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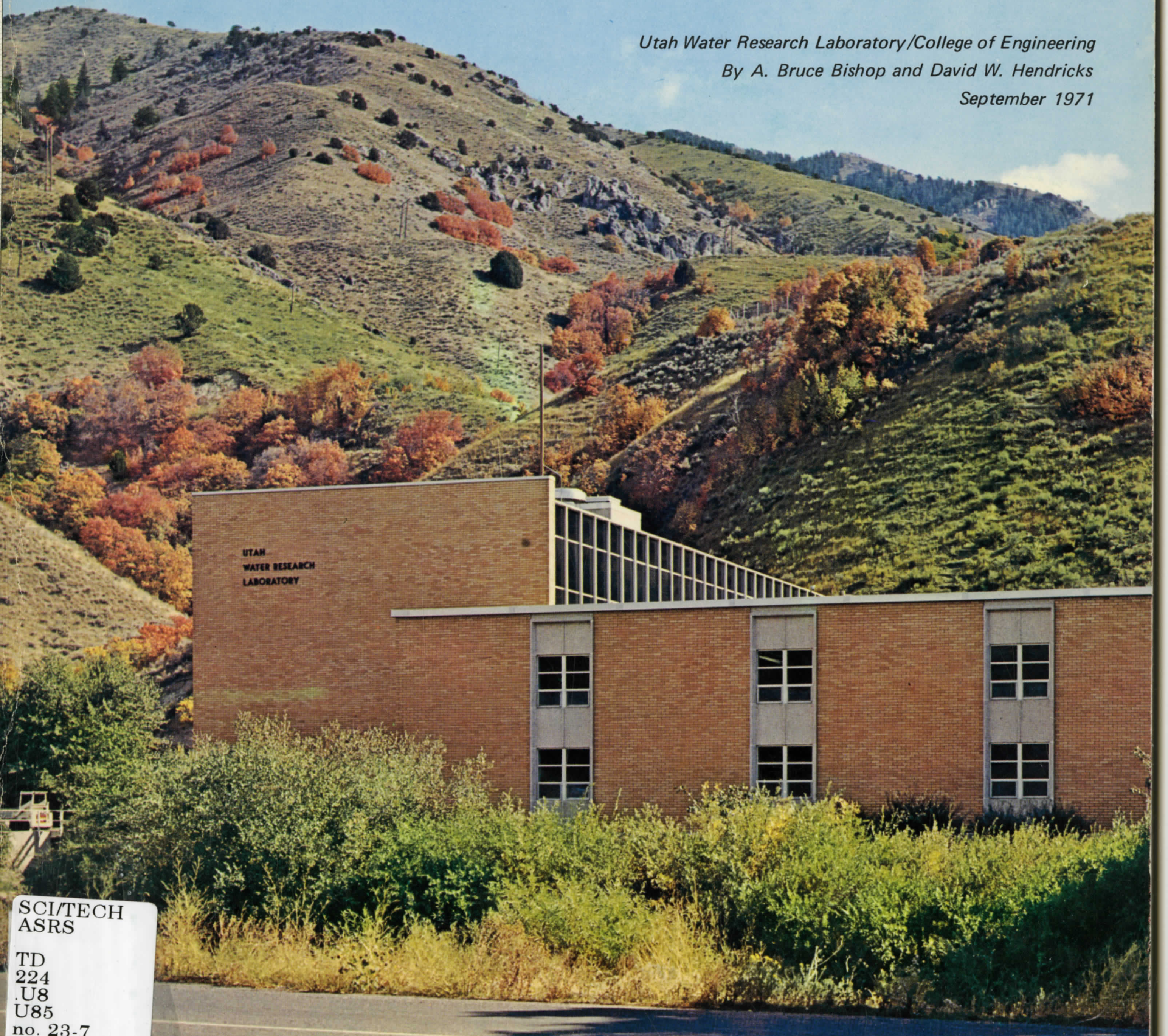

ANALYSIS OF WATER REUSE ALTERNATIVES IN AN INTEGRATED URBAN AND AGRICULTURAL AREA

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ANALYSIS OF WATER REUSE ALTERNATIVES IN AN INTEGRATED URBAN AND AGRICULTURAL AREA

Introduction

The growing demands on our existing water supplies and the current problems of water shortage emphasize the need for a comprehensive approach to analysis and planning of water reuse. The primary focus, heretofore, has been on the treatment technology for achieving water reuse.

The concept of reuse, however, should be broadened to consider a totally integrated urban and agricultural system. This necessitates a systems analysis where water reuse, together with all other water dispositions, is considered in the context of its contribution to the total water resources pool of a region.

The components of the water resource system are shown in the matrix of Figure 1, including both sources of supply and demand requirements. The water supply sources are indicated by row headings, and each origin of water is classified as: (1) primary or base supply, (2) secondary or effluent supply, or (3) supplementary or imported supply. Each row represents a different possible origin of supply. The system of water users is indicated by the column headings in Figure 1. They are grouped into the broad sectors of municipal, industrial, agriculture demand, or other uses. Both the sectors of water use, the columns, and the supply categories, the rows, can be specified to any degree of refinement desired.

In the context of broad system planning, the matrix of water supply sources and demand sector requirements depicts all possible combinations for satisfying the aggregate system demand with the aggregate available supply. Thus, each element in the matrix represents a possible means of satisfying all or part of the demand requirements of a sector with all or part of the water from a given source.

In the past water planning and management has been concerned mainly with the design and optimum operation of storage and distribution systems to regulate water allocation to each use sector in both time and space. This approach is generally adequate when water resource development is at a stage where the primary water supply is in large excess of demand requirements, and the entire demand can be satisfied by the primary supply vectors. However, in many areas the primary supply is no longer sufficient to meet the diversion requirements of all users. Thus, secondary and supplemental sources of water become important, and water demands must be met by recycle-reuse and sequential-reuse from secondary supply vectors or development of supplementary supplies. This means that all combinations in the matrix of Figure 1 need to be considered for comprehensive planning of water utilization. The purpose of this paper is to delineate the manner in which all system permutations can be explored and how the best alternatives can be selected. Specifically, the objectives are:

1. To formulate a conceptual framework for analyzing water reuse alternatives.
2. To present a model for analyzing alternatives of sequential-reuse and recycle-reuse in an integrated agricultural and urban environment. The function of the model is to determine the optimal allocations of water from each supply category to each use sector at minimum cost, which is the focus of this paper, or maximum net benefits. Quality constraints may necessitate treatment of water before reuse. Therefore, three possible levels of treatment are considered in the analysis: (a) conventional primary-secondary, (b) tertiary, and (c) desalting.
3. To illustrate the application of the reuse model by application to a specific metropolitan area.

Some questions to be answered are:

1. Which origins of primary and secondary water supply might best be allocated to which use sectors, considering quantity and quality constraints of minimum costs?
2. What should be the design capacities of wastewater treatment facilities and when should they be phased into operation?

Supply Origins	Demand Destinations	Municipal	Industrial	Agricultural	Recreation Wildlife Hydropower	System Outflow	Category Availabilities
Primary Supply	Surface Water			initial allocation of primary supply			annual outflow
	Groundwater						annual recharge
Secondary Supply	Municipal Effluent	recycle reuse	sequential reuse	sequential reuse	sequential reuse	sequential reuse	municipal waste system outflow
	Industrial Waste	sequential reuse	recycle reuse	sequential reuse	sequential reuse	sequential reuse	industrial wastewaters
	Agricultural Return Flow	sequential reuse	sequential reuse	recycle reuse	sequential reuse	sequential reuse	irrigation return flows
Supplementary Supply	Imported Water			allocation of supplementary supply			annual importation
	Desalination of Sea Water						annual desalination
	Use Sector Requirements	municipal diversion requirement	industrial diversion requirement	agricultural diversion requirement	miscellaneous diversion requirement	downstream outflow	Totals

Figure 1. Allocation alternatives for the water resource system.

A Model for Reuse Planning–Basic Principles

The transportation problem by linear programming

The problem of allocating water from various sources or origins to required points of use or destinations is closely related to the classical "transportation problem" (Gass, 1964, pp. 193-214). In the general transportation problem, a homogeneous product is available in the amounts $a_1, a_2, \ldots a_m$ from each of m shipping origins and is required in amounts $b_1, b_2, \ldots b_n$ by each of n shipping destinations. The term x_{ij} represents the amount to be shipped from the i^{th} origin to the j^{th} destination. The cost of shipping a unit amount from the i^{th} origin to the j^{th} destination is c_{ij}, a constant, and must be known for all combinations. The structure of the problem is set out in Figure 2.

The problem is to determine the amounts x_{ij} to be shipped over all routes so as to minimize costs. The mathematical statement of the transportation problem is to find values for the variables x_{ij} which minimize the total cost, TC:

$$TC = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \quad . \; . \; . \; (1)$$

Destinations

i \ j	(1)	(2)	.	.	(j)	.	.	(n)	
(1)	x_{11}	x_{12}			x_{1j}			x_{1n}	a_1
.									
.									
(i)	x_{i1}	x_{i2}			x_{ij}			x_{in}	a_i
.									
.									
(m)	x_{m1}	x_{m2}			x_{mj}			x_{mn}	a_m
	b_1	b_2			b_j			b_n	

Origins

Figure 2. The transportation problem tableau.

subject to the constraints:

$$\sum_{j=1}^{n} x_{ij} = a_i \qquad i = 1, 2, \ldots, m . \quad (2)$$

$$\sum_{i=1}^{m} x_{ij} = b_j \qquad j = 1, 2, \ldots, n . \quad (3)$$

and each $x_{ij} \geqq 0$

The sum of x_{ij}, equation (2), over the rows, i.e. over j, equals the total amount shipped, a_i, from each origin. The column sum, equation (3), equals the amount received, b_j, at each destination. For the moment, the restriction is imposed that the sum of the row sums and the sum of the column sums must be equal, i.e. that the total amount shipped must equal the total amount received. With each c_{ij} constant, the objective function, represented by equation (1), subject to the constraints equations (2) and (3), can be formulated as a linear programming problem with $m + n$ equations in $m \cdot n$ variables. The problem has an optimal feasible solution which can be obtained through linear programming or the algorithm for the "transportation problem," or by the simplex algorithm.

