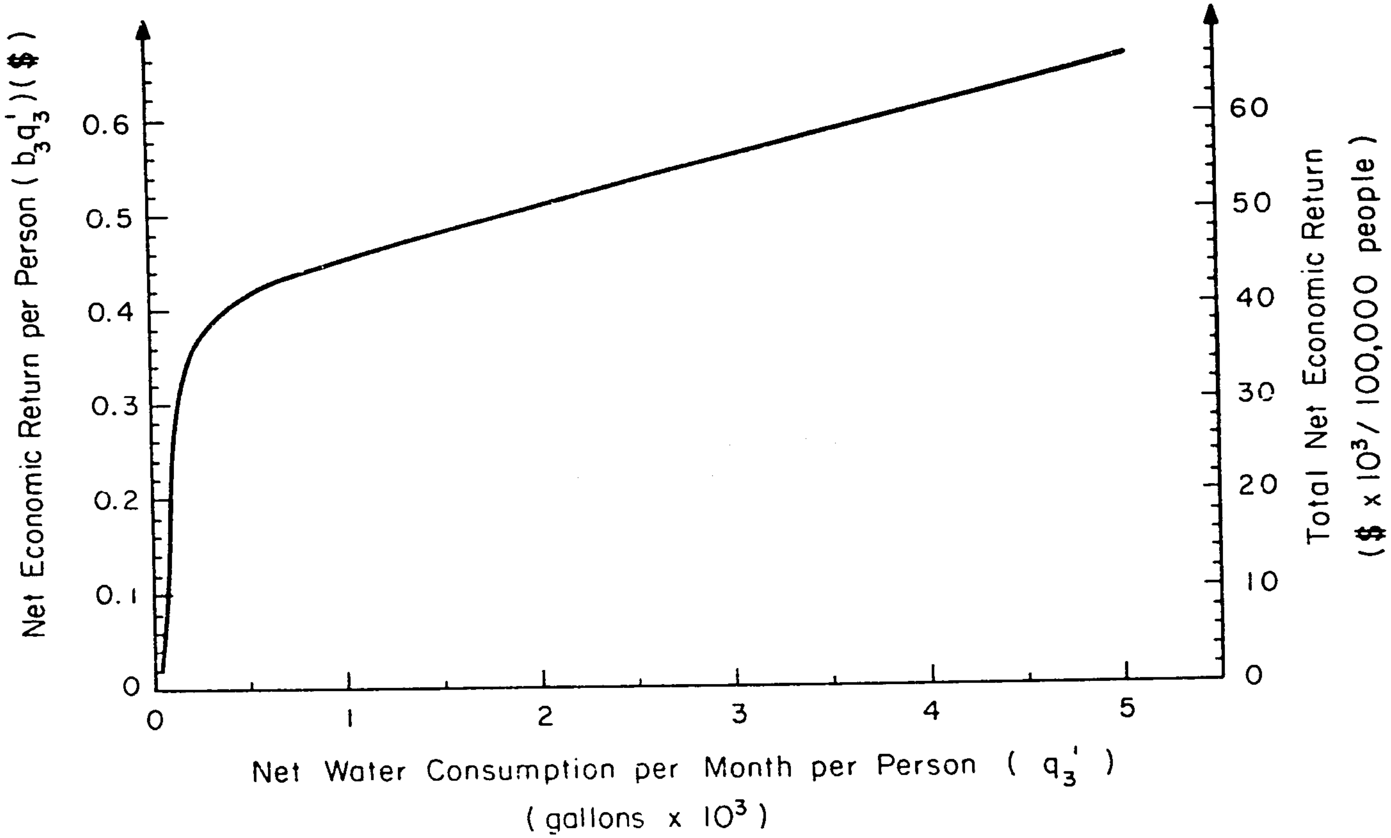

Figure 7.6 Derived $b_3q_3' - q_3'$ Relationship for Domestic Sectors.

The total net willingness to pay by the user, or the return to the allocating authority, is given by $b_3q'_3$ (population) = \$47,600, as shown in the $b_3q'_3 - q'_3$ relationship of Figure 7.6.

iv) Commercial Sector.

For Month 9

Total number of commercial businesses - 1500

Average diversion per business - $q_4 = 0.3 \times 10^6$ gallons

(Assumed constant for each month)

Gross monthly demand $= 1500 \times 0.3 \times 10^6$

$= 450 \times 10^6$ gallons

Return coefficient - $R_4 = 0.20$

Net monthly consumption per business - $q'_4 = q_4(1 - R_4)$

$= 0.3 \times 10^6\ (0.80)$

$= 0.24 \times 10^6$ gallons

From the $b_4 - q'_4$ relationship of Figure 7.7, for $q'_4 = 0.24 \times 10^6$ gallons, b_4 = \$98.00 per 10^6 gallons, and from Figure 7.8, $b_4 - q'_4$ = \$23.52 per business. The net economic return for all businesses during the month is thus \$23.52 x 1500 = \$35,280.00, for a total net monthly consumption of 360×10^6 gallons.

v) Power Generation.

For Month 9

Total number of units - 5

Average diversion per unit - $q_5 = 20 \times 10^6$ gallons

Gross demand for Month 7 $= 5 \times 20 \times 10^6$

$= 100 \times 10^6$ gallons

Return coefficient - $R_5 = 0.90$

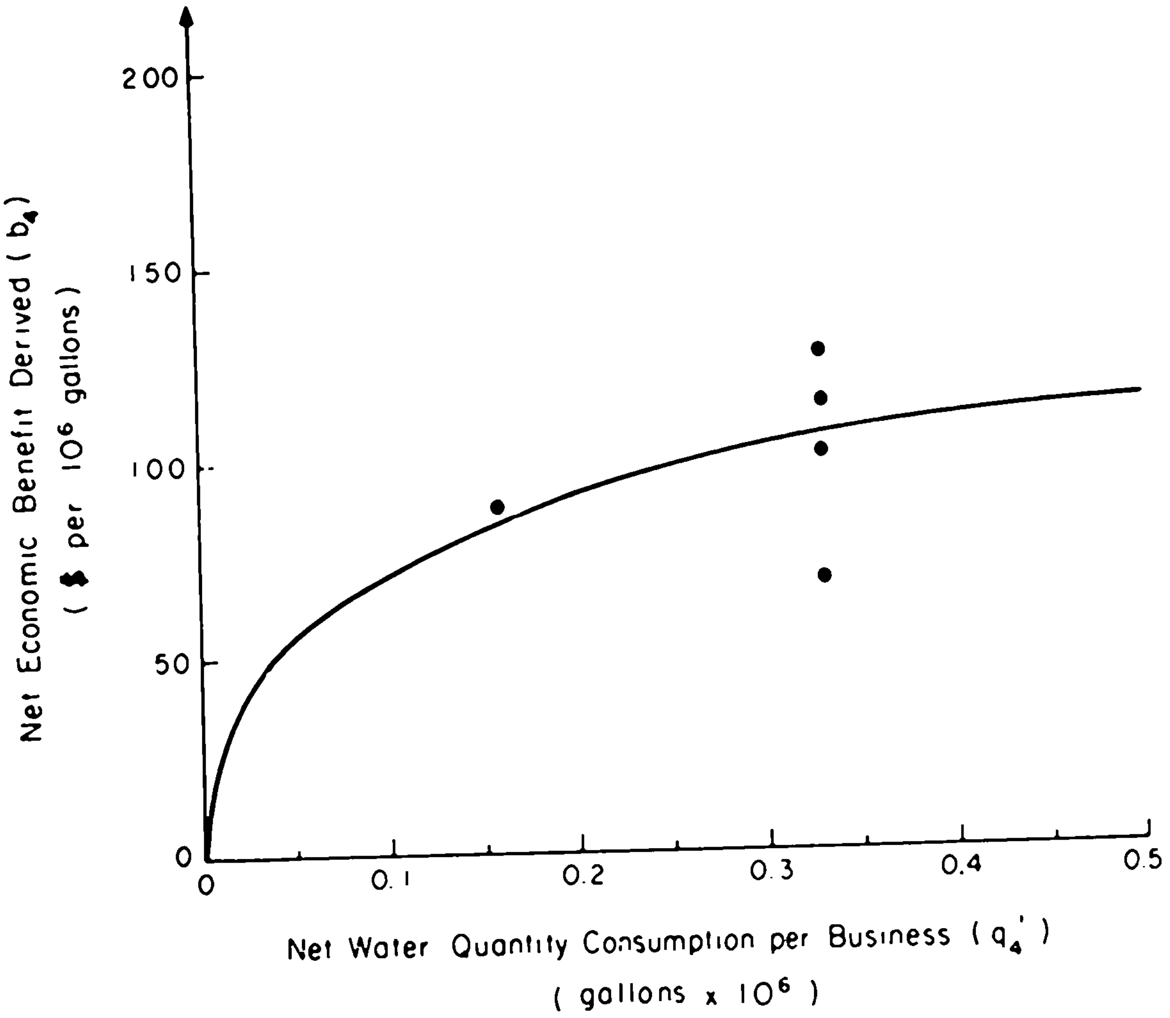

Figure 7.7 Derived $b_4 - q_4'$ Relationship for Commercial Sectors

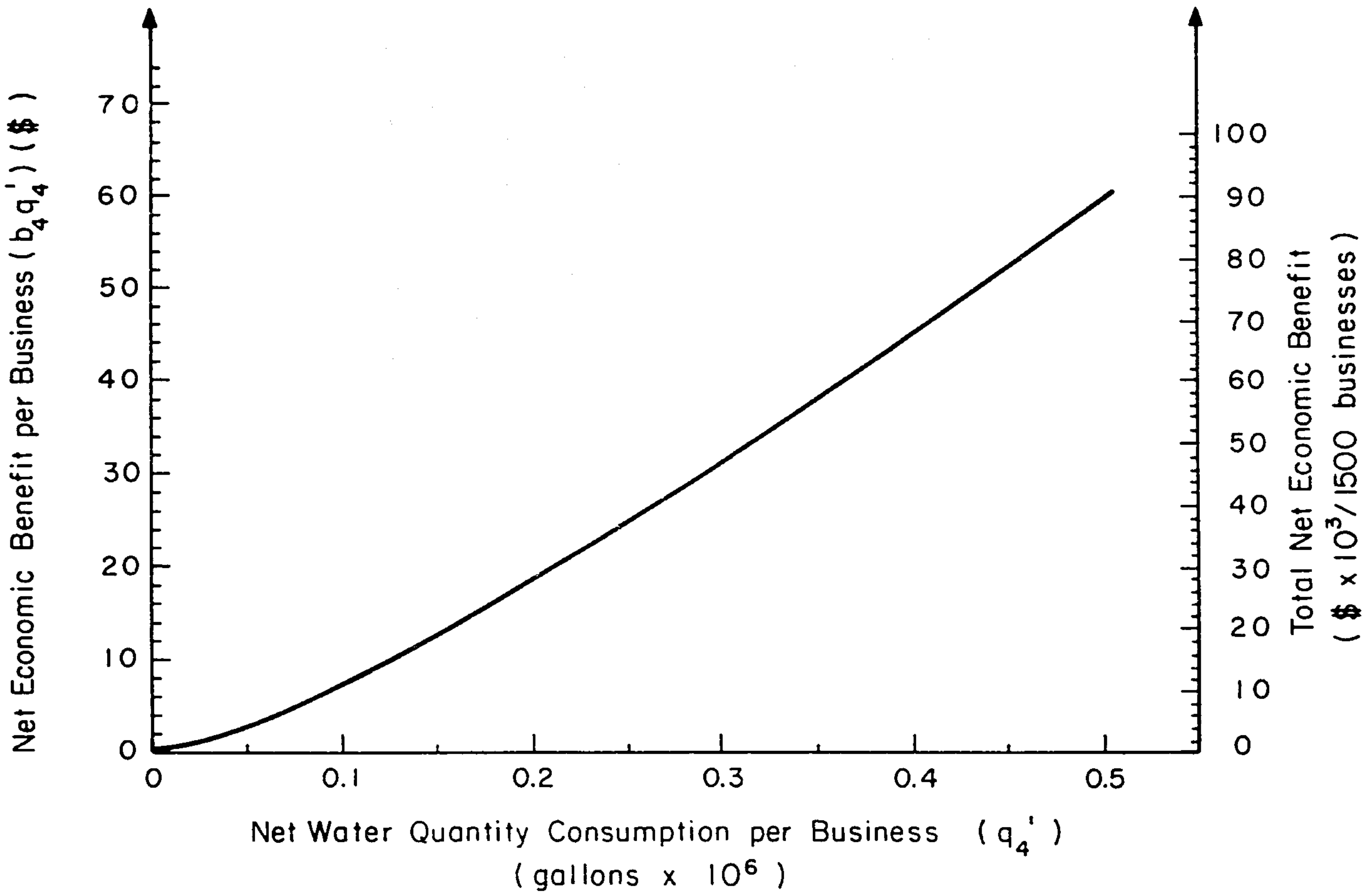

Figure 7.8 Derived $b_4 q_4' - q_4'$ Relationship for Commercial Sectors.

Net monthly consumption per unit - $q'_5 = q_5(1 - R_5)$

$= 20 \times 10^6 \ (0.10)$

$= 2.0 \times 10^6$ gallons

From the $b_5 - q'_5$ curve of Figure 7.9, for $q'_5 = 2 \times 10^6$ gallons, b_5 = \$3750.00 per 10^6 gallons, and from Figure 7.10, $b_5 q'_5$ = \$7,500.00 per power unit. The net economic return for all units during the month is thus \$7,500.00 x 5 = \$37,500.00, for a total monthly consumption of 10×10^6 gallons.

vi) Recreation Sector.

For Month 9

Number of recreational facilities - 50

Average diversion per recreation area - $q_6 = 30 \times 10^6$ gallons

Gross diversion for Month 7 - $50 \times 30 \times 10^6$

$= 1.50 \times 10^9$ gallons

Return coefficient - $R_6 = 0.80$

Net consumption per recreation area - $q'_6 = q_6(1 - R_6)$

$= 30 \times 10^6 \ (1 - 0.80)$

$= 6.0 \times 10^6$ gallons

From the $b_6 - q'_6$ curve of Figure 7.11, for $q'_6 = 6.0 \times 10^6$ gallons, b_6 = \$140.00 per 10^6 gallons, and from Figure 7.12, $b_6 q'_6$ = \$840.00 per recreation area. The net economic return for all areas during the month is thus \$840.00 x 50 = \$42,000.00, for a total monthly consumption of 0.30×10^9 gallons.

vii) Social Sector.

