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Application of Operations Research Techniques for Allocation of Water Resources in Utah

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ABSTRACT

In this report a methodology is described for determining the optimal allocation of water supplies in the State of Utah to minimize the cost of meeting an assumed set of water requirements. A linear programming model was formulated to represent the ten interconnected hydrologic study areas of the state. The comprehensive model considers virtually all uses, areas, sources, transfers and costs of water. The model has 204 constraints and 338 variables and was solved by the simplex method.

Included in the results are the following: the optimal water allocation or the groundwater, surface water, and water transfers which minimize the cost; the shadow prices of the resources; sensitivity analyses to identify the critical cost coefficients in the optimal solution; parametric analyses to test the effects of changing constraints; and manipulations of the model to test other factors such as operating rules, legal policies, political and institutional limitations. The tabulated data were carefully condensed so as to be more easily understood. Flow diagrams and graphs summarize the important information. The work is fully documented so others can follow what was done and improve the method or apply the model to other areas.

Keywords: *Water resources planning, *Water management, *Operations research, *Optimal allocation, *Utah, Hydrology, Surface water, Groundwater, Water storage, Water transfer, Water requirements, Water supply, Municipal water use, Industrial water use, Agricultural water use, Wetlands water use, Groundwater recharge, Water reuse, Mathematical model, Linear programming, Objective function, Constraints, Simplex method, Cost minimization, State water plan, Legal aspects, Social aspects, Political factors.

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SUMMARY

Water resources planners have the responsibility of developing plans which will best utilize scarce water resources. It is difficult for planners to see in advance which of the many possible alternatives will most enhance the well-being of people within a planning area. The general objective of the research reported in this study has been to assist the water resource planners of the State of Utah in particular and in other states in general by developing a methodology for optimal allocation of available water such that the broad overview and objectives of the state can be incorporated in planning decisions. The research has extended the capability for mathematical analysis of complex water resource systems to a state-wide area in which the many multiple alternatives and interrelationships can be considered simultaneously. The research was designed to enhance the quality of decisions to be finalized in the State Water Plan of Utah and in other water plans.

A particular problem to be solved is how best to utilize Utah's share of Colorado River waters. There are also some other available surface water and groundwater in the state not now being used. In this research a number of alternative patterns and levels of demand for water are postulated for the ten study areas of the state. The costs of meeting the projected demands were then minimized by solving a linear programming model of the economic-hydrologic-physical system. The cost-minimizing system consists of the various combinations of groundwater, surface water, and interregional transfer activities which minimize the cost.

A mathematical programming model with the appropriate constraints was formulated to represent the ten study areas of Utah. The constraints in the model include the following categories: groundwater and surface water availabilities in the various areas, water requirements of all kinds (including municipal and industrial, wetlands, and agriculture), present and potential reservoir storage, evaporation losses from storage, return flows, free groundwater for wetlands, groundwater recharge limits, inter-basin water transfer limits, required outflows and other physical limits on the system. The model is comprehensive and all inclusive rather than partial, and virtually all uses, areas, sources, and transfers of water have been included in the analysis.

In developing the objective function for the model, the minimum cost to supply an assumed water requirement was selected as the criteria for the optimal allocation of water by the model. It was realized that a least cost allocation is not as meaningful as an allocation done with net benefits as the measure of value. However, the available project resources precluded giving attention to the general question of the value of water. Fortunately, the important question of the value of water and its effect on the optimal allocation is already under study in another project.

A method was developed in the study which allows consideration of the full cost structure, rather than just part of the development costs. In fact, the cost coefficients in the objective function and the appropriate cost constraints can be made just as comprehensive and complete as the resources and time available might allow. Little effort was expended in trying to define the costs precisely. In many cases the best available estimate was used, since the objective was to work out a methodology of water planning rather than to carry out a specific water planning activity.

The final version of the model used in this research contains, besides the objective function, 204 constraints with 338 variables. The linear programming model was solved by an IBM 360/44 digital computer using a form of the simplex method contained in a mathematical programming package supplied by IBM and identified as MPS/360.

Results from the model are of three kinds: 1) The optimum solution to the linear programming problem—including both the optimal allocation of the water resources and the determination of the shadow prices of these resources. 2) The post-optimal analysis—including a sensitivity analysis of the cost coefficients to determine which are most crucial to the solution and a parametric analysis of the right-hand-side values of the constraints to test the effects of changing the constraints, particularly changing the projections of demand for water over time. 3) Manipulation of structural coefficients, right-hand-side values and variable bounds to determine such effects as changes in irrigation efficiency, changes in operating rules, legal policies, political and social limitations, groundwater restrictions, water transfer limitations, alternative growth projections, etc.

The computer program supplies large amounts of data and these were carefully condensed so the data could be examined, interpreted, and understood. Flow diagrams and graphs are the result of this effort to distill the important information from the voluminous computer output.

Under this research effort a methodology has been developed for determining the optimal allocation of water supplies to minimize the cost of meeting given requirements for water in a large and complex area. The research was done by an interdisciplinary team so as to utilize various viewpoints and skills. Considerable effort was made to work closely with the appropriate state and federal agencies to make the study represent real world problems in water resource allocation. The method is broad in scope and the suggested model is flexible so it can be applied in planning situations other than in the State of Utah. The work has been documented in this report so that others can follow what was done, improve upon the method, or apply the model to other areas.

INTRODUCTION

Development of the State's Water Resources

National water planning program

The concept of comprehensive water resources planning is not new. By the turn of this century the interdependencies in the development and use of water for various purposes were very evident to some of the nations leaders. President Theodore Roosevelt's instructions to the Inland Waterways Commission in 1907 outlined the idea much the same as we know it today:

> The time has come for merging local projects and uses of the inland waters in a comprehensive plan designed for the benefit of the entire country. Such a plan should consider all the uses to which streams may be put and should bring together and coordinate all the points of view of all users of water... (U.S. Congress, Senate, 1908).

Numerous national water commissions and committees have espoused this concept during the ensueing 50 years. During this period, the growth of institutional complexities and the recognition of additional uses of water have broadened the meaning of the term "comprehensive water planning" and made the implementation of this approach imperative though much more difficult.

Although Congress has continued to authorize individual projects, recently it has taken a number of significant and impressive steps toward a comprehensive approach to planning. The Senate Select Committee on National Water Resources report in 1961 contained recommendations for establishing a national water planning program and a research program under which, among other things, planning techniques might be improved (U.S. Congress, Senate, 1961). An important statement of federal policies, standards, and procedures for water planning and development was printed in Senate Document 97, 87th Congress in 1962. These policies and standards were intended to provide a common basis for formulation, evaluation and review of plans, and encouraged a comprehensive, long-range viewpoint in planning with full consideration of all types of water demands and development possibilities. Efforts to establish machinery for coordinating the diverse interests in planning represented by a large number of federal, state, and local agencies culminated in the Water Resources Planning Act of 1965, which established the Water Resources Council and provided financial assistance to states to improve state potentials for water planning. The Act further provided for the establishment of river-basin planning commissions made up of state and federal regional representatives and the implementation of a planning program to prepare and keep up-to-date plans for comprehensive water development for all major river basins in the United States. Today, under the aegis of the U.S. Water Resources Council, five congressionally authorized river basin commissions, newly established under provisions of the Water Resources Planning Act of 1965, and a number of basin interagency committees are engaged in a nationwide water planning program.

Framework plans, being prepared by these organizations, will cover large multi-state areas and provide basic information on the future requirements for resource development; inventories of available resources; interrelationships of resource uses, problems, and suggested solutions; and a broad-gaged plan to be used as a guide for development. Together these framework plans will cover the entire nation and provide the basis for a total assessment of water resources.

Regional and river basin plans covering river systems or subregions within the areas of the framework plans are also the responsibility of river basin commissions and basin interagency committees. These plans are intended to extend the scope and intensity of the framework plans.

As members of river basin commissions and interagency committees, states are participating with the federal agencies in this planning program. The State of Utah is involved in the development of framework plans for the Great Basin and for the Upper Colorado River Basin. At the same time, many states, including Utah, are developing their own statewide water development plans as well.

Utah's water planning program

Developing and conserving water resources in Utah began with small projects and moved in logical sequence to larger, more complex and costly ones as time passed. One of the first acts of the Mormon pioneers upon entering the Great Salt Lake Valley in 1847 was to divert water to irrigate the parched soil. From that time on people have built dams, canals, ditches, and pipelines to establish an irrigated agriculture and provide water for their towns, cities, and industries.

Recognizing the need for a comprehensive planning approach to achieve the best development of the state's scarce water resources, the Utah Water and Power Board in 1961 undertook a cooperative study with Utah State University. This study, which was preliminary to the preparation of a comprehensive statewide water development plan, was initiated for the purpose of showing why increased water planning was essential. It took a searching look at the problems and needs on a statewide basis, and its report outlined the general water use-water supply picture, what the major problems were, and what challenges would have to be faced in overcoming the problems. This preliminary report was published in 1963, and the Legislature in that same year appropriated special funds for the preparation of a state water plan.

Since 1963 emphasis in the planning program has been given to acquiring basic information and data for appraising available resources and potential requirements. Data have been obtained from all available sources, including local universities and several state and federal agencies. Several papers and statistical reports have been published by the Division of Water Resources (formerly the Utah Water and Power Board), the agency primarily responsible for preparing the plan.

An Interim Report on the State Water Plan, outlining progress to date in the planning program and indicating things that remain to be accomplished to complete the plan, was released in May of 1970. An updated version of the same report is in preparation for publication in 1972. The intent of publication and distribution of this report is to obtain public reaction to and discussion of the planning accomplished to date and problems remaining to be solved. After a period of public meetings and discussions on this interim report, the planning staff will complete separate appendixes for each of the 10 hydrologic study regions of the state. Each appendix will contain specific projections of water demand, inventories of supplies available to meet these demands, and alternative plans of development. Eventually a State Water Plan, culminating from these efforts, will be recommended to the Utah Legislature for approval.

Policy and institutional situation

As water development has proceeded over the years, numerous institutions have been established with concern for various aspects of water administration. At least 25 units in five departments and three major independent agencies of the federal government have significant responsibilities related to water resources. In Utah State government, there are 11 agencies engaged directly or indirectly in water activity, and in addition, there are 13 water conservancy districts, three water improvement districts, six metropolitan water districts, more than 1000 mutual irrigation companies, and unnumbered individual communities involved within the state (Bagley, 1969).

Prior to major reorganization of Utah State government in 1967, the primary functions of water resources administration were assigned to three independent agencies—the Office of the State Engineer, the Utah Water and Power Board, and the Water Pollution Control Board. The Office of State Engineer established in 1903, has been responsible for the general administration and regulation of the waters of the state, including measurement, appropriation, apportionment, and distribution. The Utah Water and Power Board, created in 1947 with the establishment of a statewide water development and conservation program, was responsible for administering a water resources development fund established at that same time and for water planning and development activities of the state. In 1963, it was given specific responsibility for preparing a statewide water development plan. The Water Pollution Control Board, the most recently established of these three water agencies, was organized in 1953 to develop programs for prevention, control, and abatement of water pollution. The board has been responsible for classifying the waters of the state and setting quality standards along with maintaining a surveillance and regulatory program for preserving water quality.

Although a major reorganization of state government in 1967 changed the names and composition of these agencies, it did not alter significantly their major functions. The Utah Water and Power Board became the Board of Water Resources retaining essentially the same powers, and its staff was redesignated as the Division of Water Resources in the newly formed Department of Natural Resources. The statewide water planning is continuing under the board and the division.

Federal agency activities related to water development in Utah are numerous and diverse. All of the federal water agencies are involved to a degree, but some have much larger roles than others. Since the Reclamation Act of 1902, the Bureau of Reclamation has built several major dams and other water projects affecting the state. The Central Utah Project presently under construction will have great impact on Utah State water problems. The bureau has also cooperated with the state in investigations of water availability, requirements, and development possibilities in other areas of the state.

Agencies of the Department of Agriculture, including the Soil Conservation Service, the Forest Service, and the Economic Research Service, are also involved in various water development activities in Utah. Aside from its small watershed projects and other activities, the Soil Conservation Service has cooperated with the Bureau of Reclamation, Utah State University, and the Board of Water Resources in a statewide land-capability survey. Along with the Forest Service and Economic Research Service, it has cooperated with the state in studies of the Sevier River, Beaver River, and Escalante Desert areas.

The Corps of Engineers has a much smaller role in constructing water projects in Utah than the Bureau of Reclamation, but nevertheless, has been studying flood problems in the state for many years. Several projects which have been planned and authorized have not been constructed because of the lack of local cooperation (financing). The state is not authorized under the present laws to participate directly with the Corps in flood control projects. The providing of lands, easements and right-of-way required for such projects, therefore, is left to the counties or local entities, who have been unable or unwilling in many cases to raise the funds needed.

The U.S. Geological Survey has had a substantial role in the collection of basic data useful in the state water planning program. Extensive data gathering networks have been set up, and much information on the quantity and quality of both surface water and groundwater has been acquired.

The colonization of Utah by the Mormon pioneers involved the establishment of many small communities, usually separated by miles of desert or mountain ranges and therefore largely self supporting. The major activities in these communities, including the management of irrigation water supplies, were carried out cooperatively. Out of these early cooperative efforts evolved the typical Utah mutual irrigation company, the dominant form of irrigation organization in the state At the other end of the spectrum at the local level is the highly organized and powerful conservancy district, which encompasses several smaller entities, such as mutual companies, irrigation districts, partnerships, individuals, etc. Conservancy districts are created under state law and have extensive powers, including limited taxing authority. The Central Utah Conservancy District, formed by several counties to contract with the federal government for construction of the Central Utah Project, is an example of this form of local organization.

The state's primary water development function with the various local water organizations has been that of providing financial and technical assistance in the construction of small water projects (primarily for irrigation). The Board of Water Resources provides financial assistance through its revolving development fund, and the Division of Water Resources provides technical assistance.

In addition to the growth over the years in number of organizations in the state concerned with water, a substantial body of law and regulations has accumulated which sets bounds to the way water may be developed and used. The influence of political boundaries, statutes, decrees, administrative rules and regulations, court decisions, ordinances, etc., greatly affects planning and development.

The appropriation doctrine of water rights is recognized in Utah, and, in general, the water of Utah streams is fully covered by applications to appropriate. Nevertheless, large quantities of water continue to flow out of the state or into the Great Salt Lake without being fully utilized. In a similar way, large quantities of groundwater remain in storage, while many groundwater basins are overflowing. Although water planning by the state has not overlooked the significance of water rights, planning studies have not been constrained by such rights. Planning has been directed toward a means of protecting existing uses while satisfying new and increasing demands. Some questions of water rights will have to be resolved when plans are implemented (Utah Division of Water Resources, 1970).

In an act approved on August 19, 1921, by the United States Congress, the States of Arizona, Nevada, New Mexico, Utah, and Wyoming entered into a compact to provide an equitable division and apportionment of the waters of the Colorado River System. The compact, known as the Colorado River Compact, basically divided the waters of the Colorado River between the upper and lower basins. This compact gave each basin the right to the exclusive beneficial consumptive use of 7,500,000 acre feet of water annually and provided that in cases of deficiencies the shortages would be allocated to each basin in equal proportions.

In a later act passed on April 6, 1949, the states of the upper basin (Arizona, Colorado, New Mexico, Utah, and Wyoming) joined together in a compact known as the Upper Colorado River Basin Compact to further divide and apportion their share of Colorado River water. This compact divided the 7,500,000 acre feet given to the upper basin as follows: 50,000 acre feet to Arizona, and of the remaining quantity 51.75 percent to the State of Colorado, 11.25 percent to the State of New Mexico, 23.00 percent to the State of Utah, and 14.00 percent to the State of Wyoming. Although this allocation would give Utah 1,714,000 acre feet per year, flow in the river generally has been less than the 15 million acre feet that was divided by the compact and Utah's potential share has been estimated at between 1,277,000 and 1,714,000 acre feet per year (Tipton and Kalmbach, 1965). An amount of 1,438,000 acre feet per year will be used in these present studies as Utah's share of the Colorado River water.

Systems approach

Fundamentally, water resources development entails the modification of a natural hydrologic system to meet man's needs. Regardless of the modifications made to certain parts of the system, the equilibrium of the system is changed and other components or elements are affected. Consequently, one of the main questions raised in connection with any water development scheme is: What will be the effect on existing uses? The interrelationships among elements of the hydrologic system, though varied and complex, are relatively simple in comparison with the social, legal, economic, and institutional interdependencies involved. These relationships, economic and social as well as physical, are so close and so strong as to require that planning of water development be accomplished on a systems basis. In fact, the general move toward comprehensive water resources planning is founded on a recognition that these close system relationships require unified treatment.

The major program now underway to formulate comprehensive water development plans for the entire nation comes at a time when fundamental changes are taking place in the pattern and composition of water uses and in water technology. Although methodology has not been devised which can consider all of the variables and parameters involved, describe their interaction in space and time, and arrive at a simultaneous solution to the whole matrix, advances in the social and physical sciences and in technology have made available a number of new and improved decision-making techniques for application to water resources planning. Operations research and systems analysis intimately associated with advances in computer technology are particularly useful.

In the application of systems analysis to water resources planning, the first step is to define the system to be analyzed. In water planning this means the identification of objectives along with associated boundary conditions or constraints. These are then transformed into optimal plans for development. In general, water resources planning is a technique of public investment decision-making. The decisions relate to the allocation of scarce resources among competing claims. To choose among alternative courses of action, a set of objectives must be specified and a decision rule developed for use as a guide to optimal design—the design or set of alternatives that best meets the objectives. Expressed more formally, the decision problem is to maximize the value of an objective function, subject to limitations imposed from outside the system and further limited by the production function imposed by nature and the state of technology (Hufschmidt, 1965).

Objectives of the Research

The development and allocation of water for the state calls for a long sequence of crucial decisions. Water planners are faced with the problem of identifying optimal development plans in order to best utilize scarce water resources. Research is needed on the interrelationships and impacts of water projects. There is no easy way to foresee which of the many possible alternatives will do most to enhance the well-being of the people of the state. Piecemeal and uncoordinated planning for water resources development is inappropriate. Long-term plans are needed which incorporate a broad overview of the state.

The general objective of this research has been to extend the capability for mathematical analysis of complex water resource systems to a statewide system. The research was designed to develop a method to enhance the quality of decisions to be finalized in the State Water Plan. A particular problem is the optimal allocation of Utah's share of Colorado River water from an engineering economic standpoint. A considerable amount of Colorado River water and other available water is not presently being used. While the research began with an emphasis on undeveloped Colorado River water, it was soon recognized that all the available water resources must be included in the analysis. In this research a number of alternative patterns and levels of demand for water are postulated for the ten study areas. The costs of meeting the projected demands were then minimized by solving a linear programming model of the economic-hydrologic-physical system. The optimal cost-minimizing system consists of the various combinations of groundwater, surface water, and interregional transfer activities which minimize the cost.

Elements of specific projects were evaluated in this research as well as other general relationships for which no project feasibility or authorizing documents are available.

Specifically, the objectives of the research were:

1. To formulate a mathematical programming model consisting of an objective function with the appropriate constraints for allocation of water within the ten hydrologic subdivisions of the state, including transfer of water between hydrologic subdivisions.

The objective function, expressed as $c_1x_1 + c_2x_2 \ldots + c_nx_n$, describes the economic inputs (costs) associated with each of the alternative allocations.

In the mathematical programming model the various allocation alternatives and the hydrologic characteristics of the system can be expressed as system "constraints" which in matrix form are as follows:

$$\begin{array}{l}
a_{11}x_1 + a_{12}x_2 + \ldots\ldots + a_{1n}x_n \leq b_1 \\
a_{21}x_1 + a_{22}x_2 + \ldots\ldots + a_{2n}x_n \leq b_2 \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
a_{m1}x_1 + a_{m2}x_2 + \ldots\ldots + a_{mn}x_n \leq b_m
\end{array}$$

In this matrix the b_i values are quantities of various resources which place limits on the system. The coefficients $a_{11}, a_{12} \ldots a_{mn}$ are the input requirements of the alternative allocations of the scarce resources. The columns contain all coefficients for each alternative allocation, and the rows contain all of the coefficients for each resource. The inequalities indicate that no more of a resource may be used than is available, but some of it may go unused.

Physical features and quantities as well as the limitations imposed by the Colorado and other river compacts have been included in the system constraints.

Cooperative effort from the State of Utah Division of Water Resources assisted in deriving the appropriate objective function, constraints, and the alternative demand projections which enter into the model.

2. To solve the mathematical model using an appropriate optimizing algorithm to determine the optimal allocation of Colorado River water and other surface and ground waters in the State of Utah with least cost as the measure of effectiveness in the objective function.

The problem is to minimize the objective function subject to the constraints. While there is no general algorithm, or systematic method of solution, for solving the general mathematical programming problem, the basic relations in this model lend themselves to a linear formulation, so the simplex algorithm was employed as the optimum seeking method. The quality of the data presently available did not justify more than linear approximations of the nonlinear relationships.

3. To optimize the allocation of Colorado River entitlement and other waters in Utah under various arbitrary operating rules and water use policies to determine the economic effects of some of the common legal, political, and social limitations.

Social policies and political limitations are often not readily formulated analytically as system constraints. In order to evaluate the effects on an economic objective function and optimal allocations which are caused by operating rules imposed on the system by social and political policies, various operating rules which reflected these effects were imposed on the model. The operational results of the imposed operating rules were examined and in this way imputed costs of such decisions were defined.

4. To evaluate the usefulness of the analytical approach for state water planning and determine its usefulness for future application to other planning areas.

The results of the first three objectives were evaluated to determine the usefulness of such an analytical approach in large scale water resources planning and to point out the advantages and disadvantages of the methodology.

Review of the State-of-the-Art: The Systems Approach to Water Resource Planning

In recent years systems analysis has become increasingly useful as a tool in water resources planning, design and development, operating procedures, and management.

According to Drobney (1968, p. 534) systems analysis is:

> . . . A strategy for problem solving which relies heavily on mathematical modeling to assess the technical and economic optimality of alternative systems designs, policies, operating procedures, etc., for performing various functions and meeting various needs with limited resources. It is important to keep in mind that systems analysis *per se* does not provide these assessments which also must incorporate professional, legal, political, and social consideration. Rather systems analysis may be employed as a decision aid in assessing the technical and economic consequence of alternative courses of action.

A mathematical model is defined as a set of equations which describe some physical, biological, or chemical process and can be classified by three methods; (1) performance versus optimization models; (2) deterministic versus stochastic models, and (3) analytical versus simulation models. Drobney (1968) further distinguishes between the usefulness of the various models and states the type of problems which might be solved by each model. The optimization model using analytical definitions of the function to be optimized and based on deterministic technology has proven to be most useful for water resource planning (James and Lee, 1971, Maass et al., 1962).

A mathematical programming problem occurs when one seeks to maximize or minimize an analytical function (called an objective function) of one or more variables subject to certain relationships involving the variables (called constraints). (See Intriligator, 1971.) Under certain limited conditions, a solution to this problem can be found using classical differential calculus, including Lagrangian multipliers and the calculus of variations. The complex engineering and economic aspects of todays water reosurce problems are far beyond the computational adequacy of the classical methods and have motivated a keen interest in programming models (Drobney, 1968). Several programming models have been developed and computational algorithms exist for some of their solutions. These are linear programming (Hadley, 1962), non-linear programming (Hadley, 1964) including quadratic programming and geometric programming (Duffin, Peterson, and Zener, 1967), and dynamic programming (Hadley, 1964).