Water reuse planning as a transportation problem

The format of the transportation problem is well adapted to the problem of water reuse planning. Water from several origins or categories of supply must be transported to various destinations or sectors of use at minimum cost. Since the effluent from a sector which is not consumptively used can be made available for reuse in the system, sectors of use (column vectors) also become origins of secondary supply (row vectors). Thus a waste treatment plant may be the destination of municipal effluent, while at the same time it becomes an origin for treated wastewater available for reuse. The effluent from any sector can be allocated for use by another sector for sequential reuse, or it can be reallocated to the same sector by a recycle reuse of the water. From the foregoing discussion, the matrix of Figure 1, illustrating the concepts of water reuse, fits closely the format of the transportation problem. Referring to the tableau of Figure 2, the a_i values are the water supply availabilities from primary and secondary sources, and the b_j values are the diversion requirements for the use sectors. Various combinations of treatment facilities are also included in the system; the system continuity is maintained by the outflow requirement.

The costs incurred in allocating water from any origin to any destination depend on the water quality of the source, the quality requirement at the destination, and the facilities required to transport and deliver the water from origin to destination. In adapting water reuse planning to the transportation problem format, the cost of "shipping" a unit amount of water from the i^{th} origin to the j^{th} destination is comprised of two components:

(1) *Treatment costs:* When the quality of the source does not meet the requirements of the use sector, then the cost of treating a unit of water to bring it to the required quality level for that sector is assigned.

(2) *Transportation cost:* A transportation cost for physically delivering the water from a given source to a given use sector is assessed for each element of the matrix.

The sum of these two components represents the cost, c_{ij}, between each origin and destination. The cost function guarantees that the quality constraints are fulfilled along with the quantity requirements.

An example application

As an example to demonstrate the concepts involved in structuring the water reuse planning model, consider an integrated urban and agricultural system with the characteristics given in Table 1. An examination of the system indicates that the total diversion requirements for all sectors exceeds the primary supply available. Hence, if the total water requirements for the system are to be met, sequential and/or recycle reuse of the water supply will be necessary. There is also a component of outflow from the system indicated by the difference between the available base supply and the consumptive use.

The tableau of Figure 3 shows the formulation of the water supply-use system as a transportation problem. Three types of information are given. The right hand column contains the water supply or effluent flow availabilities corresponding to each origin, and the bottom row contains the diversion requirements for each use sector or destination. The entries in the matrix are the total costs to "ship" a unit of water from an origin to the destination specified in a column heading. These costs are derived from two other matrices, described in detail in a later example, which contain quality improvement and transportation cost data. These costs are annual per unit costs in dollars per acre foot of water delivered, and include capital, operation, and maintenance costs for water treatment, transportation, and distribution.

"System outflow" is not strictly a system requirement, but rather depends on the amount of consumptive use and losses in the system. It can be treated in the same manner as a class of transportation problems where the requirements are less than availabilities. In order to balance the availabilities and requirements, an additional destination, requiring $\Sigma a_i - \Sigma b_j > 0$ is specified, with zero allocation costs to this destination. However, in the case of water reuse, this destination is identified as system outflow, and effluent quality constraints can be imposed

Table 1. Water supply and use characteristics of an agro-urban system.

System	Primary Supply	Diversion Requirement	Effluent or Return Flow	Consumptive Use
	(in AF/Year)			
Primary Supply	401	-	-	-
Municipal		88	74	14
Industrial		124	87	37
Agricultural		270	103	167
Wildlife Refuge		141	65	76
TOTALS	401	623	329	294

Primary Supply - Consumptive Use & Losses = System Outflow
401 - 294 = 107

Destination / Origin	Municipal Req.	Industrial Req.	Ag. Req.	Wildlife Refuge Req.	System Outflow	Availabilities (1000 AF)
Primary Supply	30[a]	23	5	5	0	401
Municipal Effluent	135	56	10	51	46	74
Industrial Wastewater	115	39	10	29	29	87
Agriculture Return Flow	108	93	5	5	0	103
Wildlife Refuge Outflow	108	93	93	193	0	65
Requirements (1000 AF)	88	124	270	141	107	730

[a] Cost data are in dollars per acre-ft.

Figure 3. Transportation tableau for example problem.

by assigning a set of costs to the system outflow vector. For example, in Figure 3 municipal and industrial wastewater must be treated at a cost of $46 and $29 per acre foot respectively before it can be discharged to the system outflow. Water from other origins, already of sufficient quality, can be released to system outflow at no cost.

The minimum cost allocation for the problem, shown in Figure 4, is obtained by applying the simplex method of solution for linear programming. The allocation from each origin to each destination is indicated in the appropriate block in the matrix. The minimum total cost is $8,352,000. While the solution to this simplified example is rather apparent, it demonstrates manner of application of the transportation problem to a more complicated system. These applications are discussed in detail in a case study of the Salt Lake area presented later in the paper.

The Augmented Transportation Model

Several additional considerations should be incorporated into the basic transportation model in order to make it applicable to the problems common to real systems. Such problems include operation of water treatment and desalting plants, blending facilities, and limitations in the physical system which render some allocation infeasible. These considerations can be included without altering the basic structure of the "transportation model." This is done by augmenting the problem with additional sets of constraint equations. These considerations are described as follows:

Wastewater treatment operations. Water and wastewater treatment operations in the system include such facilities as primary and secondary treatment plants, tertiary treatment plants, and desalting plants. The transportation matrix tableau is augmented by adding a column vector denoting the treatment facility as a destination, and a row vector which indicates that the facility is also an origin of treated water.

Where vectors represent treatment plants of certain capacities that are either existing or proposed, the right-hand-side values, as constraints on the operation of the facility, are entered as less than or equal to the plant capacity. For cases in which optimal plant capacity and

Destinations Origins	Municipal Req.	Industrial Req.	Ag. Req.	Wildlife Refuge Req.	System Outflow	Availabilities (1000 AF)
Primary Supply	88	124	109	38	42	401
Municipal Effluent			74			74
Industrial Wastewater			87			87
Agriculture Return Flow				103		103
Wildlife Refuge Outflow					65	65
Requirements (1000 AF)	88	124	270	141	107	730

Minimum Total Cost = $8,352,000

Figure 4. Optimum allocations for example problem in thousands of acre-feet.

phasing-in of operations is to be determined, the right-hand-side values are entered as greater than or equal to zero. The system balance is maintained by stipulating that the inflow to the plant as a destination must equal the outflow from the treatment plant as an origin. For example in the problem structure shown in Figure 1, if the plant capacity is represented by column j and the plant production by row i, the following relationships are included in the augmented transportation problem:

$$\sum_{j=1}^{n} x_{ij} \begin{cases} \geq 0 \\ \leq a_i \end{cases} \quad \ldots\ldots\ldots (4)$$

$$\sum_{i=1}^{m} x_{ij} \begin{cases} \geq 0 \\ \leq b_j \end{cases} \quad \ldots\ldots\ldots (5)$$

$$\sum_{j=1}^{n} x_{ij} = \sum_{i=1}^{m} x_{ij} \quad \ldots (6)$$

and always, $\Sigma a_i = \Sigma b_j$, as equation (6) implies.

The transportation problem, augmented by this set of constraints, allows treatment operations to be used at the level required for cost minimization, while equation (6) maintains the system balance and preserves the basic character of the transportation problem. This flexible approach can provide insight into optimum design capacities of proposed treatment facilities for a system, or into the best levels of operation of existing facilities.

Blending operations. Blending operations, where water too high in TDS (total dissolved solids) to meet user quality requirements is mixed with a water low in TDS to produce a product of acceptable quality, can be handled in a manner similar to that for treatment facilities. The capacity and production of the blending operation is established as in equations (4) and (5), and the inflow-outflow balance is maintained by equation (6). One additional equation is included which specifies the blending ratio of the salty and the pure water. This is determined from the TDS of the water supply categories which can be allocated to blending. The general form of the equation is:

$$\Sigma(x_{ij})_{\text{salt sources}} = R \cdot \Sigma(x_{ij})_{\text{pure sources}} \quad \ldots\ldots (7)$$

where R is the ratio of pure water to salty water necessary to achieve an acceptable product quality.[1]

Infeasible allocations. In some cases limitations in the physical system may make it impossible to allocate water between some origins and destinations. Such limitations might include (1) the physical impossibility of transferring water from a particular source to a particular user, (2) social or political constraints preventing use of water directly from a source to a user, for example the use of untreated municipal effluent for irrigation, and (3) reasonable engineering judgments, for example recognizing already pure water from a groundwater source does not need wastewater treatment or desalting before use.

These limitations are recognized in the structure of the problem matrix by assigning an unrealistically high cost to the element representing such an allocation. The high cost associated with that particular combination will prevent any allocation from taking place.

Salt loading and reuse factor. In analyzing blending and desalting operations, under some conditions it may be important to determine the optimal system allocations based on maintaining the salt balance between each origin and destination. Where the TDS of the source water is too high, it could be reduced to acceptable levels by combining with a source of make-up water of better quality. Such a procedure might be used as an alternative to desalting brackish supplies, or as a means of determining whether the operation of a desalting plant in the system should serve as a source of water for direct allocation or as make-up water for blending.

The levels of sequential or recycle reuse allowable by each entity in order to maintain the salt balance can be determined in the manner suggested by Hendricks and Bagley (1969).

Summary of model structure

The model for the augmented transportation problem for water reuse is summarized in Figure 5. The structure of constraint equations and the types of availability and requirements are indicated for each of the water supply categories and use sectors. The special conditions for system balance and blending ratios are also specified.

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[1] For the purposes herein, equation (7) is sufficient to satisfy reasonable requirements in accuracy. For a rigorus solution to the blending ratio constraint, the salinity mass balance equation for the blending operation should be used. The allocative mix to the blending operation from the various origins having different salinity levels would be determined by means of a suboptimization problem, which is described as the "refinery problem." This would consist of a least cost allocation to the blending operation (the objective function); subject to the salinity mass balance consultant.

	Diversion Requirements 1 Mun · 2 Ind · ... Ag	Treatment Capacities .. Primary Second. · j Tertiary · .. Desalt · Blend	n System Outflow	Type of Control or RHS Value (Availabilities)
1 Primary Supplies	Rows: $\sum_{j=1}^{n} x_{1j} = a_1$	Columns: $\sum_{i=1}^{m} x_{i2} = b_2$		a_1=Availability
2 Supplementary Supplies				≤ Availability
. Secondary Supplies . Municipal Eff. . Industrial Wastewater Agriculture Return F.	Rows: $\sum_{i=1}^{n} x_{3j} = a_3$	Columns: $\sum_{i=1}^{m} x_{i3} = b_3$		$=\begin{cases}\text{Availability}\\ \text{(Diversion-CU)}\end{cases}$ Consumptive Use
i Treatment/or Blending Primary-Secondary . Tert. . Desalt m Blend	Rows: $\sum_{j=1}^{n} x_{ij} \begin{cases}\geq 0 \\ \leq a_i\end{cases}$ and Input = Output $\sum_{j=1}^{n} x_{ij} = \sum_{i=1}^{m} x_{ij}$	Columns: $\sum_{i=1}^{m} x_{ij} \begin{cases}\geq 0 \\ \leq b_j\end{cases}$		≥ 0 (No Plant Capacity Specified) ≤ Plant Capacity
m+1 Special Conditions . Blending Ratios . Salt Loading m+r	Σ Salty Sources = r_i Σ (Fresh Sources) r_i = ratio TDS of Salty Sources to Fresh Sources			
Type of Constraint or/RHS Value	= Requirements	≥0 (No Plant Capacity) ≤Plant Capacity	$= \sum_{i=1}^{n} a_i - \sum_{j=1}^{n} b_j$	Total Supply (or) Demand

Figure 5. Summary of model structure.