For Month 9

Number of sectors served - 100

Month 9 diversion per sector - 2.00×10^6 gallons

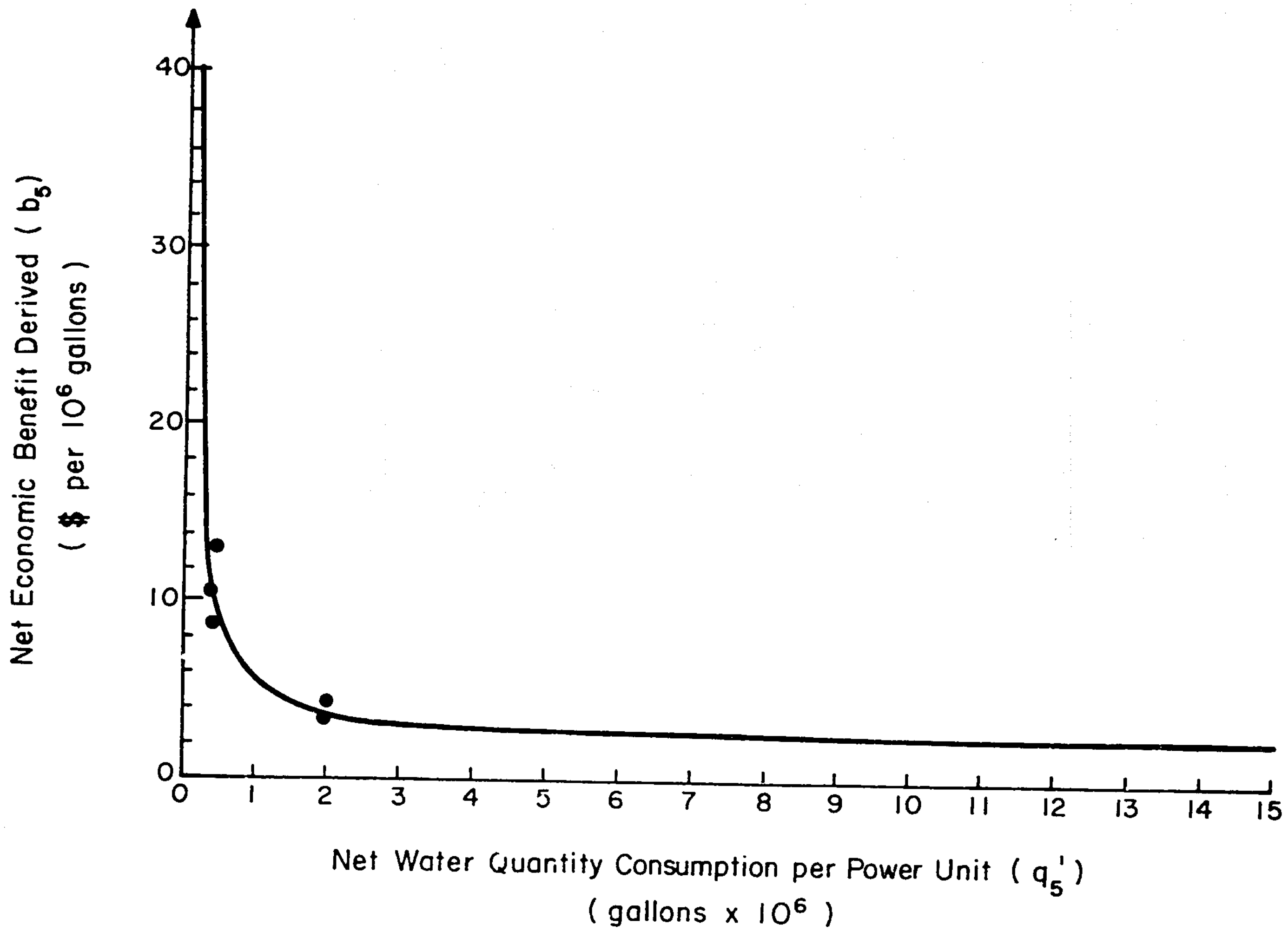

Figure 7.9 Derived $b_5 - q_5'$ Relationship for Power Generation.

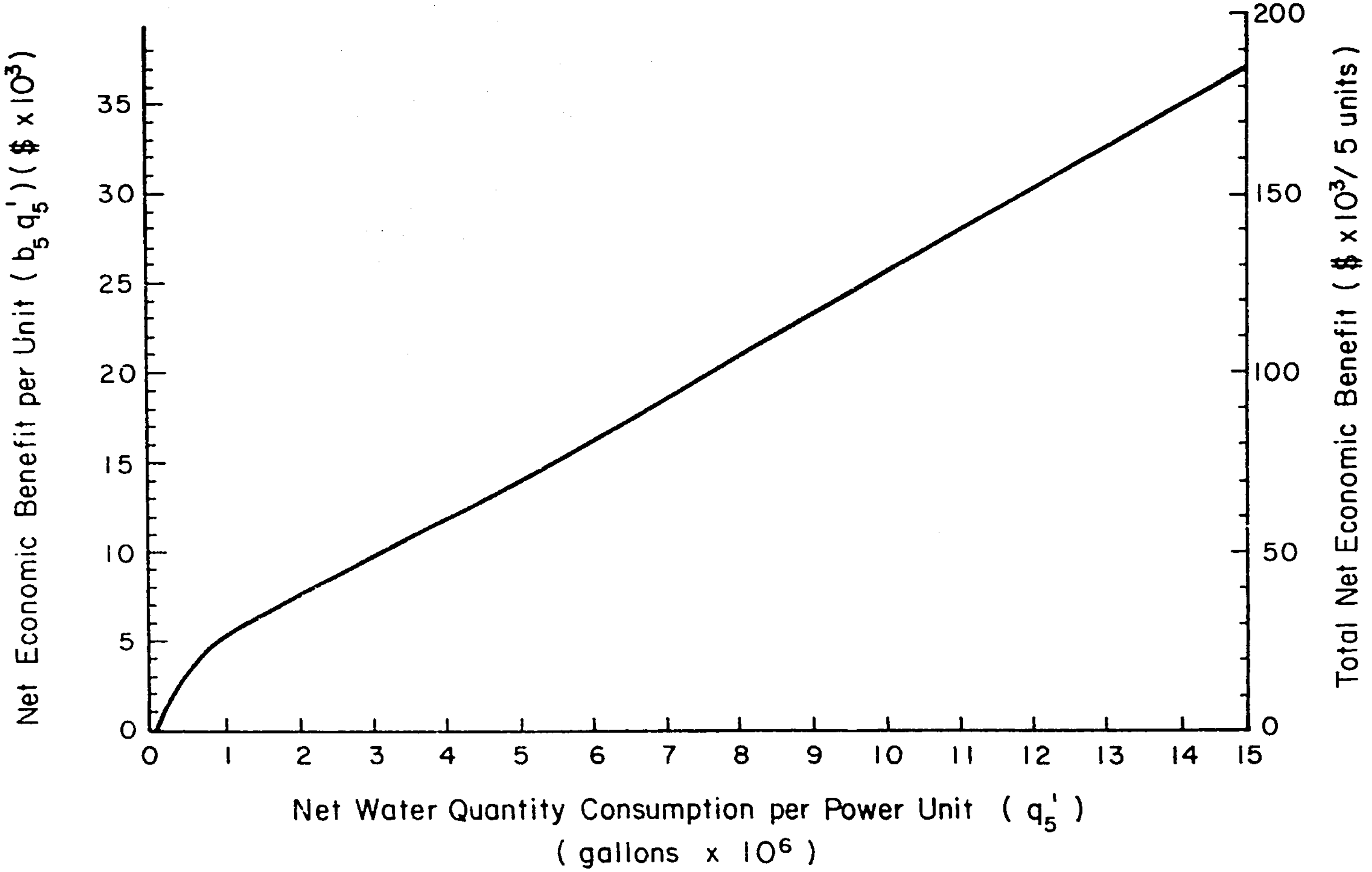

Figure 7.10 Derived $b_5 q_5' - q_5'$ Relationship for Power Generation.

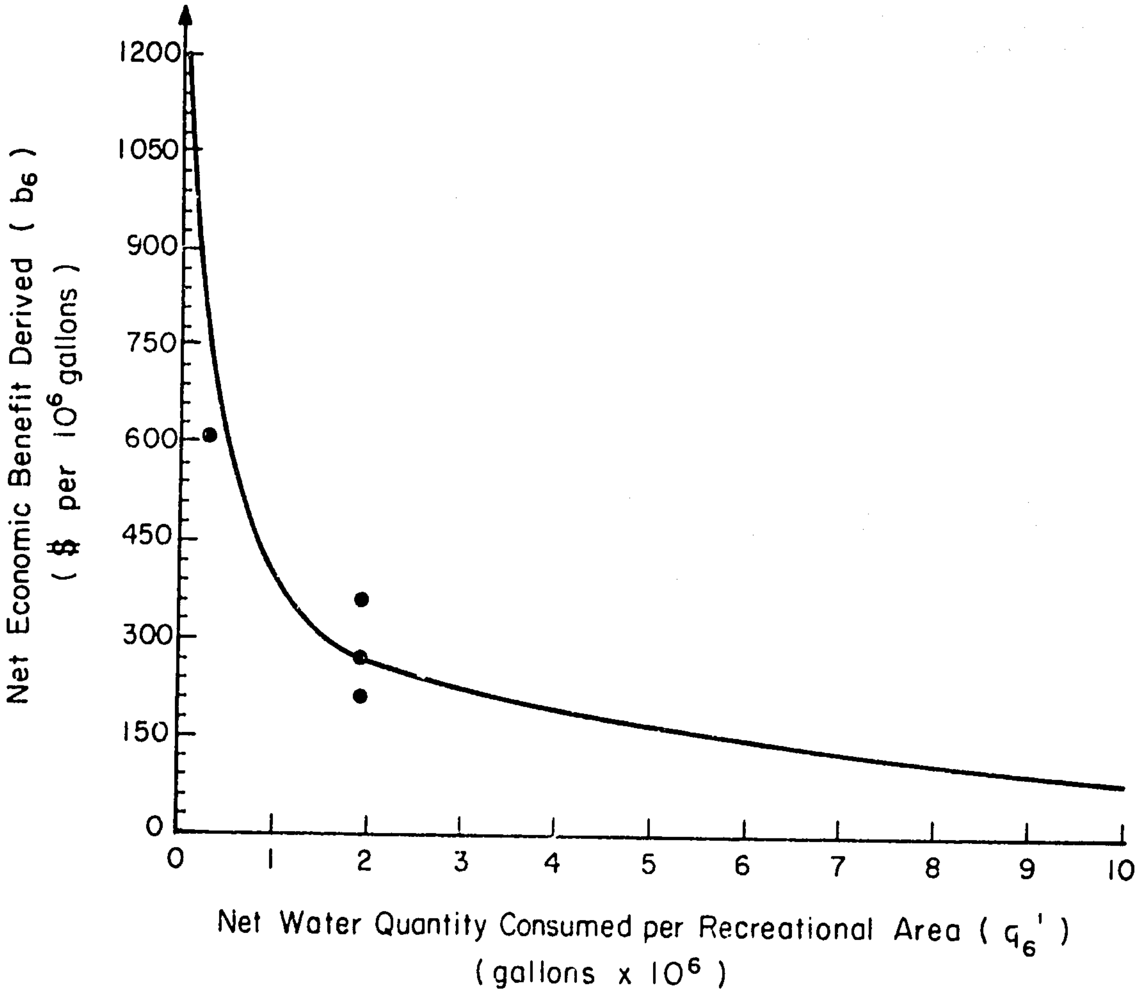

Figure 7.11 Derived $b_6 - q_6'$ Relationship for Recreation Sectors.

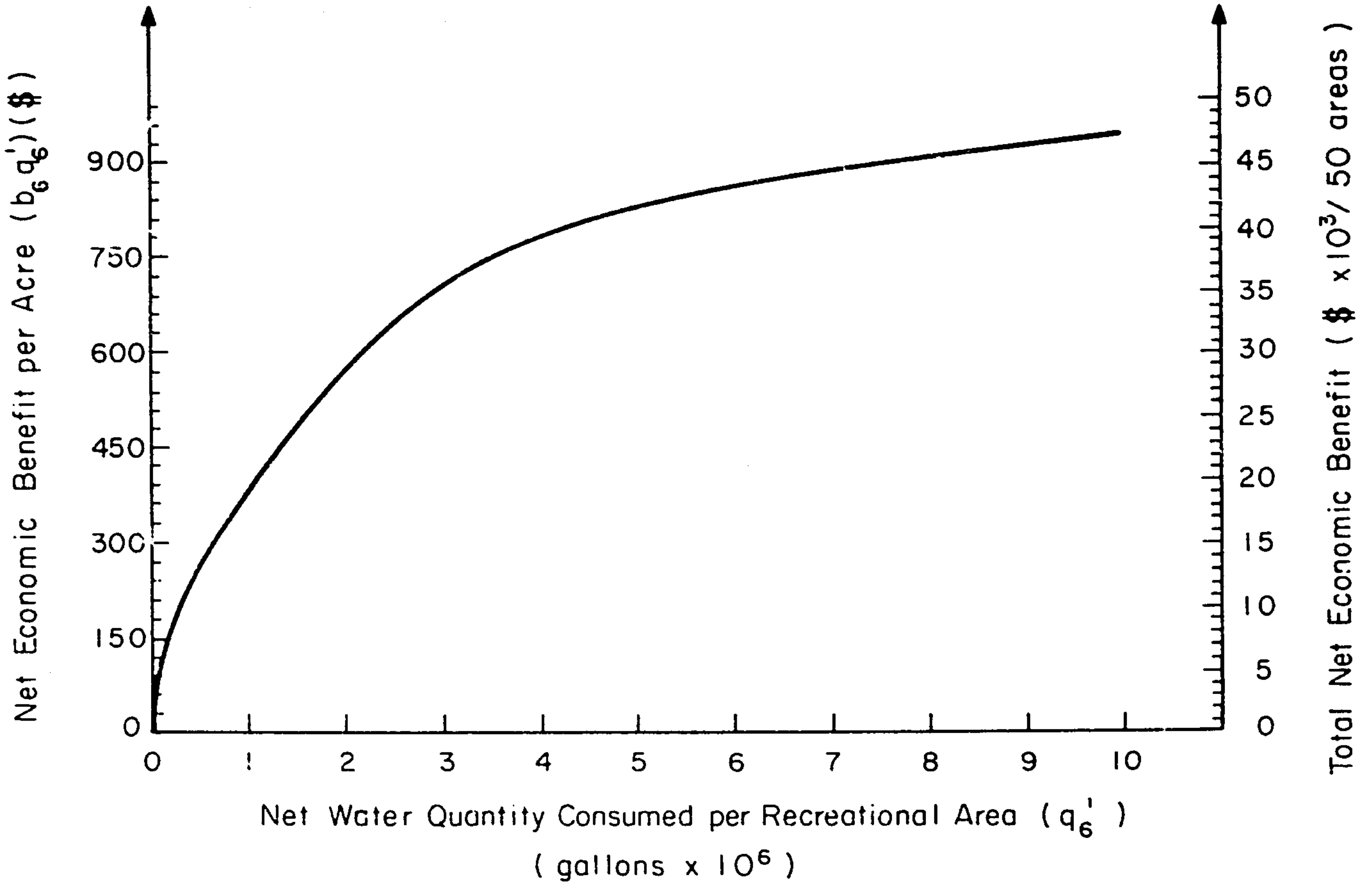

Figure 7.12 Derived $b_6 q_6' - q_6'$ Relationship for Recreation Sectors.