Linear programming is one of the most widely used of all systems analysis techniques. A statement of this problem might be:

> Given a set of m linear inequalities or equations in r variables ($r \gtreqless m$), non-negative values of these variables are sought which will satisfy the constraints and maximize or minimize some linear function of the variables. (Hadley, 1962)

Many applications have been made of the linear programming model to solve problems in water resources. Some of these are:

(1) Least costly plan for waste treatment (Loucks, Revelle, and Lynn, 1967; Johnson, 1967; Rogers and Gemmel, 1966; Sobel, 1965; Thomann, 1965)
(2) Optimum operation of large dams considering benefits from hydropower and irrigation (Thomas and Nevelle, 1966)
(3) Sewage treatment plant design (Lynn, Logan, and Charnes, 1962)
(4) Conjunctive use of surface water and groundwater (Milligan, 1969)

Non-linear programming is similar to linear programming except the objective function and constraints are not required to be linear functions of the decision variables (Hadley, 1964). One form of this non-linear problem for which numerical computation techniques have been developed is known as quadratic programming in which the objective function has quadratic terms subject to linear constraints. Quadratic programming was used by Lynn (1966) to determine a least-cost pumping schedule for wells. A more general, and consequently harder to solve, form of non-linearity occurs with an objective function that is non-linear to a higher degree than quadratic. This form is known as geometric programming (Duffin, Peterson, and Zener, 1967). Geometric programming is just in its infancy in water resources use but has been used successfully in other applications (Beightler, Crisp, and Meier, 1968; and Wilde and Beightler, 1967).

A tool that has been used quite successfully to solve sequential decision problems is dynamic programming. According to Drobney (1968, p. 543):

> A sequential decision problem is a problem in which a sequence of decisions (termed a policy) must be made and in which each decision affects future decisions. . . . unlike linear programming, there exists no standard mathematical model format according to which a problem may be structured for solution by dynamic programming. Rather dynamic programming is an approach oriented technique, and the particular equations to be used must be developed to fit the problems at hand.

Examples of its use are: (1) design and operation of multi-reservoir systems (Amir, 1967; Buras, 1965; Meier and Beightler, 1967; and Schweig and Cole, 1968), (2) optimization of individual multi-purpose reservoirs (Hall, 1964; and Hall, Butcher, and Esogbue, 1968), (3) minimization of overall cost of waste treatment among discharges (Liebman and Lynn, 1966), (4) optimal use of groundwater over time (Burt, 1964), and (5) optimization of conjunctive use of groundwater and surface water (Aron, 1969). A combination of dynamic programming with linear programming has been used to study the problem of optimal future operation of a water resource system with random streamflows (Shailendra and Shepard, 1967).

Systems analysis approach in other states

Several studies have been done in other states utilizing operations research techniques to attack regional and statewide water planning problems.

Susquehanna River Basin - New York and Pennsylvania

Howes (1966) used linear programming to develop an interregional model which specifies economically feasible water resource investments. The model enabled simultaneous estimates of the benefits resulting from a project and market prices. The model generated a spatial economic equilibrium solution. Optimal solutions were generated for ranges of production costs and resource rents and values of agricultural commodities. The dual of the linear programming problem was developed to determine marginal values of water in agriculture. Demand functions for water were then generated. These data allowed a determination of the impacts of water development upon resource owners.

River basin - Iowa

Baldwin (1970) used linear programming to construct a model of a river basin and determine optimum water use pattern and value of water. Iowa's water permit system was a major constraint. Benefits were estimated for several major water users and combined with costs to give a net benefit objective function.

Trans-Texas Division, Texas
Water System - Texas

Orlob (1970) discussed the approach taken by planners for the Texas Water System. The Trans-Texas Division of the Texas Water System would be comprised of 18 reservoirs, more than 500 miles of canals, and pumping facilities to raise the water from near sea level to over 3000 feet elevation. The planning problem is:

Given:

1. Location of all reservoirs
2. Routes of connecting canals
3. Schedules of in-basin demand for each reservoir or major junction in the system
4. Hydrology of supply for each major storage element
5. Cost of imported water, and
6. Costs of construction and O & M for all elements

Find:

The least costly alternative system and schedule for its construction to meet specified demands to the year 2020 within the prescribed legal, financial, contractual, and political constraints.

The approach was to seek "near optimum" solutions rather than exact optima to overcome limits on time and computer capability. The procedure was carried out in four phases:

1. Preliminary sizes of elements and operating rules for reservoirs were determined by a formal optimization procedure.
2. Initial screening was performed by simulation of the given hydrology, element sizes, and operating rules for each of a large number of alternative stage development schedules selected by random sampling of the cost "response surface." The most attractive schedules were improved by a method of successive perturbations.
3. Element sizes were refined by a second simulation procedure which constrained flows in some expensive canals.
4. Final screening was performed by a formal optimization of the most attractive systems and development schedules.

Entire state - Texas

McKee (1966) developed a linear programming model for determining least cost of agricultural production for the entire State of Texas. Account was made of soil classification, acreage required per unit of production, and cost of production per unit in each soil class. Constraints were the acreage in each soil class and the demand for each crop. Cost data included the cost of supplying water for each soil class and each crop. Cost of drainage was also included. On-farm production costs were estimated. Requirements for crop production were projected to year 1975 and the production allocation determined by the linear programming algorithm. Marginal costs were derived for each of the crops.

Pecos River Basin - New Mexico

Gisser (1970) applied the method of parametric linear programming to forecast the demand for imported irrigation water in the future. The objective function was net return to land and management. Acreage and salinity constraints were incorporated with a water application at unit increments from 0 to 4 acre-feet per acre.

Sacramento Basin - California

Hall et al. (1967) discuss the development of analytical techniques for optimization of water resource systems. The study area included four major streams, ten reservoirs, and the associated pumping plants, aqueducts, and power generation facilities. The objective maximized is financial feasibility based on deliveries of firm energy, firm water, off-peak energy, and off season water. The procedure decomposes the complete system by a "master wholesaler"–"individual producer" relationship. The individual reservoir operators used dynamic programming to optimize their returns based on a schedule of prices provided by the master and report the corresponding outputs over the study period. The master, using these outputs as "available resources" maximizes the actual returns he could obtain from water and power contracts using linear programming. A new set of prices is generated which reflect the value of a modified output schedule for the operators. The cycle of calculations is repeated until the improvement is negligible.

Santa Clara Valley - California

Aron (1969) developed a conceptual model of a regional water conservation and distribution system under conjunctive use of surface water and groundwater, and a set of procedures for establishing water allocation and import policies of maximum economic efficiency. Dynamic programming was chosen as the primary optimizing technique because of its flexibility of application. In particular the sequence of operations necessary to arrive at an optimal operating policy made dynamic programming the best choice of mathematical tools. Limitations on the number of state variables are noted with the suggestion that simulation may be the only practical tool for developing an efficient water allocation policy in a complex, multisource, multipurpose system.

San Joaquin Valley - California

Moore (1962) estimated a demand schedule for irrigation water in a highly commercialized farm area by constructing linear programming models to represent five farms of different size with maximization of farm income as the objective function. Cost of irrigation water was varied with the result that new combinations of crops became optimum making it possible to trace quantity used versus price. In addition, the temporal distribution of water was studied by shifting the run-off pattern to successively later times and determining the net increase in farm income, thus estimating value of storage.

Statewide - California

Lofting and McGauhey (1968) used input-output programming analysis in continuing study on the economic evaluation of water on a statewide basis. Earlier Lofting and McGauhey (1963) had presented an input-output table as a first step in establishing the procedure for developing guidelines for a statewide water resources policy. In their later work these authors up-dated the model from 1947 economic data to 1958 data. Linear programming was used as an optimizing technique to identify the time path of shadow prices of water for 24 productive water dependent sectors of the California economy. A time series Gross State Product was developed for 1940 to 1966 in 1958 constant dollars and growth projections were made to the year 1990. Ranges of final demands for the model were set and solutions obtained so as to maximize value added given different levels of fresh water availability.

Previous studies for Utah

Bradley and Gander (1968) performed an input-output analysis on the economics of water allocation in the state. A 40 sector model was employed. Direct and indirect water coefficients were estimated and water use was projected to 1975. This study is discussed by Bradley, Short, and Kolb (1970) and shows how the model is used in projecting relevant economic parameters to 1975 and 1985.

Gold, Milligan, and Clyde (1969) published an interim report for the project reported herein. The report presented the development of the mathematical model and essentially met the first objective of the study. The model and the procedures and resultant data which were generated to meet the remaining objectives are the subjects of this report.

This study advances the state-of-the-art in several ways: A *statewide* water resources planning model structured in the linear programming format is developed and applied to the State of Utah; methodology is suggested for using the model to determine the optimal allocation of water resources of the state to meet projected demands at minimum cost; methodology is suggested for bringing political and social factors, operating rules and policies and other peripheral considerations into the decision process through the model.

GENERAL BACKGROUND FOR THE PHYSICAL SYSTEM AND THE ALLOCATION MODEL

In this section a description is given of the detailed physical system to be represented by the allocation model. Such features as the general area covered and its breakdown into convenient hydrologic study units, the population and economic growth, the land areas and associated water uses and water requirements, the available water resources, the major water resource problems, the present status of water resource development, the estimated storage requirements and storage potential, and the groundwater recharge potential are each discussed as the necessary basis of the mathematical model which is described later.

Water Resources Requirements, Availability, and Problems in Utah

The area

Located in the arid southwest, Utah is one of the driest states in the nation, and in general is considered an area of chronic water shortage. A closer look at the pattern of valleys and high mountain ranges, however, reveals sharply contrasting differences of climatic conditions within the state. Although some of the valleys receive a scant 4 to 5 inches of precipitation annually, nearby mountains may receive 60 inches or more. Wide cyclic and geographical variations of precipitation added to erratic seasonal distribution makes the development and efficient útilization of the total water resources very difficult.

The state lies in three major drainage basins. Most of the 84,916 square mile area of the state is divided between the Colorado River and Great Basins with only a very small portion in the Columbia River basin.

In terms of physiography, the state may again be divided three ways. The Great Basin, lying in the western half, is an interior drainage basin with no outlets. Streams emanating from the high Wasatch Mountains on its eastern perimeter discharge into valley fills and lakes. The Great Salt Lake is located in the northern part of the basin, and much of the remaining area is desert. In the south and east, the land—most of it part of the Upper Colorado River Basin—is in the form of high plateaus. The area is characterized by a highly dissected land surface with deep, steep-walled canyons. The Rocky Mountains constitute the third physiographic region of the state. The Wasatch Range, in a line generally running north and south through the central portion of the state, divides the Great Basin portion of the state to the west from the Colorado River drainage in the east. This Wasatch Range together with the Uinta Range, running generally east and west in the northeastern part of the state, are areas of high precipitation and, consequently, the primary sources of runoff.

Hydrologic study units

The appropriate geographic unit for water resource planning and development is the river basin or a closely related group of basins which drain to a common point. Within such a hydrologic complex the visible and invisible water supplies are connected and continuous.

Within each of the two major drainage basins, many streams and stream systems make up smaller hydrologic areas which lend themselves to analysis as individual units. As a practical matter, determination of available water supplies and their quality; extent and nature of uses and requirements; estimated future needs; considerations of water management administration, and adjudication; assembly and analysis of planning data, as well as the planning itself, must be done according to such river basins or hydrologic entities.

A geographic division of the state that is acceptable to most state and federal agencies involved in water resources activities is presented in Figure 1. The proposed division consists of 11 hydrologic basins which can be grouped in various ways to correspond to the larger divisions and numbering established by various Federal Inter-Agency Groups or to the three major river basins. Referring to Figure 1 the numbers are assigned as follows:

Hydrologic Study Unit (HSU)	Area Explanation
0	Columbia River
1	Great Salt Lake Desert
2	Bear River
3	Weber River
4	Jordan River
5	Sevier River
6	Cedar-Beaver
7	Uintah Basin
8	West Colorado
9	South and East Colorado
10	Lower Colorado

The Columbia River Basin portion of the state is not included in this study.

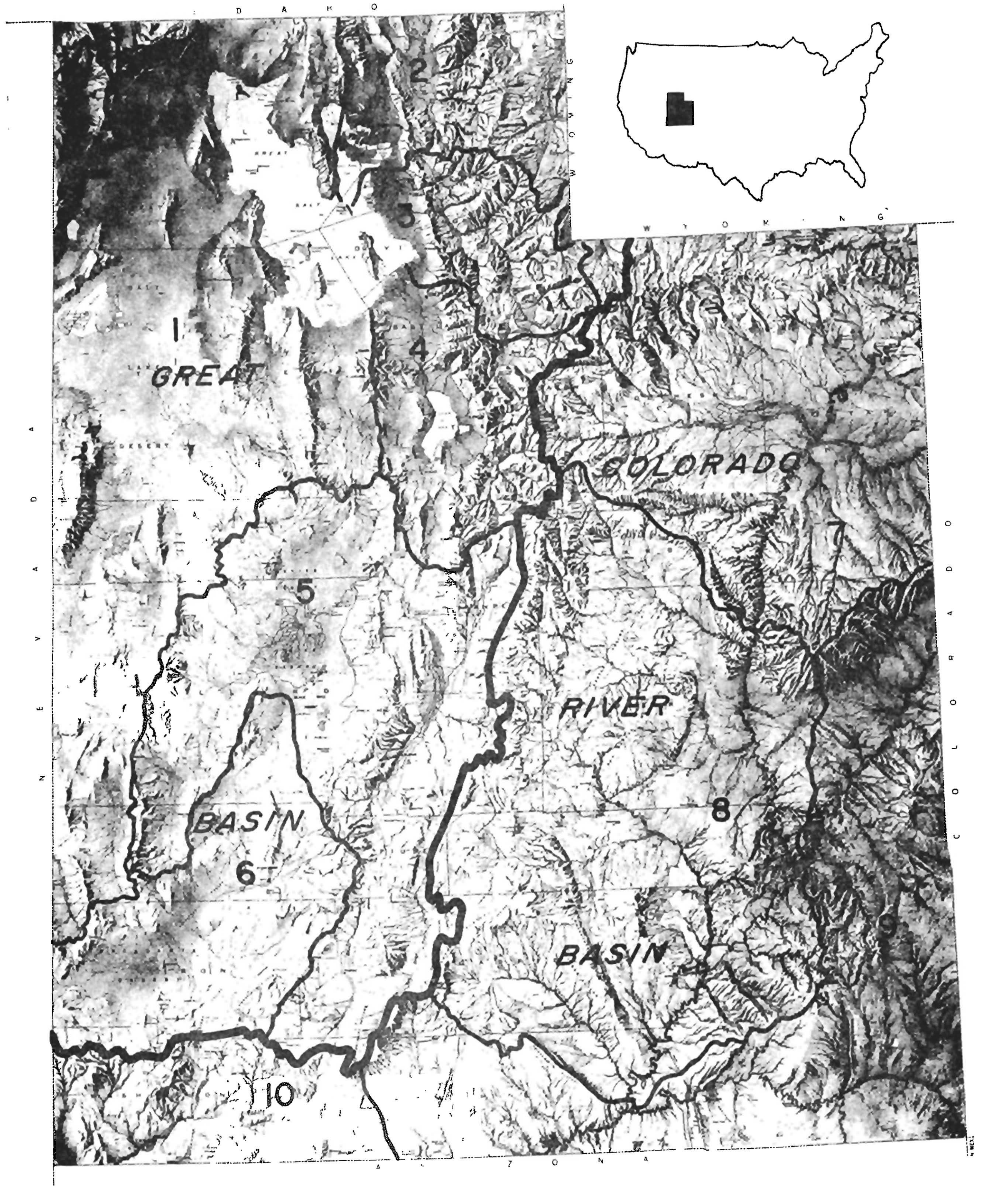

Figure 1. Hydrologic study units of Utah.

Population and economic growth

Utah's economy has a rather diverse base including as major segments agriculture, mining, manufacturing, construction, utilities, trades and services, and government (Nelson and Harline, 1964). Percentages of total personal income from these sources for Utah and the nation are compared in Table 1.

There have been some significant shifts in employment between segments of Utah's economy, and increases in population, labor force, and employment have been greater in recent years than national averages. From 1940 to 1964, Utah's increases were 81 percent for population, 100 percent for labor force, and 130 percent for employment as compared with national increases of 45 percent, 50 percent, and 60 percent respectively. For particulars about economic growth and shifts in employment patterns during this period see Cluff (1964).

The population of Utah, estimated by the U.S. Bureau of Census to be 997,000 in 1965 (U.S. Bureau of Census, 1966), is expected to continue to grow at a relatively high rate. In the future, average growth in the Great Basin region, encompassing western Utah and most of Nevada, will probably be at 2.5 percent annually according to one estimate (U.S. Water Resources Council, 1968). The eastern areas of the state are expected to show growth at a somewhat lower rate.

The greatest economic development and concentration of population in the state occurs in the Provo-Salt Lake City-Ogden-Logan area, a relatively small area on the eastern edge of the Great Basin. Increased concentration of population and economic growth projected for this Wasatch Front area in the future indicates a continuing shift of development toward urban, commercial, and industrial activities.

Water uses and projected requirements

As shown by Table 2 approximately 92.3 percent of the total precipitation over the state is used in grazing lands and watersheds, wastelands, national parks and monuments, water area (primarily Great Salt Lake), and outflow in interstate streams. It is the remaining 7.7 percent that this research project is concerned with since it is within the immediate control capability of man and can be considered as an available resource. This water appears in two forms: 1) surface runoff in rivers and streams originating in the watershed areas, and 2) groundwater in alluvial reservoirs which originated from percolation of precipitation and water bodies on the ground surface and from groundwater interflow from the watershed areas.

Man's use of his available water resource falls into three primary categories: 1) agriculture, 2) municipal and industrial, and 3) recreation and maintenance of natural

Table 1. Percentage of total income from various sources.[a]

Basic Physical Production	Percentage of total income[b] Utah	Continental U.S.
Agriculture	3.0	4.4
Mining	4.8	1.2
Manufacturing	19.7	29.2
Utilities and transportation	8.3	7.4
Contract construction	8.8	6.4
Subtotal production	44.6	48.6
Wholesale and retail trade	19.7	19.1
Finance and insurance	4.3	5.2
Service	10.2	13.5
Government	21.1	13.2
Other Miscellaneous	0.1	0.4
Subtotal service	55.4	51.4
TOTAL	100.0	100.0

[a] Source: (Nelson and Harline, 1964).

[b] Total personal income (millions of dollars): Utah $2,083; the nation $461,610. This does not include transfer payments, unemployment insurance, welfare, etc.

Table 2. **Land use and water consumed in Utah (McGuiness, 1963).**

Type of Land	Percent Total Area	Percent Water Consumed
Grazing land and watersheds	81.7	72.1
Arable but uncropped land used for grazing	2.6	1.9
Dry-farmed land	1.1	1.0
Irrigated land	2.1	4.6
Cities and towns, industrial sites	.5	.2
Wasteland, national parks, and monuments	9.0	6.4
Water area	3.0	9.5
	100.0	95.7
Outflow to interstate streams		4.3
		100.0

vegetation and wildlife. Water appearing in rivers and streams is diverted by man through canals and other irrigation works to flood croplands during the dry months of the year. In those areas where local surface water is not available in sufficient supply, pumps are installed to utilize the groundwater. Excess water not used by the crops either runs off as surface water back to the streams or percolates into the groundwater reservoir for use again. Likewise surface and groundwater resources are diverted by man through municipal and industrial systems. The sewage and other excess water can be treated before being returned to the sources. Water for recreation and maintenance of natural vegetation and wildlife primarily appears as part of the water storage and conveyance systems. Some water used by non-beneficial phreatophytes could be made available for other use by proper management of wetlands.

Beginning with the settlement of the Mormon pioneers in the middle 1800's, irrigation has been one of the major uses of water in Utah. In fact, the practice of irrigation by pioneers in the Great Basin is held to be the first on an extensive scale by Anglo-Saxons in the United States.

Because of water scarcity and the development of needs other than irrigation, the annual amount diverted for irrigation has not increased greatly in recent years. This has occurred in spite of the fact that a considerable acreage of arable land remains undeveloped. The withdrawal uses estimated by the U.S. Geological Survey between 1950 and 1965 reflect only a 14 percent overall increase for this 15-year period (U.S. Geological Survey, 1951, 1968). Total arable land in the state has been estimated at approximately 5 million acres of which only about 1½ million are irrigated (Utah State University, 1968). The breakdown of arable and irrigated lands by hydrologic study unit is presented in Table 3.

In the foreseeable future, irrigation will undoubtedly maintain its position as the largest water user in the state despite a trend for rural areas in general not to keep pace economically with urban areas. While additional water alone will not reverse present trends, more water for supplemental irrigation and new irrigation in established agricultural communities will assist in establishing a more viable economy in rural areas. Water will be needed to eliminate present irrigation shortages and to bring new lands into cultivation as demands for agricultural products increase in the future.

Some other major water uses will probably increase faster than irrigation. In the Provo-Salt Lake City-Ogden-Logan area of relatively high population growth, demands for industrial and municipal water supplies will increase rapidly. Other areas of the state showing little urban growth in the past could experience such growth in the future as government policies designed to alleviate pressing problems of the cities may encourage development of sparsely populated regions. Water supplies will be needed to enable and facilitate this growth. Population and municipal-industrial water use by hydrologic region in 1965 are shown in Table 4.

With greater emphasis being placed on environmental and recreational goals by society, demands for water related to these goals will increase throughout the state. Managed water fowl areas, for example, will require supplemental water supplies and additional supplies for expansion.

Available resources

There are four basic sources of water that may be more fully developed to provide for future requirements in Utah (Haycock, 1968):

1. Water resources along the Wasatch Front including Bear River.

2. The Virgin River and minor streams draining into the lower Colorado River.
3. Groundwater basins within the state.
4. Upper Colorado River water belonging to Utah.

Streams within the state have been measured or gaged extensively, and surface-water availability is well defined.

Although there already has been considerable groundwater development in Utah, extensive groundwater supplies remain available. Water availability by hydrologic area is presented in Table 5.

One of the state's greatest sources of undeveloped water is in the Upper Colorado River Basin separated from the most significant population growth areas by the Wasatch Mountains. Because of this separation of present growth areas from potential supply, much of Utah's share of the Colorado River water currently flows out of the state unused. Even with the transfer of a sizeable amount of Upper Colorado River Basin water to the Great Basin by the Central Utah Project, a large scale project of the U.S. Bureau of Reclamation, some of Utah's share of this water may still be unused (Haycock, 1968). Other projects or expansion of current projects will be required to fully utilize this supply.

Several other means by which available supplies can probably be increased include: control of phreatophytes and evaporation, saline water conversion, waste water reclamation and reuse, and better watershed management. Weather modification and importation schemes also may eventually provide additional supplies.

Table 3. Land use and water use in the hydrologic study units.

Hydrologic Study Unit	Arable Land Acres	Irrigated Land Acres	Water Consumed ac-ft/yr
1	1,483,200	52,000	59,000
2	445,400	246,000	354,000
3	194,100	166,700	236,000
4	448,400	207,200	310,000
5	1,022,200	293,000	436,000*
6	838,300	71,800	137,000
7	340,700	195,000	293,000
8	206,200	98,100	114,000
9	531,300	16,000	30,000
10	89,000	17,500	34,000
Total	5,598,800	1,363,300	2,003,000

*Includes 105,000 ac-ft direct groundwater use.

Source: Utah State University, 1968.

Table 4. Population and municipal and industrial demand.

Hydrologic Study Unit	Population	Municipal and Industrial Water Use ac-ft/yr
1	23,000	3,000
2	70,000	15,000
3	215,000	28,000
4	567,000	94,000
5	33,000	9,000
6	16,000	4,000
7	20,000	4,000
8	26,000	5,000
9	16,000	5,000
10	12,000	1,000
Total	997,000	168,000

Source: Utah Division of Water Resources, 1970.

Table 5. Available water resources in Utah.

Hydrologic Study Unit	Water Availability Groundwater ac-ft/yr	Local Surface Water ac-ft/yr	Local Surface Water Plus Groundwater ac-ft/yr
1	187,000	613,000	800,000
2	138,000	917,000	1,055,000
3	65,000	660,000	725,000
4	394,000	560,000	954,000
5	356,000	417,000	773,000
6	130,000	80,000	210,000
7	40,000	1,319,000	1,359,000*
8	---	650,000	650,000*
9	---	430,000	430,000*
10	10,000	250,000	260,000*
Total	1,320,000	5,896,000	7,216,000

*Much of this water considered as available for transfer.
Source: Utah Division of Water Resources, 1970, and the U.S. Geological Survey.