A Case Study: Water Reuse Model of the Salt Lake City, Utah, Area

A case study of the Salt Lake City, Utah, area is presented here (1) to demonstrate how the model is applied to an actual water reuse system, and (2) to show the utility and range of applications in water resources planning. The case study is intended to show methods and types of results; therefore data used in the model, while they are based on the best sources available for this type of cursory study, would require further refinement if the results were to be used for actual planning and decision making. However, the results obtained in the case study do indicate trends and orders of magnitude.

Construction of the model

Description of study area. The Salt Lake City area of north-central Utah is a major urban center in which varied uses of a limited water supply for municipal, industrial, agriculture, wildlife and recreation purposes all lie in close proximity. The study area includes Salt Lake County and most of Davis County to the north. The sources of primary water supply in the area are (1) the Jordan River, which originates at Utah Lake and enters the Salt Lake Valley at the South and flows 45 miles northward to the Great Salt Lake, (2) a number of streams flowing from the Wasatch Mountains on the East and some imported water from Deer Creek Reservoir, and (3) groundwater. Possible sources of imported water are not considered in this study.

The 1965 population of the area was estimated at 500,000. The trend is toward industrial development and continuing population growth. Mining and manufacturing are the principal industries of the area, but agriculture still plays a major role in the valley in terms of water use.

Water supply and demand quantities. The water supply and demand quantities for the study area are described as follows:

1. *Primary water supply availabilities:* Three primary sources make up the base supply of

Table 2. Summary of water use projections through 2020.

	Diversion Requirement				Secondary Supply Effluent Return Flow				Consumptive Use[d]			
	1965[a]	1980[b]	2000[b]	2020[b]	1965[a]	1980[c]	2000[c]	2020[c]	1965	1980	2000	2020
Municipal	88	165	253	341	74	139	213	287	14	26	40	54
Industrial	124	204	290	376	87	143	203	263	37	61	87	113
Agricultural	270	224	209	194	103	86	80	74	167	138	129	120
Bird Refuge[a]	141	141	141	141	65	65	65	65	76	76	76	76
Totals	623	734	893	1052	329	433	561	689	294	301	332	363

[a] See Appendix A.

[b] From Harline (1963).

[c] Projection for 1980, 2000, and 2020 are made using same ratio of diversion to return flow as in the 1965 data.

[d] Calculated diversion minus return flow.

water in the system model. The quantities of water from each of these sources are:

a. surface water supplies from small streams on the Wasatch front ------------------ 83,000 AF
b. present level of groundwater use ------------------- 48,000 AF
c. the Jordan River supply--- 270,000 AF
Total Primary Supply-------- 401,000 AF

Supporting data for supply availabilities are given in Appendix A.

2. *Diversion requirements:* The diversion requirements needed to satisfy the demand by each of the water use sectors in the model are summarized in Table 2. The table contains projected requirements for target demand years out to the year 2020.
3. *Secondary supplies:* The secondary supplies consist of user effluents or return flows from the municipal, industrial, and agricultural sectors, as well as the Farmington Bay Bird refuge. This information is also presented in Table 2.
4. *Consumptive use.* The consumptive use, calculated from the other data in Table 2, is simply diversions minus the effluent or return flow.
5. *System outflow.* The difference between the total primary or base supply of 401,000 AF and the total consumptive use calculated in Table 2 is the system outflow. This is shown for the projected years in Table 3. This represents water flowing from the study area into the Great Salt Lake.

Table 3. Primary water supply consumptive use and system outflow in 1000's AF.

	1965	1980	2000	2020
Primary Supply	401	401	401	401
Consumptive Use	294	301	332	362
System Outflow	107	100	69	38

Influent and effluent qualities. The differences in quality between water available from each supply origin and water required by each demand destination are tabulated in a matrix of water quality differences, Δq_{ij}, in Figures 6 and 7. This provides the basis for determining the treatment costs necessary to match each source with its possible uses. The two quality criterion considered to be critical in this study are biological oxygen demand (BOD) and total dissolved solids (TDS). Both of these quality criteria must be satisfied in allocating water from a source to a user. The matrix of Figure 6 contains nominal values for BOD in the primary and secondary water sources, and the BOD quality requirement for each water

Demand Distinations / Supply Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Treatment	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Supply Source Quality (BOD mg/l)
	Required BOD Removal									
Surface Water Supply	20	<0	<0	<0	0	<0	20	0	0	20
Groundwater Supply	0	<0	<0	<0	<0	<0	0	20	<0	0
Jordan River Supply	20	<0	<0	<0	0	20	20	0	0	20
Municipal Effluent	300	270	0	280	300	300	300	280	280	300
Industrial Effluent	300	270	0	280	300	300	300	280	280	300
Agricultural Return Flow	5	<0	<0	<0	5	5	5	<0	<0	5
Secondary Treatment	20	<0	<0	<0	0	80	20	0	0	20
Tertiary Treatment	0	<0	<0	<0	N/A	0	0	<0	<0	0
Desalting	0	<0	<0	<0	0	0	0	<0	<0	0
Blending	0	<0	<0	<0	0	0	0	<0	<0	0
Bird Refuge	20	<0	<0	0	20	20	20	0	0	20
Influent Requirement or Treated Product Quality (BOD mg/l)	0	30	300	20	0	0	0	20	20	

Figure 6. Matrix of water quality differences for BOD in mg/l.

use sector. The elements of the matrix indicate the amount of BOD that must be removed from the water source in order to meet the quality requirements of a given use. If the BOD quality requirement is already met, this value is zero. Thus, the matrix gives the initial and terminal BOD numbers between any origin and destination, and the required BOD removal, as a basis for determining the necessary treatment processes and estimating treatment costs.

Figure 7 presents the same type of information for TDS. The matrix indicates nominal values for the salt content of the water sources, and the allowable TDS for the water uses. The difference between initial and terminal values for TDS between any supply origin and demand destination indicates whether desalting or blending is required, and provides a basis for estimating costs.

Water costs. The water quality analysis given by the matrices of Figures 6 and 7, and the supply and demand quantities from Tables 2 and 3 provide the necessary information for specifying the treatment required, whether conventional, tertiary, or desalting, and for estimating commensurate unit costs to make water available between all combinations of supply origin and use sectors. When applicable, the costs of pumping, transporting, and deliv-

Destinations Demand / Supply Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondaray Treatment	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Supply Source Quality (BOD mg/l)
	Required TDS Removal									
Surface Water Supply	<0	<0	<0	<0	<0	N/A	<0	<0	<0	300
Groundwater Supply	<0	<0	<0	<0	<0	N/A	<0	<0	<0	300
Jordan River Supply	300	0	<0	<0	<0	790	300	<0	<0	800
Municipal Effluent	400	100	0	<0	<0	890	400	<0	<0	900
Industrial Effluent	400	100	0	<0	<0	890	400	<0		0
Agricultural Return Flow	500	200	100	<0	<0	990	500	<0	<0	1000
Secondary Treatment	500	200	100	<0	<0	990	500	<0	<0	1000
Tertiary Treatment	400	100	0	<0	<0	890	400	<0		0
Desalting	<0	<0	<0	<0	<0	N/A	<0	<0	<0	10
Blending	0	<0	<0	<0	<0	N/A	<0	<0	<0	500
Bird Refuge	1000	700	600	<0	<0	1490	1000	<0	<0	1500
TDS Influent Requirement or Treated Product Quality (TDS mg/l)	500	800	900	2000	2000	10	500	3000	1500	

Figure 7. Matrix of water quality differences for TDS in mg/l.

ering the water are included. The cost data are presented in the "transportation tableau" of Figure 8. Documentation of unit cost data is given in Appendix B. Where allocations between a source of supply and a demand sector are infeasible, a unit cost of $1,000 per acre-foot is entered. For the purposes of this study it was assumed that all costs are constant; they are average costs. Actually, costs will vary with the quantity of water and level of treatment required. This can be taken into account in the model analysis through iterative solutions obtained by updating cost figures for sensitive variables.

Investigation of water reuse system alternatives

With the flexibility of the reuse model and the operations research techniques used in conjunction with linear programming, a number of investigations can be per-

Supply Origins \ Demand Destinations	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Treatment	Tertiary Treatment[e]	Desalting[d]	Blending	Bird Refuge	System Outflow	Available Supply (1000 AF)
	Water Allocation Costs $/AF									
Surface Water[b] Supply	38[a]	38	5	1000	1000	1000	38	5	0	83
Groundwater[b] Supply	23	23	10	1000	1000	1000	23	10	0	48
Jordan River Supply	108	10[b]	5[b]	1000	30	59	1000	0	0	270
Municipal[c] Effluent	135[d]	56	51	46	77	105	1000	46	46	74
Industrial Effluent	115[d]	39	10	29	1000	88	1000	29	29	87
Agricultural Return Flow	108[d]	93	5	1000	30	59	1000	5	0	103
Secondary Treatment	80[d]	10	5	1000	33	59	1000	5	0	50
Tertiary Treatment	1000	1000	10	1000	1000	1000	11	0	0	100
Desalting[d]	15	10	5	1000	1000	1000	11	5	0	56
Blending	0	0	5	1000	1000	1000	1000	5	0	100
Bird Refuge	1000	1000	1000	1000	1000	59	1000	1000	0	65
Demand Requirement (1000 AF)	88	124	270	50	100	56	100	141	107	

[a] Cost in dollars per acre-ft.

[b] Milligan, Andersen, and Clyde (1970).

[c] Weighted cost of municipal treatment based upon writers' analysis of data in the publication, "Industrial Wastewater Facilities in Utah," Utah State Department of Health, 1966.

[d] Haycock, Shiozawa, and Roberts (no date given).

[e] All other cost data from Smith (1969).

Figure 8. Transportation model tableau.

formed to evaluate water reuse system alternatives. Such investigations are accomplished through appropriate changes in one or more of the three basic model components: (1) The right hand-side values of the constraint equations, (2) the cost coefficients of the objective function, and (3) the coefficients of variables in the constraint equations which describe the structural relationships of the problem. As an aid in manipulating components of the model, techniques of sensitivity analysis and parametric programming are available. Results of the case study investigations are offered here as examples of the types of analysis that can be performed, and the information and evaluations for planning decisions that can be derived.