Gross diversion for Month 9 - 200.00 x 10^6 gallons

Return coefficient - $R_7 = 0.30$

Net consumption per social sector - $q_7' = q_7(1 - R_7)$

$$= 2.00 \times 10^6\ (0.70)$$

$$= 1.40 \times 10^6 \text{ gallons}$$

From the $b_7 - q_7'$ relationship of Figure 7.13, for $q_7' = 1.40 \times 10^6$ gallons, b_7 = \$305.00 per 10^6 gallons, and from Figure 7.14, b_7q_7' = \$427.00 per social sector. The net economic return from all social sectors for the month is thus \$427.00 x 100 = \$42,700.00 for a total monthly consumption of 140 x 10^6 gallons.

7.24 Basic Annual Input-Output Table:

As discussed in Chapter 6.00, under Data Acquisition, it is necessary to tabulate the total net economic returns for each sector in terms of the produce purchased from, or sold to other sectors within the basin. The interchange of goods and services between the sectors is classified through the basic input-output table, though these values reflect the total output derived from all resources, and are not specifically orientated to water. The basic input-output table adopted is given in Table 7.6 following, with note also being made that the final demand and payments sectors refer solely to the economic value of goods and services, and not the net total economic return or cost of exported, accumulated, imported or depleted water.

7.25 Initial Water Transactions Tables:

Following the discrete steps of section 7.17, derivation of the M_1 and M_2 multipliers for Month 9 is given in the following

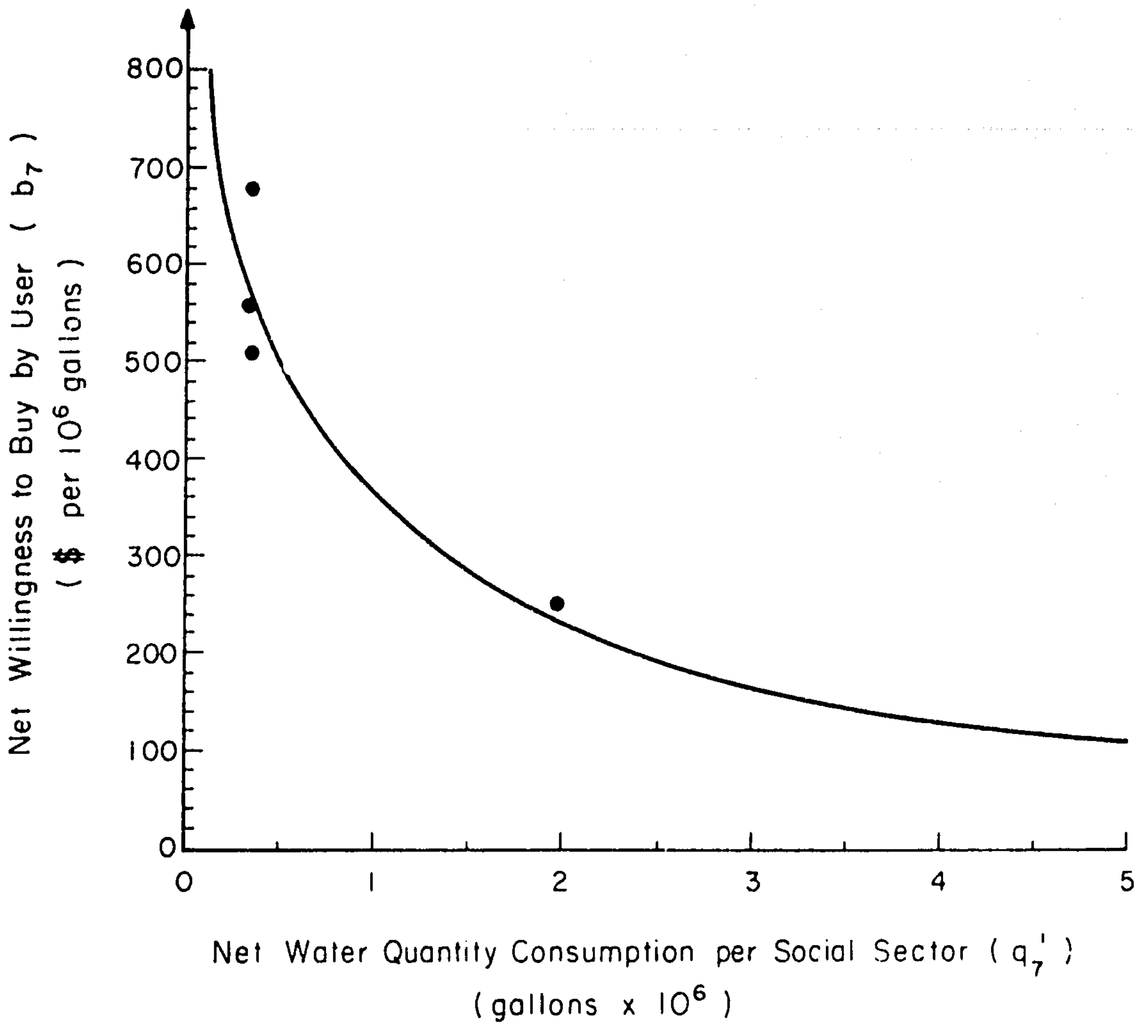

Figure 7. 13 Derived $b_7 - q_7'$ Relationship for Social Sectors.

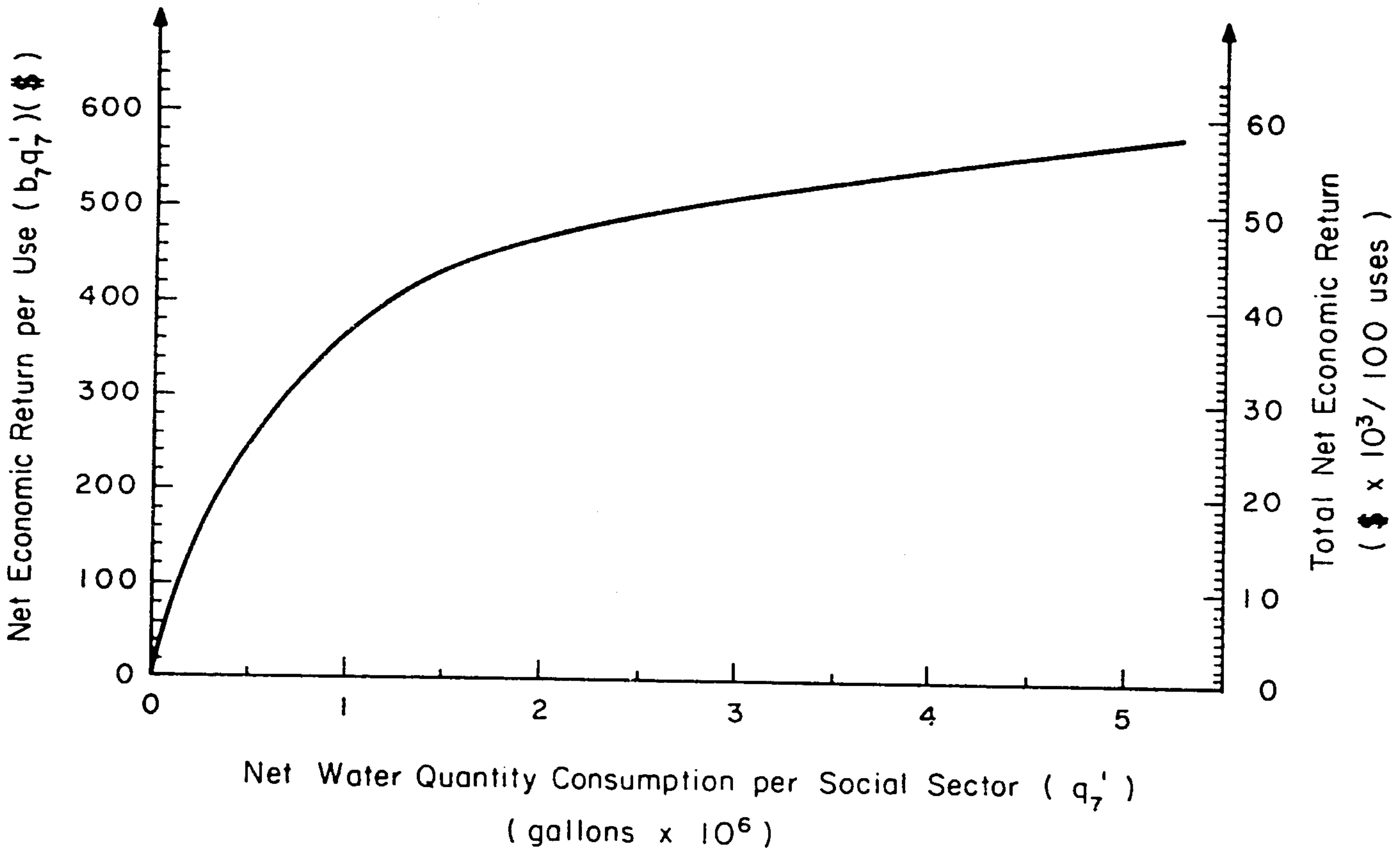

Figure 7.14 Derived $b_7q_7' - q_7'$ Relationship for Social Sectors.

MONTH		SECTOR														$\Sigma b_i q_i'$
		IRRIG'N		INDUST'L		DOM'		COMM'		POWER		REC'N		SOCIAL		
		b_1	$b_1 q_1'$	b_2	$b_2 q_2'$	b_3	$b_3 q_3'$	b_4	$b_4 q_4'$	b_5	$b_5 q_5'$	b_6	$b_6 q_6'$	b_7	$b_7 q_7'$	
1	Jan	0.00	0.00	160.00	91.20	510.00	43.10	98.00	35.28	2800.00	72.80	1050.00	4.20	335.00	39.87	286.45
2	Feb	0.00	0.00	160.00	91.20	510.00	43.10	98.00	35.28	2800.00	72.80	1050.00	4.20	335.00	39.87	286.45
3	Mar	0.00	0.00	160.00	91.20	490.00	44.60	98.00	35.28	2800.00	72.80	840.00	8.40	335.00	39.87	292.15
4	Apr	0.00	0.00	160.00	91.20	420.00	44.70	98.00	35.28	2850.00	71.25	230.00	32.20	335.00	39.87	314.50
5	May	17.50	42.00	160.00	91.20	380.00	46.93	98.00	35.28	3000.00	60.00	215.00	34.40	335.00	39.87	349.68
6	Jun	20.00	64.00	160.00	91.20	310.00	48.36	98.00	35.28	3000.00	60.00	205.00	36.90	325.00	40.95	376.69
7	Jul	29.25	236.25	160.00	91.20	220.00	47.60	98.00	35.28	3250.00	48.75	196.00	39.25	307.00	41.00	539.33
8	Aug	29.80	262.24	160.00	91.20	210.00	51.87	98.00	35.28	3750.00	37.50	140.00	42.00	305.00	42.70	562.79
9	Sep	28.20	203.00	160.00	91.20	220.00	47.60	98.00	35.28	3750.00	37.50	140.00	42.00	305.00	42.70	499.28
10	Oct	25.60	143.36	160.00	91.20	290.00	49.01	98.00	35.28	3250.00	48.75	196.00	39.25	325.00	40.95	447.80
11	Nov	0.00	0.00	160.00	91.20	390.00	45.63	98.00	35.28	2800.00	64.40	215.00	34.40	335.00	39.87	310.78
12	Dec	0.00	0.00	160.00	91.20	420.00	44.70	98.00	35.28	2850.00	71.25	790.00	9.48	335.00	39.87	291.78
$\Sigma b_i q_i'$			950.85		1094.40		557.20		423.36		717.80		326.68		487.39	4557.68

Note. All b_i values in \$ per 10^6 gallons , All $b_i q_i'$ values in $\$ \times 10^3$

Table 7.5 Unit Benefits and Total Economic Returns for Average Monthly Conditions.

OUTPUTS INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			X_{ij}	X_{i1}	X_{i2}	X_{i3}	X_{i4}	X_{i5}	X_{i6}	X_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	X_{1j}	18.00	11.00	30.00	10.00	10.00	9.00	14.00	9.00	9.00	120.00
		INDUST'L	X_{2j}	19.00	20.00	14.00	17.00	20.00	7.00	14.00	17.00	17.00	145.00
		DOM'	X_{3j}	10.00	14.00	10.00	5.00	11.00	12.00	10.00	9.00	9.00	90.00
		COMM'	X_{4j}	20.00	25.00	10.00	4.00	6.00	6.00	5.00	12.00	12.00	100.00
		POWER	X_{5j}	23.00	30.00	8.00	12.00	6.00	4.00	3.00	17.00	17.00	120.00
		REC'N	X_{6j}	8.00	14.00	5.00	4.00	14.00	6.00	9.00	10.00	10.00	80.00
		SOCIAL	X_{7j}	10.00	15.00	7.00	8.00	9.00	8.00	10.00	14.00	14.00	95.00
	PAYMENTS	IMPORTS	I_j	6.00	8.00	3.00	23.00	19.00	14.00	15.00	0.00	0.00	88.00
		DEPLET'N	L_j	6.00	8.00	3.00	23.00	19.00	14.00	15.00	0.00	0.00	88.00
TOTAL OUTLAY			G_j	120.00	145.00	90.00	100.00	120.00	80.00	95.00	88.00	88.00	926.00

Table 7.6 Basic Annual Input-Output Table ($\$ \times 10^4$).

steps, together with complete derivation of the initial transactions table of net production arising due solely to water use.

i) Summation of the consuming sector rows of the annual input-output table, 7.6, yields the following column vector,

$$|T_i'|_C = \begin{vmatrix} 102.00 \\ 111.00 \\ 72.00 \\ 76.00 \\ 86.00 \\ 60.00 \\ 67.00 \end{vmatrix}$$

with all values expressed in \$ x 10^4. Note should be made that this vector remains constant for all months.

ii) After subtracting the initial unit values allocated to the export and accumulation columns the net economic returns for the month to each sector, $b_i q_i'$ from Table 7.5, may be written as

$$|B_i|_C = \begin{vmatrix} 20.100 \\ 8.920 \\ 4.560 \\ 3.328 \\ 3.550 \\ 4.000 \\ 4.070 \end{vmatrix}$$

with all values expressed in \$ x 10^4.

iii) From the above two column vectors, the allocation multiplier is computed from

$$M_1 = \frac{|B_i|_C}{|T_i'|_C} \qquad (7.4)$$

to give

$$M_1 = \left| \begin{matrix} 0.19706 \\ 0.08036 \\ 0.06333 \\ 0.04379 \\ 0.04128 \\ 0.06667 \\ 0.06075 \end{matrix} \right|$$

for Month 9. Multipliers for all months are given in Table 7.7 following.

iv) Multiplying each row of the annual input-output table (excluding the final demand sector) by the respective M_1 value yields the consuming sector of Table 7.8 following.

v) Final demand columns are assigned an initial value of 1.00 and entered in Table 7.8.

vi) Row summation of the table gives the total gross output column, and may be expressed as:

$$|(T_i)_w|_C = \left| \begin{matrix} 203.00 \\ 91.20 \\ 47.60 \\ 35.28 \\ 37.50 \\ 42.00 \\ 42.70 \end{matrix} \right|$$

with all values expressed in \$ x 10^3. This vector should be equivalent to the expression

$$|(T_i)_w|_C = 10.00|B_i|_C . \tag{7.9}$$

vii) Transposition of the $|T_i|_C$ vector yields

$$|(T_i)_w|_C^T = |(G_j)_w|_R$$

$$= |203.00 \quad 91.20 \quad 47.60 \quad 35.28 \quad 37.50 \quad 42.00 \quad 42.70|$$

which gives the total gross outlay row of Table 7.8.