Major water and related land resources problems

Utah, generally considered an area of chronic water shortage, has access to only partial supplies for nearly two-thirds of its irrigated land. Yet, it has over 2 million acres of swamp land, marshes, mud flats, and valley bottoms suffering from an excess of water. In addition, water evaporation from reservoirs and lakes, as well as transpiration by phreatophytes, amounts to far more than is withdrawn for public supplies. Herein lies the challenge for water planning and management in Utah (Utah Water and Power Board-Utah State University, 1963).

In spite of the fact that there are more than 3 million acres of land in Utah that could be added to agricultural production if water were available, and industrial and urban areas in the state need water to sustain growth, a substantial share of Utah's portion of Colorado River water continues to flow out of the state unused.

Maximum development of Utah's vast groundwater reservoirs will require changes or at least more realistic interpretations of present state statutes in harmony with natural hydrologic laws. In the past, well owners have commonly held the view that their rights involve a guarantee by the state to maintain given water pressures or water table levels in wells. Such control, though not physically possible, would limit the use of groundwater to a fraction of the amount available in storage. Recent court decisions indicate that some improvement in this condition is imminent.

Despite the large sums of money invested in municipal and agricultural waterworks in Utah, much remains to be done. Worn out and obsolete control and conveyance works must be replaced, new water projects must be constructed to meet growing demands, and some legal and institutional changes must be implemented. Problems of water quality are intimately interwoven with other development problems, and will require careful consideration. In general, in spite of aridity, Utah's major concern in water development is not in deficiency of total supply, but in the maldistribution of water resources seasonally and geographically. The challenge is to store, transport, treat, and distribute the available water in an optimal manner.

Present Status of Water Resource Development

A summary of the status of water resource development in the State of Utah is shown in Table 6. Explanation and reference information are given in the following paragraphs.

a. Basin Yield—These data are the same as shown previously in Table 5.
b. Net Evaporation Loss—Large Lakes—These data show the loss of water as a result of evaporation from Bear Lake in Hydrologic Study Unit (HSU) 2 and from Utah Lake in HSU 4. Account was taken of the precipitation on the lake surface to calculate the net loss. Since about one-half of the surface area of Bear Lake is in Idaho, only one-half the net evaporation loss was charged to Utah. Water budget studies were used to determine the loss which was assumed to be equally divided between surface and groundwater.
c. Net Evaporation Loss—Other Major Reservoirs—These data were determined as discussed in b except that in HSU 5 the loss was

distributed 75 percent to surface water and 25 percent to groundwater and in HSU 7 and 8 where no groundwater is available.

d. Storage Capacity—The storage capacity data were taken from several sources:
   1. An early report on the state water plan published March 1963, PR-EC4Bg-20,
   2. Investigations by the Utah Division of Water Resources (DWR), and
   3. Investigations by the Pacific South-West Inter-agency Committee, Water Resources Council.

e. Direct Use of Groundwater by Croplands—These data were only calculated in the water budget for the Sevier Basin. It was included there as a reduction in the available groundwater to make the data compatible in all study units.

f. Excess Precipitation on Irrigated Croplands, October-April—These data were determined from the water budget for HSU 2, 3, 4, 5, and 7. The values represent the amount of precipitation which is in excess of the amount consumptively used by the crops. This represents an addition to the water supply since it would appear as runoff into the streams or an addition to groundwater.

g. Transbasin Diversions—These data were obtained from two sources:
   1. Water budgets for HSU 2, 3, 4, 5, and 7, and
   2. Utah Division of Water Resources Interim Report published March 1970.

h. Gross Supply—These data are the summation of: Basin Yield; Net Evaporation Loss Large Lakes; Net Evaporation Loss Other Major Reservoirs; Direct Use of Groundwater by Croplands; Excess Precipitation on Irrigated Croplands, October-April; and Net Imported Water from Transbasin Diversions.

i. In-Basin Water Availability—These data are the summation of: Basin Yield; Net Evaporation Loss Large Lakes; Direct Use of Groundwater by Croplands; and Excess Precipitation on Irrigated Croplands, October-April.

j. Diversions—The total diversions to agriculture and to municipal and industrial for HSU 2, 3, 4, 5, and 7 were taken from the water budget studies. Total diversions to the other five units were based primarily on data from Utah DWR except where modified to account for Utah Water Research Laboratory (UWRL) studies on the return flow coefficient for agriculture and to approximate the return flow coefficient indicated for the year 2020. This latter modification was made since the LP model must hold the coefficient constant over time. Groundwater pumpage was determined by using the average figure from 1964-1968 given by DWR-USGS in yearly reports on "Ground Water Conditions in Utah." Surface water diversions were obtained by subtraction.

k. Return Flows—The return flows for HSU 2, 3, 4, 5, and 7 were obtained from the water budget studies. Agriculture return flow for HSU 1, 6, 8, and 10 were based on Utah DWR data while for HSU 9 was based on UWRL studies. Municipal and industrial return flows for HSU 1 and 6 were based on Utah DWR data whereas for HSU 8, 9, and 10 were based on approximations to the expected return flow coefficients projected by Utah DWR for the year 2020.

l. Depletions Other Than Reservoir Evaporation—Depletions for HSU 2, 3, 4, 5, and 7 were based on the UWRL water budget studies while for HSU 1, 6, 8, 9, and 10 were based on Utah DWR data. The division between surface water and groundwater was determined using individual budgets for each knowing the groundwater outflow. It is recognized that much of the water in the upper areas of the river basins which is below ground may rise to the surface in the lower areas and be consumed by wetlands, etc. This fact is reflected by the large depletions of groundwater by wetlands.

m. Outflow from HSU—The groundwater outflow to Great Salt Lake from HSU 1, 2, 3, and 4 was estimated using the results of several studies conducted on this subject by UWRL and others. HSU 5 and 6 have groundwater mining which is shown by negative outflow. Groundwater outflow for HSU 7 was obtained from the water budget study. Surface water outflow was determined by balancing water availability, depletions, and groundwater outflow.

Storage Requirements

Storage requirements, including amounts needed to regulate seasonal fluctuations in stream flow as well as to provide the long-term carryover needed to meet extended series of dry years, were estimated for each of the 10 hydrologic study areas. The required storage for a given water requirement depends on the magnitude and frequency distribution of the streamflow.

Estimates of long-term carryover storage requirements are based upon the results of frequency mass-curve analyses completed for 76 streams located throughout the state and published in the Hydrologic Atlas of Utah (Utah State University—Utah Department of Natural Resources, 1968). A frequency mass-curve is obtained by plotting, for any selected probability of occurrence, the expected values of accumulated volumes of runoff during each of many sequences of consecutive months (through several years) against the carryover period in months. Separate frequency mass-curves are obtained for each probability of occurrence selected.

Since the volume of required storage can be considered a function of probability, carryover period, and the water demand level, the frequency mass-curve analysis provides information necessary for plotting demand vs. storage curves. A computer program developed to carry out the large amount of computation involved (Jeppson, 1967) was used to analyze monthly runoff data and provide the information necessary to compute draft vs. storage curves for the 76 streams considered in the Hydrologic Atlas. Draft was expressed in percent of mean annual flow for values of 50, 65, 80, 95, and 110 percent. Storage was given in inches over the watershed. Probability values of 75, 90, and 95 percent were used.

The long-term storage requirement corresponded to the maximum values of storage as a function of the carryover period. These values were determined for each of the streams at each of the five draft values and three probability levels. The total long-term storage for each of the hydrologic study areas was then determined by weighting each stream's watershed area to the total watershed area.

The seasonal storage was determined for each hydrologic study area by calculating the difference between the annual supply curve on a monthly basis and the draft requirement for each of the five draft values. Where water budgets were available (areas 2, 3, 4, 5, and 7) the draft curves were based on these data. Where water budgets were not available, the draft curves were based on calculations using Munson's Index (Munson, 1966). The supply curve was based on monthly stream flow data from the Hydrologic Atlas weighted for the watershed area as before.

The seasonal storage was added to the long-term storage to determine the total storage required for HSU 2 through 10. Insufficient stream flow data were available for HSU 1. Figures 3 through 11 show the storage required vs. draft at probability levels of 75, 80, 85, 90, and 95 percent where the intermediate values were obtained by cross plots. The curves for HSU 1 shown on Figure 2 were obtained from Figures 12 and 13 which are a summary of HSU 2 through 10 in non-dimensional form. An average value for HSU 2, 3, and 5 was used to determine storage requirements for HSU 1 at a probability of 75 percent while an average value for HSU 2 through 6 was used to determine storage requirements at a probability of 95 percent.

The use of these storage-draft curves can be illustrated by the following example using Figure 5.

Assume it is desired to know how much storage would be required in the Jordan River study unit (HSU 4) to meet a total draft in the area equal to 80 percent of the mean annual flow or 450,000 ac-ft/yr. From Figure 5 the required storage is seen to be 460,000 ac-ft at the 95 percent probability level. The interpretation of the probability level is that approximately 95 percent of the time one would expect to be able to provide the draft of 450,000 ac-ft/yr by building 460,000 ac-ft of storage. Both long-term holdover storage and annual storage requirements would be provided.

Groundwater Recharge Potential

The groundwater recharge potential or opportunity was assessed in each study unit in order to define the recharge constraint. The problem was to designate the areas where artificial recharge to the groundwater basin is practicable, provided the water table is low enough to permit recharge, and to estimate for each area the amount of water that could be put underground in basins and/or through wells.

In HSU 2, 3, and 4 the reservoirs are essentially alluvial fans intercalated with and overlapped by lake-bottom sediments of Pleistocene Lake Bonneville. The aquifers in these fans are sheets or trains of stream gravel that spread outward from the canyon mouths and thin and decrease in particle size toward the valley bottom. Recharge to these reservoirs is largely at the apex of the alluvial fans, where the stream gravel is coarse, and where lake bottom sediments, deposited over the fan during high stages of the lake, have been stripped away by the stream after the lake lowered. These recharge areas are surrounded, valleyward, by the most productive parts of the artesian basins, where pressures, yields and water quality are best. The areas near the apexes of the fans, where a recharge basin would not be perched on lake-bottom sediments, are small, and their position can be judged only partly by the present surface layer of coarse stream alluvium. In any case, it is a limited area very near the mouth of the canyon from which the fan material came.

In practically all cases the fans are at present full or nearly full of water, and a program of artificial recharge would depend upon lowering of the water table in the fans so that additional recharge could be accommodated.

Based on results of the few artificial recharge experiments that have been conducted in Utah, and experience elsewhere, a possible recharge rate of 2 feet per day for 300 days of the year was selected.

The favorable position for recharge wells would also have to be high on the alluvial fan where the aquifers are relatively thick and coarse-grained. Based on experience in Utah and elsewhere, a value of 2500 gallons per minute per well was selected as a reasonable estimate, with the wells spaced one to a quarter section.

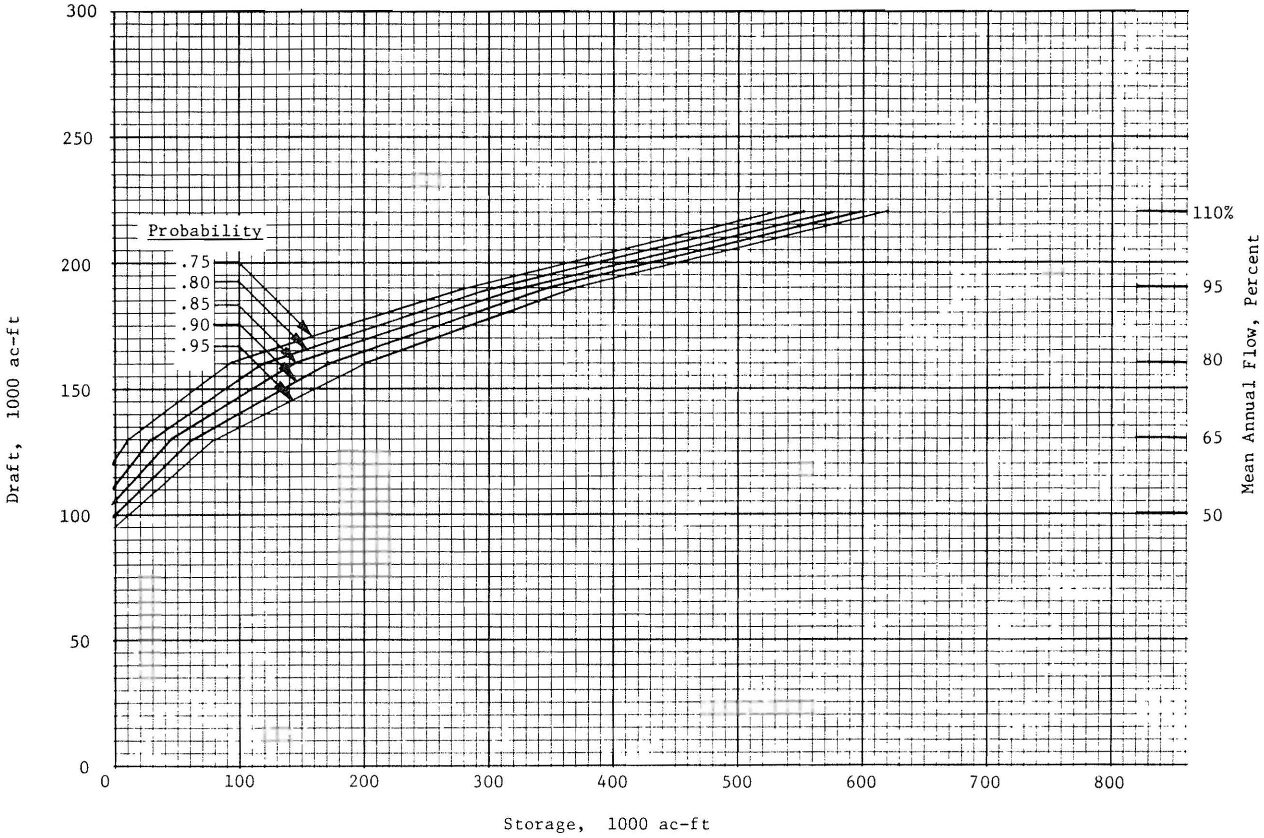

Figure 2. Reservoir storage requirement for the Great Salt Lake Desert hydrologic study unit.

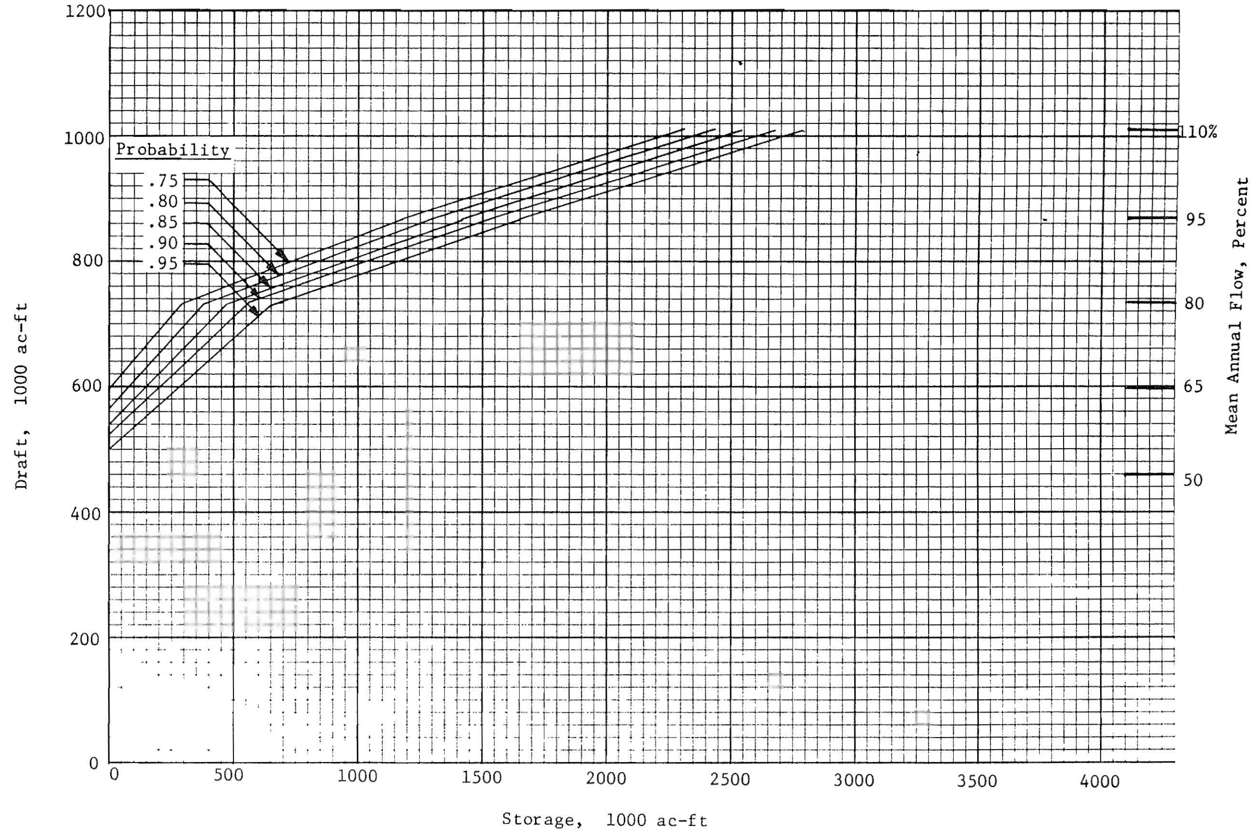

Figure 3. Reservoir storage requirement for the Bear River hydrologic study unit.

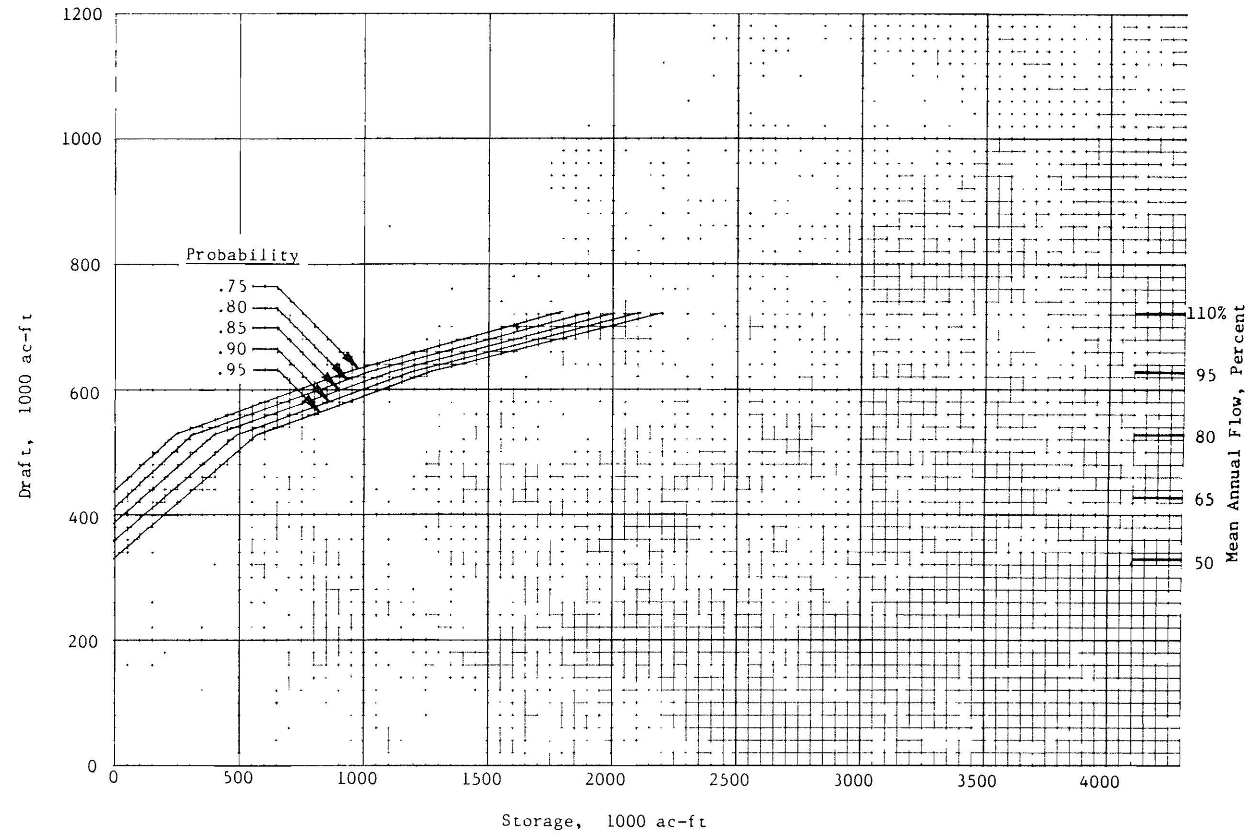

Figure 4. Reservoir storage requirement for the Weber River hydrologic study unit.

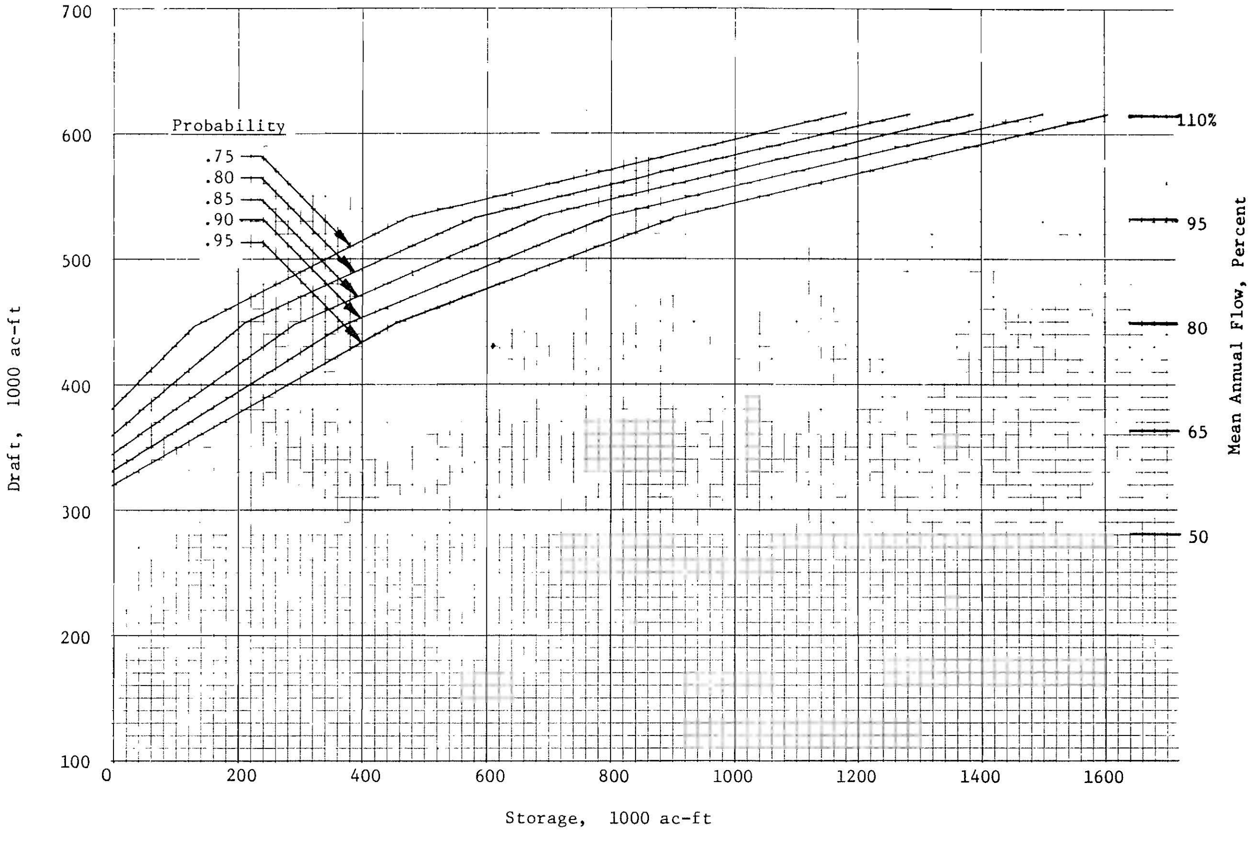

Figure 5. Reservoir storage requirement for the Jordan River hydrologic study unit.