A comparative study of optimal system configurations in general seeks to answer the question: What is the optimal allocation pattern given the conditions for operating the system? For example, one may desire to know the allocations at present levels of demand and the changes in the allocation pattern as demands increase to projected levels in the future, assuming that the primary water supply cannot be expanded. A similar study could be carried out allowing for possible importation of supplementary water supplies. Another important study might center on the operation of various types of treatment facilities in the system including conventional, tertiary, desalting and blending operations. This type of investigation would include optimal allocation patterns assuming certain locations and capacities for various treatment plants, and what should be the design capacity and timing of construction of possible treatment operations.

Plant design capacities and construction timing

This section discusses the results of the model investigation on plant design capacity and construction timing. The treatment and blending operations were entered as constraints of greater than or equal to zero. This allows treatment operations to be brought in at any level consistent with the minimum cost allocation. Figures 9, 10, 11, and 12 show the allocation patterns for demand at 1965, 1980, 2000, and 2020 levels, assuming no expansion of the primary water supply. Part A of each figure presents the optimal allocation pattern in matrix form, and part B shows the corresponding flow diagram.

In 1965 (see Figure 9) no allocation was made to any of the treatment and blending operations. In other words, with present supplies at 1965 demands, the use of any treatment operations to reclaim effluent water for reuse is not required. If they were incorporated into the system the result would be increased water costs. Rather, municipal industrial requirements are satisfied from primary sources and agricultural requirements are met by sequential use of effluent from municipal and industrial systems, and recycling of irrigation return flow.

However, as Figure 10 indicates, in order to satisfy the 1980 municipal requirements the minimum cost allocation brings a tertiary treatment process into the optimal solution at a level of 34,000 acre feet annually. The influent to the plant, water from Jordan River and irrigation return flow, with TDS of 1000 mgl is blended in a one to one ratio with the surface water supply of low TDS to produce a quality water acceptable for the municipal system. Hence, careful consideration ought to be given to the use of a tertiary treatment and blending operation with a minimum capacity of 34,000 acre feet for meeting expected demand in 1980.

Examination of Figure 11 for the year 2000 indicates that the 1980 trend has continued to increase with municipal demands being met almost entirely by mixing tertiary treated Jordan River water and irrigation return flow with surface water and groundwater supplies. Industrial requirements are satisfied by sequential use of municipal effluent, and agriculture demands by the use of industrial effluent.

Finally at 2020 levels, as surface water and groundwater supplies are entirely used up in the blending operation, a desalting plant is brought into the minimum cost basis to supply the additional blending water required to meet the municipal demand. This suggests, then, that the future water planning should include consideration of a desalting plant with minimum capacity of 39,500 acre feet annually prior to 2020. Parametric analysis shows the plant should be phased-in just after the turn of the century because of the continuous nature of the demand function.

The particular analysis described in the previous paragraphs points up three useful aspects of the reuse model and the information it provides:

1. It indicates the optimum sequential and recycle reuse allocation from the primary and secondary sources of supply to satisfy user requirements.
2. Given a constant water supply and the projections of increased future demands, it points up the types of treatment process for water reuse to meet demands at the least cost.
3. The least cost allocation indicates as part of the solution the required capacities for treatment facilities and through parametric analysis the time at which they should be phased into the system.

System evaluation with specified plant capacities. In situations where a system presently includes treatment operations of given capacities, or where particular treatment facilities of certain capacities are proposed, an evaluation of optimal water reuse can be made by entering treatment operations with constraints of less than or equal to specified plant capacities.

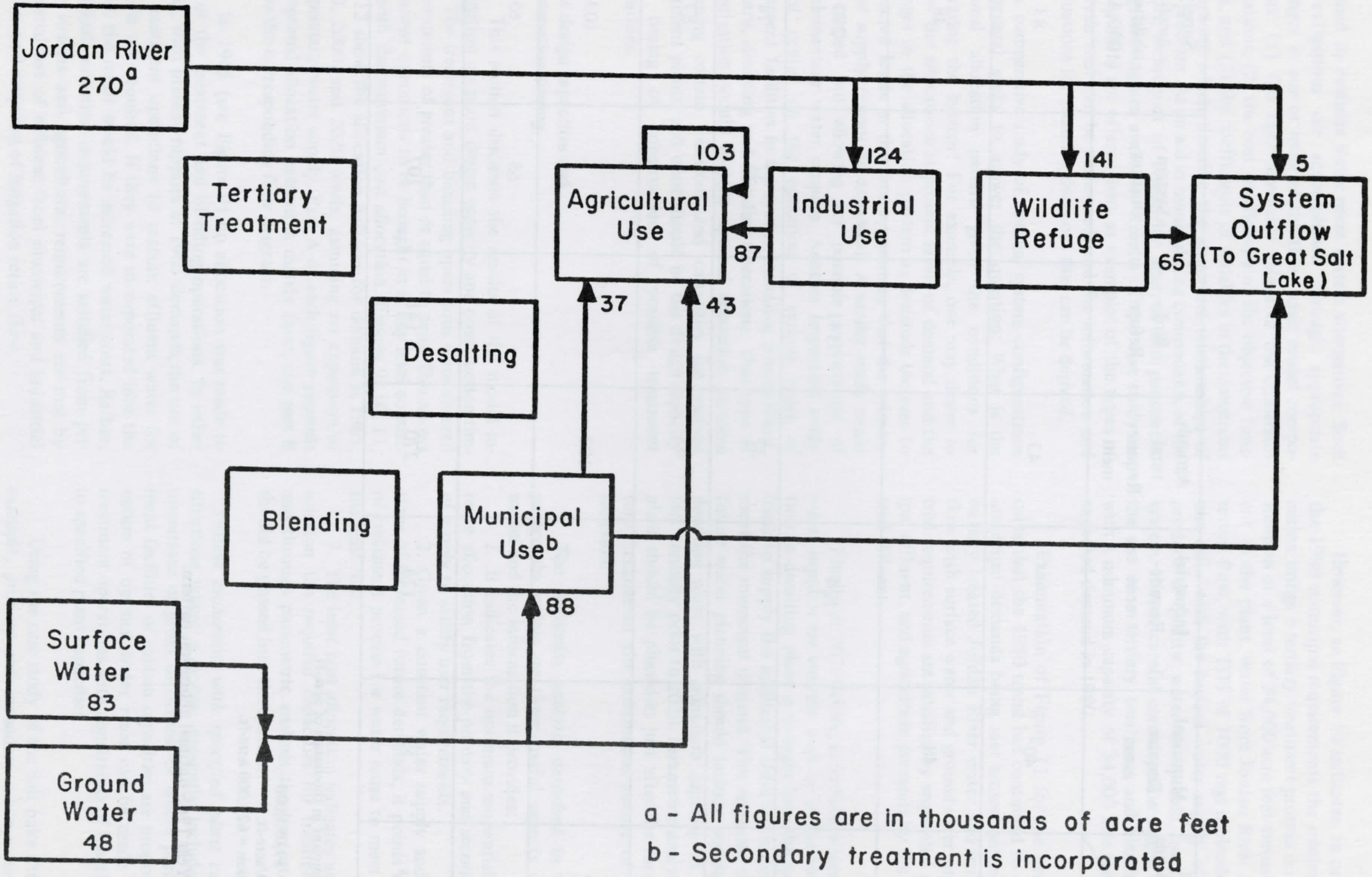
Using the case study of the Salt Lake City area as an example, primary and secondary waste water treatment

Demand Destinations / Supply Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Bird Refuge	System Outflow	Supply Availabilities (1000 AF)
Surface Water Supply	40[a]		43			83
Groundwater Supply	48					48
Jordan River Supply		124		141	5	270
Municipal Effluent			37		37	74
Industrial Effluent			87			87
Agricultural Return Flow			103			103
Bird Refuge					65	65
Demand Requirements (1000 AF)	88	124	270	141	107	

[a] Allocation amount in thousands of acre-ft.

Total Cost = $9,053,000
or $14.50/acre-ft.
Total Diversion = 623,000 acre-ft.

Figure 9A. Year 1965 optimal allocation pattern.



a - All figures are in thousands of acre feet

b - Secondary treatment is incorporated

Figure 9B. Year 1965 optimal allocation pattern.

Demand Destinations Supply Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Treatment	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Available Supply (1000 AF)
Surface Water Supply	49						34			83
Groundwater Supply	48									48
Jordan River Supply		100			29			141		270
Municipal Effluent		104							35	139
Industrial Effluent			143							143
Agricultural Return Flow			81		5					86
Secondary Treatment										
Tertiary Treatment							34			34
Desalting										
Blending	68									68
Bird Refuge									65	65
Demand Requirement	165	204	224		34		68	141	100	

Total Cost = $15,921,000
Total Diversions = 734,000 AF
Unit Cost = $21.60/AF

Figure 10A. Year 1980 allocation pattern with no constraint on treatment plant capacities.