SECTOR	MONTH					
	Jan	Feb	Mar	Apr	May	Jun
IRRIG'N	0.00000	0.00000	0.00000	0.00000	0.03922	0.06078
INDUST'L	0.09696	0.09696	0.09696	0.09696	0.08036	0.08036
DOM'	0.06629	0.06629	0.06871	0.06887	0.06240	0.06439
COMM'	0.05943	0.05943	0.05943	0.05943	0.04379	0.04379
POWER	0.11238	0.11238	0.11238	0.10992	0.06744	0.06744
REC'N	0.00423	0.00423	0.01231	0.05808	0.05400	0.05817
SOCIAL	0.06644	0.06644	0.06644	0.06644	0.05652	0.05813

SECTOR	MONTH					
	Jul	Aug	Sep	Oct	Nov	Dec
IRRIG'N	0.22966	0.25514	0.19706	0.13859	0.00000	0.00000
INDUST'L	0.08036	0.08036	0.08036	0.08036	0.09696	0.09696
DOM'	0.06333	0.06926	0.06333	0.06529	0.07037	0.06887
COMM'	0.04379	0.04379	0.04379	0.04379	0.05943	0.05943
POWER	0.05436	0.04128	0.04128	0.05436	0.09905	0.10992
REC'N	0.06208	0.06667	0.06667	0.06208	0.06231	0.01438
SOCIAL	0.05821	0.06075	0.06075	0.05813	0.06644	0.06644

Table 7.7 M_I Multipliers for Average Annual Conditions.

OUTPUTS INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	35.45	21.68	59.12	19.71	19.71	17.74	27.59	1.00	1.00	203.00
		INDUST'L	x_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	x_{3j}	6.33	8.87	6.33	3.17	6.97	7.60	6.33	1.00	1.00	47.60
		COMM'	x_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
		POWER	x_{5j}	9.50	12.38	3.30	4.95	2.48	1.65	1.24	1.00	1.00	37.50
		REC'N	x_{6j}	5.33	9.33	3.33	2.67	9.34	4.00	6.00	1.00	1.00	42.00
		SOCIAL	x_{7j}	6.08	9.11	4.25	4.86	5.47	4.86	6.07	1.00	1.00	42.70
	PAYMENTS	IMPORTS	I_j	58.14	1.41	-22.18	-7.75	-12.58	-1.05	-8.99	0.00	0.00	7.00
		DEPLET'N	L_j	58.14	1.40	-22.18	-7.74	-12.59	-1.05	-8.98	0.00	0.00	7.00
TOTAL OUTLAY			G_j	203.00	91.20	47.60	35.28	37.50	42.00	42.70	7.00	7.00	513.28

Table 7.8 Initial Distribution of Produce Between Sectors for Average September Water Consumption.

viii) The payments sector of the table is computed from the expression

$$|(I_j + L_j)_w|_R = |(G_j)_w|_R - \Sigma|(x_{ij})_w|_C \qquad (7.6)$$

which yields, for the irrigation sector,

$$|(I_j + L_j)_w|_R = 203.00 - 86.72$$

$$= 116.28.$$

Adopting $|(I_j)_w|_A = |(L_j)_w|_R$ yields the imports and depletion row vectors of

$$|(I_j)_w|_R = |58.14 \quad 1.41 \quad -22.18 \quad -7.75 \quad -12.58 \quad -1.05 \quad -8.99|.$$

Negative values in these vectors indicate negative payments made by the purchasing sectors, which in reality, are reflected as positive values within the final demand sector in the maximized transactions table.

The resulting Table 7.8 reflects the initial input-output table of net produce transactions between sectors arising solely from the water resource for the month of September. A similar table is constructed for each month and these are given in Appendix C.

7.26 Final Demand Modification:

Optimal allocation of available water for a particular month is achieved through static iteration of the initial input-output table with iteration changes being manually induced in the final demand sector. Incremental changes in the final demand sector rely upon the use of a second allocation multiplier M_2, which are direct functions of unit net economic benefits within each sector. Using the month of September again, monthly tabulations for M_2 multipliers are established as follows:

i) From Table 7.5 the unit net economic benefits for all sectors (for full demand satisfaction) are summed to give

$$\sum_{i=1}^{i=7} b_i = 4701.20 \text{ \$ per } 10^6 \text{ gallons}$$

ii) M_2 multipliers for each sector are then computed from the expression

$$M_2 = \frac{b_i}{\sum_{i=1}^{i=7} b_i} \qquad (7.7)$$

which, for September, yields

$$M_2 = \begin{vmatrix} 0.00600 \\ 0.03403 \\ 0.04680 \\ 0.02085 \\ 0.79767 \\ 0.02978 \\ 0.06488 \end{vmatrix}$$

The summation of these multipliers for any particular month should be equal to unity, and a complete listing of all multipliers for average annual consumption conditions are given in Table 7.9 following.

iii) Incremental changes within the final demand sector for each producing sector, are then made through the expression

$$(\Delta Y_i)_w = 2[aM_2 + 1.00]. \qquad (7.8)$$

For September, a month under restriction conditions, the initial iteration commences with the variable "a" equal to

SECTOR	MONTH					
	Jan	Feb	Mar	Apr	May	Jun
IRRIG'N	0.00000	0.00000	0.00000	0.00000	0.00416	0.00486
INDUST'L	0.03230	0.03230	0.03388	0.03909	0.03805	0.03885
DOM'	0.10297	0.10297	0.10375	0.10261	0.09036	0.07528
COMM'	0.01979	0.01979	0.02075	0.02394	0.02330	0.02380
POWER	0.56531	0.56531	0.59284	0.69631	0.71335	0.72851
REC'N	0.21199	0.21199	0.17785	0.05619	0.05112	0.04978
SOCIAL	0.06764	0.06764	0.07093	0.08185	0.07966	0.07892

SECTOR	MONTH					
	Jul	Aug	Sep	Oct	Nov	Dec
IRRIG'N	0.00687	0.00635	0.00600	0.00589	0.00000	0.00000
INDUST'L	0.03756	0.03409	0.03403	0.03683	0.04002	0.03439
DOM'	0.05164	0.04475	0.04680	0.06675	0.09755	0.09026
COMM'	0.02300	0.02088	0.02085	0.02256	0.02451	0.02106
POWER	0.76286	0.79910	0.79767	0.74806	0.79035	0.61251
REC'N	0.04601	0.02983	0.02978	0.04511	0.05378	0.16978
SOCIAL	0.07206	0.06499	0.06488	0.07481	0.08379	0.07200

Table 7.9 M_2 Multipliers for Average Annual Conditions.

10.00 to give

$$(\Delta Y_i)_w = 2[10.00(M_2) + 1.00] \qquad (7.10)$$

Thus, the initial incremental changes in both the exports and accumulation columns may be given by the column vector

$$|(\Delta P_i)_w|_C = |(\Delta D_i)_w|_C = \begin{vmatrix} 1.06 \\ 1.34 \\ 1.47 \\ 1.21 \\ 8.97 \\ 1.30 \\ 1.65 \\ 0.00 \end{vmatrix}$$

where

$$|(\Delta P_i)_w|_C + |(\Delta D_i)_w|_C = |(\Delta Y_i)_w|_C . \qquad (7.11)$$

These new final demand values are then read into the input-output program to give a new input-output table of $b_i q_i'$ values for all sectors.

iv) The total output values give a column vector of the total net economic output from each sector. For the initial iteration, these values are given below for September.

$$|b_i q_i'|_C = \begin{vmatrix} 36.91 \\ 20.05 \\ 11.95 \\ 7.64 \\ 23.59 \\ 10.83 \\ 11.21 \end{vmatrix}$$

v) Actual consumptions necessary to give the above $b_i q_i'$ values are then determined from the $b_i q_i' - q_i'$ relationships, which results in the following column vector:

$$|q'_i|_C = \begin{vmatrix} 2.160 \\ 0.168 \\ 0.008 \\ 0.123 \\ 0.004 \\ 0.018 \\ 0.016 \end{vmatrix}$$

vi) Summation of the above vector yields the total water consumed during the month. This is given by

$$\sum_{i=1}^{i=7} q'_i = 2.497 \times 10^9 \text{ gallons.}$$

As the above value is greater than the actual water quantity available for consumption (2.150×10^9 gallons) (determined from the water allocation model), a reduction in the final demand values is required. The second iteration adopts an "a" value of 5.00, and the process repeated.

vii) Iteration is continued until $\sum_{i=1}^{i=7} q'_i = Q'_i$. Actual iteration steps are given in Table 7.10 following for the month, with the final input-output listing given in Table 7.11.

7.30 Operational Results:

7.31 Average Demand Conditions:

Table 7.12 following summarizes the average monthly consumptive demand and optimal consumptive allocations for each month during the hypothetical year considered. From this tabulation it can be seen that increases in the next economic return to the area occur during the months of January, February, May, June, July and August, with reductions occurring during the other months. These changes are relative to the net economic returns for average monthly consumptive demands, which

SECTOR	Monthly Demand Values		ITERATION N°										Actual Water Available
			1		2		3		4		5		
			$\frac{(\Delta Y_1)_w}{2} = 10.00 M_2 + 1.00$		$\frac{(\Delta Y_1)_w}{2} = 5.00 M_2 + 1.00$		$\frac{(\Delta Y_1)_w}{2} = 4.00 M_2 + 1.00$		$\frac{(\Delta Y_1)_w}{2} = 4.58 M_2 + 1.00$				
	$b_i q_i'$	q_i'	$b_i q_i'$	q_i'	$b_i q_i'$	q_i'	$b_i q_i'$	q_i'	$b_i q_i'$	q_i'	$b_i q_i'$	q_i'	Q_i'
IRRIG'N	203.00	7.200	36.91	2.160	28.52	1.890	26.82	1.860	27.83	1.875			
INDUST'L	91.20	0.570	20.05	0.168	15.31	0.134	14.37	0.130	14.93	0.133			
DOM'	47.60	0.210	11.95	0.008	9.25	0.008	8.72	0.007	9.01	0.008			
COMM'	35.28	0.360	7.64	0.123	6.16	0.116	5.87	0.104	6.06	0.112			
POWER	37.50	0.010	23.59	0.004	14.28	0.001	12.41	0.001	13.49	0.001			
REC'N	42.00	0.300	10.83	0.018	8.40	0.010	7.90	0.009	8.20	0.009			
SOCIAL	42.70	0.140	11.21	0.016	8.63	0.011	8.10	0.010	8.41	0.011			
TOTALS	499.28	8.790	122.18	2.497	90.55	2.170	84.19	2.121	87.93	2.149			2.150

Note: All $b_i q_i'$ values in \$ x 10^3. All q_i' values in gallons x 10^3.

Table 7.10 Iteration for September.

INPUTS \ OUTPUTS			PURCHASING SECTORS									TOTAL OUTPUT
			CONSUMING SECTOR							FINAL DEMAND		
			IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
		x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N x_{1j}	1.53	2.51	5.63	3.82	4.18	3.78	4.32	1.03	1.03	27.83
		INDUST'L x_{2j}	0.66	1.86	1.07	2.65	3.41	1.20	1.76	1.16	1.16	14.93
		DOM' x_{3j}	0.27	1.03	0.60	0.61	1.48	1.62	0.99	1.20	1.20	9.01
		COMM' x_{4j}	0.38	1.27	0.42	0.34	0.56	0.56	0.34	1.10	1.10	6.06
		POWER x_{5j}	0.41	1.43	0.31	0.96	0.53	0.35	0.19	4.65	4.65	13.49
		REC'N x_{6j}	0.23	1.08	0.32	0.52	1.98	0.85	0.94	1.14	1.14	8.20
		SOCIAL x_{7j}	0.27	1.06	0.40	0.94	1.16	1.03	0.95	1.30	1.30	8.41
	PAYMENTS	IMPORTS I_j	12.04	2.35	0.13	-1.89	0.16	-0.60	-0.55	0.00	0.00	11.59
		DEPLET'N L_j	12.04	2.34	0.13	-1.89	0.10	-0.60	-0.55	0.00	0.00	11.57
TOTAL OUTLAY		G_j	27.83	14.93	9.01	6.06	13.49	8.20	8.41	11.58	11.58	111.09

Table 7.11 Final Input-Output Table for September.

MONTH		Average Consumptive Demand Conditions		Optimal Consumptive Demand Conditions		COMMENTS
		Average Monthly Consumptive Demands	Net Economic Returns for Consumptive Demands	Optimal Consumptive Allocation	Optimal Net Economic Returns	
		q_i'(demand)	$b_i q_i'$(demand)	q_i'(optimal)	$b_i q_i'$(optimal)	
1	Jan	1.160	286.45	1.159	291.68	
2	Feb	1.160	286.45	1.159	291.68	
3	Mar	1.176	292.15	1.182	291.03	
4	Apr	1.315	314.50	1.314	310.75	
5	May	3.750	349.68	3.749	351.62	
6	Jun	4.610	376.69	4.610	376.98	
7	Jul	9.485	539.33	9.487	681.74	
8	Aug	10.430	562.79	10.341	791.43	Restrictions
9	Set	8.790	499.28	2.149	87.93	Restrictions
10	Oct	7.045	447.80	3.260	187.67	Restrictions
11	Nov	1.353	310.78	1.351	307.92	
12	Dec	1.295	291.78	1.297	276.00	
TOTAL ANNUAL		51.569	4557.68	41.058	4246.43	

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in $ x 10^3

Table 7.12 Total Monthly Average Optimal Conditions.

remain constant within the optimal conditions except for the months of August, September and October which are under water restriction conditions.