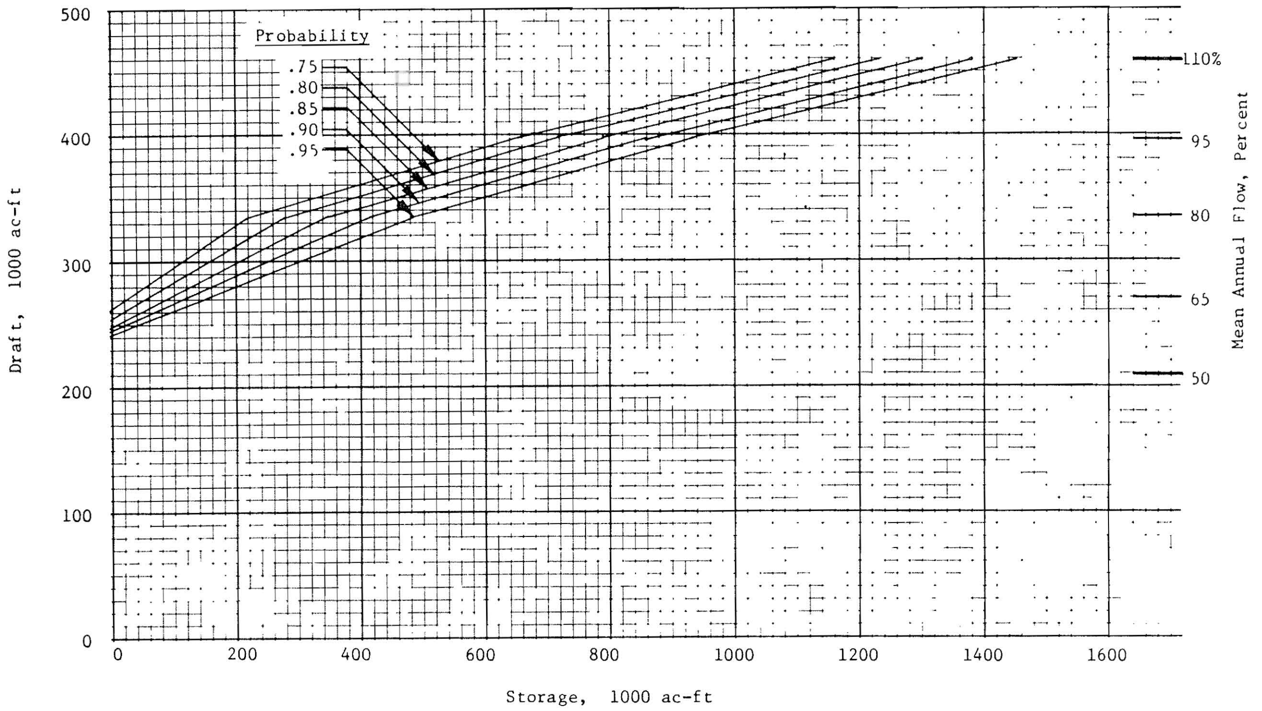

Figure 6. Reservoir storage requirement for the Sevier River hydrologic study unit.

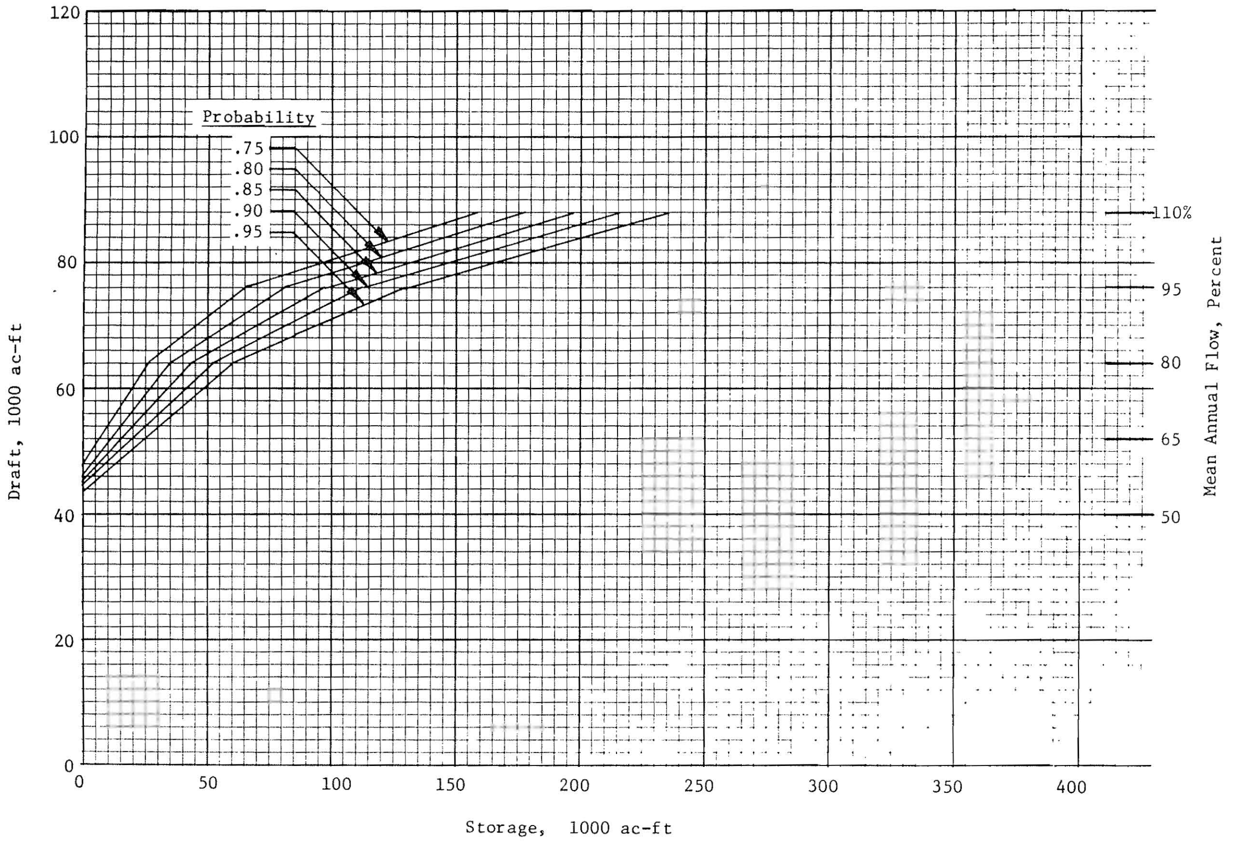

Figure 7. Reservoir storage requirement for the Cedar-Beaver hydrologic study unit.

The limit on Colorado River outflow was established as follows:

HSU	Present (1965) Depletions (ac-ft/yr)		Difference	Total Basin Yield (ac-ft/yr)
	Man Caused	Total		
7	468,300	692,100	223,800	1,359,000
8	156,000	174,500	18,500	650,000
9	39,400	43,100	3,700	430,000
			246,000	2,439,000

Total Yield Upper Basin			2,439,000
Realistic Allocation to Utah	1,438,000		
Net Mainstem Evaporation	152,000		
Net Allocation to Meet Demands		1,286,000	
Additional Water Allocation Due to Definition that Only Man Caused Depletions are Chargeable Against the Allocation		246,000	
Total Allocation			1,532,000
Water that Must be Released as Colorado River Outflow			907,000

A complete matrix of the model is shown on Figure 31. As indicated, the letters of the alphabet show the order of magnitude of the coefficients. There is one objective function, 204 constraints, and 338 variables in the model.

Variable bounds

Bounds have been established on several groups of variables in the model. These groups are: 1) inter-basin transfer, 2) additional surface water storage, and 3) surface water and groundwater outflow from each of the hydrologic study units. In addition, an upper bound of unity was placed on each of the dummy variables as part of the separable programming algorithm.

Table 9. Variable bounds on new inter-basin transfers.

Variable	Bound (ac-ft/yr)	Type of Bound
QBULSW5	29,000	Upper
QBUMP5	136,600	Upper
QUILSW3	20,000	Upper
QUILSW5	57,000	Upper
QUIMPT	420,000	Upper
QSALSW4	15,000	Upper
QSAMPT	22,400	Upper
QLSW2SW1	90,000	Upper
QLSW2SW3	130,000	Upper
QLSW3SW4	146,000	Upper
QLSW4SW5	69,000	Upper
QLSW5SW6	60,000	Upper
QLSWOSW6	47,000	Upper

Inter-basin transfer

Bounds or presently existing inter-basin transfers were established primarily from the water budget studies. Average values to represent approximate 1965 conditions were used in the model. Bounds on new development were taken from the DWR Interim Report of 1970 and from consultation with Bureau of Reclamation personnel associated with the Central Utah Project. New development bounds are shown on Table 9.

Additional surface water storage

These bounds were established from data of the USGS, the Utah DWR, the Pacific Southwest Inter-Agency Committee, and from studies conducted at UWRL. These results are shown on Table 10.

Surface and groundwater outflow

These bounds were established from a consideration of minimum river flow to achieve a salt balance, studies conducted by the USGS on groundwater outflow, and on studies made at UWRL. The bounds are shown on Table 11.

Constraint Name	Constraint			Explanations and Comments
GWRC1	1.0 QLSW1R1 + 1.0 QWW1R1	≤	0.0	These inequalities show the conconstraint on groundwater recharge. The RHS was estimated from geologic and hydrologic considerations discussed earlier in this report.
GWRC2	1.0 QLSW2R2 + 1.0 QWW2R2	≤	60.0	
GWRC3	1.0 QLSW3R3 + 1.0 QWW3R3	≤	366.0	
GWRC4	1.0 QLSW4R4 + 1.0 QWW4R4	≤	434.0	
GWRCU4	1.0 QLSW4RU4 + 1.0 QWW4RU4	≤	100.0	
GWRC5	1.0 QLSW5R5 + 1.0 QWW5R5	≤	52.0	
GWRCU5	1.0 QLSW5RU5 + 1.0 QWW5RU5	≤	52.0	
GWRC6	1.0 QLSW6R6 + 1.0 QWW6R6	≤	65.0	
GWRC7	1.0 QLSW7R7 + 1.0 QWW7R7	≤	0.0	
GWRC0	1.0 QLSW0R0 + 1.0 QWW0R0	≤	0.0	

Figure 28. Constraints for groundwater artificial recharge limits.

Constraint Name	Constraint			Explanation and Comments
BUMPT	1.0 QBULSW4 + 1.25 QBULSW5 - 1.0 QBUMPT	=	0	These equations calculate the total water imported to the Great Basin from each of the three sources in the CUP. The 1.25 coefficient accounts for transport losses.
UIMPT	1.0 QUILSW3 + 1.0 QUILSW4 + 1.25 QUILSW5 - 1.0 QUIMPT	=	0	
SAMPT	1.0 QSALSW4 + 1.0 QSALSW5 - 1.0 QSAMPT	=	0	
TLSW3SW4	1.0 PLSW3SW4 + 1.0 QLSW3SW4 - 1.0 RLSW3SW4	=	0	These equations show the constraint on inter-basin transfer in those basins presently having some transfer.
TLSW0SW6	1.0 PLSW0SW6 + 1.0 QLSW0SW6 - 1.0 RLSW0SW6	=	0	

Figure 29. Constraints for inter-basin transfer limits.

Constraint Name	Constraint			Explanation and Comments
INFLOGSL	1.0 QLSW1OF1 + 1.0 QLSW2OF2 + 1.0 QLSW3OF3 + 1.0 QLSW4OF4 + 1.0 QGW1OF1 + 1.0 QGW2OF2 + 1.0 QGW3OF3 + 1.0 QGW4OF4	≥	201.0	This inequality shows the constraint on total inflow to the Great Salt Lake. The RHS will change depending upon the ground rules for the particular run being made. The number 201.0 is simply the sum of the individual minimum inflows.
CROUT	1.0 QLSW7OF7 + 1.0 QLSW8OF8 + 1.0 QLSW9OF9 + 1.0 QGW7OF7	≥	907.0	This inequality shows the constraint on the Colorado River water which is allocated to Utah from the Upper Basin Compact. The RHS was calculated as shown in the text.

Figure 30. Constraints for inflow and outflow limits.

Constraint Name	Constraint		Explanation and Comments
AGRFSW1	.4000 RLSW1AG1 + .4000 RGW1AG1 - 1.0 QAR1LSW1	= 0	These equations calculate the amount of agriculture return flow that goes to local surface water. The non-unity coefficient is called the return flow coefficient to surface water.
AGRFSW2	.5077 RLSW2AG2 + .5077 RGW2AG2 + .5077 PLSW3AG2 - 1.0 QAR2LSW2	= 0	
AGRFSW3	.4833 RLSW3AG3 + .4833 RGW3AG3 - 1.0 QAR3LSW3	= 0	
AGRFSW4	.4609 RLSW4AG4 + .4609 RGW4AG4 - 1.0 QAR4LSW4	= 0	
AGRFSW5	.5250 RLSW5AG5 + .5250 RGS5AG5 + .5250 PLSW8AG5 - 1.0 QAR5LSW5	= 0	
AGRFSW6	.4000 RLSW6AG6 + .4000 RGW6AG6 - 1.0 QAR6LSW6	= 0	
AGRFSW7	.4788 RLSW7AG7 + .4788 RGW7AG7 - 1.0 QAR7LSW7	= 0	
AGRFSW8	.6250 RLSW8AG8 - 1.0 QAR8LSW8	= 0	
AGRFSW9	.8000 RLSW9AG9 + .8000 PLSW5AG9 - 1.0 QAR9LSW9	= 0	
AGRFSW0	.5000 RLSW0AG0 + .5000 RGW0AG0 - 1.0 QAR0LSW0	= 0	
AGRFGW1	.1242 RLSW1AG1 + .1242 RGW1AG1 - 1.0 QAR1GW1	= 0	These equations calculate the amount of agriculture return flow that goes to groundwater. The non-unity coefficient is called the return flow coefficient to groundwater.
AGRFGW2	.1500 RLSW2AG2 + .1500 RGW2AG2 + .1500 PLSW3AG2 - 1.0 QAR2GW2	= 0	
AGRFGW3	.1500 RLSW3AG3 + .1500 RGW3AG3 - .10 QAR3GW3	= 0	
AGRFGW4	.1500 RLSW4AG4 + .1500 RGW4AG4 - 1.0 QAR4GW4	= 0	
AGRFGW5	.1500 RLSW5AG5 + .1500 RGW5AG5 + .1500 PLSW8AG5 - 1.0 QAR5GW5	= 0	
AGRFGW6	.1447 RLSW6AG6 + .1447 RGW6AG6 - 1.0 QAR6GW6	= 0	
AGRFGW7	.1500 RLSW7AG7 + .1500 RGW7AG7 - 1.0 QAR7GW7	= 0	
AGRFGW0	0.0 RLSW0AG0 + 0.0 RGW0AG0 - 1.0 QAR0GW0	= 0	

Figure 26. Constraints for return flow from agricultural use.

Constraint Name	Constraint		Explanations and Comments
FGWAVWL1	1.0 QFGW1WL1 - 0.50 QAR1GW1	= 166.8	These equations calculate the amount of groundwater that is used from natural sources by wetlands. These sources are; 1) the groundwater that returns to the surface in the wetlands by natural conditions and 2) the groundwater which is available for wetland consumption which had as its source the agriculture return flow to the groundwater. The coefficient of 0.50 for the return flow and the RHS were estimated using present conditions based on water budgets and accounting for groundwater outflow.
FGWAVWL2	1.0 QFGW2WL2 - 0.50 QAR2GW2	= 147.5	
FGWAVWL3	1.0 QFGW3WL3 - 0.50 QAR3GW3	= 51.8	
FGWAVWL4	1.0 QFGW4WL4 - 0.50 QAR4GW4	= 96.0	
FGWAVWL5	1.0 QFGW5WL5 - 0.50 QAR5GW5	= 209.1	
FGWAVWL6	1.0 QFGW6WL6 - 0.50 QAR6GW6	= 42.5	
FGWAVWL7	1.0 QFGW7WL7 - 0.50 QAR7GW7	= 59.2	
FGWAVWL0	1.0 QFGW0WL0	= 10.0	

Figure 27. Constraints for free groundwater for wetlands.

Constraint Name	Constraint	Explanations and Comments
EVLSW1	0.070 RLSW1ST1 - 1.0 QLSW1EV1 = 0	These equations calculate the amount of evaporation loss from the major reservoirs (except Bear and Utah lakes) as function of the reservoir storage. In HSU 2 and 4 the evaporation loss-storage relationship is highly non-linear and is calculated using the separable programming algorithm of MPS 360.
EVLSW2	0.50 QEV2 - 1.0 QLSW2EV2 = 0	
EVLSW3	0.023 RLSW3ST3 - 1.0 QLSW3EV3 = 0	
EVLSW4	0.50 QEV4 - 1.0 QLSW4EV4 = 0	
EVLSW5	0.093 RLSW5ST5 - 1.0 QLSW5EV5 = 0	
EVLSW6	0.0525 RLSW6ST6 - 1.0 QLSW6EV6 = 0	
EVLSW7	0.028 RLSW7ST7 - 1.0 QLSW7EV7 = 0	
EVLSW8	0.045 RLSW8ST8 - 1.0 QLSW8EV8 = 0	
EVLSW9	0.070 RLSW9ST9 - 1.0 QLSW9EV9 = 0	
EVLSW0	0.070 RLSW0ST0 - 1.0 QLSW0EV0 = 0	
EVGW1	0.0 RLSW1ST1 - 1.0 QGW1EV1 = 0	
EVGW2	0.5 QEV2 - 1.0 QGW2EV2 = 0	
EVGW3	0.023 RLSW3ST3 - 1.0 QGW3EV3 = 0	
EVGW4	0.5 QEV4 - 1.0 QGW4EV4 = 0	
EVGW5	0.031 RLSW5ST5 - 1.0 QGW5EV5 = 0	
EVGW6	0.0175 RLSW6ST6 - 1.0 QGW6EV6 = 0	
EVGW7	0.0 RLSW7ST7 - 1.0 QGW7EV7 = 0	
EVGW0	0.0 RLSW0ST0 - 1.0 QGW0EV0 = 0	
EV2ST2	208.0 E21 + 103.0 E22 + 1500.0 E23 - 1.0 RLSW2ST2 = 0	These equations calculate the amount of evaporation loss as function of storage in HSU 2 and 4.
EV2	0.0 E21 + 3.0 E22 + 105.0 E23 - 1.0 QEV2 = 0	
EV4ST4	220.0 E41 + 196.0 E42 + 1500.0 E43 - 1.0 RLSW4ST4 = 0	
EV4	0.0 E41 + 25.5 E42 + 105.0 E43 - 1.0 QEV4 = 0	

Figure 24. Constraints for net evaporation loss from Reservoirs (other than Bear and Utah Lakes).

Constraint Name	Constraint	Explanations and Comments
WWRF1	.7000 RLSW1MI1 + .7000 RGW1MI1 - 1.0 QWW1LSW1 - 1.0 QWW1R1 = 0	These equations calculate the amount of waste water return flow from municipal and industrial uses. The return flow can go either to local surface water or ground water depending upon economics and need. The non-unity coefficients are called the return flow coefficients.
WWRF2	.6600 RLSW2MI2 + .6600 RGW2MI2 - 1.0 QWW2LSW2 - 1.0 QWW2R2 = 0	
WWRF3	.4366 RLSW3MI3 + .436 6RGW3MI3 - 1.0 QWW3LSW3 - 1.0 QWW3R3 = 0	
WWRF4	.6889 RLSW4MI4 + .6889 RGW4MI4 + .6889 PLSW1MI4 - 1.0 QWW4LSW4 - 1.0 QWW4R4 - 1.0 QWW4RU4 = 0	
WWRF5	.4588 RLSW5MI5 + .4588 RGW5MI5 - 1.0 QWW5LSW5 - 1.0 QWW5R5 - 1.0 QWW5RU5 = 0	
WWRF6	.6970 RLSW6MI6 + .6970 RGW6MI6 - 1.0 QWW6LSW6 - 1.0 QWW6R6 = 0	
WWRF7	.6500 RLSW7MI7 + .6500 RGW7MI7 - 1.0 QWW7LSW7 - 1.0 QWW7R7 = 0	
WWRF8	.3000 RLSW8MI8 - 1.0 QWW8LSW8 = 0	
WWRF9	.2500 RLSW9MI9 - 1.0 QWW9LSW9 = 0	
WWRF0	.3000 RLSW0MI0 + .3000RGW0MI0 - 1.0 QWW0LSW0 - 1.0 QWW0R0 = 0	

Figure 25. Constraints for waste water return flow from municipal and industrial use.