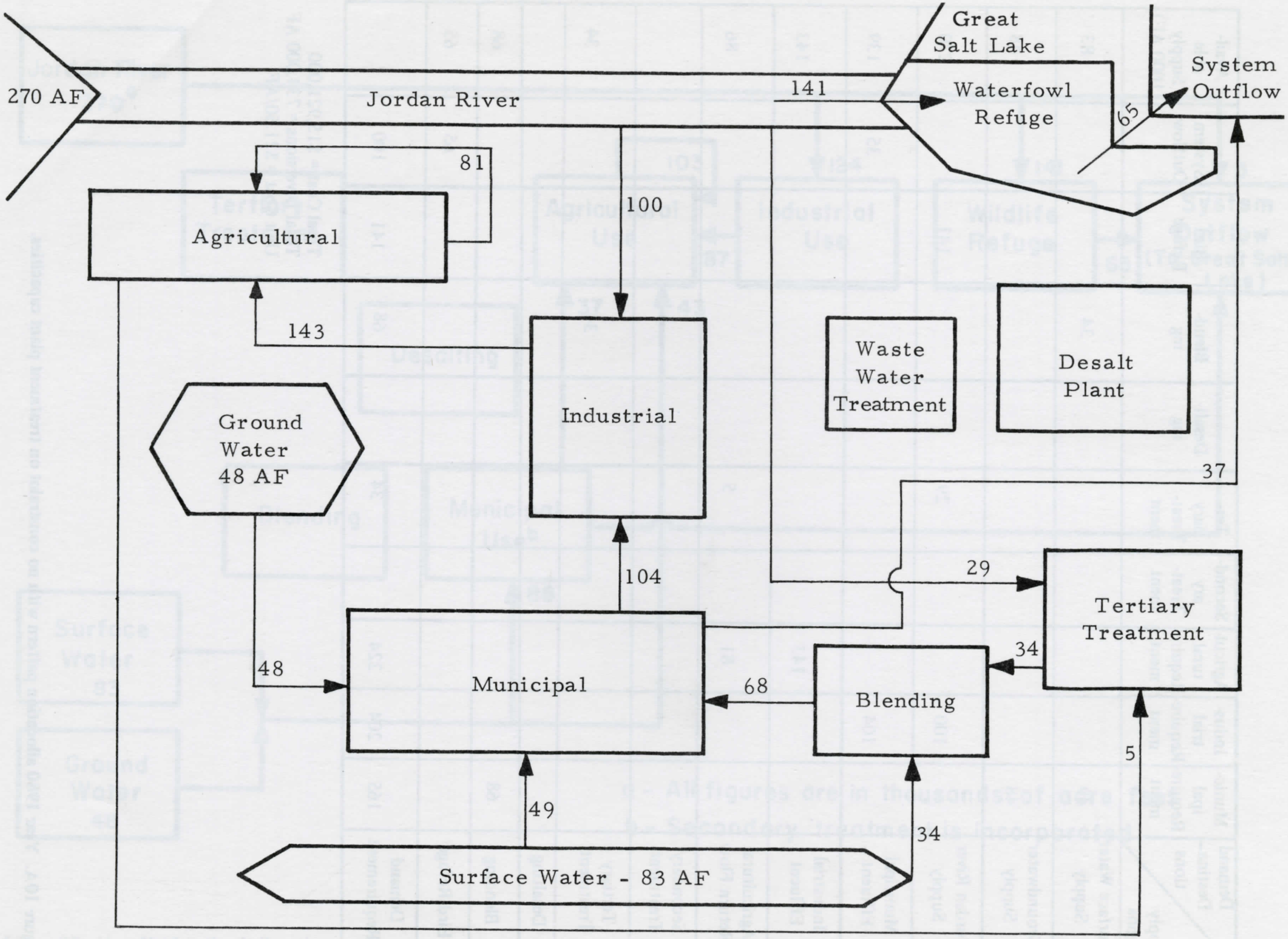


Figure 10B. Year 1980 allocation with constrained (or) unconstrained treatment capacities.

Demand Destinations / Supply Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Treatment	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Available Supply (1000 AF)
Surface Water Supply							83			83
Groundwater Supply	9				48		39			48
Jordan River Supply		81						141		270
Municipal Effluent		209							4	213
Industrial Effluent			203							203
Agricultural Return Flow			6		74					80
Secondary Treatment										0
Tertiary Treatment							122			122
Desalting										0
Blending	244									244
Bird Refuge									65	65
Demand Requirement	253	290	209	0	122	0	244	141	69	

Total Cost = $24,018,000
Total Diversions = 893,000 AF
Unit Cost = $26.90/AF

Figure 11A. Year 2000 allocation pattern with no constraint on treatment plant capacities.

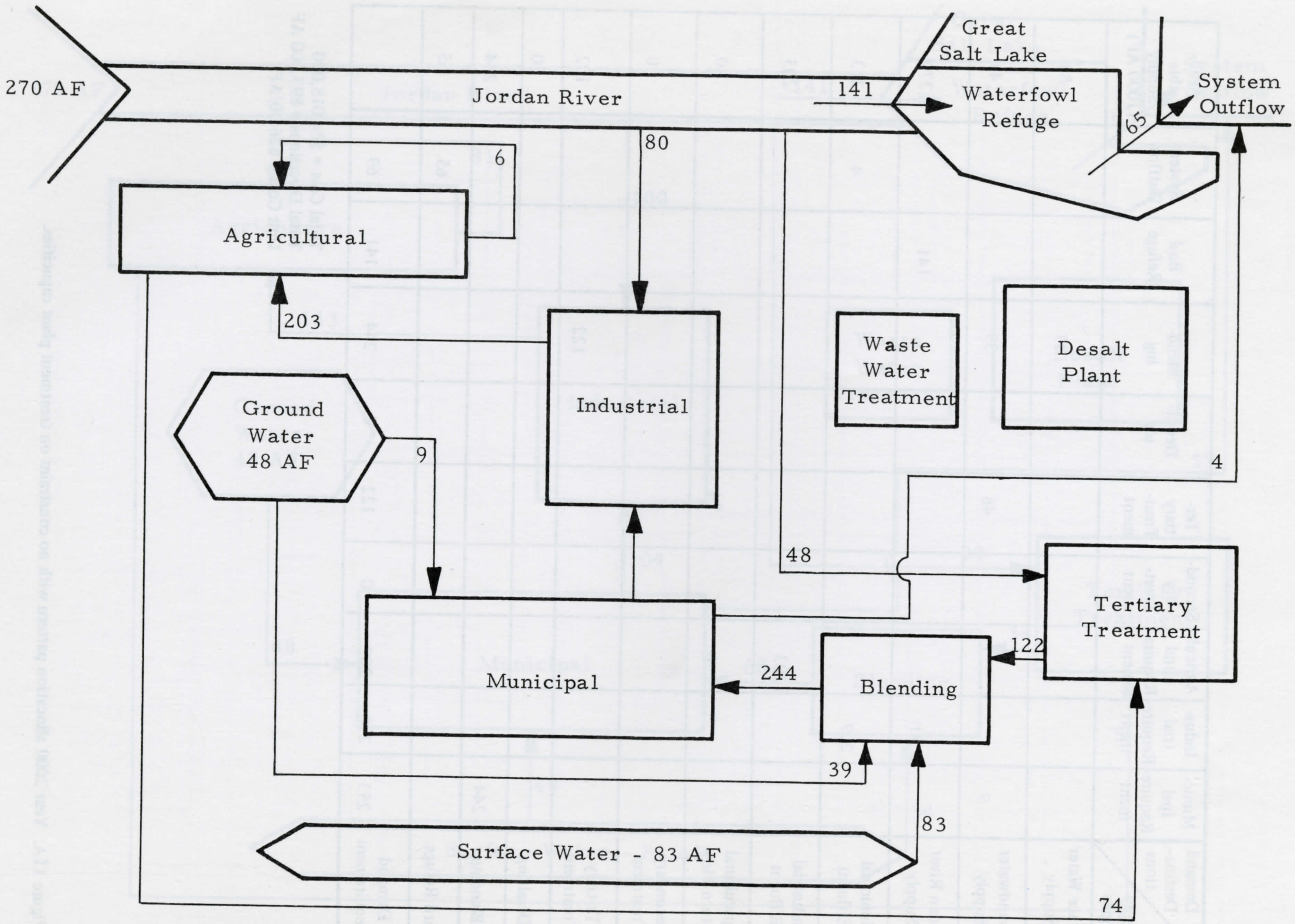
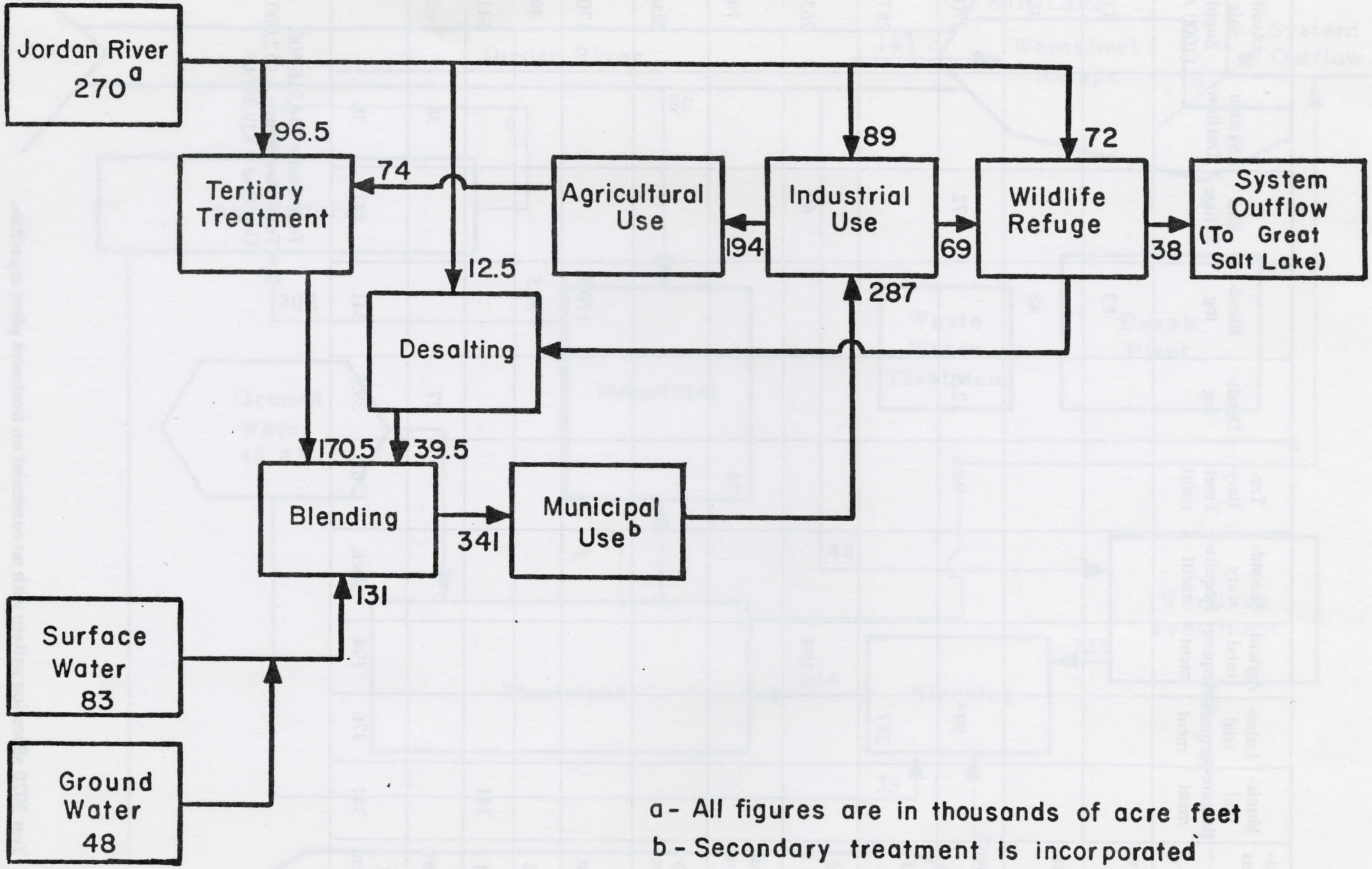


Figure 11B. Year 2000 allocation with no constraints on treatment plant capacity.