For the month of August, under a 0.85 percent water restriction, the net economic return has been increased 40.62 percent, and it is anticipated that the months of September and October would have similar percentage increases if water restrictions were not imposed. If these three months are disregarded from the entire year of consideration, the net annual economic return for demand conditions is $\$3,047.81 \times 10^3$, and the optimal net economic return is $\$3,179.40 \times 10^3$, indicating a 4.32 percent increase for these nine months.

Significant percentage increases occur durng the months of higher demands, especially July and August, with minimal overall changes occurring in the other months not subject to restriction conditions. These increases in the net economic returns are caused primarily by the demand function relationship for the power generation sector, where comparatively high b_i values exist for small water consumption values. This induces a shift in the water available to this sector from all other sectors, consequently inducing the higher net economic returns.

Table C-2-1 through Table C-2-11 in Appendix C-2 list the final optimal results for each month. Comparison of the individual sectoral values with the initial input-output tables reveals both increases and decreases in sectoral net economic returns, irrespective of an increase or decrease in the total monthly net economic return.

7.32 Valuation of Exported Water:

During months of full demand satisfaction, water transferred out of the basin area does not affect the net economic return to the basin, and under such conditions, the exported water has zero marginal value. When full demand satisfaction is not achieved, export water demands cause a reduction in the net economic returns to each sector, and in doing so, takes on a positive economic value.

The real value of exported water during months of partial demand satisfaction may be determined by adding the export water quantity to the total monthly demand until full demand satisfaction is obtained. With this additional water available for allocation, the optimization process is rerun to determine the new total net economic benefits. The difference between this value and the original value of net economic benefit without export water gives the real value of the exported water or the value of the water had it been placed in productive use within the catchment.

Considering interbasin allocation alternatives, the net economic value lost by the basin considered should be gained by downstream users if the water transfer is to be economically viable. A further alternative interpretation is that users outside of the considered basin should be willing to buy the exported water at, or greater than, the net economic loss suffered by the upstream user. However, this concept does not consider base flow requirements imposed upon natural river reaches.

For the water restricted months of August, September and October, Table 7.13 following gives the value of the export water, together with water quantities used, for the basin under consideration. From this table, the unit values of the export water (b_E) for the three months are \$237.22 per 10^6 gallons, \$83.24 per 10^6 gallons and \$86.86 per 10^6 gallons, respectively. Note should be made that not all of the export water available has been used during August.

MONTH		Average Monthly Consumptive Demands	Consumptive Demands Including Export Water	Export Water Allocated	Optimal Net Economic Returns	Economic Returns Including Export Water	Net Economic Value of Export Water	Unit Economic Value of Export Water
		q_i'	$q_i' + q_E$	q_E	$\sum b_i q_i'$	$\sum b_i q_i' + b_E q_E$	$b_E q_E$	b_E
8	Aug	10.430	10.430	0.09	791.43	812.78	21.35	237.22
9	Sep	8.790	5.150	3.00	87.93	337.65	249.72	83.24
10	Oct	7.045	6.260	3.00	187.67	448.24	260.57	86.86

Note:

All q_i' and q_E values in gallons x 10^9

All $b_i q_i'$ and $b_E q_E$ values in \$ x 10^3

All b_E values in \$ per 10^6 gallons

Table 7.13 Export Water Valuation

7.33 Valuation of Imported Water:

The value of the imported water to the basin may be determined in a similar manner to that of exported water. If full demand satisfaction is achieved within all sectors from storage held within the basin and natural monthly inflow, the marginal value of imported water is zero. However, if all demands are not satisfied, then imported water assumes a real positive value.

For the optimal net economic returns computed in Table 7.12, water has been imported for demand satisfaction during the restriction months of August, September and October. Valuation of imported water may be determined by subtracting the import water quantity amounts from the actual allocated quantities, and rerunning the optimization process to determine new net economic benefits derived per month for all sectors. These new benefits are then subtracted from optimal net economic returns to give the net economic value of imported water ($b_I q_I$) for all sectors for the month.

Table 7.14 following lists the import water values for the restricted months of August, September and October, together with water quantities consumed. From this table, the unit values of imported water (b_I) for the three months are \$74.68 per 10^6 gallons, \$41.02 per 10^6 gallons and \$76.98 per 10^6 gallons, respectively. All months have consumed the maximum amount of import water available during the month (2.00×10^9 gallons).

For both imported and exported water quantities, demand functions may be established by considering incremental increases in imported water (up to full demand satisfaction) and incremental decreases in exported water (until all exported water has been consumed within the

MONTH		Average Monthly Consumptive Demands	Consumptive Demands Excluding Import Water	Import Water Allocated	Optimal Net Economic Returns	Economic Returns Excluding Import Water	Net Economic Value of Import Water	Unit Economic Value of Import Water
		q_i'	$q_i' - q_I$	q_I	$\sum b_i q_i'$	$\sum b_i q_i' - b_I q_I$	$b_I q_I$	b_I
8	Aug	10.430	8.340	2.00	791.43	642.08	149.35	74.68
9	Sep	8.790	0.150	2.00	87.93	5.89	82.04	41.02
10	Oct	7.045	1.260	2.00	187.67	33.71	153.96	76.98

Note:

All q_i' and q_I values in gallons x 10^9
All $b_i q_i'$ and $b_I q_I$ values in \$ x 10^3
All b_I values in \$ per 10^6 gallons

Table 7.14 Import Water Valuation.

basin, or full demand satisfaction occurs) and reallocating the available water through the optimization process. The resulting demand functions would serve as an exceptionally useful valuation tool for incremental purchases of import water, and incremental sale of export water quantities.

8.00 CONCLUSIONS AND RECOMMENDATIONS:

The following chapter deals with the conclusions of the model operation and the prime recommendations regarding the use of the model under real data conditions, together with modifications and further research requirements.

8.10 Conclusions:

The model developed allows the optimization of water allocation for net economic return maximization within a river basin. Using average monthly sectoral demands initially, the model reallocates water between sectors to maximize the net economic return to the entire basin through a process of static iteration. Actual water available for the particular year considered was 20.38 percent lower than the average annual consumptive demand conditions, though the actual net economic return was only 6.83 percent lower. Disregarding the months of September and October, during which severe restrictions were imposed, the net economic return to the basin was increased by 9.07 percent through use of the model indicating its viability to increase economic returns through rational allocation decisions.

For the water restricted months, August, with a 0.85 percent reduction in available water, gave a 40.62 percent increase in net economic return; September with a 56.32 percent water reduction indicates a 82.39 percent decrease in net economic return, and October, with a 37.65 percent water reduction gave a 50.89 percent reduction in net economic benefit compared to full demand satisfaction, within non-restricted months, increases in net economic benefit ranged from 0.08 percent to 26.40 percent and decreases from 0.38 to 5.41 percent.

Incorporation of input-output analysis within a physical water allocation system has allowed comparative economic evaluation of water between consuming sectors, though the method indicates a high degree of data sensitivity. This sensitivity occurs within the input-output program, primarily within the matrix inversion and the computations associated with new final demand allocations. This is particularly evident when large final demand changes induced in one particular sector detrimentally effect the total net economic benefit within a sector that demands a comparatively small water consumption quantity. The model's sensitivity also stems from its reliance upon the basic annual input-output transactions table for the entire basin, and recommendations regarding this table's use are given in the following section.

In general, the model gives an increase in total net economic returns by reallocating the actual water available for consumption between the sectors, under the assumption that no constraints exist within the allocation criteria other than the real water quantity available with the basin. As legal, political and social constraints play a large part in the actual allocation criteria of water within the United States, the implementation of such a model is, at present, hypothetical within an entire river basin. However, for future planned cities, or developing countries, the model may be applicable to smaller areas, under the assumption that a rational allocation authority is established.

8.20 Recommendations:

The following suggestions for increasing the overall operational efficiency of the model are offered, together with facets of the model that require further individual research and investigation.

1) For the existing model, a great deal more computer orientation is required within the iteration process. A further computer program could be incorporated within the input-output model to read directly the resulting total outlays for each sector, modify the final demand values appropriately, and continuing iteration until all available water has been consumed.

2) The direct correlation of net economic benefits arising from sectoral water use in relation to the annual input-output transactions table implies a water resource-use mix exactly the same as all other resource-use mixes. This assumption may not be held valid for all sectors, and a far more accurate method would be attained through the use of a data collected (or generated) monthly water use input-output table. However, data collection of this nature adds further to the cost of model operation within a real system. As discussed previously, the validity of the above assumption may be increased through the use of monthly input-output tabulations, though this again will add significantly to the overall operational cost of the model.

3) As discussed in Chapter 5.00, a great deal more research is required in the field of economic evaluation of water, and the development of demand functions for the various sectors. The economic effect of the imposition of constraint conditions, especially upon the domestic and social sectors, also requires further consideration and research.

4) The flow chart of Figure 1.1 includes the possibility of a compensation criteria for sectors that suffer a reduction in available water at the conclusion of allocation optimization. The requirements

of a compensation criteria, its format and the valuation of compensation costs also require a great deal more research for existing basins. However, if water restrictions are imposed upon a particular sector, the produce from this sector may take on a higher value in a future time period due to its scarcity during the restricted month. Should this happen in reality, constant modifications to the demand functions will be necessary for all sectors.

5) In relation to recommendation 1), an increase in the accuracy of the model may be obtained by defining the $b_i q_i' - q_i'$ relationships in terms of parabolic or hyperbolic equations.

6) Optimization within the model relies upon the allocation of actual water available for consumption ($\sum_{i=0}^{i=n} q_i'$) derived from average annual demand conditions. A more realistic approach results through the consideration of the actual gross water quantities available to each sector ($\sum_{i=0}^{i=n} q_i$) during the defined time period. However, the optimization of q_i values must also include spatial and relative temporal considerations within the water allocation program. As discussed in Chapter 5.00, any particular water allocation program may be used in conjunction with the optimization model, though the inclusion of spatial considerations within the model will require a far more sophisticated water allocation model than the one adopted here.

7) A further refinement may be made within the model by modifying the M_2 multipliers to include minimum consumption constraints. Note should also be made that within the model, the M_2 values will change slightly following each iteration due to the changes resulting in the b_i values. However this variation has been considered insignificant within the model.

8) In the consideration of final demand changes, it is recommended that different functions between the incremental final demand change and the respective M_2 value be considered. A polynomial function, in preference to the linear function adopted, may eradicate the necessity of a compensation criteria, and automatically consider minimum water quantity constraints to any particular sector.