Constraint Name	Constraint	Explanation and Comments
GRID1	123. D11 + 7. D12 + 30. D13 + 30. D14 - 1.0 QDREQ1 = 0	These equations calculate the amount of storage required as function of the draft required. The draft-storage relationship is highly non-linear and these equations represent the approximation for the separable programming algorithm in the MPS 360.
LSW1ST1	0. D11 + 10. D12 + 80. D13 + 190. D14 - 1.0 RLSW1ST1 = 0	
GRID2	596. D21 + 138. D22 + 137. D23 + 138. D24 - 1.0 QDREQ2 = 0	
LSW2ST2	0. D21 + 300. D22 + 880. D23 + 1140. D24 - 1.0 RLSW2ST2 = 0	
GRID3	435. D31 + 93. D32 + 99. D33 + 99. D34 - 1.0 QDREQ3 = 0	
LSW3ST3	0. D31 + 240. D32 + 690. D33 + 870. D34 - 1.0 RLSW3ST3 = 0	
GRID4	382. D41 + 66. D42 + 84. D43 + 84. D44 - 1.0 QDREQ4 = 0	
LSW4ST4	0. D41 + 130. D42 + 340. D43 + 710. D44 - 1.0 RLSW4ST4 = 0	
GRID5	262. D51 + 71. D52 + 63. D53 + 62. D54 - 1.0 QDREQ5 = 0	
LSW5ST5	0. D51 + 220. D52 + 430. D53 + 510. D54 - 1.0 RLSW5ST5 = 0	
GRID6	48. D61 + 16. D62 + 12. D63 + 12. D64 - 1.0 QDREQ6 = 0	
LSW6ST6	0. D61 + 26. D62 + 38. D63 + 94. D64 - 1.0 RLSW6ST6 = 0	
GRID7	870. D71 + 185. D72 + 198. D73 + 198. D74 - 1.0 QDREQ7 = 0	
LSW7ST7	0. D71 + 320. D72 + 600. D73 + 1280. D74 - 1.0 RLSW7ST7 = 0	
GRID8	394. D81 + 126. D82 + 98. D83 + 97. D84 - 1.0 QDREQ8 = 0	
LSW8ST8	0. D81 + 200. D82 + 300. D83 + 710. D84 - 1.0 RLSW8ST8 = 0	
GRID9	272. D91 + 72. D92 + 65. D93 + 64. D94 - 1.0 QDREQ9 = 0	
LSW9ST9	0. D91 + 120. D92 + 150. D93 + 280. D94 - 1.0 RLSW9ST9 = 0	
GRID0	160. D01 + 40. D02 + 38. D03 + 37. D04 - 1.0 QDREQ0 = 0	
LSW0ST0	0. D01 + 75. D02 + 100. D03 + 285. D04 - 1.0 RLSW0ST0 = 0	
TST1	1.0 PLSW1ST1 + 1.0 QLSW1ST1 - 1.0 RLSW1ST1 = 0	These equations sum the present developed storage and new development of storage to get the total storage.
TST2	1.0 PLSW2ST2 + 1.0 QLSW2ST2 - 1.0 RLSW2ST2 = 0	
TST3	1.0 PLSW3ST3 + 1.0 QLSW3ST3 - 1.0 RLSW3ST3 = 0	
TST4	1.0 PLSW4ST4 + 1.0 QLSW4ST4 - 1.0 RLSW4ST4 = 0	
TST5	1.0 PLSW5ST5 + 1.0 QLSW5ST5 - 1.0 RLSW5ST5 = 0	
TST6	1.0 PLSW6ST6 + 1.0 QLSW6ST6 - 1.0 RLSW6ST6 = 0	
TST7	1.0 PLSW7ST7 + 1.0 QLSW7ST7 - 1.0 RLSW7ST7 = 0	
TST8	1.0 PLSW8ST8 + 1.0 QLSW8ST8 - 1.0 RLSW8ST8 = 0	
TST9	1.0 PLSW9ST9 + 1.0 QLSW9ST9 - 1.0 RLSW9ST9 = 0	
TST0	1.0 PLSW0ST0 + 1.0 QLSW0ST0 - 1.0 RLSW0ST0 = 0	

(a) Probability of 0.75

Constraint Name	Constraint	Explanation and Comments
GRID1	96. D11 + 34. D12 + 30. D13 + 30. D14 - 1.0 QDREQ1 = 0	
LSW1ST1	0 D11 + 80. D12 + 120. D13 + 170. D14 - 1.0 RLSW1ST1 = 0	
GRID2	500. D21 + 234. D22 + 137. D23 + 138. D24 - 1.0 QDREQ2 = 0	
LSW2ST2	0 D21 + 660. D22 + 1000. D23 + 1140. D24 - 1.0 RLSW2ST2 = 0	
GRID3	330. D31 + 198. D32 + 99. D33 + 99. D34 - 1.0 QDREQ3 = 0	
LSW3ST3	0 D31 + 570. D32 + 690. D33 + 940. D34 - 1.0 RLSW3ST3 = 0	
GRID4	320. D41 + 128. D42 + 84. D43 + 84. D44 - 1.0 QDREQ4 = 0	
LSW4ST4	0 D41 + 450. D42 + 450. D43 + 710. D44 - 1.0 RLSW4ST4 = 0	
GRID5	242. D51 + 91. D52 + 63. D53 + 62. D54 - 1.0 QDREQ5 = 0	
LSW5ST5	0 D51 + 480. D52 + 450. D53 + 520. D54 - 1.0 RLSW5ST5 = 0	
GRID6	44. D61 + 20. D62 + 12. D63 + 12. D64 - 1.0 QDREQ6 = 0	
LSW6ST6	0 D61 + 60. D62 + 68. D63 + 107. D64 - 1.0 RLSW6ST6 = 0	
GRID7	730. D71 + 325. D72 + 198. D73 + 198. D74 - 1.0 QDREQ7 = 0	
LSW7ST7	0 D71 + 650. D72 + 820. D73 + 1350. D74 - 1.0 RLSW7ST7 = 0	
GRID8	340. D81 + 180. D82 + 98. D83 + 97. D84 - 1.0 QDREQ8 = 0	
LSW8ST8	0 D81 + 430. D82 + 450. D83 + 750. D84 - 1.0 RLSW8ST8 = 0	
GRID9	228. D91 + 116. D92 + 65. D93 + 64. D94 - 1.0 QDREQ9 = 0	
LSW9ST9	0 D91 + 220. D92 + 185. D93 + 345. D94 - 1.0 RLSW9ST9 = 0	
GRID0	127. D01 + 73. D02 + 38. D03 + 37. D04 - 1.0 QDREQ0 = 0	
LSW0ST0	0 D01 + 130. D02 + 150. D03 + 295. D04 - 1.0 RLSW0ST0 = 0	

(b) Probability of 0.95.

Figure 23. Constraints for water storage requirements.

Constraint Name	Constraint		Explanation and Comments
WLREQ1	1.0 QLSW1WL1 + 1.0 QCGW1WL1 + 1.0 QFGW1WL1	= 715.0	These equations show the constraint on water to meet the depletion requirement for wetland use. The RHS is the 1965 wetland demand shown earlier.
WLREQ2	1.0 QLSW2WL2 + 1.0 QCGW2WL2 + 1.0 QFGW2WL2	= 240.0	
WLREQ3	1.0 QLSW3WL3 + 1.0 QCGW3WL3 + 1.0 QFGW3WL3	= 143.1	
WLREQ4	1.0 QLSW4WL4 + 1.0 QCGW4WL4 + 1.0 QFGW4WL4	= 276.4	
WLREQ5	1.0 QLSW5WL5 + 1.0 QCGW5WL5 + 1.0 QFGW5WL5	= 332.6	
WLREQ6	1.0 QLSW6WL6 + 1.0 QCGW6WL6 + 1.0 QFGW6WL6	= 130.0	
WLREQ7	1.0 QLSW7WL7 + 1.0 QCGW7WL7 + 1.0 QFGW7WL7	= 315.0	
WLREQ8	1.0 QLSW8WL8	= 36.0	
WLREQ9	1.0 QLSW9WL9	= 8.0	
WLREQ0	1.0 QLSWOWLO + 1.0 QCGWOWLO + 1.0 QFGWOWLO	= 19.0	

Figure 21. Constraints for water depletion requirements for wetland use.

Constraint Name	Constraint		Explanation and Comments
DREQ1	1.0 RLSW1AG1 + 1.0 RLSW1MI1 + 1.0 PLSW1MI4 - 1.0 QLSW2SW1 - 0.0 QWW1LSW1 - 0.2 QAR1LSW1 - 1.0 QDREQ1	= 0	These equations calculate the amount of draft required from water in storage reservoirs. Provision is made to include a portion of the M&I waste water return flow and agriculture return flow in the equation. This portion of the return flow is that which is available for re-use downstream. The coefficient for M&I return flow was estimated to be zero since the geographic location of the major cities and towns indicated negligible re-use of waste water downstream. The coefficient for agriculture return flow was estimated from an examination of the present relationship between draft and storage.
DREQ2	1.0 RLSW2AG2 + 1.0 RLSW2MI2 + 1.0 QLSW2SW1 + 1.0 QLSW2SW3 - 0.0 QWW2LSW2 - 0.8 QAR2LSW2 - 1.0 QDREQ2	= 0	
DREQ3	1.0 RLSW3AG3 + 1.0 RLSW3MI3 + 1.0 PLSW3AG2 + 1.0 RLSW3SW4 - 1.0 QLSW2SW3 - 1.0 QUILSW3 - 0.0 QWW3LSW3 - 0.5 QAR3LSW3 - 1.0 QDREQ3	= 0	
DREQ4	1.0 RLSW4AG4 + 1.0 RLSW4MI4 + 1.2 5QLSW4SW5 - 1.0 RLSW3SW4 - 1.0 QBULSW4 - 1.0 QUILSW4 - 1.0 QSALSW4 - 1.0 PLSW7SW4 - 0.0 QWW4LSW4 - 0.7 QAR4LSW4 - 1.0 QDREQ4	= 0	
DREQ5	1.0 RLSW5AG5 + 1.0 RLSW5MI5 + 1.0 QLSW5SW6 + 1.0 PLSW5AG9 - 1.0 QLSW4SW5 - 1.0 QBULSW5 - 1.0 QUILSW5 - 1.0 QSALSW5 - 0.0 QWW5LSW5 - 0.8 QAR5LSW5 - 1.0 QDREQ5	= 0	
DREQ6	1.0 RLSW6AG6 + 1.0 RLSW6MI6 - 1.0 QLSW5SW6 - 1.0 RLSWOSW6 - 0.0 QWW6LSW6 - 0.6 QAR6LSW6 - 1.0 QDREQ6	= 0	
DREQ7	1.0 RLSW7AG7 + 1.0 RLSW7MI7 + 1.0 PLSW7SW4 + 1.0 QBUMPT + 1.0 QUIMPT - 0.0 QWW7LSW7 - 0.3 QAR7LSW7 - 1.0 QDREQ7	= 0	
DREQ8	1.0 RLSW8AG8 + 1.0 RLSW8MI8 + 1.0 PLSW8AG5 + 1.0 QSAMPT - 0.0 QWW8LSW8 - 0.2 QAR8LSW8 - 1.0 QDREQ8	= 0	
DREQ9	1.0 RLSW9AG9 + 1.0 RLSW9MI9 - 0.0 QWW9LSW9 - 0.2 QAR9LSW9 - 1.0 QDREQ9	= 0	
DREQ0	1.0 RLSWOAGO + 1.0 RLSWOMIO + 1.0 RLSWOSW6 - 0.0 QWWOLSWO - 0.3 QAROLSWO - 1.0 QDREQO	= 0	

Figure 22. Constraints for reservoir draft requirements.

Figure 22. Constraints for reservoir draft requirements.

Constraint Name	Constraint		Explanations and Comments
AGREQ1	1.0 RLSW1AG1 + 1.0 RGW1AG1	≥ 124.0	These inequalities show the constraints on water to meet the diversion requirements for agricultural use. The RHS is the 1965 agriculture demand shown earlier.
AGREQ2	1.0 RLSW2AG2 + 1.0 RGW2AG2 + 1.0 PLSW3AG2	≥ 1034.0	
AGREQ3	1.0 RLSW3AG3 + 1.0 RGW3AG3	≥ 643.4	
AGREQ4	1.0 RLSW4AG4 + 1.0 RGW4AG4	≥ 796.7	
AGREQ5	1.0 RLSW5AG5 + 1.0 RGW5AG5 + 1.0 PLSW8AG5	≥ 1017.9	
AGREQ6	1.0 RLSW6AG6 + 1.0 RGW6AG6	≥ 300.0	
AGREQ7	1.0 RLSW7AG7 + 1.0 RGW7AG7	≥ 789.1	
AGREQ8	1.0 RLSW8AG8	≥ 303.0	
AGREQ9	1.0 RLSW9AG9 + 1.0 PLSW5AG9	≥ 150.0	
AGREQ0	1.0 RLSW0AG0 + 1.0 RGW0AG0	≥ 68.0	
TLSW1AG1	1.0 PLSW1AG1 + 1.0 QLSW1AG1 - 1.0 RLSW1AG1	= 0	These equations sum the diversion from present developments to agriculture from local surface water with the new development diversions to get the total diversions to agriculture from local surface water.
TLSW2AG2	1.0 PLSW2AG2 + 1.0 QLSW2AG2 - 1.0 RLSW2AG2	= 0	
TLSW3AG3	1.0 PLSW3AG3 + 1.0 QLSW3AG3 - 1.0 RLSW3AG3	= 0	
TLSW4AG4	1.0 PLSW4AG4 + 1.0 QLSW4AG4 - 1.0 RLSW4AG4	= 0	
TLSW5AG5	1.0 PLSW5AG5 + 1.0 QLSW5AG5 - 1.0 RLSW5AG5	= 0	
TLSW6AG6	1.0 PLSW6AG6 + 1.0 QLSW6AG6 - 1.0 RLSW6AG6	= 0	
TLSW7AG7	1.0 PLSW7AG7 + 1.0 QLSW7AG7 - 1.0 RLSW7AG7	= 0	
TLSW8AG8	1.0 PLSW8AG8 + 1.0 QLSW8AG8 - 1.0 RLSW8AG8	= 0	
TLSW9AG9	1.0 PLSW9AG9 + 1.0 QLSW9AG9 - 1.0 RLSW9AG9	= 0	
TLSW0AG0	1.0 PLSW0AG0 + 1.0 QLSW0AG0 - 1.0 RLSW0AG0	= 0	
TGW1AG1	1.0 PGW1AG1 + 1.0 QGW1AG1 - 1.0 RGW1AG1	= 0	These equations sum the diversion from present developments to agriculture from groundwater with the new development diversions to get the total diversions to agriculture from groundwater.
TGW2AG2	1.0 PGW2AG2 + 1.0 QGW2AG2 - 1.0 RGW2AG2	= 0	
TGW3AG3	1.0 PGW3AG3 + 1.0 QGW3AG3 - 1.0 RGW3AG3	= 0	
TGW4AG4	1.0 PGW4AG4 + 1.0 QGW4AG4 - 1.0 RGW4AG4	= 0	
TGW5AG5	1.0 PGW5AG5 + 1.0 QGW5AG5 - 1.0 RGW5AG5	= 0	
TGW6AG6	1.0 PGW6AG6 + 1.0 QGW6AG6 - 1.0 RGW6AG6	= 0	
TGW7AG7	1.0 PGW7AG7 + 1.0 QGW7AG7 - 1.0 RGW7AG7	= 0	
TGW0AG0	1.0 PGW0AG0 + 1.0 QGW0AG0 - 1.0 RGW0AG0	= 0	
AGEXC3	1.0 QAG3LSW3 + 1.0 QAG3GW3	= 0	These equations are for use in transferring excess water from agriculture where these depletions reduce with time.
AGEXC4	1.0 QAG4LSW4 + 1.0 QAG4GW4	= 0	
AGEXC8	1.0 QAG8LSW8	= 0	

Figure 20. Constraints for water diversion requirements for agricultural use.

Constraint Name	Constraint		Explanation and Comments
MIREQ1	1.0 RLSW1MI1 + 1.0 RGW1MI1	≥ 10.0	These inequalities show the constraint on water to meet the diversion requirements for municipal and industrial use. The RHS is the 1965 M&I demand shown earlier.
MIREQ2	1.0 RLSW2MI2 + 1.0 RGW2MI2	≥ 44.0	
MIREQ3	1.0 RLSW3MI3 + 1.0 RGW3MI3	≥ 49.7	
MIREQ4	1.0 RLSW4MI4 + 1.0 RGW4MI4 + 1.0 PLSW1MI4	≥ 302.5	
MIREQ5	1.0 RLSW5MI5 + 1.0 RGW5MI5	≥ 17.0	
MIREQ6	1.0 RLSW6MI6 + 1.0 RGW6MI6	≥ 13.0	
MIREQ7	1.0 RLSW7MI7 + 1.0 RGW7MI7	≥ 10.0	
MIREQ8	1.0 RLSW8MI8	≥ 7.0	
MIREQ9	1.0 RLSW9MI9	≥ 6.8	
MIREQ0	1.0 RLSW0MI0 + 1.0 RGW0MI0	≥ 1.5	
TLSW1MI1	1.0 PLSW1MI1 + 1.0 QLSW1MI1 - 1.0 RLSW1MI1	= 0	These equations sum the diversion from present development to M&I from local surface water with the new development diversions to get the total diversion to M&I from local surface water.
TLSW2MI2	1.0 PLSW2MI2 + 1.0 QLSW2MI2 - 1.0 RLSW2MI2	= 0	
TLSW3MI3	1.0 PLSW3MI3 + 1.0 QLSW3MI3 - 1.0 RLSW3MI3	= 0	
TLSW4MI4	1.0 PLSW4MI4 + 1.0 QLSW4MI4 - 1.0 RLSW4MI4	= 0	
TLSW5MI5	1.0 PLSW5MI5 + 1.0 QLSW5MI5 - 1.0 RLSW5MI5	= 0	
TLSW6MI6	1.0 PLSW6MI6 + 1.0 QLSW6MI6 - 1.0 RLSW6MI6	= 0	
TLSW7MI7	1.0 PLSW7MI7 + 1.0 QLSW7MI7 - 1.0 RLSW7MI7	= 0	
TLSW8MI8	1.0 PLSW8MI8 + 1.0 QLSW8MI8 - 1.0 RLSW8MI8	= 0	
TLSW9MI9	1.0 PLSW9MI9 + 1.0 QLSW9MI9 - 1.0 RLSW9MI9	= 0	
TLSW0MI0	1.0 PLSW0MI0 + 1.0 QLSW0MI0 - 1.0 RLSW0MI0	= 0	
TGW1MI1	1.0 PGW1MI1 + 1.0 QGW1MI1 - 1.0 RGW1MI1	= 0	These equations sum the diversion from present developments to M&I from groundwater with the new development diversion to get the total diversion to M&I from groundwater.
TGW2MI2	1.0 PGW2MI2 + 1.0 QGW2MI2 - 1.0 RGW2MI2	= 0	
TGW3MI3	1.0 PGW3MI3 + 1.0 QGW3MI3 - 1.0 RGW3MI3	= 0	
TGW4MI4	1.0 PGW4MI4 + 1.0 QGW4MI4 - 1.0 RGW4MI4	= 0	
TGW5MI5	1.0 PGW5MI5 + 1.0 QGW5MI5 - 1.0 RGW5MI5	= 0	
TGW6MI6	1.0 PGW6MI6 + 1.0 QGW6MI6 - 1.0 RGW6MI6	= 0	
TGW7MI7	1.0 PGW7MI7 + 1.0 QGW7MI7 - 1.0 RGW7MI7	= 0	
TGW0MI0	1.0 PGW0MI0 + 1.0 QGW0MI0 - 1.0 RGW0MI0	= 0	

Figure 19. Constraints for water diversion requirements for municipal and industrial use.

Constraint Name	Constraint	Explanations and Comments
AVAILSW1	1.0 RLSW1AG1 + 1.0 QLSW1R1 + 1.0 RLSW1MI1 + 1.0 QLSW1WL1 + 1.0 PLSW1MI4 + 1.0 QLSW1EV1 - 1.0 QWW1LSW1 - 1.0 QAR1LSW1 - 1.0 QLSW2SW1 + 1.0 QLSW1OF1 = 613.0	The equations calculate the maximum surface water outflow in each of the HSU. The RHS is the local surface water availability.
AVAILSW2	1.0 RLSW2AG2 + 1.0 QLSW2R2 + 1.0 RLSW2MI2 + 1.0 QLSW2WL2 + 1.0 QLSW2SW1 + 1.0 QLSW2SW3 + 1.0 QLSW2EV2 - 1.0 QWW2LSW2 - 1.0 QAR2LSW2 + 1.0 QLSW2OF2 = 941.5	
AVAILSW3	1.0 RLSW3AG3 + 1.0 QLSW3R3 + 1.0 RLSW3MI3 + 1.0 QLSW3WL3 + 1.0 PLSW3AG2 + 1.0 RLSW3SW4 + 1.0 QLSW3EV3 - 1.0 QAG3LSW3 - 1.0 QWW3LSW3 - 1.0 QAR3LSW3 - 1.0 QUILSW3 - 1.0 QLSW2SW3 + 1.0 QLSW3OF3 = 789.2	
AVAILSW4	1.0 RLSW4AG4 + 1.0 QLSW4R4 + 1.0 QLSW4RU4 + 1.0 RLSW4MI4 + 1.0 QLSW4WL4 + 1.25QLSW4SW5 + 1.0 QLSW4EV4 - 1.0 QAG4LSW4 - 1.0 QWW4LSW4 - 1.0 QAR4LSW4 - 1.0 QBULSW4 - 1.0 QUILSW4 - 1.0 QSALSW4 - 1.0 RLSW3SW4 - 1.0 PLSW7SW4 + 1.0 QLSW4OF4 = 513.6	
AVAILSW5	1.0 RLSW5AG5 + 1.0 QLSW5R5 + 1.0 QLSW5RU5 + 1.0 RLSW5MI5 + 1.0 QLSW5WL5 + 1.0 QLSW5SW6 + 1.0 PLSW5AG9 + 1.0 QLSW5EV5 - 1.0 QLSW4SW5 - 1.0 QBULSW5 - 1.0 QUILSW5 - 1.0 QSALSW5 - 1.0 QWW5LSW5 - 1.0 QAR5LSW5 + 1.0 QLSW5OF5 = 453.2	
AVAILSW6	1.0 RLSW6AG6 + 1.0 QLSW6R6 + 1.0 RLSW6MI6 + 1.0 QLSW6WL6 + 1.0 QLSW6EV6 - 1.0 QWW6LSW6 - 1.0 QAR6LSW6 - 1.0 RLSW0SW6 - 1.0 QLSW5SW6 + 1.0 QLSW6OF6 = 80.0	
AVAILSW7	1.0 QBUMPT + 1.0 QUIMPT + 1.0 Q7LSW7 + 1.0 PLSW7SW4 + 1.0 QLSW7EV7 + 1.0 QLSW7OF7 = 1351.6	
AVAILSW8	1.0 QSAMPT + 1.0 Q8LSW8 + 1.0 PLSW8AG5 + 1.0 QLSW8EV8 - 1.0 QAG8LSW8 + 1.0 QLSW8OF8 = 650.0	
AVAILSW9	1.0 RLSW9AG9 + 1.0 RLSW9MI9 + 1.0 QLSW9WL9 + 1.0 QLSW9EV9 - 1.0 QWW9LSW9 - 1.0 QAR9LSW9 + 1.0 QLSW9OF9 = 430.0	
AVAILSW0	1.0 RLSW0AG0 + 1.0 QLSW0R0 + 1.0 RLSW0MI0 + 1.0 QLSW0WL0 + 1.0 QLSW0EV0 + 1.0 RLSW0SW6 - 1.0 QWW0LSW0 - 1.0 QAR0LSW0 + 1.0 QLSW0OF0 = 250.0	
LSWU7	1.0 RLSW7AG7 + 1.0 QLSW7R7 + 1.0 RLSW7MI7 + 1.0 QLSW7WL7 - 1.0 QWW7LSW7 - 1.0 QAR7LSW7 - 1.0 Q7LSW7 = 0	These equations calculate the surface water use in HSU 7 and 8 and are for convenience in writing other constraints.
LSWU8	1.0 RLSW8AG8 + 1.0 RLSW8MI8 + 1.0 QLSW8WL8 - 1.0 QWW8LSW8 - 1.0 QAR8LSW8 - 1.0 Q8LSW8 = 0	

Figure 17.. Constraints for availability of local surface water.

Constraints Name	Constraint	Explanation and Comments
AVAILGW1	1.0 RGW1AG1 + 1.0 RGW1MI1 + 1.0 QCGW1WL1 + 1.0 QFGW1WL1 + 1.0 QGW1EV1 - 1.0 QWW1R1 - 1.0 QAR1GW1 - 1.0 QLSW1R1 + 1.0 QGW1OF1 = 187.0	These equations calculate the maximum groundwater outflow in each of the HSU except 8 and 9 where groundwater is negligible. The RHS is the groundwater availability.
AVAILGW2	1.0 RGW2AG2 + 1.0 RGW2MI2 + 1.0 QCGW2WL2 + 1.0 QFGW2WL2 + 1.0 QGW2EV2 - 1.0 QWW2R2 - 1.0 QAR2GW2 - 1.0 QLSW2R2 + 1.0 QGW2OF2 = 103.5	
AVAILGW3	1.0 RGW3AG3 + 1.0 RGW3MI3 + 1.0 QCGW3WL3 + 1.0 QFGW3WL3 + 1.0 QGW3EV3 - 1.0 QWW3R3 - 1.0 QAR3GW3 - 1.0 QAG3GW3 - 1.0 QLSW3R3 + 1.0 QGW3OF3 = 94.9	
AVAILGW4	1.0 RGW4AG4 + 1.0 RGW4MI4 + 1.0 QCGW4WL4 + 1.0 QFGW4WL4 + 1.0 QGW4EV4 - 1.0 QWW4R4 - 1.0 QWW4RU4 - 1.0 QAR4GW4 - 1.0 QAG4GW4 - 1.0 QLSW4R4 - 1.0 QLSW4RU4 + 1.0 QGW4OF4 = 272.1	
AVAILGW5	1.0 RGW5AG5 + 1.0 RGW5MI5 + 1.0 QCGW5WL5 + 1.0 QFGW5WL5 + 1.0 QGW5EV5 - 1.0 QWW5R5 - 1.0 QWW5RU5 - 1.0 AR5GW5 - 1.0 QLSW5R5 - 1.0 QLSW5RU5 + 1.0 QGW5OF5 = 254.6	
AVAILGW6	1.0 RGW6AG6 + 1.0 RGW6MI6 + 1.0 QCGW6WL6 + 1.0 QFGW6WL6 + 1.0 QGW6EV6 - 1.0 QWW6R6 - 1.0 QAR6GW6 - 1.0 QLSW6R6 + 1.0 QGW6OF6 = 130.0	
AVAILGW7	1.0 RGW7AG7 + 1.0 RGW7MI7 + 1.0 QCGW7WL7 + 1.0 QFGW7WL7 + 1.0 QGW7EV7 - 1.0 QWW7R7 - 1.0 QLSW7R7 - 1.0 QAR7GW7 + 1.0 QGW7OF7 = 40.0	
AVAILGW0	1.0 RGW0AG0 + 1.0 RGW0MI0 + 1.0 QCGW0WL0 + 1.0 QFGW0WL0 + 1.0 QGW0EV0 - 1.0 QWW0R0 - 1.0 QAR0GW0 - 1.0 QLSW0R0 + 1.0 QGW0OF0 = 10.0	

Figure 18. Constraints for availability of groundwater.