Destinations / Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Requirement	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Available Supply (1000 AF)
Surface Water Supply							83			83
Groundwater Supply							48			48
Jordan River Supply		89[a]			96.5	12.5		72		270
Municipal Effluent		287								287
Industrial Effluent			194					69		263
Agricultural Return Flow					74					74
Secondary Treatment										Slack
Tertiary Treatment							170.5			170.5
Desalting							39.5			39.5
Blending	341									341
Bird Refuge						27			38	65
Demand Requirement	341	376	194	slack	170.5	39.5	341	141	38	

Total Cost = $34,916,500
Total Diversions = 1,052,000 AF
Unit Cost = $33.20/AF

Figure 12A. Year 2020 allocation pattern with no constraint on treatment plant capacities.



a - All figures are in thousands of acre feet

b - Secondary treatment is incorporated

Figure 12B. Year 2020 optimal allocation pattern.

are entered at a capacity of 50,000 acre feet, tertiary treatment and blending at 100,000 acre feet, and the desalting plant at 56,000 acre feet annually.

The allocation for present and 1980 conditions, of course, remained the same as those indicated in Figures 9 and 10, since there was no allocation to treatment operations or else they were used at less than capacity. However, by the year 2000, the effects of the capacity limitation on treatment facilities become apparent. As Figure 13 shows, the teritary treatment and desalting plants are used to capacity. Furthermore, 16,000 acre feet of municipal wastewater is recycled in the municipal system in order to meet demands. Such recycling implies, of course, tertiary treatment and desalting or blending, indicating the need for expanding the capacities for these types of operations.

Figure 14 for the year 2020, shows a continuation and intensification of the 2000 trends which, in addition to a larger amount of municipal recycle, also requires sequential reuse of water from industrial effluents and wastewater treatment plants. These allocations again imply the need for complete treatment including desalting or blending.

Examination of these allocations, then, indicate to the decision maker what expansion of facilities will be necessary in the future if treatment operations represent presently installed capacities. If they represent proposed plants in the system, then this provides an evaluation of design capacities and time for phasing into the system.

Summary

The case study described here, with its particular conditions, emphasizes three aspects of the reuse model and the information it provides. This example has:

1. Indicated how sequential and recycle allocation can be made from primary and secondary sources of supply to water use destinations for the least cost.
2. Projected increasing future demands against a constant water supply and then cited the types of treatments that could rehabilitate water for reuse to meet demands at the least cost.
3. Established a least cost allocation that incorporates the required capacities for treatment facilities and indicates the times when they should be phased-in to the system.

Destinations / Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Treatment	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Available Supply (1000 AF)
Surface Water Supply	83									83
Groundwater Supply	48									48
Jordan River Supply		97				32		141		270
Municipal Effluent	16	193							4	213
Industrial Effluent			203							203
Agricultural Return Flow			6		50	24				80
Secondary Treatment										Slack (50)
Tertiary Treatment							50			50
Desalting	6						50			56
Blending	100									100
Bird Refuge									65	65
Demand Requirements	253	290	209	Slack (50)	50	56	100	141	69	

Total Cost = $26,434,000
Total Diversions = 893,000 AF
Unit Cost = 29.60/AF

Figure 13A. Year 2000 allocation pattern for fixed capacities on treatment plants; 50:50 blend ratio.

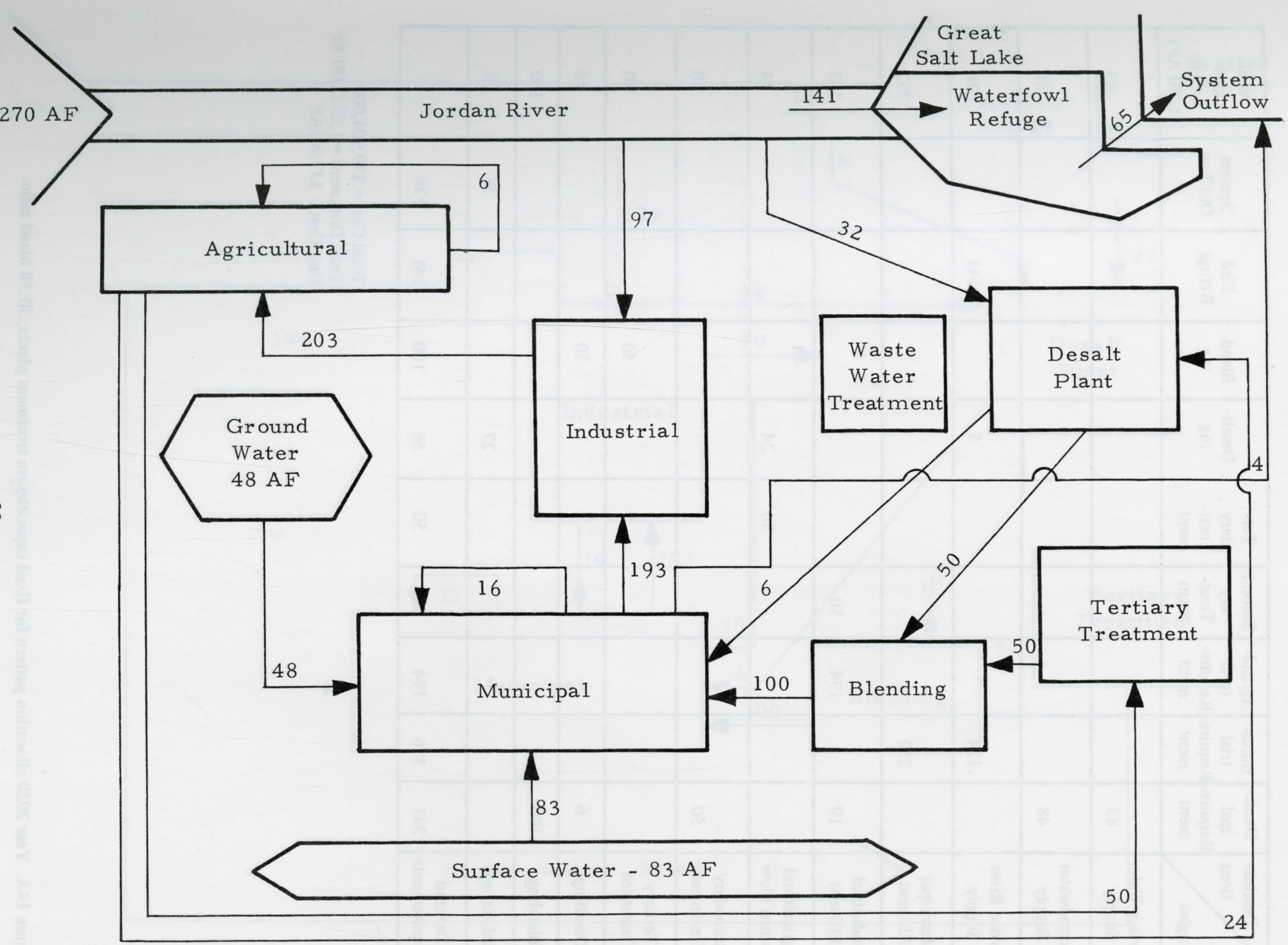


Figure 13B. Year 2000 allocation with constraints on treatment plant capacity.

Destinations Origins	Municipal Requirement	Industrial Requirement	Agricultural Requirement	Secondary Treatment	Tertiary Treatment	Desalting	Blending	Bird Refuge	System Outflow	Available Supply (1000 AF)
Surface Water Supply	83									83
Groundwater Supply	48									48
Jordan River Supply		124				5		141		270
Municipal Effluent		252								252
Industrial Effluent	19		194	50						263
Agricultural Return Flow					50	24				74
Secondary Treatment	50									50
Tertiary Treatment							50			50
Desalting	6						50			56
Blending	100									100
Bird Refuge						27			38	65
Demand Requirements	341	376	194	50	50	56	100	141	38	

Total Cost = $39,904,000
Total Diversions = 1,052,000 AF
Unit Cost = $37.90/AF

Figure 14A. Year 2020 allocation pattern for fixed capacities on treatment plants; 50:50 blend ratio.

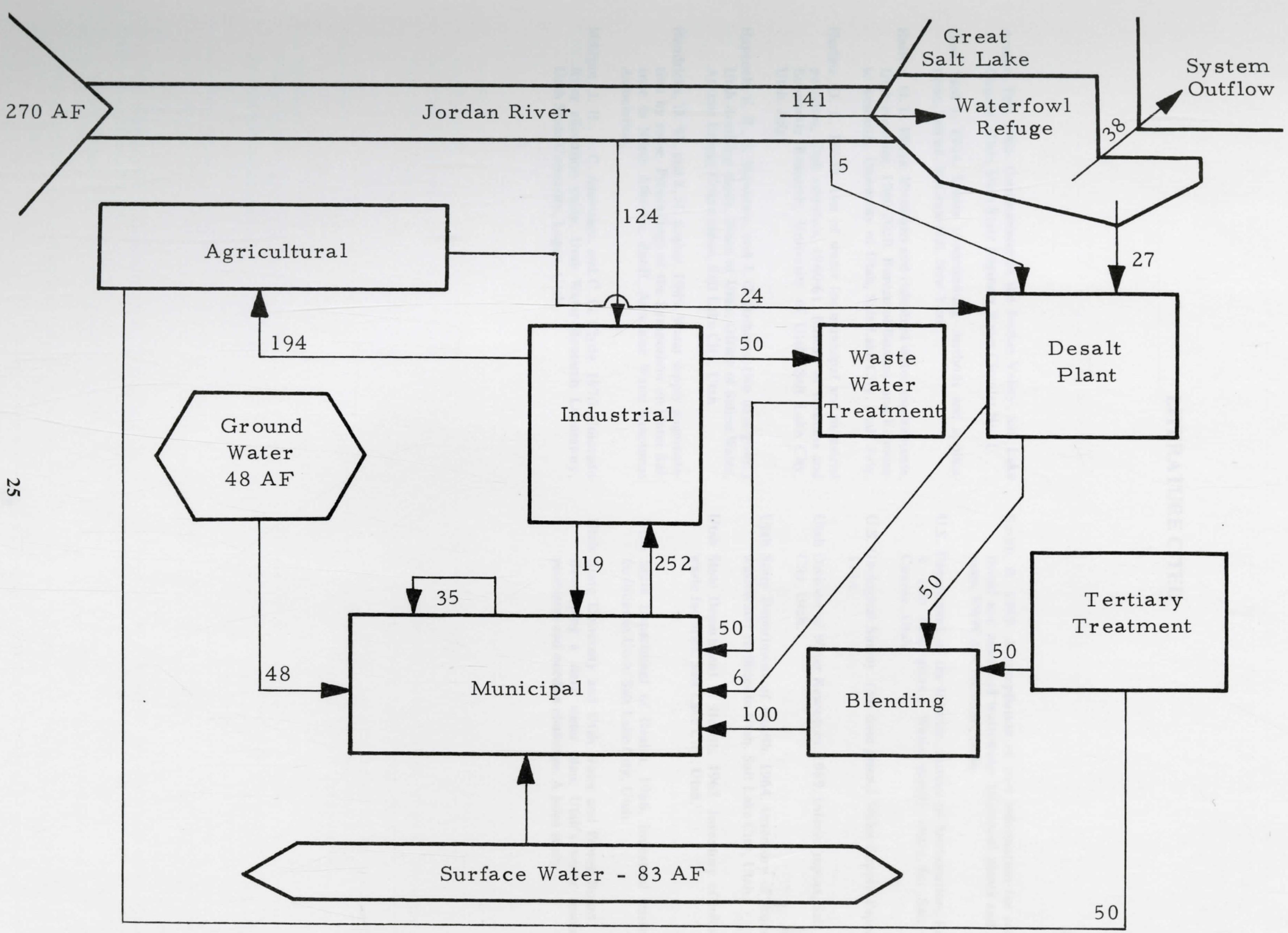


Figure 14B. Year 2020 allocation with constraints on treatment plant capacity.