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APPENDIX A-1

INPUT-OUTPUT PROGRAM AND INPUT-OUTPUT PLOT PROGRAM

```
C----------------------------------------------------------------------C
C----------------------------------------------------------------------C

C------INPUT-OUTPUT PROGRAM AND INPUT-OUTPUT PLOT PROGRAM--------------C

C----------------------------------------------------------------------C
C----------------------------------------------------------------------C


      PROGRAM INOUT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE2)
      DIMENSION  X( 7, 7),PI( 7),PJ( 9),DI( 7),DJ( 9),TI( 9),TJ( 9),
     1A( 7, 7),Y( 9),AI( 7, 7),YP( 7),T( 7),PR(10,10),AT(7,7),DIV(7)
      DIMENSION EJ(7),DIR(7),CP(7),F(7),R(7)
      COMMON N
      CALL LOCAT(2RAT)
C---------READ N  SIZE OF MATRIX
      READ(5,10)N
10    FORMAT(I2)
      M=N+2
C---------READ X  INPUT MATRIX
      DO 100 I=1,N
           READ(5,20) (X(I,J),J=1,N)
20    FORMAT(7F10.0)
  100 CONTINUE
C---------READ PAYMENTS SECTOR
      READ(5,20) (PI(I),I=1,N)
      READ(5,20) (DI(I),I=1,N)
C---------READ FINAL DEMAND
      READ(5,30)(PJ(I),I=1,M)
      READ(5,30)(DJ(I),I=1,M)
30    FORMAT(6F10.0)
      DO 2 I=1,M
      Y(I)=PJ(I)+DJ(I)
2     CONTINUE
      DO 3 I=1,N
      TI(I)=Y(I)
      DO 4 J=1,N
      TI(I)=TI(I)+X(I,J)
4     CONTINUE
3     CONTINUE
51    TI(M)=Y(M)
      TI(N+1)=Y(N+1)
      DO 5 I=1,N
      TI(N+1)=TI(N+1)+PI(I)
      TI(M)=TI(M)+DI(I)
5     CONTINUE
C-----CONTINUED
```

```
      DO 6 I=1,N
      TJ(I)=PI(I)+DI(I)
      DO 7 J=1,N
      TJ(I)=TJ(I)+X(J,I)
7     CONTINUE
6     CONTINUE
      TJ(N+1)=0.
      TJ(M)=0.
      DO 8 I=1,M
      TJ(N+1)=TJ(N+1)+PJ(I)
      TJ(M)=TJ(M)+DJ(I)
8     CONTINUE
      SUMTJ=0.
      DO 9 I=1,M
9     SUMTJ=SUMTJ+TI(I)
C--------PUT DATA IN PR MATRIX FOR PLOTTED CHART
      DO 43 I=1,N
      DO 43 J=1,N
      PR(I,J)=X(I,J)
43    CONTINUE
      DO 44 I=1,M
      PR(I,N+1)=PJ(I)
      PR(I,N+2)=DJ(I)
      PR(I,N+2)=DJ(I)
      PR(I,N+3)=TI(I)
      PR(N+3,I)=TJ(I)
      IF(I.GT.N) GO TO 44
      PR(N+1,I)=PI(I)
      PR(N+2,I)=DI(I)
   44 CONTINUE
      IF (N .EQ. 7) GO TO 45
      PR(9,9) = SUMTJ
   45 PR(10,10)=SUMTJ
      CALL CHART(PR)
      DO 11 I=1,N
      EJ(I)=TI(I)-DI(I)
11    CONTINUE
      DO 22 I=1,N
      DO 22 J=1,N
      A(I,J)= X(I,J)/EJ(J)
22    CONTINUE
      DO 23 J=1,N
16    DIR(J)=0.
      DO 24 I=1,N
      DIR(J)=DIR(J)+A(I,J)
24    CONTINUE
      IF(DIR(J).LT.1.0) GO TO 23
C-----CONTINUED
```

```
      DO 25 I=1,N
      A(I,J)=A(I,J)*.99
25    CONTINUE
      GO TO 16
23    CONTINUF
      WRITE(6,39)
   39 FORMAT(* DIRECT TECHNICAL COEFFICIENTS*/)
      DO 200 I=1,N
           WRITE(6,40) (A(I,J),J=1,N)
   40 FORMAT(7(2X,F6.2))
  200 CONTINUE
C---------SET UP IDENTITY MATRIX
      DO 93 I=1,N
      DO 91 J=1,N
      AI(I,J)=0.
91    CONTINUF
      AI(I,I)=1.
93    CONTINUE
C---------SUBTRACT A FROM I
      DO 92 I=1,N
      DO 92 J=1,N
      AI(I,J)=AI(I,J)-A(I,J)
92    CONTINUE
C---------CALL MATRIX TO INVERT I-A
      CALL MATRIX(10,N,N,0,AI,7,DET)
      WRITE(6,49)
   49 FORMAT(* DIRECT AND INDIRECT TECHNICAL COEFFICIENTS*/)
      DO 201 I=1,N
           WRITE(6,40) (AI(I,J),J=1,N)
  201 CONTINUE
C---------READ CORRECTED FINAL DEMAND
      READ(5,30)(PJ(I),I=1,M)
      IF(EOF(5))17,21
21    READ(5,30)(DJ(I),I=1,M)
      DO 31 I=1,N
31    YP(I)=PJ(I)+DJ(I)
C---------CALCULATE ADJUSTMENT RATIO
      HI=0.
      DO 27 I=1,N
27    HI=HI+Y(I)
      DMI=0.
      DO 18 I=1,N
      DMI=DMI+DI(I)
18    CONTINUE
      IF(HI.EQ.0.) GO TO 19
      IF(DMI.EQ.0.) GO TO 19
      Z=1.-(DMI/HI)
C-----CONTINUED
```

```
      DO 52 I=1,N
      YP(I)=YP(I)*Z
52    CONTINUE
C---------MULTIPLY AT BY FINAL DEMAND
      DO 12 I=1,N
      DO 12 J=1,N
      AI(I,J)=AI(I,J)*YP(I)
12    CONTINUE
C---------CALL MATRIX TO TRANSPOSE AI
      CALL MATRIX(0,N,N,0,AI,7,AT,7)
C---------SUM ROWS OF AT*YP AND PUT INTO T
      DO 13 I=1,N
      T(I)=0.
      DO 13 J=1,N
      T(I)=T(I)+AT(I,J)
13    CONTINUE
C---------MULTIPLY A (DIRECT COEFF. MATRIX) BY T TRANSPOSE
      DO 14 I=1,N
      DO 14 J=1,N
      A(I,J)=A(I,J)*T(J)
14    CONTINUE
C---------REPLACE ORIGINAL X WITH RESULT AND RECALCULATE TABLE
      DO 15 I=1,N
      DO 15 J=1,N
      X(I,J)=A(I,J)
15    CONTINUE
19    DO 53 J=1,N
      CP(J)=0.
      DO 53 I=1,N
      CP(J)=CP(J)+X(I,J)
53    CONTINUE
      DO 58 I=1,M
      Y(I)=PJ(I)+DJ(I)
58    CONTINUE
      DO 54 I=1,N
      TI(I)=Y(I)
      DO 54 J=1,N
      TI(I)=TI(I)+X(I,J)
54    CONTINUE
      DO 55 I=1,N
      F(I)=TI(I)-CP(I)
55    CONTINUE
      DO 56 I=1,N
      IF(DI(I).NE.0) GO TO 66
      R(I)=1.
      GO TO 56
66    R(I)=PI(I)/DI(I)
C-----CONTINUED
```

```
56    CONTINUE
      DO 57 I=1,N
      DI(I)=F(I)/(R(I)+1.)
      PI(I)=F(I)-DI(I)
57    CONTINUE
      GO TO 51
17    CONTINUE
      STOP
      END
      SUBROUTINE CHART(DATA)
      COMMON N
      DIMENSION DATA(10,10),XLAB(9),YLAB(9),XPD(10)
      DATA XLAB/10HIRRIGATION ,10HINDUSTRIAL  ,8HDOMESTIC,10HCOMMERCIAL ,
     1,10HPOWER GEN. ,10HRECREATION ,10HSOCIAL USE ,7HIMPORTS ,9HDEPLETI
     2ON/
      DATA THETAX,THETAY/90.0,180.0/,HT/.14/
      DATA XPD/2HQ1,2HQ2,2HQ3,2HQ4,2HQ5,2HQ6,2HQ7,1HP,1HD,1HT/
      DATA IPN/0/
      CALL INIT(2)
      NUM3=N
      NUM2=N+1
      NUM1=N+2
      NUM=N+3
      NUMP=N+4
      YSPAC=.825
      CALL FACTOR(.8)
      DO 1 J=1,NUM3
    1 YLAB(J)=XLAB(J)
      YLAB(NUM2)=10HEXPORTS
      YLAB(NUM1)=10HACCUM.
C    X MAIN TITLES
      CALL SYMBOL(6.0,0.25,HT,17HPRODUCING SECTORS,THETAY,17)
      CALL SYMBOL(3.5,0.5,HT,9HCONSUMING,THETAX,9)
      CALL SYMBOL(4.0,0.5,HT,7H SECTOR, THETAX,7)
      CALL SYMBOL(2.2+.667*NUM2,0.5,HT,8HPAYMENTS,THETAX,8)
      CALL SYMBOL(2.2+.667*NUM1,.5,HT,7H SECTOR ,THETAX,7)
      CALL SYMBOL(2.2+.667*NUM,.5,HT,18HTOTAL GROSS OUTLAY,THETAX,18)
      CALL SYMBOL(1.8,1.4,HT,6HINPUTS,THETAX,6)
C    X LINE LABELS
      POS=2.2
      DO 10 J=1,NUM1
      POS=POS+.667
   10 CALL SYMBOL(POS,1.8,HT,XLAB(J),THETAX,10)
      POS=POS+.667
      DO 11 J=1,NUM
      K=NUMP-J
      IF(J.GT.3) GO TO 12
C-----CONTINUED
```

```
      CALL SYMBOL(POS,3.1,HT,XPD(K),THETAX,1)
      GO TO 13
12    CALL SYMBOL(POS,3.1,HT,XPD(K),THETAX,2)
13    POS=POS-.667
11    CONTINUE
      CALL SYMBOL(POS,3.1,HT,1HQ,THETAX,1)
C    Y MAIN TITLES
      CALL SYMBOL(1.2,2.1,HT,7HOUTPUTS,THETAX,7)
      CALL SYMBOL(.25,6.0,HT,17HPURCHASING SECTOR,THETAX,17)
      CALL SYMBOL(0.5,5.7,HT,16HCONSUMING SECTOR,THETAX,16)
      FIN=4.0+NUM3*YSPAC
      CALL SYMBOL(0.43,FIN,HT,5HFINAL,THETAX,5)
      CALL SYMBOL(.65,FIN,HT,6HDEMAND,THETAX,6)
      TOT=3.7+NUM1*YSPAC
      CALL SYMBOL(.667,TOT,HT,5HTOTAL,THETAX,5)
      CALL SYMBOL(1.0,TOT,HT,5HGROSS,THETAX,5)
      CALL SYMBOL(1.33,TOT,HT,6HOUTFUT,THETAX,6)
C     YLINE LABELS
      POS=3.9
      DO 20 J=1,NUM1
      CALL SYMBOL(1.88,POS,HT,YLAB(J),THETAY ,10)
   20 POS=POS+YSPAC
      POS=POS-.12
      DO 21 J=1,NUM
      K=NUMP-J
      IF(J.GT.3) GO TO 22
      CALL SYMBOL(2.2,POS,HT,XPD(K),THETAX,1)
      GO TO 23
22    CALL SYMBOL(2.2,POS,HT,XPD(K),THETAX,2)
23    POS=POS-YSPAC
21    CONTINUE
C     NUMBERS
      DO 30 I=1,NUM
      DO 30 J=1,NUM
   30 CALL NUMBER(2.2+.667*I,3.40+YSPAC*J,-HT,DATA(I,J),THETAX,2)
C     LINES
      YBORD=3.75+YSPAC*NUM
      XBORD=2.3+.667*NUM
      CALL PLOT(.09,.09,3)
      CALL PLOT(.09,YBORD,2)
      CALL PLOT(XBORD,YBORD,2 )
      CALL PLOT(XBORD,.09,2)
      CALL PLOT(.09,.09,2)
      CALL PLOT(1.94,3.0,2)
      CALL PLOT(1.94,YBORD,2)
      CALL PLOT(2.23,YBORD,3)
      CALL PLOT(2.23,.09,2)
C-----CONTINUED
```

```
CALL PLOT(2.23,0.3,3)
CALL PLOT(2.30+.667*NUM1,0.3,2)
CALL PLOT(2.30+.667*NUM1,1.73,3)
CALL PLOT(2.23,1.73,2)
CALL PLOT(1.94,3.0,3)
CALL PLOT(XBOPD,3.0,2)
CALL PLOT(XBORD,3.5,3)
CALL PLOT(.09,3.5,2)
CALL PLOT(.27,3.5,3)
CALL PLOT(.27,TOT-.3,2)
CALL PLOT(.67,TOT-.3,3)
CALL PLOT(.67,3.5,2)
CALL PLOT(.27,FIN-.55,3)
CALL PLOT(XBORD,FIN-.55,2)
CALL PLOT(XBORD-.667,YBOPD,3)
CALL PLOT(XBORD-.667,.09,2)
CALL PLOT(XBORD-2.,.30,3)
CALL PLOT(XBORD-2.,YBORD,2)
CALL PLOT(XBORD,TOT-.3,3)
CALL PLOT(.09,TOT-.3,2)
IPN=1-IPN
CALL RSTR(IPN)
RETURN
END
```

APPENDIX A-2

COMPUTER PLOT OUTPUT FOR SEPTEMBER

INITIAL ALLOCATION

OUTPUTS / INPUTS			PURCHASING SECTOR									
			CONSUMING SECTOR							FINAL DEMAND		TOTAL GROSS OUTPUT
			IRRIGATION	INDUSTRIAL	DOMESTIC	COMMERCIAL	POWER GEN.	RECREATION	SOCIAL USE	EXPORTS	ACCUM.	
		Q	Q1	Q2	Q3	Q4	Q5	Q6	Q7	P	Q	T
PRODUCING SECTORS: CONSUMING SECTOR	IRRIGATION	Q1	35.45	21.68	59.12	19.71	19.71	17.74	27.59	1.00	1.00	203.00
	INDUSTRIAL	Q2	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
	DOMESTIC	Q3	6.33	8.87	6.33	3.17	6.97	7.60	6.33	1.00	1.00	47.60
	COMMERCIAL	Q4	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
	POWER GEN.	Q5	9.50	12.38	3.30	4.95	2.48	1.65	1.24	1.00	1.00	37.50
	RECREATION	Q6	5.33	9.33	3.33	2.67	9.34	4.00	6.00	1.00	1.00	42.00
	SOCIAL USE	Q7	6.08	9.11	4.25	4.86	5.47	4.86	6.07	1.00	1.00	42.70
PAYMENTS SECTOR	IMPORTS	P	58.14	1.41	-22.18	-7.75	-12.58	-1.05	-8.99	0.00	0.00	7.00
	DEPLETION	D	58.14	1.40	-22.18	-7.74	-12.59	-1.05	-8.98	0.00	0.00	7.00
TOTAL GROSS OUTLAY		T	203.00	91.20	47.60	35.28	37.50	42.00	42.70	7.00	7.00	513.28

APPENDIX A-3

COMPUTER PLOT OUTPUT FOR SEPTEMBER

OPTIMAL ALLOCATION

INPUTS \ OUTPUTS				PURCHASING SECTOR									TOTAL GROSS OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIGATION	INDUSTRIAL	DOMESTIC	COMMERCIAL	POWER GEN.	RECREATION	SOCIAL USE	EXPORTS	ACCUM.	
			Q	Q1	Q2	Q3	Q4	Q5	Q6	Q7	P	C	T
PRODUCING SECTORS	CONSUMING SECTOR	IRRIGATION	Q1	1.53	2.51	5.63	3.82	4.18	3.78	4.32	1.03	1.03	27.83
		INDUSTRIAL	Q2	0.66	1.86	1.07	2.65	3.41	1.20	1.76	1.16	1.15	14.93
		DOMESTIC	Q3	0.27	1.03	0.60	0.61	1.48	1.02	0.99	1.20	1.20	9.01
		COMMERCIAL	Q4	0.38	1.27	0.42	0.34	0.56	0.56	0.34	1.10	1.10	5.06
		POWER GEN.	Q5	0.41	1.43	0.31	0.96	0.53	0.35	0.13	4.65	4.55	13.49
		RECREATION	Q6	0.23	1.08	0.32	0.52	1.96	0.85	0.94	1.14	1.14	8.20
		SOCIAL USE	Q7	0.26	1.06	0.40	0.94	1.10	1.03	0.95	1.30	1.30	8.41
	PAYMENTS SECTOR	IMPORTS	P	12.04	2.35	0.13	-1.89	0.10	-0.30	-0.55	0.00	0.00	11.59
		DEPLETION	C	12.04	2.34	0.13	-1.89	0.10	-0.30	-0.55	0.00	0.00	11.57
TOTAL GROSS OUTLAY			T	27.83	14.93	9.01	6.06	13.49	8.20	8.41	11.58	11.58	111.09