Diversion to agriculture. The general forms of the cost coefficients for diverting local surface water and ground water to agriculture are:

Variable	Component of Cost Coefficient
QLSWXAGX	CLSWXDAG
QGWXAGX	CGWXDAG + CPXAG

Diversion to municipal and industrial. The general forms of the cost coefficient for diverting local surface water and groundwater to municipal and industrial use includes the cost of treatment. These forms are:

Variable	Component of Cost Coefficient
QLSWXMIX	CLSWDMI + CTCSWX
QGWXMIX	CGWDMI + CPXMI + CBMI + CTGWX

Diversion of groundwater to wetlands. The cost coefficient has only a single component which is the cost to pump water for agriculture. The general form is:

Variable	Component of Cost Coefficient
QCGWXWLX	CPXAG

Groundwater recharge. The general forms for these cost coefficients are shown below. The municipal and industrial waste water must be treated before it can be used for recharge.

Variable	Component of Cost Coefficient
QLSWXRX	CRC + CC
QLSWXRUX	CRC + CC + CTRC
QWWXRX	CRC + CTWWRC
QWWXRUX	CRC + CTWWRC + CTRC

Reclaiming municipal and industrial waste water. These variables represent the reclamation of waste water when it is returned to local surface water. The general form of the cost coefficient is:

Variable	Component of Cost Coefficient
QWWXLSWX	CTWWLSW

Storage of local surface water. The general form of the cost coefficient is:

Variable	Component of Cost Coefficient
QLSWXSTX	CSTX

Constraints

The model constraints consist of both equations and inequalities and are described in the following paragraphs. Each equation is given a name for the computer solution. The equations are grouped according to the classifications discussed earlier.

Water availability

The constraints related to water availability are divided into two groups: (1) those related to available local surface water shown in Figure 17 and (2) those related to available groundwater shown in Figure 18.

Water requirements

The constraints related to water requirements are divided into three groups: (1) those related to diversion requirements for municipal and industrial shown in Figure 19, (2) those related to diversion requirements for agriculture shown in Figure 20, and (3) those related to depletion requirements for wetlands shown in Figure 21.

Reservoir storage and evaporation loss

These constraints are divided into three groups: (1) those related to the storage draft requirements shown in Figure 22, (2) those related to the determination of the storage required shown in Figure 23, and (3) those related to determination of the net loss by reservoir evaporation shown in Figure 24.

Return flows

The constraints related to the return flows are divided into two groups: (1) those related to waste water return flow from municipal and industrial use shown in Figure 25 and (2) those related to return flow from agriculture shown in Figure 26.

Free groundwater for wetlands

The constraints related to the groundwater that can be used freely by wetlands are shown in Figure 27.

Limits

The constraints defining additional limits other than water availability and demands are divided into three groups: (1) those limiting the amount of groundwater recharge shown in Figure 28, (2) those limiting the amount of the interbasin transfers shown in Figure 29, and (3) those limiting the outflow from the various study units shown in Figure 30.

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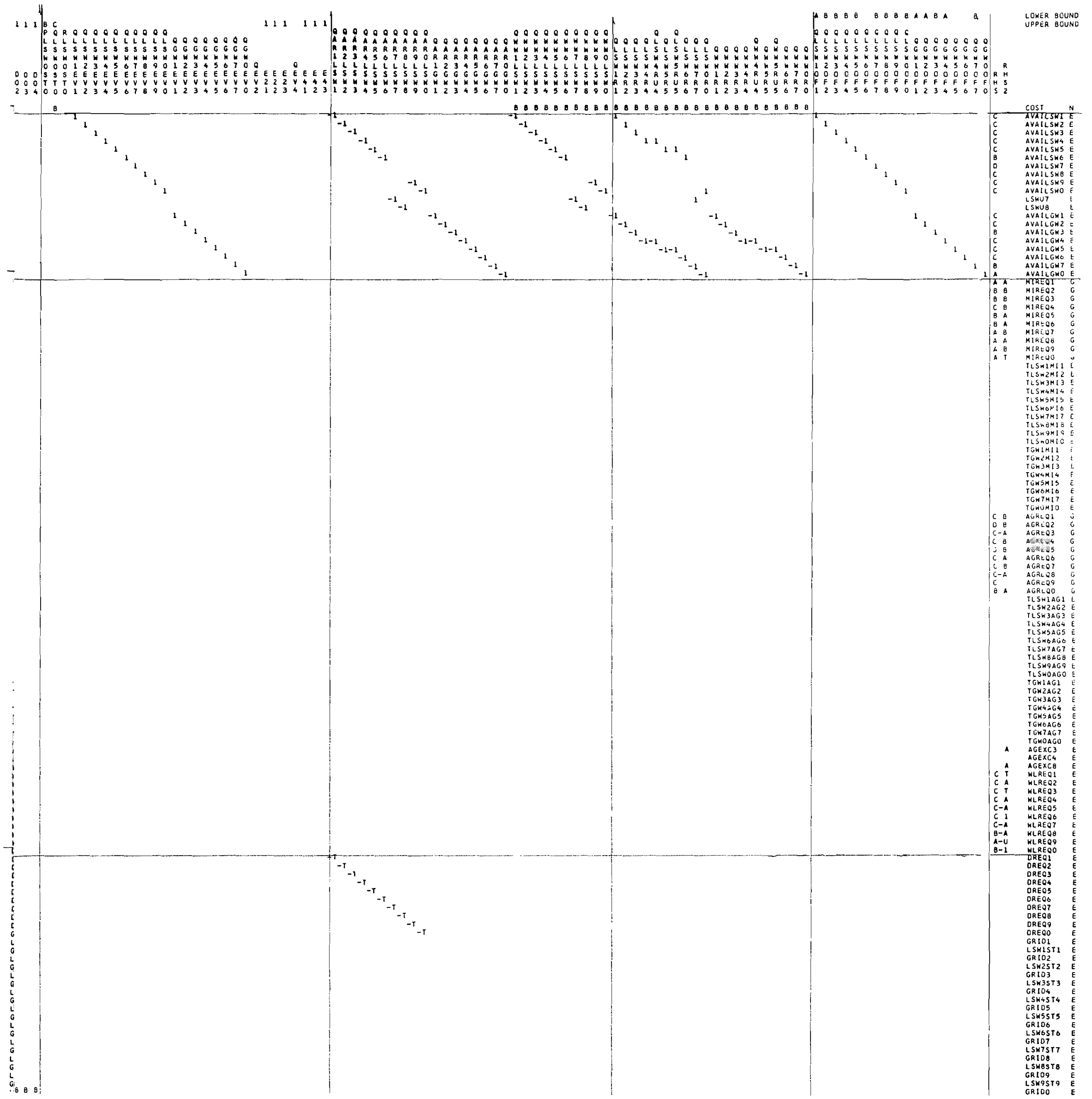


Figure 31. Complete matrix of the allocation model.

Table 10. Variable bounds on additional surface water storage.

Variable	Bound (ac-ft/yr)	Type of Bound
QLSW1ST1	25,000	Upper
QLSW2ST2	1,200,000	Upper
QLSW3ST3	125,000	Upper
QLSW4ST4	1,050,000	Upper
QLSW5ST5	125,000	Upper
QLSW6ST6	100,000	Upper
QLSW7ST7	1,500,000	Upper
QLSW8ST8	285,000	Upper
QLSW9ST9	140,000	Upper
QLSW0ST0	280,000	Upper

Table 11. Variable bounds on surface and groundwater outflow.

Variable	Bound (ac-ft/yr)	Type of Bound
QLSW1OF1	7,000	Lower
QLSW2OF2	50,000	Lower
QLSW3OF3	50,000	Lower
QLSW4OF4	50,000	Lower
QLSW5OF5	13,700	Lower
QLSW6OF6	0,000	Lower
QLSW7OF7	100,000	Lower
QLSW8OF8	100,000	Lower
QLSW9OF9	100,000	Lower
QLSW0OF0	100,000	Lower
QGW1OF1	6,000	Lower
QGW2OF2	5,000	Lower
QGW3OF3	25,000	Lower
QGW4OF4	8,000	Lower
QGW5OF5	0,000	Lower
QGW6OF6	0,000	Lower
QGW7OF7	40,000	Lower
QGW0OF0	0,000	Lower

RESULTS FROM THE MODEL

Results from the model can be classified in three general categories: 1) those which are available as part of the optimum solution to the linear programming problem, 2) those available in a post-optimal analysis, and 3) those which can be obtained only through a manipulation of the structural coefficients, right-hand-side values, and variable bounds. Included in the first category are the optimal solution (the optimum value of the objective function and the minimum cost allocation of water) and the determination of the shadow prices of the various resources. In the second are the sensitivity analysis of the cost coefficients and the parametric analysis of the right-hand-side. In the third category are included the effect of changing irrigation efficiency, and effect of various policies such as groundwater restrictions, inter-basin transfer limitations, changing growth projections with time, etc.

Computer print-outs of the control cards and data cards are shown in Tables B-1 and B-2 of Appendix B. The example includes the necessary control cards and data cards to systematically vary (or parameterize) the right-hand-side. The parameterized RHS values are the estimated values as time passes from the year 1965 to the year 2020. This 55 year time interval was divided into 5.5 year increments. The symbol θ (Theta) is the time parameter and takes values between 0 and 10. Thus the optimum allocation can be found for the year 1965 (θ = 0) and at each 5.5 year time interval thereafter to the year 2020 (θ = 10). A computer print-out of the optimum allocation for 1965 is also shown in Table B-3 of Appendix B.

Results from the Optimal Solution

Solution to the linear programming problem consists of several parts including the optimum value of the objective function, the optimal activity levels or values of the real and slack variables, and the solution of the dual to the linear programming problem.

Optimum value of the objective function

The optimum value of the objective function is used primarily to compare one optimum solution with another. In this project, the optimum value (scaled in thousands of dollars) represents the minimum annual cost of development of new facilities to meet the specified demands for water under a particular set of assumptions. For example, the computer print-out shown in Appendix B lists the optimum value of the objective function as $9722.44726 thousands. This solution is based on the water demands for the year 1965 and the assumption is made in the model that groundwater mining is not permitted. Since facilities existing in 1965 are in the model at zero cost, the value of the objective function in this case represents the yearly cost of developing new facilities to eliminate groundwater mining in HSU 5 and 6. Cost projections over time are made by examining the changes in the value of the objective function as the right-hand-side values of the demand constraints are changed as shown in a later paragraph.

Optimal allocation

For a given set of water requirements and constraints, the minimum cost allocation of water in the state is given by the activity levels or values of the variables in the optimal solution. As an aid in the analysis of the allocation pattern, these activity levels are transferred to flow diagrams as shown on Figure 15. For example data from the computer print-out in Appendix B were transferred to the flow diagram shown on Figure 32. As discussed in the previous paragraph, the allocations represent those values of the variables which bring about the minimum cost to develop new facilities to eliminate groundwater mining in HSU 5 and 6 and to meet water demands for the year 1965. The actual water allocations existing in 1965 are shown on the flow diagram of Figure 16. A comparison of these two flow diagrams shows that the water which is being mined can be replaced by importing additional water from HSU 4, 7, 8, and 10. This imported water together with M & I waste water is used to recharge the groundwater aquifers at an annual rate equal to the present mining rate so that presently existing pumping facilities can be continued. The additional imported water totals about 148,000 ac-ft/yr whereas only about 89,000 ac-ft/yr is presently being mined. An examination of the flow diagram shows that this extra water is dumped into the Sevier River. The reason for this apparent discrepancy or waste lies in the storage probability. One of the assumptions made in generating the data for the no groundwater mining case was that the probability of having sufficient surface water storage was 75 percent. Since the runoff in the Sevier Basin is highly variable from year to year, some of the runoff in high flow years will be lost down the river to the Sevier Dry Lake. The difference between the average outflow of about 14,000 ac-ft/yr under 1965 conditions and the calculated outflow of 74,000 ac-ft/yr under conditions that would eliminate groundwater mining must then represent a difference in

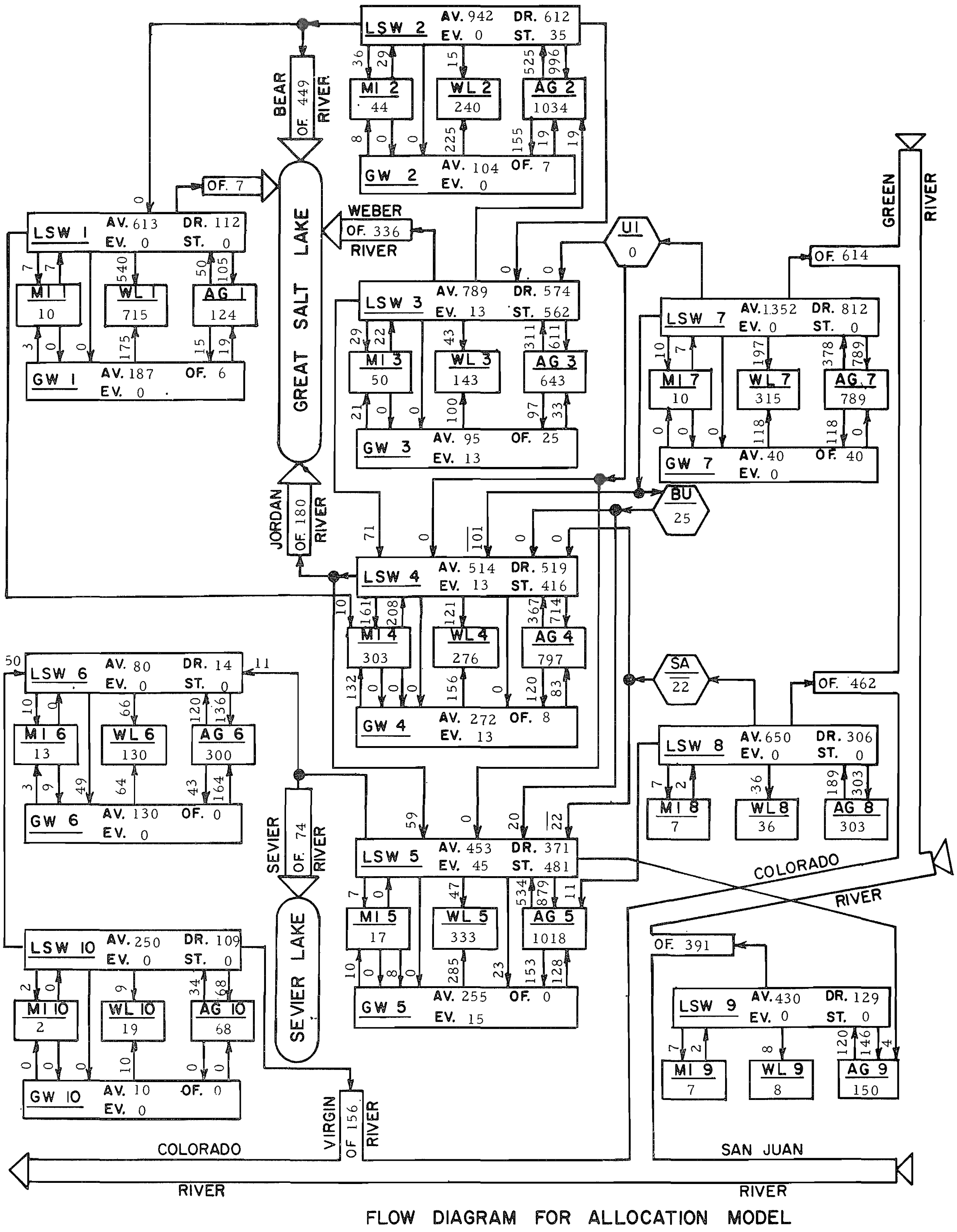


Figure 32. Flow diagram for the basic model (1965).

the probability of having sufficient storage. Computations were made at lower probability levels and a value of about 65 percent reduces the outflow to 14,000 ac-ft/yr. As shown the storage on the two diagrams is the same, and the presently existing storage facilities must be providing sufficient storage at a probability of about 65 percent. Thus the existing storage provides the needed water about two thirds of the years.

Resource shadow prices

Resource shadow prices are determined from the solution of the dual of the linear programming problem. The economic interpretation of the dualism property of linear programming lies in the concept that resource allocation and pricing are two aspects of the same problem. The dual problem is formulated as follows:

a) transpose rows and columns of the constraint matrix,
b) transpose the right-hand-side of constraints with the objective function coefficients,
c) change the sense of the inequality signs in the constraints,
d) change the sense of the objective function (e.g. maximize instead of minimize).

The optimal solution to this dual problem gives the values of the dual variables which are referred to as shadow prices and indicate the rate at which costs increase or decrease for a corresponding increase or decrease in the amount of resource given by the right-hand-side value of the resource constraint. These values are listed under the heading "dual activity" of the rows section of the computer print-out as shown in Appendix B. For example, the shadow price or value of the resource "available surface water in HSU 6, AVAILSW6" (shown on line 7), is $14.00 per ac-ft/yr. This says that the value of the objective function (which is new development cost) would change by $14.00 per year if the available surface water in HSU 6 were changed one ac-ft/yr, thus the value of this resource is defined.

Post-Optimal Analysis

Analysis of the linear programming problem after an optimal solution has been achieved is referred to as post-optimal analysis and consists primarily of two possible phases of analysis; sensitivity analysis and parametric analysis.

Sensitivity analysis

Practical problems formulated in the linear programming framework are seldom completely "solved" by the optimal solution. The coefficients of the model (objective function coefficients, structural coefficients of the constraint matrix, and constraint right-hand-side values) are seldom known with the desired degree of certainty. Also, the linear relationships assumed for a given problem formulation may not hold in the range indicated by the model solution. Therefore it is usually desirable to carry out some sort of sensitivity analysis to determine the effect on the optimal solution of changing certain coefficients or constants to other possible values. If such an analysis indicates the optimal solution is very sensitive to small changes in the coefficients or constants, then special care should be taken in checking the values of these coefficients or constants. Thus one of the greatest helps which can come from a sensitivity analysis is the identification of those coefficients or constants which are critical to the solution, thereby reducing the number which must be reexamined. For example, an examination of the sensitivity analysis shown in sections 2 and 4 in Table B-4 of Appendix B reveals three variables for which a change in their related cost coefficients of less than 10 percent would change the allocation pattern. These variables are:

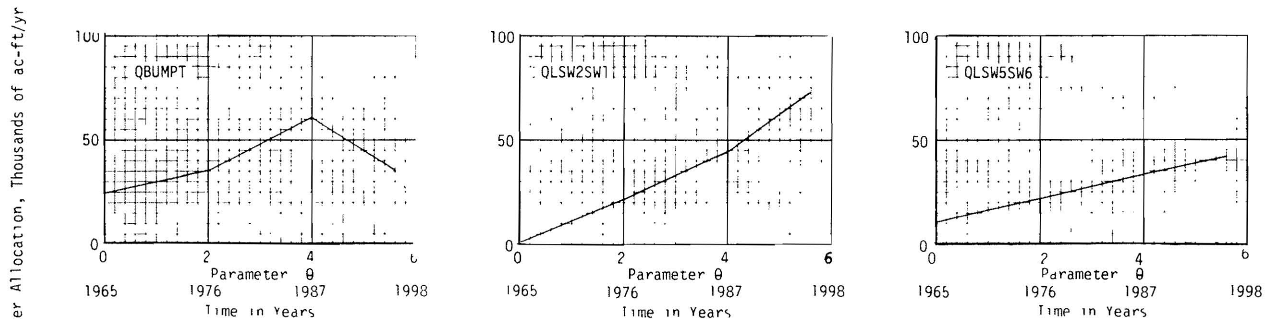
a) QLSW3SW4 (new imported water from HSU 3 to HSU 4)
b) QBULSW5 (water imported to HSU 5 via Bonneville Unit of CUP)
c) QLSW4SW5 (new imported water from HSU 4 to HSU 5)

Further examination of the activity range over which the solution is valid for each of these three variables reveals narrow ranges for each, thus leading to the conclusion that these three variables have critical cost coefficients which should be determined as accurately as possible. Similar analyses can be made for the constraint right-hand-side values using data from sections 1 and 3 of the sensitivity analysis. Thus the constraint RHS values describing surface water availability, groundwater availability, M & I diversion requirements, wetland requirements, reservoir draft requirements, evaporation loss, return flow, artificial recharge, inter-basin transfer limits, inflow or outflow limits, etc., can be investigated to see which RHS values are critical limitations on the optimal solution. The critical RHS values would deserve careful review and checking.

Parametric analysis

Parametric analysis is a procedure for generating new optimal solutions from an original optimal solution while allowing one or more parameters (constraints or coefficients) to vary systematically over a specified range of values. Either the objective function coefficients or the constraint right-hand-side values or both can be varied over a desired range either singularly or in any combination. Use is made of this procedure to vary the right-hand-side values of some of the constraint equations, in particular those showing the demand for water. Thus projections of demand over time can be inserted in the model and new optimal solutions generated quite easily.