LITERATURE CITED

Arnow, Ted. 1965. Groundwater in the Jordan Valley, Salt Lake County, Utah. Utah State Engineer Water Circular No. 1.

Gass, Saul I. 1964. Linear programming–methods and applications. 2nd ed. McGraw-Hill, New York.

Harline, O. L. 1963a. Municipal and industrial water requirements, Utah counties, 1960-2020. Bureau of Business and Economic Research, University of Utah, Salt Lake City, Utah. July.

Harline, O. L. 1963b. Use of water for municipal and industrial purposes, Utah counties, 1960-61. Bureau of Business and Economic Research, University of Utah, Salt Lake City, Utah. July.

Haycock, E. B., S. Shiozawa, and J. O. Roberts. (No date given.) Utah desalting study. State of Utah, Office of Saline Water, Atomic Energy Commission. Salt Lake City, Utah.

Hendricks, D. W., and J. M. Bagley. 1969. Water supply augmentation by reuse. Proceedings of the Symposium on Water Balance in North America, Banff, American Water Resources Association.

Milligan, J. H., J. C. Andersen, and C. G. Clyde. 1970. Colorado River allocation study. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Smith, R. 1969. A compilation of cost information for conventional and advanced wastewater treatment plants and processes. FWPCA, Cincinnati, Ohio.

U.S. Department of the Interior, Bureau of Reclamation, Region 4. (No date given.) Water supply study for Salt Lake County, Utah.

U.S. Geological Survey. (No date given.) Water Supply Paper No. 1714.

Utah Division of Water Resources. 1969. Interim report. Salt Lake City, Utah.

Utah State Department of Health. 1964. Inventory of municipal wastewater facilities in Utah. Salt Lake City, Utah.

Utah State Department of Health. 1965. Inventory of industrial waste facilities. Salt Lake City, Utah.

Utah State Department of Health. 1966. Industrial wastewater facilities in Utah. Salt Lake City, Utah.

Utah State University and Utah Water and Power Board. 1963. Developing a state water plan, Utah's water resources–problems and needs a challenge. A joint study.

APPENDIX A:

WATER SUPPLY AND DEMAND DATA

This appendix summarizes and documents the water supply and demand figures used in the water reuse model of the Salt Lake County, Utah, area.

Primary Water Supply (Present-1965 Figures)

The base supply of water presently developed for the Salt Lake and Davis County areas is divided into three sources in order to identify the origin and quality of the water. These are (1) the local surface water supplies for the public water systems, (2) the Jordan River, and (3) presently developed groundwater. These data are summarized in Table A-1.

Table A-1. Annual primary water supply available.

Source		Amount (AF)
Surface Water:		
Local Creeks	48,800	
Mt. Dell Reservoir	700	
Provo River Project	33,500	
	83,000	83,000[a]
Jordan River		270,000[b]
Groundwater:		
Public Water Supply System	11,000[a]	
Private Industrial Sources	37,000[c]	
	48,000	48,000

[a] U.S. Department of the Interior, Bureau of Reclamation–Region 4 (no date given) p. 5.

[b] U.S. Geological Survey (no date given) Water Supply Paper No. 1714.

[c] Bureau of Reclamation–Region 4. Water Supply Study for Salt Lake County, Utah. p. 6.

Municipal and Industrial Diversions, Consumptive Use and Effluent Flow

The municipal and industrial water diversion requirements are summarized in Table A-2, along with the effluent from each of these systems which could be made available for reuse. The effluent flows of Table A-2 are not completely accurate, since some industrial users dump wastewater into the municipal sewage system. The final figures for effluent flow adjusted on the basis of Utah State Department of Health data to reflect this, are presented in Table A-3.

Table A-2. Municipal and industrial water use.

System	Diversions	Effluent	Consumptive Use
Municipal	88,222	77,400[b]	10,822
Industrial			
Public supply	12,121		
Self-supply	111,716		
	123,837[a]	84,000[c]	39,837

[a] Harline (1963a) p. 21 (Table 2) and p. 25 (Table 5).

[b] Utah State Department of Health (1964).

[c] Since no specific figure was available, this number was derived from related data as follows: Haycock et al. (1968, p. 24) give total M & I diversions for the Jordan River drainage (Salt Lake, Davis, and Utah Counties) as 331,000 AF, with a consumptive use of 85,000 AF. According to Harline (1963, p. 21, 25) total diversions are 310,133 AF. Proportioning the Haycock figures down to the levels of Harline gives a consumptive use of 80,000 AF, leaving a difference of 230,000 AF as effluent for the M & I system. Utah State Health Department (1964) indicates that 97,700 AF is effluent from the municipal system, leaving the remaining 132,300 as effluent from industrial uses. Harline et al. (1963) places industrial diversions in the Salt Lake-Davis County area as 123,837 AF, and in the Utah County area at 71,430 AF. Assuming the same proportion of diversion to effluent exists in both areas, the effluent for the Salt Lake-Davis area is:

$$\frac{123,857}{123,857 + 71,430} \times 132,300 = 84,000 \text{ AF}$$

Incomplete data from Utah State Health Department place industrial effluent at 26,367 AF/yr.

Table A-3. Effluent flow from M & I (corrected).

System	Effluent Flow	Adjustment	Corrected Effluent Flow
Municipal	77,400[a]	-3,215[b]	74,185
Industrial	84,000	---	84,000

[a] Table A-2.

[b] Utah State Department of Health (1965).

Agriculture Diversions and Return Flow

The irrigation diversions for the Lower Jordan were calculated from data in Division of Water Resources, Interim Report, May 1969, pp. E-6, as follows:

Total irrigation diversion	797,000
(Less) Upper basin irrigation diversion	527,000
Lower Jordan Irrigation Div.	270,000

Data on the water actually available in the lower Jordan is given in Table A-4 below.

Table A-4. Flow in Lower Jordan River.

Jordan River at Jordan Narrows	269,000 AF
Underflow through Jordan Narrows[a]	29,000 AF
Inflow of tributaries (Cottonwood, etc.)[b]	10,630 AF 50,670 AF 42,440 AF
Total	401,740 AF

---

[a] Arnow (1965). p. 10. States the underflow through Jordan Narrow is 40 cfs. This yields 29,000 AF/yr.

[b] "Developing a State Water Plan" (1963), p. 12.

The flow of the river in the lower reach (at 21st South Street), where it is still possible to capture water for reuse is 234,700 acre feet (USGS WSP No. 1714). Using this figure, the manner of deducing the irrigation return flow is shown by the following calculations:

Water Available in Lower Jordan	401,740
(Less) Diversions for Irrigation	270,000
Residual Flow in Stream	131,740

then,

Gaged Flow at 21st S.	234,700
(less) Residual Flow in Stream	131,740
Return Flow	102,960

The return flow figure is also substantiated by the following information. Arnow (1965, p. 10) states the groundwater inflow to Jordan River between the Jordan Narrows and Great Salt Lake is 180,000 af/year. Of that 23,000 af/year enters tributaries below gaging stations in the canyon mouths. The remainder, therefore, can be attributed to return flow. Hence:

Groundwater Inflow to Jordan		180,000
Underground Flow at Narrows	29,000	
Flow from Tributaries	23,000	52,000
Return Flow		128,000 af/year

Farmington Bay Bird Refuge

The water diversion requirements and consumptive use of the Farmington Bay Bird Refuge were obtained through conversations with Mr. Reuben Dietz, manager of the refuge, on January 8, 1970. The refuge consists of a total of 10,600 acres, of which 8,040 are presently developed with another 2560 acres to be added in the Crystal Spring Creek Unit. The water supply is derived from three sources, Jordan River, Jordan River Surplus Canal, and Spring Creek. Between 60 and 70 cfs is diverted from each of these sources. The consumptive use requirement for maintaining the refuge is 1 cfs per 100 acres. The diversion requirement, consumptive use, and outflow are calculated as follows:

Total diversion = 65 cfs x 1.98 af/cfs-day x 365 days/year x 3 diversions

= 141,000 af/year

Consumptive use = 1 cfs/100 acres x 10,600 acres x 1.98 af/cfs-day x 365 d

= 76,600 af/year

Outflow to Salt Lake = 141,000 - 76,600 = 64,400

APPENDIX B

WATER QUALITY SPECIFICATIONS AND COMPUTATION OF TREATMENT AND DELIVERY COSTS

This appendix summarizes the specifications for treatment necessary to make water available from the origins of supply to each demand sector. These data are summarized for each of the primary and secondary supply sources in the case study area in two tables:

a. Quality specifications for BOD and TDS removal and the maximum quantity of water to be treated.

b. Unit water costs, including treatment costs to meet required quality specifications, and costs for collection, conveyance and distribution.

Cost data from Smith (1969) are used to compute total treatment and conveyance costs.

Supply Origin: Jordan River

Table B-1a. Quality and quantity specifications.

Sector of Use	BOD			TDS			Quantity[a]	
	Source Level	Required Level	Amount Removed	Source Level	Req'd Level	Amount Removed	mg/d	1000 af/yr.
Municipal	20	0	20	800	500	300	78	88
Industrial	20	30	0	800	800	0		
Agriculture	20	300	0	800	900	0		
Secondary Treatment	20	20	0	800	2000	0		
Tertiary Treatment	20	0	20	800	2000	0	44.5	50
Desalting	20	1000	20	800	10	790	25	

[a] As required when no specific figure is given.