APPENDIX B-1

WATER ALLOCATION PROGRAM

```
C----------------------------------------------------------------------C
C----------------------------------------------------------------------C

C---------WATER ALLOCATION PROGRAM--------------------------------------C

C----------------------------------------------------------------------C
C----------------------------------------------------------------------C


      PROGRAM WADIS(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION Q(7),R(7),QIP(7)
C----------------------------------------------------------------------C
C---------Q(I) = INITIAL AVERAGE MONTHLY DIVERSION TO USER
C---------R(I) = RETURN COEFFICIENT OF USER
C---------QIP(I) = INITIAL NET MONTHLY CONSUMPTION BY USER
C---------QN = AVERAGE NET INFLOW TO STREAM FOR MONTH
C---------AMS = MAXIMUM STORAGE CAPACITY
C---------SI = STORAGE VOLUME AT BEGINNING OF MONTH 1
C---------QEB = MINIMUM BASE EXPORT FLOW REQUIRED PER MONTH
C---------QI = IMPORTED WATER AVAILABLE DURING MONTH
C---------QT = TOTAL MONTHLY CONSUMPTION BY ALL USERS PLUS MINIMUM
C---------      BASE EXPORT FLOW REQUIRED
C---------QX1 = SUM OF DOMESTIC, POWER, AND SOCIAL DEMANDS FOR MONTH
C---------QX2 = MONTHLY COMSUMPTION DEMAND IN IRRIGATION, INDUSTRY,
C---------        COMMERCIAL AND RECREATION SECTORS
C---------QA = MONTHLY ACTUAL WATER AVAILABLE
C---------RR = RESTRICTION RATIO
C---------QE = ACTUAL EXPORT FLOW AVAILABLE
C----------------------------------------------------------------------C
C---------READ AMS AND SI
      READ(5,10) AMS,SI
C---------PRINT HEADINGS
      WRITE(6,19)
   19 FORMAT(1H1,12(/))
      WRITE(6,20) SI
   20 FORMAT(* *43X,*MONTHLY SECTORAL WATER ALLOCATION*//43X*ALL VALUE
     1S IN GALLONS X 10E9*///17X*NET MONTHLY SECTORAL CONSUMPTION*/* MO*
     23X*IRRIG*3X*INDUST*3X*DOM*4X*COMM*4X*POWER*4X*REC*3X*SOCIAL*5X*MO.
     4*5X*MO.*5X*MO.*5X*MO.*5X*MO.*3X*STORAGE*2X*ACC*4X*DEPL.*/62X*DEMAN
     5D*2X*DISTRN*2X*INFLOW*2X*IMPORT*2X*EXPORT*//102X,F5.2)
      DO 12 J=1,12
C---------STORE SI VALUE FOR COMPUTATION OF ACCUMULATION OR DEPLETION
      SIL=SI
C---------READ Q(I) AND R(I)
      READ(5,10)(Q(I),I=1,7),(R(I),I=1,7)
   10 FORMAT(7F10.0)
C---------READ QN, QEB, AND QI
      READ(5,10) QN,QEB,QI
C-----CONTINUED
```

```
C---------COMPUTE INITIAL NET MONTHLY CONSUMPTION (QIP(I))
   13 DO 2 I=1,7
      QIP(I)=Q(I)*(1.-R(I))
    2 CONTINUE
      QT=0.0
C---------COMPUTE TOTAL MONTHLY CONSUMPTION + EXPORT (QT)
      DO 3 I=1,7
      QT=QT+QIP(I)
    3 CONTINUE
      QT=QT+QEB
      QD=QT
      QA=SIL+0.5*QN
C---------IF STORAGE VOLUME GREATER THAN TOTAL CONSUMPTION THERE ARE
C---------  NO RESTRICTIONS
      IF(QA.GE.QT) GO TO 16
C---------ADD STORAGE AND IMPORTED WATER
      QA=QA+QI
C---------IF THIS TOTAL IS GREATER THAN TOTAL CONSUMPTION, IMPORT WATER
      IF(QA.GE.QT) GO TO 17
C---------IF NOT, CALCULATE RESTRICTIONS
      IF(QA.LT.QEB) QEB=0.0
      QA=QA-QEB
C---------TOTAL DEMANDS FOR SECTORS 3,5, AND 7
      QX1=QIP(3)+QIP(5)+QIP(7)
C---------IF TOTAL STORAGE LESS THAN THIS TOTAL DISTRIBUTE WATER AMONG
C--------- THESE SECTORS IN RATIO OF INITIAL MONTHLY CONSUMPTION
C---------SECTORS 1,2,4, AND 6 GET NO WATER
      IF(QA.GE.QX1) GO TO 5
      RR=QA/QX1
      QIP(3)=RR*QIP(3)
      QIP(5)=RR*QIP(5)
      QIP(7)=RR*QIP(7)
      QIP(1)=0.0
      DO 7 I=2,6,2
      QIP(I)=0.0
    7 CONTINUE
      GO TO 21
   16 QI=0.0
   17 SI=QA-QT+0.5*QN
      GO TO 6
C---------IF TOTAL STORAGE IS GREATER THAN DEMANDS FOR 3,5, AND 7
C---------DISTRIBUTE REMAINING AMOUNT AMONG SECTORS 1,2,4, AND 6 IN
C---------RATIO OF INITIAL MONTHLY CONSUMPTION
    5 QA=QA-QX1
      QX2=QIP(1)+QIP(2)+QIP(4)+QIP(6)
      RR=QA/QX2
      QIP(1)=QIP(1)*RR
C-----CONTINUED
```

```
      QIP(2)=QIP(2)*RR
      QIP(4)=QIP(4)*RR
      QIP(6)=QIP(6)*RR
   21 SI=0.5*QN
      QT=0.0
      DO 22 I=1,7
      QT=QT+QIP(I)
   22 CONTINUE
      QT=QT+QER
C---------COMPUTE NF= STORAGE VOLUME FOR NEXT MONTH
    6 IF(SI.GE.AMS) GO TO 8
      QE=QER
      IF(SI.GE.0.) GO TO 15
    9 SI=0.0
      GO TO 15
C---------COMPUTE ACTUAL EXPORT FLOW AVAILABLE
    8 QE=(SI-AMS)+QER
C---------IF TOTAL STORAGE GREATER THAN MAX. CAPACITY,STORAGE FOR NEXT
C---------MONTH IS MAXIMUM
      SI=AMS
C---------COMPUTE ACCUMULATION OR DEPLETION VALUE
   15 ACC=SI-SIL
      IF(ACC.LT.0) GO TO 14
C---------PRINT OUTPUT
      WRITE(6,30) J,(QIP(I),I=1,7),QD,QT,QN,QI,QE,SI,ACC
   30 FORMAT(1X,I2,14(3X,F5.2))
      GO TO 12
   14 ACC=ACC*(-1.0)
      WRITE(6,40) J,(QIP(I),I=1,7)-QD,QT,QN,QI,QE,SI,ACC
   40 FORMAT(1X,I2,13(3X,F5.2),11X,F5.2)
   12 CONTINUE
      STOP
      END
```

APPENDIX B-2

WATER ALLOCATION PROGRAM OUTPUT

```
                                          MONTHLY SECTORAL WATER ALLOCATION

                                         ALL VALUES   IN GALLONS X 10E9

                      NET MONTHLY SECTORAL CONSUMPTION
MO   IRRIG   INDUST   DOM   COMM   POWER   REC   SOCIAL    MO.     MO.     MO.     MO.     MO.   STORAGE  ACC    DEPL.
                                                         DEMAND  DISTRN  INFLOW  IMPORT  EXPORT

                                                                                                  3.02
 1    0.00     .57    .08    .36    .03    .00    .12     4.16    4.16    5.35    0.00    3.00    4.21   1.19
 2    0.00     .57    .08    .36    .03    .00    .12     4.16    4.16    5.60    0.00    3.00    5.64   1.44
 3    0.00     .57    .09    .36    .03    .01    .12     4.18    4.18    7.06    0.00    3.00    8.53   2.88
 4    0.00     .57    .10    .36    .03    .14    .12     4.32    4.32    9.73    0.00    3.00   13.94   5.41
 5    2.40     .57    .12    .36    .02    .16    .12     6.75    6.75   10.46    0.00    3.00   17.65   3.71
 6    3.20     .57    .16    .36    .02    .18    .13     7.61    7.61    9.49    0.00    4.52   18.00    .35
 7    8.00     .57    .21    .36    .02    .20    .13    12.49   12.49    4.38    0.00    3.00    9.89           8.11
 8    8.73     .57    .25    .36    .01    .30    .14    13.43   13.34    2.91    2.00    3.00    1.45           8.43
 9    1.53     .12    .21    .08    .01    .06    .14    11.79    5.15    3.40    2.00    3.00    1.70    .25
10    2.45     .25    .17    .16    .02    .09    .13    10.04    6.26    5.12    2.00    3.00    2.56    .86
11    0.00     .57    .12    .36    .02    .15    .12     4.35    4.35    6.08    0.00    3.00    4.29   1.73
12    0.00     .57    .10    .36    .03    .01    .12     4.19    4.19    2.92    0.00    3.00    3.02           1.27
```

APPENDIX C-1

INITIAL DISTRIBUTION OF PRODUCE BETWEEN SECTORS FOR AVERAGE MONTHLY WATER CONSUMPTIONS

OUTPUTS / INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		INDUST'L	x_{2j}	0.00	19.39	13.57	16.48	19.39	6.79	13.58	1.00	1.00	91.20
		DOM'	x_{3j}	0.00	9.28	6.63	3.31	7.29	7.96	6.63	1.00	1.00	43.10
		COMM'	x_{4j}	0.00	14.86	5.94	2.38	3.56	3.57	2.97	1.00	1.00	35.28
		POWER	x_{5j}	0.00	33.71	8.99	13.49	6.75	4.49	3.37	1.00	1.00	72.80
		REC'N	x_{6j}	0.00	0.59	0.21	0.18	0.59	0.25	0.38	1.00	1.00	4.20
		SOCIAL	x_{7j}	0.00	9.97	4.65	5.32	5.97	5.32	6.64	1.00	1.00	39.87
	PAYMENTS	IMPORTS	I_j	0.00	1.70	1.56	-2.94	14.62	-12.09	3.15	0.00	0.00	6.00
		DEPLET'N	L_j	0.00	1.70	1.55	-2.94	14.63	-12.09	3.15	0.00	0.00	6.00
TOTAL OUTLAY			G_j	0.00	91.20	43.10	35.28	72.80	4.20	39.87	6.00	6.00	298.45

Table C-1-1 Months: January and February

OUTPUTS INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		INDUST'L	x_{2j}	0.00	19.39	13.57	16.48	19.39	6.79	13.58	1.00	1.00	91.20
		DOM'	x_{3j}	0.00	9.62	6.87	3.44	7.56	8.24	6.87	1.00	1.00	44.60
		COMM'	x_{4j}	0.00	14.86	5.94	2.38	3.56	3.57	2.97	1.00	1.00	35.28
		POWER	x_{5j}	0.00	33.71	8.99	13.49	6.75	4.49	3.37	1.00	1.00	72.80
		REC'N	x_{6j}	0.00	1.72	0.62	0.49	1.72	0.74	1.11	1.00	1.00	8.40
		SOCIAL	x_{7j}	0.00	9.97	4.65	5.32	5.97	5.32	6.64	1.00	1.00	39.87
	PAYMENTS	IMPORTS	I_j	0.00	0.97	1.98	-3.16	13.92	-10.37	2.66	0.00	0.00	6.00
		DEPLET'N	L_j	0.00	0.96	1.98	-3.16	13.93	-10.38	2.67	0.00	0.00	6.00
TOTAL OUTLAY			G_j	0.00	91.20	44.60	35.28	72.80	8.40	39.87	6.00	6.00	304.15

Table C-1-2 Month: March

OUTPUTS / INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		INDUST'L	x_{2j}	0.00	19.39	13.57	16.48	19.39	6.79	13.58	1.00	1.00	91.20
		DOM'	x_{3j}	0.00	9.64	6.89	3.44	7.58	8.26	6.89	1.00	1.00	44.70
		COMM'	x_{4j}	0.00	14.86	5.94	2.38	3.56	3.57	2.97	1.00	1.00	35.28
		POWER	x_{5j}	0.00	32.98	8.79	13.19	6.60	4.40	3.29	1.00	1.00	71.25
		REC'N	x_{6j}	0.00	8.13	2.90	2.32	8.13	3.49	5.23	1.00	1.00	32.20
		SOCIAL	x_{7j}	0.00	9.97	4.65	5.32	5.97	5.32	6.64	1.00	1.00	39.87
	PAYMENTS	IMPORTS	I_j	0.00	-1.88	0.98	-3.93	10.01	0.18	0.64	0.00	0.00	6.00
		DEPLET'N	L_j	0.00	-1.87	0.98	-3.92	10.01	0.19	0.63	0.00	0.00	6.00
TOTAL OUTLAY			G_j	0.00	91.20	44.70	35.28	71.25	32.20	39.87	6.00	6.00	326.50

Table C-1-3 Month: April

OUTPUTS / INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	7.06	4.31	11.77	3.92	3.92	3.53	5.49	1.00	1.00	42.00
		INDUST'L	x_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	x_{3j}	6.24	8.74	6.24	3.12	6.86	7.49	6.24	1.00	1.00	46.93
		COMM'	x_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
		POWER	x_{5j}	15.51	20.23	5.40	8.09	4.05	2.70	2.02	1.00	1.00	60.00
		REC'N	x_{6j}	4.32	7.56	2.70	2.16	7.56	3.24	4.86	1.00	1.00	34.40
		SOCIAL	x_{7j}	5.65	8.48	3.96	4.52	5.09	4.52	5.65	1.00	1.00	39.87
	PAYMENTS	IMPORTS	I_j	-10.40	7.43	0.61	-0.97	6.91	2.34	1.08	0.00	0.00	7.00
		DEPLET'N	L_j	-10.41	7.43	0.62	-0.97	6.91	2.33	1.09	0.00	0.00	7.00
TOTAL OUTLAY			G_j	42.00	91.20	46.93	35.28	60.00	34.40	39.87	7.00	7.00	363.68

Table C-1-4 Month: May

OUTPUTS INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	10.94	6.69	18.23	6.08	6.08	5.47	8.51	1.00	1.00	64.00
		INDUST'L	x_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	x_{3j}	6.44	9.02	6.44	3.22	7.08	7.73	6.43	1.00	1.00	48.36
		COMM'	x_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
		POWER	x_{5j}	15.51	20.23	5.40	8.09	4.05	2.70	2.02	1.00	1.00	60.00
		REC'N	x_{6j}	4.65	8.14	2.91	2.33	8.14	3.49	5.24	1.00	1.00	36.90
		SOCIAL	x_{7j}	5.81	8.72	4.07	4.65	5.23	4.65	5.82	1.00	1.00	40.95
	PAYMENTS	IMPORTS	I_j	-1.69	5.69	-2.16	-2.25	5.36	2.31	-0.26	0.00	0.00	7.00
		DEPLET'N	L_j	-1.69	5.69	-2.16	-2.25	5.36	2.30	-0.25	0.00	0.00	7.00
TOTAL OUTLAY			G_j	64.00	91.20	48.36	35.28	60.00	36.90	40.95	7.00	7.00	390.69

Table C - 1 - 5 Month: June

OUTPUTS INPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			X_{ij}	X_{i1}	X_{i2}	X_{i3}	X_{i4}	X_{i5}	X_{i6}	X_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	X_{1j}	41.34	25.26	68.89	22.97	22.97	20.67	32.15	1.00	1.00	236.25
		INDUST'L	X_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	X_{3j}	6.33	8.87	6.33	3.17	6.97	7.60	6.33	1.00	1.00	47.60
		COMM'	X_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.23
		POWER	X_{5j}	12.50	16.31	4.35	6.52	3.26	2.17	1.64	1.00	1.00	48.75
		REC'N	X_{6j}	4.97	8.69	3.10	2.48	8.69	3.73	5.59	1.00	1.00	39.25
		SOCIAL	X_{7j}	5.82	8.73	4.08	4.66	5.24	4.66	5.81	1.00	1.00	41.00
	PAYMENTS	IMPORTS	I_j	70.63	-1.84	-27.39	-9.96	-8.54	-3.92	-11.98	0.00	0.00	7.00
		DEPLET'N	L_j	70.63	-1.84	-27.39	-9.87	-8.54	-3.91	-11.98	0.00	0.00	7.00
TOTAL OUTLAY			G_j	236.25	91.20	47.60	35.28	48.75	39.25	41.00	7.00	7.00	553.33