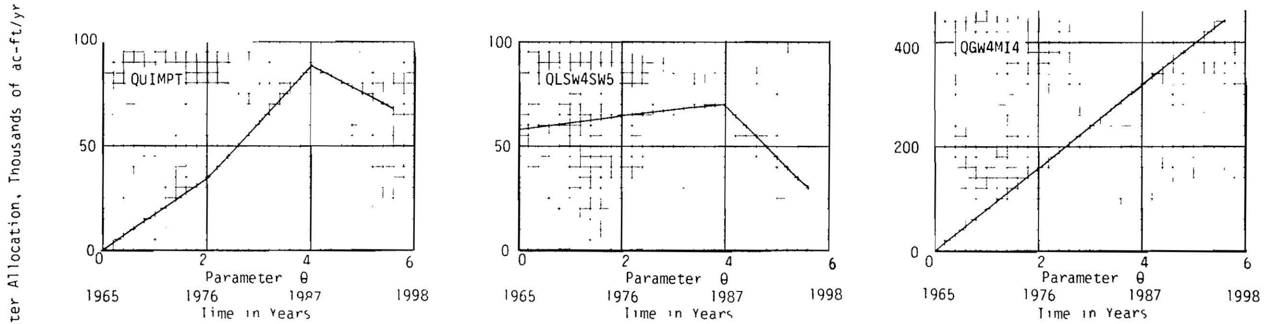
The Division of Water Resources Alternate 1 projections of growing demand in the future were put into the model as increasing values with time and the resulting optimal allocations are shown on Figures C-1 (a) through C-1 (d) of Appendix C. Some of the more significant allocation changes are plotted versus time (or the parameter θ) on Figure 33. These data show, for the assumptions of no groundwater mining and a minimum inflow to the Great Salt Lake of 500,000 ac-ft/yr, that these activities generally increase as time passes except for QBUMPT (Bonneville Unit import), QUIMPT (Ute Indian Unit import), and QLSW4SW5 (HSU 4 import to HSU 5). Examination of the data from the computer print-out indicated the reason the computation stopped about the year 1996 (θ = 5.57) instead of continuing to the year 2020 was that the maximum achievable surface water storage was reached in HSU 2. Other significant data from this example are shown in Figure 34. This plot shows the excess water above the minimum required for outflow of the Upper Colorado River drainage and inflow to the Great Salt Lake. As indicated the excess inflow to the Great Salt Lake goes to zero about the year 1996 (θ = 5.57). Almost 400,000 ac-ft/yr of water is still available at that time for use from the Upper Colorado River allocation. This indicates further development can take place provided the problem of surface water storage in HSU 2 can be resolved. Thus the first place to look for improving the model would be to determine more accurately just what can be done about storage in HSU 2. Since storage in HSU 2 is critical in the solution, the cost



a) Bonneville Unit Imports

b) Surface Water 2 to Surface Water 1

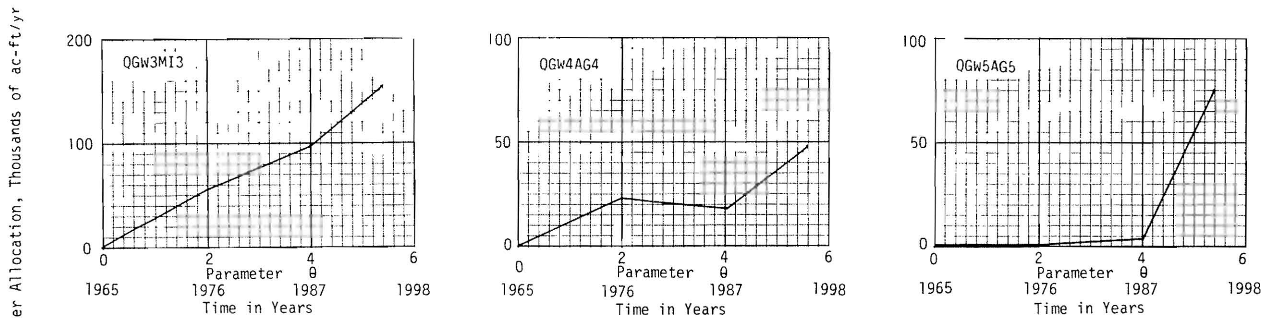
c) Surface Water 5 to Surface Water 6



d) Ute Indian Unit Imports

e) Surface Water 4 to Surface Water 5

f) Groundwater 4 to M&I 4



g) Groundwater 3 to M&I 3

h) Groundwater 4 to AG 4

i) Groundwater 5 to AG 5

Figure 33. Allocations for the basic model as function of time.

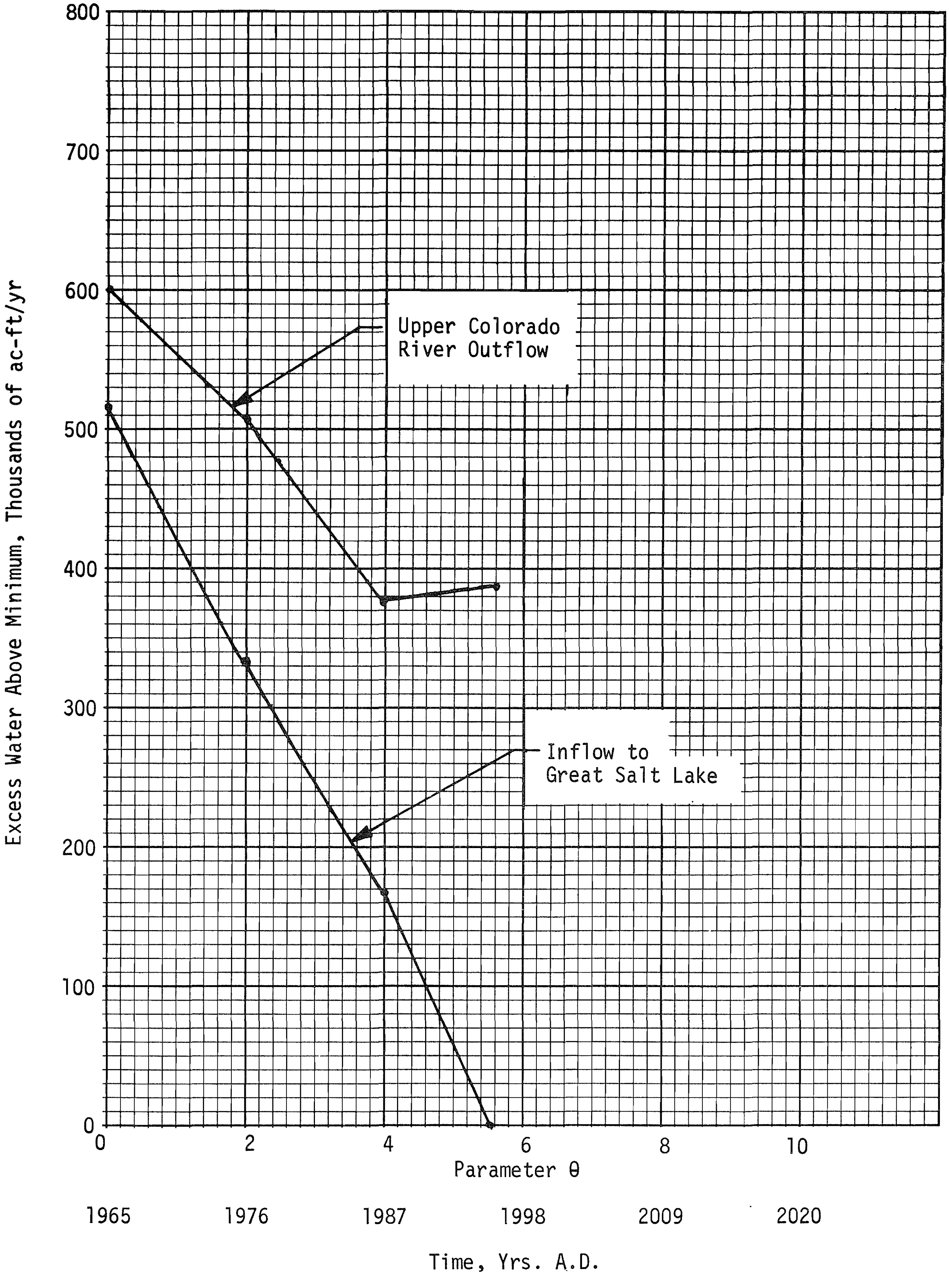


Figure 34. Excess water for the basic model as function of time.

should be reexamined to be sure it is accurate. Possibly an acceptable non-linear cost relationship could be developed which would be more accurate than the linear approximation.

Other Results

The effect of such things as changing irrigation efficiency, groundwater policy, inter-basin transfer limits, and changing growth projections can be determined by a manipulation of the model structural coefficients, right-hand-side values, and variable bounds.

Effect of changing irrigation efficiency

The effect of changing irrigation efficiency can be determined by changing the agriculture return flow coefficients in the constraints shown on Figure 26 and the right-hand-side values of the constraints shown on Figure 20. Return flow coefficients to local surface water and to groundwater must be redetermined by considering the possible changes in irrigation efficiency due to such practices as land leveling, canal and ditch lining, pipeline installations, sprinkler irrigation, and trickler irrigation. Areas affected by each improved practice must also be known and then the new return flow coefficients can be estimated and applied to the model to test the effects of improved irrigation efficiency.

Effect of changing groundwater policy

There are two rather obvious groundwater policy changes which might be investigated; 1) no groundwater recharge allowed, and 2) no further development of the groundwater allowed. Both policies should include the condition of not allowing groundwater mining as presently occurs in HSU 5 and 6. The effect of a policy of no groundwater recharge can be determined by simply setting to zero the right-hand-side values of the recharge constraints shown on Figure 28. The results of this condition are plotted on Figures C-2 (a) through C-2 (c) of Appendix C. A comparison with data from the basic model (Figures C-1 (a) through C-1 (d)) shows that the effect of the policy change is primarily greater water import to HSU 5 and 6. This import increase resulted in a halt in the computation about 1978 ($\theta = 2.36$) due to reaching maximum levels on the four import possibilities to HSU 5. The effect of a policy of no additional groundwater development (i.e. no increased pumpage but allowing recharge) can be determined by setting zero bounds on the variables representing future groundwater diversions. The results of this condition are plotted on Figures C-3 (a) through C-3 (c) of Appendix C. A comparison with data from the basic model shows the Bonneville and Ute Indian Units of the Central Utah Project (CUP) to be required at greater levels earlier in time. The model stopped about 1986 ($\theta = 3.91$) due to upper limits on new storage development in HSU 2 and 3 and minimum limit on outflow from HSU 7.

Effect of limitation on inter-basin transfer

There are many limitations on inter-basin transfer which could be examined. One of the more interesting is the condition that no further transfer be allowed from the Upper Colorado River Basin to the Great Basin other than the Bonneville Unit of CUP. The effect of this limitation can be determined by setting zero bounds on the two variables representing the other transfers. The results of this condition are plotted on Figures C-4 (a) through C-4 (c). A comparison with data from the basic model shows that the Bonneville Unit does not reach maximum size before the computation stops about 1986 ($\theta = 3.91$). The additional water demands were supplied by reducing the inflow to the Great Salt Lake. The model computation stopped due to reaching an upper limit on imports to HSU 5.

Effect of changing growth projections

The projected growth as shown by the Division of Water Resources as alternate 1 in the Interim Report of 1970 is higher than earlier projections made about June 1969. Likewise the alternate 2, 3, and 4 projections in the Interim Report are significantly different from alternate 1 projections and reflect different possibilities of growth and different means to meet the water demands of the growth. The effect of changing the growth projections to those of the earlier estimate can be determined by changing the increments used in parameterizing the right-hand-side of the water demand constraints shown on Figures 19, 20, and 21. The results of this condition are plotted on Figures C-5 (a) through C-5 (f). A comparison with the data from the basic model shows that the lower growth projection allows the computation to run to the year 2020 ($\theta = 10$). Neither the Bonneville Unit nor Ute Indian Unit of CUP were developed completely, and the additional water requirements were supplied by reducing the inflow to the Great Salt Lake.

Effect of giving up some present diversions

It may be more efficient to give up some of the presently developed facilities and replace them with larger or different facilities in later years. The effect of this policy can be determined by changing the bounds on the variables representing present development from fixed bounds (which forces the model to keep all present developments) to upper bounds (which allows the model to choose how much of the present development should be kept for minimum cost). The results of this condition are plotted on Figures C-6 (a) through C-6 (d). A comparison with the data from the basic model shows the only significant difference between the two models is that this new model does not recharge the groundwater in HSU 6 but chooses to give up some of the present pumpage.

Effect of changing the probability on storage

It may be desired to determine the effect on the allocation pattern of changing the probability of having sufficient storage to supply the required draft. This effect can be determined by changing the draft-storage relationship coefficients as given in Figure 23. The basic model assumed a probability of 0.75 and used the coefficients from Figure 23 (a). Coefficients for other probability levels can be determined using the non-linear curves shown on Figures 2 through 11. These coefficients have been determined for a probability of 0.95 and are shown on Figure 23 (b). The results of assuming a probability of 0.95 are plotted on Figures C-7 (a) through C-7 (d). A comparison with the data from the basic model shows greatly increased storage is required earlier in HSU 2, 3, and 7. As a result the model could only go to about the year 1988 (θ = 4.15) before reaching a limit on new storage in HSU 2.

Effect of changing policy of maintaining Great Salt Lake level

Requirements for mineral rights, recreation, and ecological demands may require maintaining the level of Great Salt Lake at some particular elevation. The average inflow to Great Salt Lake from Utah drainage over recent years, has been about 1,088,000 ac-ft/yr. The effect of having some particular inflow requirement can be determined by simply changing the right-hand-side value of the inflow constraint as given on Figure 30. The results of this policy are plotted on Figures C-8 (a) through C-8 (d) for an inflow $\geq$ 800,000 ac-ft/yr and on Figures C-9 (a) through C-9 (d) for an inflow $\geq$ 1,088,000 ac-ft/yr. A comparison with data from the basic model (which assumes an inflow $\geq$ 500,000 ac-ft/yr) shows no change from the basic model in early years for the 800,000 ac-ft/yr model. Later this model required more import from HSU 7 and greater storage in HSU 5, however, this model stopped at the same time and for the same reason as the basic model. Results from the 1,088,000 ac-ft/yr case showed the requirement for greater import from HSU 7 started even earlier than the 800,000 ac-ft/yr inflow model. This computation stopped in about the year 1988 (θ = 4.10) due to a limit on minimum outflow from HSU 7. A comparison of some of the more significant allocations is shown on Figure 35.

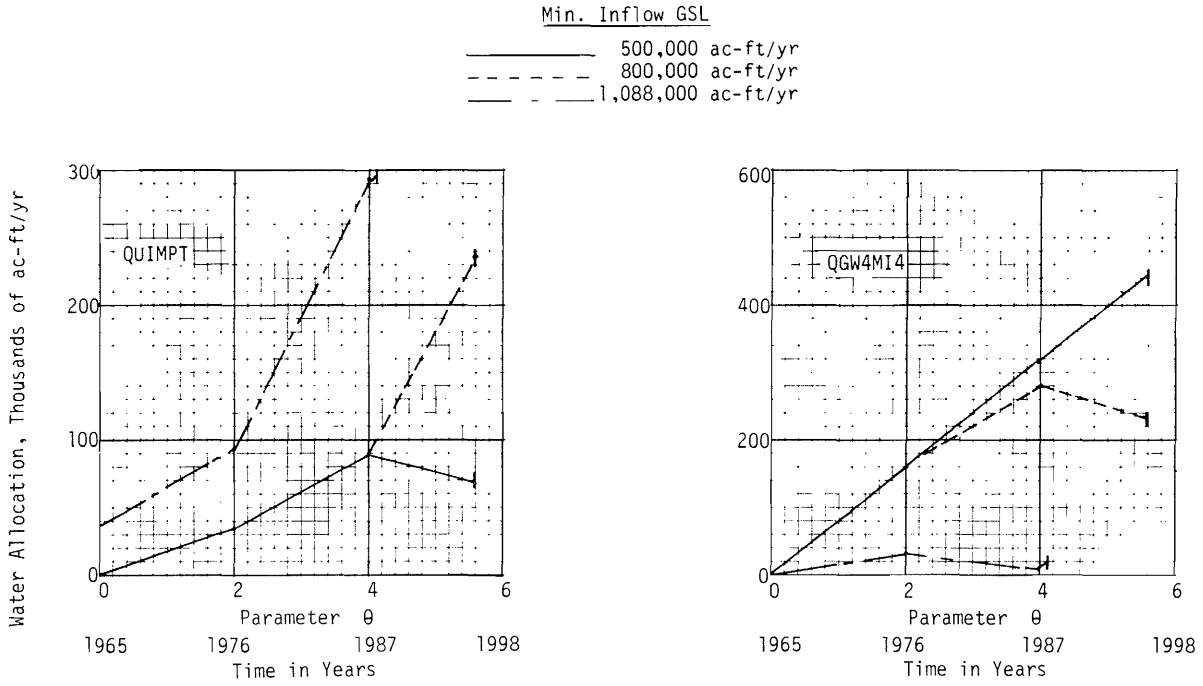
Effect of assuming no development has taken place

This model shows what would be the optimum allocation had no previous developments been made and all new facilities must be constructed to meet the projected demands. This gives an opportunity to see how far from the optimum the past policies and constraints have pushed the present development in the state. This effect can be determined by changing to zero the bounds on those variables representing present development. The results of this consideration are plotted on Figures C-10 (a) through C-10 (d). A comparison with the data from the basic model shows in general a significant reduction in the amount of surface water storage facilities that would be constructed and a substantial increase in groundwater utilization. The only exception to this is in HSU 2 where eventually the maximum storage limit was reached and the model stopped about the year 1997 (θ = 5.73).

Effect of continually relieving constraints and bounds

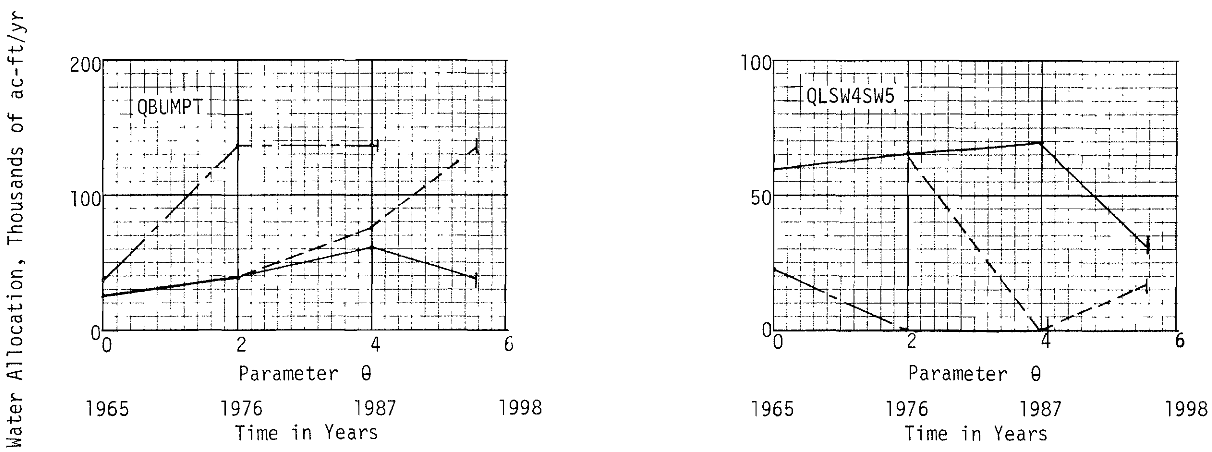
One of the more enlightening manipulations which can be done is to run the model until it stops due to some constraint or bound, then relieve the limiting constraint and continue the parametric solution until the model stops again, and continue the process until the model cannot go further in increasing time no matter what is done. This allows a sequence of events to be generated which indicates the order that studies should be made on various development practices or policies. The results of such an investigation are shown on Figures C-11 (a) through C-11 (i). The model started with the basic model which ran to about the year 1996 (θ = 5.57) where it stopped due to the limit on surface water storage in HSU 2. With this bound relieved the model ran to about the year 2000 (θ = 6.36) where it stopped due to minimum limit on outflow from HSU 2. The only way to relieve this bound is to stop further development in HSU 1 and 2. With this done the model ran to about the year 2010 (θ = 8.14) where it stopped due to the limit on new storage in HSU 7. With this bound relieved the model ran to about the year 2011 (θ = 8.37) where it stopped due to import limits to HSU 5. Attempts to run the model further resulted in infeasible solutions.

The data discussed in the preceding paragraphs should be considered as examples only and not final results. Many more investigations can be made for other policies or for any combination of policies. The additional investigations to be made using the model should include a variety of political and institutional factors since these are often just as important (or more so) than the economic factors. Such studies are needed before a thorough picture of future development for the State of Utah can be determined.



a) Ute Indian Unit Imports

b) Groundwater 4 to M&I 4



c) Bonneville Unit Imports

d) Surface Water 4 to Surface Water 5

Figure 35. Allocations as affected by time and inflow to the Great Salt Lake.

EVALUATION OF THE METHOD

Now that the results of the study have been reported, an evaluation will be made of the advantages and disadvantages, the strengths and weaknesses, the compliments and the cautions related to this method for reaching a water resources planning goal.

In general it is clear that the first objective of the study has indeed been realized. That is, a mathematical programming model with the appropriate constraints has been formulated for a least cost allocation of water within the State of Utah. The model is comprehensive and all inclusive rather than partial and all uses, all areas, all sources, and all transfers of water have been included in the analysis. On the other hand one might argue that the application of the method was too gross with the state divided into only 10 regions. Some of the study areas should have been subdivided further from hydrologic considerations alone. Certainly the model could be greatly improved by dividing the state into a network of smaller areas. Breaking the study areas into smaller geographical subunits would make it easier to utilize functional economic areas so that a determination of economic activity and water use projections would be easier to accomplish.

Similarly, the second objective was realized in the study. The linear programming model was solved with an appropriate algorithm in order to determine the optimal water allocation in the state for various sets of assumptions. While this part of the study was a good beginning, it certainly was not all inclusive and the investigation should be continued to determine the optimal allocation under many other sets of conditions.

The third objective of the study was also accomplished. The model was able to demonstrate how various operating rules, legal policies, and political and social limitations might affect the water allocation. Other such investigations would be needed before such a planning effort might be viewed as complete. Actually a planning effort should probably never be viewed as finished, since as conditions change in the future, the study should be updated to determine the effect of the new conditions.

The computer program used in this study supplies large amounts of data which must be interpreted. There is almost a danger of being "buried" in information. Much effort went into ways of condensing the important data so it could be examined and interpreted and understood. The flow diagrams and graphs are the result of this effort to distill the important data out of voluminous computer output. This effort in data presentation could well be extended and improved.

A method was developed in this study which allows one to consider the full cost structure, rather than just part of the development costs. In fact the cost coefficients in the objective function and the appropriate cost constraints can be made just as comprehensive and complete as the resources and time available might allow. In this study, not a great deal of effort was expended in trying to precisely define the costs. In many cases the best available estimate was used, since the objective of this study was to work out a methodology of water planning rather than to carry out a specific water planning activity. As has been pointed out, one of the most useful contributions of this kind of a method is that the sensitivity analysis pinpoints those cost coefficients which are crucial and important to the solution and thus identifies those aspects of the problem that should be given more detailed and intensive attention.

One of the important considerations in favor of this kind of a water planning method is that it enables one to look forward into time with respect to the decision making process, rather than to just be concerned with present or past decisions. The method allows one to continuously change various parameters as a function of time and thereby take a look at the changing problem of the optimal water allocation as time passes.

The particular type of mathematical model used, that is the linear programming format, may or may not fit some real world situations exactly. For some situations, the linearization of the problem may so greatly distort reality as to make the results of questionable use. Thus the method must be used with judgment and caution. In this study of the State of Utah, for a rather gross examination of the water allocation problem, the linear programming format worked quite well. Some linear approximations of non-linear relationships were utilized in the method and perhaps more of these should be incorporated into any improvements made in the model. Some kinds of economic, political and social objectives have not been considered in the model and attention should be given to these in future improvements. For example, how could one work into the model the objective of stimulating the economy in lagging areas, or the objective of causing a more equitable distribution of the income in the region. Some of these objectives might be quite important and consideration should be given to making it possible to assess the effect of such objectives on water allocation.

Considerable effort was made to work closely with the appropriate state and federal agencies who are interested in this problem, so as to make the study represent real world problems in water resource allocation. For example the hydrologic inventories and water demand projections of the Utah Division of Water Resources were used throughout the study. Only two sets of assumptions as to the growth of water demand throughout the state were used in the study. More consideration should be given to alternative growth patterns that might make certain other areas build up with respect to the demand of water at a particular time. Thus the different regions of the state might behave quite differently with respect to growth in water demand. This possibility was not adequately considered in the current application of this model.

In the development of the methodology, not enough attention was given to the effects of water quality on the cost and use of the water. Water treatment costs *were* included for those supplies such as municipal waste water, which are known to be of such poor quality as to require treatment. Otherwise in the model, adequate consideration was not given to the water quality problem. In future improvements of the methodology, water quality should be given more attention.

The question of water availability should be investigated more thoroughly. This might be done by changing the water available from various sources by various increments in the model. These changes could occur together in various areas or in varying amounts in different regions and the effects of such changes on the allocation of water should be tested.

It is realized, of course, that a fixed requirement for water such as used in this study, which is not dependent on water price, is unrealistic. In fact it was recognized from the beginning that a least cost allocation of the state's water supplies is not as meaningful as an allocation with net benefits as the measure of value in the objective function. The amount of water used should be dependent on the price charged for the water. However, the resources available for this project precluded giving attention to the general question of the value of water. It is realized that the methodology developed herein addresses itself to a lesser type of objective; that is, to determine the optimal allocation of water in the state so as to minimize the cost of the water. Fortunately resources have been found to continue this research effort and the important question of the value of the water and its effect on the optimal allocation is already under study in another project.