Table B-1b. Unit water costs.

	Primary TRT and/or Collection, Conveyance, Distribution	Secondary TRT	Tertiary Treatment			Desalt	Total Cost	
			Coagulation & Sedimentation	Activated Carbon	Chlorination		¢/1000 gal.	$/AF
Municipal	3.6	4.5				25.3[a]	33.4	108
Industrial	$10/AF[c]							10
Agriculture	$5/AF[c]							5
Secondary Treatment								1000[b]
Tertiary Treatment			3.5	5.0	0.7		9.2	30
Desalting								59[d]

[a] Assume specifications met by 50 MGD-ED desalting plant in Jordan Delta.

[b] Jordan River water is of quality superior to effluent from waste treatment ∴ large cost assigned to prevent this allocation.

[c] Based on data used in Millegan et al., 1970.

[d] Desalting costs are based on an assumed 25 MGD-MSF plant, Table 9-3, Haycock et al., 1968.

Supply Origin: Municipal Wastewater

Table B-2a. Quality and quantity specifications.

Sector of Use	BOD			TDS			Quantity	
	Source Level	Required Level	Amount Removed	Source Level	Req'd Level	Amount Removed	mg/l	1000 af/yr.
Municipal	300	0	300	900	500	400	66.2	74.2
Industrial	300	30	270	900	800	100		
Agricultural	300	300	0	900	900	0		
Secondary Treatment	300	20	280	900	2000	0		
Tertiary Treatment	300	20	300	900	2000	0		
Desalting	300	0	300	900	10	890		

Table B-2b. Unit water costs.

	Primary TRT and/or Collection, Conveyance, Distribution	Secondary TRT	Tertiary Treatment			Desalt	Total Cost	
			Coagulation & Sedimentation	Activated Carbon	Chlorination		¢/1000 gal.	$/AF
Municipal		$46/AF[a]	4.4	4.5	0.6	17.8		135
Industrial								56[a]
Agriculture								51[b]
Secondary Treatment								46
Tertiary Treatment		$46/AF	← $31/AF →					77
Desalting		$46/AF				59[c]		105

[a] Treatment performed at existing waste treatment facilities with weighted cost municipal treatment calculated at $46/AF (Harline, 1963) plus $10/AF for conveyance and distribution.

[b] Weighted cost of municipal treatment at $46/AF plus $5/AF conveyance and distribution.

[c] Desalting costs are based on an assumed 25 MGD-MSF plant, Table 9-3, Haycock et al. (1968).

Supply Origin: Industrial Wastewater

Table B-3a. Quality and quantity specifications.

Sector of Use	BOD			TDS			Quantity	
	Source Level	Required Level	Amount Removed	Source Level	Req'd Level	Amount Removed	mg/d	1000 af/yr
Municipal	300	0	300	900	500	400	77.8	87
Industrial	300	30	270	900	800	100		
Agriculture	300	300	0	900	900	0		
Secondary	300	20	280	900	2000	0	78.8	87
Treatment	300	0	300	900	2000	0		
Desalting	300	0	300	900	10	890		

Table B-3b. Unit water costs.

	Primary TRT and/or Collection, Conveyance, Distribution	Secondary TRT	Tertiary Treatment			Desalt	Total Cost	
			Coagulation & Sedimentation	Activated Carbon	Chlorination		¢/1000 gal.	$/AF
Municipal	7.4	5.0	3.4	4.3	0.6	$47/AF [a]		115
Industrial								39[b]
Agriculture								10[c]
Secondary	3.8	5.0					8.8	29
Treatment								1000[d]
Desalting		$29/AF				$59/AF[e]		88[e]

[a] 50 MGD-ED 1000 ppm feed, Table 9-3, Haycock et al., 1968.

[b] Cost of secondary treatment ($29/AF) plus conveyance and recycle distribution ($10/AF).

[c] Quality sufficient for direct use in Ag. Costs are assumed at $10/AF fr transportation and distribution.

[d] System is constructed so water cannot be allocated direct from industrial to these uses. It must first be processed by industrial waste water facilities.

[e] Desalting costs are based on an assumed 25 MGD-MSF plant, Table 9-3, Haycock et al. (1968).

Supply Origin: Agriculture/Irrigation Return Flow

Table B-4. Quality and quantity specifications and unit water costs.

Sector of Use	BOD			TDS			Unit Water Costs $/AF
	Source Level	Required Level	Amount Removed	Source Level	Req'd Level	Amount Removed	
Municipal	5	0	5	1000	500	500	108[a]
Industrial	5	30	0	1000	800	200	93[b]
Agriculture	5	300	0	1000	900	100	5[c]
Secondary	5	20	0	1000	N/A	0	1000
Treatment	5	0	5	1000	2000	0	30[d]
Desalting	5	0	5	1000	10	990	59[d]

[a] Quality specifications are met by 50 MGD-ED desalting plant in the Jordan Delta. Treatment cost of $108 is derived from Table 9-12, Haycock et al. (1968, p. 149).

[b] The supply from the desalting plant (footnote a above) can be delivered to industry without the cost of final treatment of 4.5c/K gal or $15/AF. The total cost is $108 less $15 or $93.

[c] Return flow used in Ag at same price as Jordan River water, $5.

[d] Desalting costs are based on an assumed 25 MGD-MSF plant, Table 9-3, Haycock et al. (1968).

Supply Origin: Secondary Treatment Plant

Table B-5a. Quality and quantity specifications.

Sector of Use	BOD			TDS			Quantity	
	Source Level	Required Level	Amount Removed	Source Level	Req'd Level	Amount Removed	mg/d	1000 af/yr
Municipal	20	0	20	1000	500	500	45	50
Industrial	20	30	0	1000	800	200		
Agriculture	20	300	0	1000	900	100		
Secondary	20	N/A	N/A	1000	2000	0		
Treatment	20	0	20	1000	2000	0		
Desalting	20	0	20	1000	10	990		

Table B-5b. Unit water costs.

	Primary TRT and/or Collection, Conveyance, Distribution	Secondary TRT	Tertiary Treatment			Desalt	Total Cost	
			Coagulation & Sedimentation	Activated Carbon	Chlorination		¢ /1000 gal.	$/AF
Municipal			4.5	5.0	0.7	$47/AF [a]		80
Industrial	$10/AF[b]							10
Agriculture	$10/AF[b]							5
Secondary								1000
Treatment			4.5	5.0	0.7		10.2	33
Desalting								59[c]

[a] 25 MGD-MSF plant, Table 9-3, Haycock et al., 1968.

[b] Conveyance and distribution cost of $5/AF based on data from Milligan et al. (1970).

[c] Cost of water delivered from desalt plant from Table B-1a.

Supply Origin: Tertiary Treatment Plant

Tertiary treatment is specifically to supply blending water for the municipal system. It cannot be used directly since TDS is too high; hence, it is allocated to blending at conveyance cost of $11/AF and allocation to other systems is prevented by assignment of high cost ($1000/AF).

Supply Origin: Desalting Plant

Desalted water is allocated to the municipal system for the cost of final treatment of the product water. In Table 9-12, Haycock et al. (1968, p. 149) this is given as 4.5c/K gal or $15/AF. Desalted water can be used for industry or agricultural for a cost of $10/AF, and $5/AF respectively, for conveyance and distribution.

For blending purposes desalted water from 25 MGD-MSF plant has TDS of 25 ppm. This can be blended with water of higher TDS than acceptable in order to expand product quantity. The blending and storage cost, taken from Table 9-11, Haycock et al. (1968), are $11/AF. This is computed as follows based on a capital cost of $2.8 million for blending and storage facilities:

Annual Cost (5%-50 yr.) = 2.8 x 106(.0548)	=$154,000
Annual Cost of Operation & Maintenance	= 500,000
Total Annual Cost	$164,000

The blended water delivered is 56,000 AF or $164,000/56,000 AF for $11/AF

Supply Origin: Blending Operation

Blend water is developed for use specifically in the municipal system. Blended water costs are reflected in previous treatment operations and is thus allocated to the municipal system at zero cost. All other allocations prevented by assigning cost of $1000.

Supply Origin: Bird Refuge

Because of location and quality considerations the only feasible allocation of effluent water from the bird refuge is to the desalting plant at the same cost as allocation from other sources of $59/AF.

Supply Origin: Tertiary Treatment Plant

Tertiary treatment is specifically to supply blending water for the municipal system. It cannot be used directly since TDS are too high; hence, it is allocated to blending at conveyance cost of $11/AF and allocation to other systems is prevented by assignment of high cost ($1000/AF).

Supply Origin: Desalting Plant

Desalted water is allocated to the municipal system for the cost of final treatment of the product water. In Table 9-12, Haycock et al. (1968, p. 149) this is given as 4.5¢/1000 gal or $15/AF. Desalted water can be used for industry or agricultural for a cost of $10/AF, and $5/AF respectively, for conveyance and distribution.

For blending purposes desalted water from 25 MGD-MSF plant has TDS of 25 ppm. This can be blended with water of higher TDS than acceptable in order to expand product quantity. The blending and storage cost, taken from Table 9-11, Haycock et al. (1968), are $11/AF. This is computed as follows based on a capital cost of $2.8 million for blending and storage facilities:

Annual Cost [illegible] = $164,000
Annual Cost of Operation & Maintenance = 500,000
Total Annual Cost $[illegible]64,000

The blended water delivered is 56,000 AF or $[illegible]64,000/56,000 AF for $1[illegible]/AF.

Supply Origin: Blending Operation

Blend water is developed for use specifically by the municipal system. Blended water costs are reflected in previous treatment operations and is thus allocated to the municipal system at zero cost. All other allocations prevented by assigning cost of $1000.

Supply Origin: Bird Refuge

Because of location and quality considerations the only feasible allocation of effluent water from the bird refuge is to the desalting plant at the same cost as allocation from other sources of $59/AF.

Table 8-51. Unit water costs.

	Primary TRT and/or Collection, Conveyance, Distribution	Secondary TRT	Tertiary Treatment			Desalt	Total Cost
			Coagulation & Sedimentation	Activated Carbon	Chlorination		¢ /1000 gal.
Municipal			4.5	5.0	0.7	$49/AF^a	
Industrial	$10/AF^b						
Agriculture	$10/AF^b						
Secondary Treatment			4.5	5.0	0.7		10.2
Desalting							

^a 25 MGD-MSF plant, Table 9-3, Haycock et al., 1968.

^b Conveyance and distribution cost of $5/AF based on data from Milligan et al. (1970).

^c Cost of water delivered from desalt plant from Table [illegible].