Table C-1-6 Month: July

				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
INPUTS			OUTPUTS	IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	45.93	28.07	76.54	25.51	25.51	22.96	35.72	1.00	1.00	262.24
		INDUST'L	x_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	x_{3j}	6.93	9.70	6.93	3.46	7.62	8.31	6.92	1.00	1.00	51.87
		COMM'	x_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
		POWER	x_{5j}	9.50	12.38	3.30	4.95	2.48	1.65	1.24	1.00	1.00	37.50
		REC'N	x_{6j}	5.33	9.33	3.33	2.67	9.34	4.00	6.00	1.00	1.00	42.00
		SOCIAL	x_{7j}	6.08	9.11	4.25	4.86	5.47	4.86	6.07	1.00	1.00	42.70
	PAYMENTS	IMPORTS	I_j	82.22	-2.21	-29.05	-10.79	-15.81	-4.02	-13.34	0.00	0.00	7.00
		DEPLET'N	L_j	82.22	-2.20	-29.06	-10.79	-15.81	-4.01	-13.35	0.00	0.00	7.00
TOTAL OUTLAY			G_j	262.24	91.20	51.87	35.28	37.50	42.00	42.70	7.00	7.00	576.79

Table C - I - 7 Month : August

		OUTPUTS / INPUTS		PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	35.45	21.68	59.12	19.71	19.71	17.74	27.59	1.00	1.00	203.00
		INDUST'L	x_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	x_{3j}	6.33	8.87	6.33	3.17	6.97	7.60	6.33	1.00	1.00	47.60
		COMM'	x_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
		POWER	x_{5j}	9.50	12.38	3.30	4.95	2.48	1.65	1.24	1.00	1.00	37.50
		REC'N	x_{6j}	5.33	9.33	3.33	2.67	9.34	4.00	6.00	1.00	1.00	42.00
		SOCIAL	x_{7j}	6.08	9.11	4.25	4.86	5.47	4.86	6.07	1.00	1.00	42.70
	PAYMENTS	IMPORTS	I_j	58.14	1.41	-22.18	-7.75	-12.58	-1.05	-8.99	0.00	0.00	7.00
		DEPLET'N	L_j	58.14	1.40	-22.18	-7.74	-12.59	-1.05	-8.98	0.00	0.00	7.00
TOTAL OUTLAY			G_j	203.00	91.20	47.60	35.28	37.50	42.00	42.70	7.00	7.00	513.28

Table C-1-8 Month: September

		OUTPUTS		PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
INPUTS				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	24.95	15.24	41.58	13.86	13.86	12.47	19.40	1.00	1.00	143.36
		INDUST'L	x_{2j}	15.27	16.07	11.25	13.66	16.07	5.63	11.25	1.00	1.00	91.20
		DOM'	x_{3j}	6.54	9.14	6.53	3.26	7.18	7.83	6.53	1.00	1.00	49.01
		COMM'	x_{4j}	8.76	10.95	4.38	1.75	2.63	2.62	2.19	1.00	1.00	35.28
		POWER	x_{5j}	12.50	16.31	4.35	6.52	3.26	2.17	1.64	1.00	1.00	48.75
		REC'N	x_{6j}	4.97	8.69	3.10	2.48	8.69	3.73	5.59	1.00	1.00	39.25
		SOCIAL	x_{7j}	5.81	8.72	4.07	4.65	5.23	4.65	5.82	1.00	1.00	40.95
	PAYMENTS	IMPORTS	I_j	32.28	3.04	-13.12	-5.45	-4.09	0.07	-5.73	0.00	0.00	7.00
		DEPLET'N	L_j	32.28	3.04	-13.13	-5.45	-4.08	0.08	-5.74	0.00	0.00	7.00
TOTAL OUTLAY			G_j	143.36	91.20	49.01	35.28	48.75	39.25	40.95	7.00	7.00	461.80

Table C-1-9 Month: October

INPUTS \ OUTPUTS				PURCHASING SECTORS									
				CONSUMING SECTOR							FINAL DEMAND		TOTAL OUTPUT
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		INDUST'L	x_{2j}	0.00	19.39	13.57	16.48	19.39	6.79	13.58	1.00	1.00	91.20
		DOM'	x_{3j}	0.00	9.85	7.04	3.52	7.74	8.44	7.04	1.00	1.00	45.63
		COMM'	x_{4j}	0.00	14.86	5.94	2.38	3.56	3.57	2.27	1.00	1.00	35.28
		POWER	x_{5j}	0.00	29.72	7.92	11.89	5.94	3.96	2.17	1.00	1.00	64.40
		REC'N	x_{6j}	0.00	8.72	3.12	2.49	8.72	3.74	5.61	1.00	1.00	34.40
		SOCIAL	x_{7j}	0.00	9.97	4.65	5.32	5.97	5.32	6.64	1.00	1.00	39.87
	PAYMENTS	IMPORTS	I_j	0.00	-0.65	1.69	-3.40	6.54	1.29	0.53	0.00	0.00	6.00
		DEPLET'N	L_j	0.00	-0.66	1.70	-3.40	6.54	1.29	0.53	0.00	0.00	6.00
TOTAL OUTLAY			G_j	0.00	91.20	45.63	35.28	64.40	34.40	39.87	6.00	6.00	322.78

Table C-1-10 Month: November

INPUTS \ OUTPUTS				PURCHASING SECTORS									TOTAL OUTPUT
				CONSUMING SECTOR							FINAL DEMAND		
				IRRIG'N	INDUST'L	DOM'	COMM'	POWER	REC'N	SOCIAL	EXPORTS	ACCUM'N	
			x_{ij}	x_{i1}	x_{i2}	x_{i3}	x_{i4}	x_{i5}	x_{i6}	x_{i7}	P_i	D_i	T_i
PRODUCING SECTORS	CONSUMING SECTOR	IRRIG'N	x_{1j}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		INDUST'L	x_{2j}	0.00	19.39	13.57	16.48	19.39	6.79	13.58	1.00	1.00	91.20
		DOM'	x_{3j}	0.00	9.64	6.89	3.44	7.58	8.26	6.89	1.00	1.00	44.70
		COMM'	x_{4j}	0.00	14.86	5.94	2.38	3.56	3.57	2.97	1.00	1.00	35.28
		POWER	x_{5j}	0.00	32.98	8.79	13.19	6.60	4.40	3.29	1.00	1.00	71.25
		REC'N	x_{6j}	0.00	2.02	0.72	0.58	2.01	0.86	1.29	1.00	1.00	9.48
		SOCIAL	x_{7j}	0.00	9.97	4.65	5.32	5.97	5.32	6.64	1.00	1.00	39.87
	PAYMENTS	IMPORTS	I_j	0.00	1.17	2.07	-3.06	13.07	-9.86	2.61	0.00	0.00	6.00
		DEPLET'N	L_j	0.00	1.17	2.07	-3.05	13.07	-9.86	2.60	0.00	0.00	6.00
TOTAL OUTLAY			G_j	0.00	91.20	44.70	35.28	71.25	9.48	39.87	6.00	6.00	303.78

Table C-I-11 Month: December

APPENDIX C-2

INITIAL CONSUMPTIVE DEMANDS AND FINAL OPTIMAL RESULTS

SECTOR	MONTH: January and February				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	0.000	0.000	0.00	0.00	0.000
INDUST'L	0.570	0.570	91.20	86.00	0.542
DOM'	0.080	0.080	43.10	46.72	0.130
COMM'	0.360	0.360	35.28	30.88	0.320
POWER	0.026	0.026	72.80	76.81	0.027
REC'N	0.004	0.004	4.20	10.64	0.018
SOCIAL	0.120	0.120	39.87	40.63	0.122
TOTAL MONTHLY	1.160	1.160	286.45	291.68	1.159

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in $ x 10^3

Table C-2-1

SECTOR	MONTH: March				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i'(allocated)	$b_i q_i'$ (demand)	$b_i q_i'$(optimal)	q_i' (optimal)
IRRIG'N	0.000	0.000	0.00	0.00	0.000
INDUST'L	0.570	0.570	91.20	85.65	0.546
DOM'	0.090	0.090	44.60	47.38	0.142
COMM'	0.360	0.360	35.28	30.62	0.323
POWER	0.026	0.026	72.80	74.68	0.027
REC'N	0.010	0.010	8.40	12.49	0.023
SOCIAL	0.120	0.120	39.87	40.21	0.121
TOTAL MONTHLY	1.176	1.176	292.15	291.03	1.182

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-2

SECTOR	MONTH: April				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i'(allocated)	$b_i q_i'$(demand)	$b_i q_i'$(optimal)	q_i' (optimal)
IRRIG'N	0.000	0.000	0.00	0.00	0.000
INDUST'L	0.570	0.570	91.20	89.85	0.570
DOM'	0.100	0.100	44.70	47.73	0.145
COMM'	0.360	0.360	35.28	31.64	0.335
POWER	0.025	0.025	71.25	69.15	0.024
REC'N	0.140	0.140	32.20	31.30	0.118
SOCIAL	0.120	0.120	39.87	41.08	0.122
TOTAL MONTHLY	1.315	1.315	314.50	310.75	1.314

Note: All q_i' vclues in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-3

SECTOR	MONTH: May				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	2.400	2.400	42.00	42.48	2.400
INDUST'L	0.570	0.570	91.20	89.02	0.566
DOM'	0.120	0.120	46.93	48.59	0.175
COMM'	0.360	0.360	35.28	30.66	0.326
POWER	0.020	0.020	60.00	66.68	0.023
REC'N	0.160	0.160	34.40	33.63	0.135
SOCIAL	0.120	0.120	39.87	40.56	0.124
TOTAL MONTHLY	3.750	3.750	349.68	351.62	3.749

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-4

SECTOR	MONTH: June				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	3.200	3.200	64.00	64.87	3.215
INDUST'L	0.570	0.570	91.20	90.38	0.572
DOM'	0.160	0.160	48.36	49.87	0.178
COMM'	0.360	0.360	35.28	31.11	0.328
POWER	0.020	0.020	60.00	62.54	0.022
REC'N	0.180	0.180	36.90	36.37	0.165
SOCIAL	0.130	0.130	40.95	41.84	0.130
TOTAL MONTHLY	4.610	4.610	376.69	376.98	4.610

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in $\$ \times 10^3$

Table C-2-5

SECTOR	MONTH: July				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	b_iq_i' (demand)	b_iq_i' (optimal)	q_i' (optimal)
IRRIG'N	8.000	8.000	236.25	200.82	7.160
INDUST'L	0.570	0.570	91.20	98.34	0.618
DOM'	0.210	0.210	47.60	57.53	0.328
COMM'	0.360	0.360	35.28	32.29	0.338
POWER	0.015	0.015	48.75	187.42	0.078
REC'N	0.200	0.200	39.25	51.27	0.580
SOCIAL	0.130	0.130	41.00	54.07	0.385
TOTAL MONTHLY	9.485	9.485	539.33	681.74	9.487

Note: All q_i' values in gallons x 10^9. All b_iq_i' values in $\$$ x 10^3

Table C-2-6

SECTOR	MONTH: August				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	8.800	8.730	262.24	221.24	7.690
INDUST'L	0.570	0.560	91.20	103.71	0.646
DOM'	0.250	0.250	51.87	64.89	0.475
COMM'	0.360	0.350	35.28	33.50	0.350
POWER	0.010	0.010	37.50	251.94	0.101
REC'N	0.300	0.300	42.00	55.93	0.479
SOCIAL	0.140	0.140	42.70	60.22	0.600
TOTAL MONTHLY	10.430	10.340	562.79	791.43	10.341

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-7

SECTOR	MONTH: September				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	7.200	1.530	203.00	27.83	1.875
INDUST'L	0.570	0.120	91.20	14.93	0.133
DOM'	0.210	0.210	47.60	9.01	0.008
COMM'	0.360	0.080	35.28	6.06	0.112
POWER	0.010	0.010	37.50	13.49	0.001
REC'N	0.300	0.060	42.00	8.20	0.009
SOCIAL	0.140	0.140	42.70	8.41	0.011
TOTAL MONTHLY	8.790	2.150	499.28	87.93	2.149

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-8

SECTOR	MONTH: October				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	5.600	2.440	143.36	51.26	2.727
INDUST'L	0.570	0.250	91.20	35.81	0.268
DOM'	0.170	0.170	49.01	21.28	0.010
COMM'	0.360	0.160	35.28	12.64	0.171
POWER	0.015	0.020	48.75	31.42	0.007
REC'N	0.200	0.090	39.25	17.18	0.044
SOCIAL	0.130	0.130	40.95	18.08	0.033
TOTAL MONTHLY	7.045	3.260	447.80	187.67	3.260

Note: All q_i' values in gallons $\times 10^9$. All $b_i q_i'$ values in \$ $\times 10^3$

Table C - 2 - 9

SECTOR	MONTH: November				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	0.000	0.000	0.00	0.00	0.000
INDUST'L	0.570	0.570	91.20	91.33	0.578
DOM'	0.120	0.120	45.63	48.24	0.164
COMM'	0.360	0.360	35.28	31.83	0.326
POWER	0.023	0.023	64.40	61.81	0.021
REC'N	0.160	0.160	34.40	33.66	0.136
SOCIAL	0.120	0.120	39.87	41.05	0.126
TOTAL MONTHLY	1.353	1.353	310.78	307.92	1.351

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-10

SECTOR	MONTH: December				
	Average Monthly Consumptive Demands	Actual Monthly Consumptive Allocation	Net Economic Returns for Consumptive Demands	Optimal Net Economic Returns	Optimal Consumptive Distribution
	q_i' (demand)	q_i' (allocated)	$b_i q_i'$ (demand)	$b_i q_i'$ (optimal)	q_i' (optimal)
IRRIG'N	0.900	0.000	0.00	0.00	0.000
INDUST'L	0.570	0.570	91.20	81.79	0.528
DOM'	0.100	0.100	44.70	44.83	0.091
COMM'	0.360	0.360	35.28	29.23	0.318
POWER	0.025	0.025	71.25	69.43	0.025
REC'N	0.120	0.120	9.48	12.37	0.225
SOCIAL	0.120	0.120	39.87	38.35	0.110
TOTAL MONTHLY	1.295	1.295	291.78	276.00	1.297

Note: All q_i' values in gallons x 10^9. All $b_i q_i'$ values in \$ x 10^3

Table C-2-11