The inadequacy of available information and a limitation on project resources have required that estimates be made of some hydrologic values and relationships used in the model as well as some cost information. These should be more accurately determined in future work by extending and completing the necessary hydrologic studies. Some of the values and relationships which were estimated in the model because better information was not available are as follows:

1. The relationship between a change in groundwater storage and the corresponding change in wetland consumptive use.
2. The portions of available water yield in a basin which are available as surface water and as groundwater in some study areas.
3. The percents of return flows which enter the surface water system and the groundwater system.
4. The percent of consumptive-use requirements met by direct use of groundwater for both wetland consumptive use and cropland consumptive use.
5. The relationship between a change in groundwater storage and the corresponding change in groundwater outflow from the study area.
6. The amount of groundwater outflow from each study area flowing into sink areas such as Great Salt Lake, Utah Lake, and Sevier Lake.
7. Perennial yield of groundwater for some study areas.
8. Cost data for some proposed storage, recharge, and water transfer projects.

Under this research effort a methodology has been developed for determining the optimal allocation of water supplies to minimize the cost of meeting given demands for water in a large and complex area. The research was done by an interdisciplinary team so as to utilize various viewpoints and skills. The writers have tried to make the method as broad in scope as possible and the suggested model was made flexible so it can be applied in planning situations other than in the State of Utah. The work done has been thoroughly documented in this report so others can follow what was done, improve upon the method, or apply the model to other areas.

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APPENDIX A

GENERAL THEORY OF THE ALLOCATION MODEL

by

James H. Milligan

The basic problem of allocating water resources from alternative sources to competing points of use is closely related to mathematical programming problems which deal with determining optimal allocations of resources to meet certain objectives. In general, allocation problems are characterized by the large number of alternatives which could satisfy the system constraints, but the problem becomes more complex when the effect of each alternative on some stated or implied objective must be evaluated in order that some best or optimal alternative can be chosen.

In this study the resources to be allocated in an optimal manner are the quantities of water available in each of the 10 study areas of the state from groundwater supplies, from local surface water supplies, from interbasin transfers, or from transfers from the Colorado Basin to the Great Basin. The total supply system is to be managed optimally to satisfy existing and projected demands in the various study areas.

Mathematical Form of the Model

The allocation problem has been formulated mathematically as a linear programming model. Linear programming is the systems analysis tool which has come to be most closely associated with resource allocation problems and is a mathematical technique for solving the class of problems in optimization which deal with the interactions of large numbers of variables or alternative activities subject to given constraint conditions. A linear programming problem differs from the general mathematical programming problem in that the mathematical relationship used to describe the objectives and constraints must be linear or "straight-line" relationships. Mathematically the linear programming problem can be stated as follows:

Find the values of $x_1, x_2, \ldots, x_n$ which minimize (maximize) the linear objective function

$$Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n \quad \ldots . (1)$$

subject to the constraints,

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n &\ (\leq, =, \geq)\ b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n &\ (\leq, =, \geq)\ b_2 \\ &\ \ \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n &\ (\leq, =, \geq)\ b_n \end{aligned} \quad \ldots (2)$$

and

$$x_1 \geq 0,\ x_2 \geq 0,\ \ldots,\ x_n \geq 0$$

where the a_{ij}, b_i, and c_j are given constants. The a_{ij}'s are coefficients which relate a unit of activity to the amount of resource use by that activity. The b_i's represent the resource demands and availabilities, and the c_j's represent the unit costs associated with each alternative activity. The x_j's are referred to as decision variables. Equation 1 is referred to as the objective function and Equations 2 are referred to as the system of constraints. The sign associated with each individual constraint may be less than or equal to (≤), equality (=), or greater than or equal to (≥) as the individual case may be.

Physical interpretation of the objective function and of the system of constraints in the context of water resources allocation is already suggested by the interpretation of the coefficients and right-hand-side elements above. The objective function describes the economic relationships of the area being modeled. The value of the objective function might be the total cost of all of th alternative water activities considered in the solution, or i might represent the total net benefits, depending upo whether the problem is formulated as a cost minimizatio problem or a net benefit maximization problem. Th system of constraints defines the technical relationships

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subject to the constraints,

$$\begin{array}{l} a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \ (\leq, =, \geq)\ b_1 \\ a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \ (\leq, =, \geq)\ b_2 \\ \qquad\qquad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \ (\leq, =, \geq)\ b_n \end{array} \quad \ldots (2)$$

and

$$x_1 \geq 0,\ x_2 \geq 0,\ \ldots,\ x_n \geq 0$$

where the a_{ij}, b_i, and c_j are given constants. The a_{ij}'s are coefficients which relate a unit of activity to the amount of resource use by that activity. The b_i's represent the resource demands and availabilities, and the c_j's represent the unit costs associated with each alternative activity. The x_j's are referred to as decision variables. Equation 1 is referred to as the objective function and Equations 2 are referred to as the system of constraints. The sign associated with each individual constraint may be less than or equal to ($\leq$), equality (=), or greater than or equal to ($\geq$) as the individual case may be.

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Obtaining Optimal Solutions

In the terminology of linear programming any set of x_j's which satisfy the constraints and the non-negativity conditions is a *feasible solution.* A feasible solution which also minimizes or maximizes the value of the objective function is called an *optimal feasible solution* (Loomba, 1964). The intersection of the linear constraints forms a convex set, and only points within this set can satisfy the constraint conditions and become feasible solutions to the linear programming problem. The extreme points of the convex set of feasible solutions are defined as *basic feasible solutions.* The theorems of linear programming state that if an optimal solution exists, at least one of the extreme point solutions, or basic feasible solutions, will be the optimal solution. In some cases where the optimal solution is not unique, points between two extreme point solutions are also optimal.

Techniques used for solving the linear programming problem to obtain optimal solutions are iterative, and the most efficient method of solution is called the simplex algorithm. This algorithm is an algebraic iterative procedure which will solve, exactly, any properly formulated linear programming problem in a finite number of steps. Computer routines for solving linear programming problems use the simplex algorithm or some modification of it. The simplex procedure assures that each iteration yields a better (or at least not a worse) solution than the preceding iteration. Therefore, the number of iterations required to obtain the optimal solution is generally small compared to the number of existing basic feasible solutions. In simple terms the solution process can be described as a method of moving along the edge of the region of feasible solutions from one corner to the adjacent corner which will give the most improvement in the value of the objective function. At each corner the method indicates whether or not that corner is optimal, and if not, which corner will be the next one examined.

If at any stage in the solution process a point is examined which has an edge leading to infinity (an unbounded convex set) and if the objective function can be improved by moving along this edge, then an unbounded solution is indicated.

When the linear programming problem is formulated using inequality constraints the method of solution requires the addition of slack variables to the constraints to convert the inequalities to equations so the problem is treated as a system of linear equations in the solution process. These slack variables take on a physical interpretation in applied problems. Their values represent the amount of resource being allocated which is surplus or redundant to the optimal quantities indicated by the final solution.

For a more detailed discussion of the theory of linear programming and of the modified simplex procedures used in computer solutions, see Hadley (1962), Gass (1964), or Hillier and Lieberman (1967).

Interpretation of Solutions

Solutions to linear programming problems consist of several parts including the optimal value of the objective function, the optimal activity levels of the real and slack variables, and the solution of the dual to the linear programming problem. The optimal value of the objective function is useful primarily for comparing one solution with another. The optimal activity levels of the real and slack variables show which activities are included in the optimal solution as well as the optimal quantities associated with those activities. For example, the solution would indicate which inter-basin transfers of water are in the optimal solution, or which groundwater reservoirs should be pumped. The solution would also give the optimal number of acre-feet for each of these activities.

The essence of the economic interpretation of the dualism property of linear programming lies in the concept that resource allocation and pricing are two aspects of the same problem (Dorfman, Samuelson, and Solow, 1958).

The formulation of a typical linear programming problem was given as Equations 1 and 2. The linear programming problem formulated in this manner is known as the *primal* problem. The *dual* problem corresponding to the primal problem is formulated from the primal problem in the following manner:

1. Constraints in the primal problem are restructured to contain only inequalities in the same sense.
2. Rows and columns of the constraint coefficients are transposed.
3 The right-hand-side values of the constraints are transposed with the objective coefficients.
4. The sense of the inequality signs in the constraints is changed.
5. The objective function is maximized instead of minimized (or minimized instead of maximized, as the case may be).

According to this procedure the dual problem may be stated mathematically as: Find $w_i \geq 0 \, (i = 1, 2, \ldots m)$

in order to maximize (minimize)

$$Z' = b_1w_1 + b_2w_2 + \dots + b_mw_m \quad \dots . \quad (3)$$

subject to the constraints,

$$\begin{aligned} a_{11}w_1 + a_{21}w_2 + \dots + a_{m1}w_m &\ (\leq, \geq)\ c_1 \\ a_{12}w_1 + a_{22}w_2 + \dots + a_{m2}w_m &\ (\leq, \geq)\ c_2 \\ &\ \vdots \\ a_{1n}w_1 + a_{2n}w_2 + \dots + a_{mn}w_m &\ (\leq, \geq)\ c_n \end{aligned} \quad \dots . \quad (4)$$

In this formulation there is one dual constraint for each primal variable, and one dual variable for each primal constraint. Dorfman, Samuelson, and Solow (1958) summarize the relationship between the primal problem and the corresponding dual as follows:

1. The dual has one variable for each constraint in the original problem.
2. The dual has as many constraints as there are variables in the primal.
3. The dual of the minimizing problem is a maximizing problem, and vice versa.
4. The coefficients of the objective function of the primal problem appear as the constant terms of the dual constraints, and the constant terms of the primal constraints are the objective coefficients in the dual.
5. The coefficients of a single variable in the primal constraints become the coefficients of a single constraint in the dual. Thus each column of coefficients in the primal becomes a row of coefficients in the dual.
6. The sense of the inequalities in the dual is the reverse of the sense of the inequalities in the primal, except that non-negativity conditions apply to the dual variables in the same sense that they apply to the primal variables.

The optimal solution to the dual problem is obtained as a by-product of the optimal solution of the primal problem and provides an interesting and useful economic interpretation of the primal problem. The optimal values of the dual variables (w_i's) are often referred to as *shadow prices* or the marginal costs of introducing marginal amounts of the non-optimal slack variables from the primal problem into the optimal solution. Thus the optimal values of the dual variables (or shadow prices) indicate the rate at which costs increase or decrease for a corresponding increase or decrease in the amount of resource given by the right-hand-side value of the primal constraint. The range of values over which the right-hand-side value can vary for a given shadow price to be valid is given in the sensitivity analysis and is the range of values of that right-hand-side value for which the original optimal basis is not changed. Thus the optimal value of a dual variable w_i may be interpreted as the marginal cost of resource i. However, shadow prices merely reflect the marginal cost of the resource within the context of the model and in no way should they be considered as the *actual* costs of the resource.

Post-Optimal Analysis

Analysis of the linear programming problem after an optimal solution has been achieved is referred to as post-optimal analysis and consists primarily of two possible phases of analysis: sensitivity analysis and parametric analysis. Practical problems formulated as linear programming problems are seldom completely "solved" by the optimal solution produced by the simplex procedure. The coefficients of the model (c_j's, a_{ij}'s, and b_i's) are seldom known with the desired degree of certainty. Also, the linear relationships assumed for a given problem formulation may not hold in the range indicated by the model solution. Therefore, it is usually desirable to carry out some sort of sensitivity analysis to determine the effect on the optimal solution of changing certain coefficients or constants to other possible values without having to re-solve the problem. This provision is provided for on most computer routines for solving linear programming problems. If the sensitivity analysis indicates the optimal solution may change for a small change in the constants or coefficients, then special care should be taken in checking the values of these coefficients or constants. It is not always necessary to re-solve the problem from the beginning each time a minor change is made in the model coefficients or constants. Given the previous optimal solution, it is usually possible through the use of sensitivity analysis to determine whether the same basis is optimal.

Parametric analysis is a procedure for generating new optimal solutions from an original optimal solution while allowing one or more parameters (constants or coefficients) to vary. The parametric procedure allows an evaluation of the optimal solution as one or more parameters are allowed to vary over a specified range of values. When using parametric analysis a "change vector" is specified which indicates the parameters which are to be varied and the increment by which each will be varied. Then the parameters are continuously changed over a specified range. Thus, if coefficients in the objective function are to be changed the cost coefficients are changed according to the relationship

$$COST_2 = COST_1 + \alpha\theta$$

in which

$COST_2$	is the new value of the cost vector
$COST_1$	is the original value of the cost vector
α	is the change vector
θ	is the parameter interval at which new

solutions are to be obtained up to some value of θ_{max}

The function of the parametric procedure is to maintain optimality and feasibility as the problem continues to change. Solutions to this continuously changing problem can usually be obtained at intervals of the parameter values specified by θ, at required basis changes, or at both. Parametric analysis greatly facilitates examination of changes in water demands, for example.

Computer Facilities and Routine

The linear programming problems formulated for this study were solved using an IBM 360/44 digital computer and an advanced, large scale linear programming routine provided by IBM for the 360 machines. The linear programming routine is contained in a mathematical programming package identified as MPS/360. The linear programming procedures of MPS/360 use the bounded variable/product form of the inverse/revised simplex method. In the product form, the inverse matrix, from which basic feasible solutions are obtained, is represented by the product of a sequence of m x n matrices in which only one column of each matrix differs from a column of the unit matrix. This particular form simplifies the iterative procedure in obtaining an optimal solution. Details of using the MPS/360 package for obtaining linear programming solutions can be found in the MPS/360 Users Manual.

APPENDIX B

COMPUTER PRINT–OUT OF THE SOLUTION OF THE BASIC ALLOCATION MODEL

Table B-1. Print-out of the program control cards.

```
                    CONTROL PROGRAM COMPILER

          0001                        PROGRAM
          0002                        INITIALZ
          0061                        MOVE(XDATA,'MODEL')
          0062                        MOVE(XPBNAME,'PBFILE')
          0063                        CONVERT('CHECK','SUMMARY')
          0064                        BCDOUT
          0065                        SETUP('BOUND','BOUNDX')
          0066                        MOVE(XOBJ,'COST')
          0067                        MOVE(XPHS,'RHS')
          0068                        PRIMAL
          0069                        SOLUTION
          0070                        RANGE
          0071                        XPARAM=0.0
          0072                        XPARMAX=10.0
          0073                        XPARDELT=2.0
          0074                        MOVE(XCHCOL,'RHS2')
          0075                        PARARHS
          0076                        SOLUTION
          0077                        RANGE
          0078                        EXIT
          0079                        PEND
```

Table B-2. Print-out of the program data cards.

```
                     EXECUTOR.     MPS/360 V2-M5

NAME               MODEL
ROWS
 N  COST
 E  AVAILSW1          G  AGREQ4           E  GRID4            E  WWRF9
 E  AVAILSW2          G  AGREQ5           E  LSW4ST4          E  WWRF0
 E  AVAILSW3          G  AGREQ6           E  GRID5            E  AGRFSW1
 E  AVAILSW4          G  AGREQ7           E  LSW5ST5          E  AGRFSW2
 E  AVAILSW5          G  AGREQ8           E  GRID6            E  AGRFSW3
 E  AVAILSW6          G  AGREQ9           E  LSW6ST6          E  AGRFSW4
 E  AVAILSW7          G  AGREQ0           E  GRID7            E  AGRFSW5
 E  AVAILSW8          E  TLSW1AG1         E  LSW7ST7          E  AGRFSW6
 E  AVAILSW9          E  TLSW2AG2         E  GRID8            E  AGRFSW7
 E  AVAILSW0          E  TLSW3AG3         E  LSW8ST8          E  AGRFSW8
 E  LSWU7             E  TLSW4AG4         E  GRID9            E  AGRFSW9
 E  LSWU8             E  TLSW5AG5         E  LSW9ST9          E  AGRFSW0
 E  AVAILGW1          E  TLSW6AG6         E  GRID0            E  AGRFGW1
 E  AVAILGW2          E  TLSW7AG7         E  LSW0ST0          E  AGRFGW2
 E  AVAILGW3          E  TLSW8AG8         E  TST1             E  AGRFGW3
 E  AVAILGW4          E  TLSW9AG9         E  TST2             E  AGRFGW4
 E  AVAILGW5          E  TLSW0AG0         E  TST3             E  AGRFGW5
 E  AVAILGW6          E  TGW1AG1          E  TST4             E  AGRFGW6
 E  AVAILGW7          E  TGW2AG2          E  TST5             E  AGRFGW7
 E  AVAILGW0          E  TGW3AG3          E  TST6             E  AGRFGW0
 G  MIREQ1            E  TGW4AG4          E  TST7             E  FGWAVWL1
 G  MIREQ2            E  TGW5AG5          E  TST8             E  FGWAVWL2
 G  MIREQ3            E  TGW6AG6          E  TST9             E  FGWAVWL3
 G  MIREQ4            E  TGW7AG7          E  TST0             E  FGWAVWL4
 G  MIREQ5            E  TGW0AG0          E  EVLSW1           E  FGWAVWL5
 G  MIREQ6            E  AGEXC3           E  EVLSW2           E  FGWAVWL6
 G  MIREQ7            E  AGEXC4           E  EVLSW3           E  FGWAVWL7
 G  MIREQ8            E  AGEXC8           E  EVLSW4           E  FGWAVWL0
 G  MIREQ9            E  WLREQ1           E  EVLSW5           L  GWRC1
 G  MIREQ0            E  WLREQ2           E  EVLSW6           L  GWRC2
 E  TLSW1MI1          E  WLREQ3           E  EVLSW7           L  GWRC3
 E  TLSW2MI2          E  WLREQ4           E  EVLSW8           L  GWRC4
 E  TLSW3MI3          E  WLREQ5           E  EVLSW9           L  GWRCU4
 E  TLSW4MI4          E  WLREQ6           E  EVLSW0           L  GWRC5
 E  TLSW5MI5          E  WLREQ7           E  EVGW1            L  GWRCU5
 E  TLSW6MI6          E  WLREQ8           E  EVGW2            L  GWRC6
 E  TLSW7MI7          E  WLREQ9           E  EVGW3            L  GWRC7
 E  TLSW8MI8          E  WLREQ0           E  EVGW4            L  GWRC0
 E  TLSW9MI9          E  DREQ1            E  EVGW5            E  BUMPT
 E  TLSW0MI0          E  DREQ2            E  EVGW6            E  UIMPT
 E  TGW1MI1           E  DREQ3            E  EVGW7            E  SAMPT
 E  TGW2MI2           E  DREQ4            E  EVGW0            E  TLSW3SW4
 E  TGW3MI3           E  DREQ5            E  EV2ST2           E  TLSW0SW6
 E  TGW4MI4           E  DREQ6            E  EV2              G  INFLOGSL
 E  TGW5MI5           E  DREQ7            E  EV4ST4           G  CROUT
 E  TGW6MI6           E  DREQ8            E  EV4
 E  TGW7MI7           E  DREQ9            E  WWRF1
 E  TGW0MI0           E  DREQ0            E  WWRF2
 G  AGREQ1            E  GRID1            E  WWRF3
 G  AGREQ2            E  LSW1ST1          E  WWRF4
 G  AGREQ3            E  GRID2            E  WWRF5
                      E  LSW2ST2          E  WWRF6
                      E  GRID3            E  WWRF7
                      E  LSW3ST3          E  WWRF8
```

Table B-2. Continued.

```
COLUMNS
    QBULSW4   COST                 7.00000   BUMPT                1.00000
    QBULSW4   AVAILSW4    -        1.00000   DREQ4        -       1.00000
    QBULSW5   COST                10.00000   BUMPT                1.25000
    QBULSW5   AVAILSW5    -        1.00000   DREQ5        -       1.00000
    QBUMPT    BUMPT       -        1.00000   AVAILSW7             1.00000
    QBUMPT    DREQ7                1.00000
    QUILSW3   COST                10.00000   UIMPT                1.00000
    QUILSW3   AVAILSW3    -        1.00000   DREQ3        -       1.00000
    QUILSW4   COST                10.00000   UIMPT                1.00000
    QUILSW4   AVAILSW4    -        1.00000   DREQ4        -       1.00000
    QUILSW5   COST                13.00000   UIMPT                1.25000
    QUILSW5   AVAILSW5    -        1.00000   DREQ5        -       1.00000
    QUIMPT    UIMPT       -        1.00000   AVAILSW7             1.00000
    QUIMPT    DREQ7                1.00000
    QSALSW4   COST                 8.00000   SAMPT                1.00000
    QSALSW4   AVAILSW4    -        1.00000   DREQ4        -       1.00000
    QSALSW5   COST                 4.00000   SAMPT                1.00000
    QSALSW5   AVAILSW5    -        1.00000   DREQ5        -       1.00000
    QSAMPT    SAMPT       -        1.00000   AVAILSW8             1.00000
    QSAMPT    DREQ8                1.00000
    PLSW1AG1  TLSW1AG1             1.00000
    QLSW1AG1  COST                 5.00000   TLSW1AG1             1.00000
    RLSW1AG1  AVAILSW1             1.00000   AGREQ1               1.00000
    RLSW1AG1  TLSW1AG1    -        1.00000   AGRFSW1               .40000
    RLSW1AG1  AGRFGW1               .12420   DREQ1                1.00000
    PLSW1MI1  TLSW1MI1             1.00000
    QLSW1MI1  COST                31.00000   TLSW1MI1             1.00000
    RLSW1MI1  AVAILSW1             1.00000   MIREQ1               1.00000
    RLSW1MI1  TLSW1MI1    -        1.00000   WWRF1                 .70000
    RLSW1MI1  DREQ1                1.00000
    QLSW1WL1  AVAILSW1             1.00000   WLREQ1               1.00000
    PLSW1MI4  AVAILSW1             1.00000   MIREQ4               1.00000
    PLSW1MI4  WWRF4                 .68890   DREQ1                1.00000
    PLSW2AG2  TLSW2AG2             1.00000
    QLSW2AG2  COST                 5.00000   TLSW2AG2             1.00000
    RLSW2AG2  AVAILSW2             1.00000   AGREQ2               1.00000
    RLSW2AG2  TLSW2AG2    -        1.00000   AGRFSW2               .50770
    RLSW2AG2  AGRFGW2               .15000   DREQ2                1.00000
    PLSW2MI2  TLSW2MI2             1.00000
    QLSW2MI2  COST                32.00000   TLSW2MI2             1.00000
    RLSW2MI2  AVAILSW2             1.00000   MIREQ2               1.00000
    RLSW2MI2  TLSW2MI2    -        1.00000   WWRF2                 .66000
    RLSW2MI2  DREQ2                1.00000
    QLSW2WL2  AVAILSW2             1.00000   WLREQ2               1.00000
    QLSW2SW1  COST                 4.00000   AVAILSW1     -       1.00000
    QLSW2SW1  AVAILSW2             1.00000   DREQ2                1.00000
    QLSW2SW1  DREQ1       -        1.00000
    QLSW2SW3  COST                 4.00000   AVAILSW2             1.00000
    QLSW2SW3  AVAILSW3    -        1.00000   DREQ2                1.00000
    QLSW2SW3  DREQ3       -        1.00000
    PLSW3AG3  TLSW3AG3             1.00000
    QLSW3AG3  COST                 6.00000   TLSW3AG3             1.00000
    RLSW3AG3  AVAILSW3             1.00000   AGREQ3               1.00000
    RLSW3AG3  TLSW3AG3    -        1.00000   AGRFSW3               .48330
    RLSW3AG3  AGRFGW3               .15000   DREQ3                1.00000
    PLSW3MI3  TLSW3MI3             1.00000
    QLSW3MI3  COST                43.00000   TLSW3MI3             1.00000
    RLSW3MI3  AVAILSW3             1.00000   MIREQ3               1.00000
    RLSW3MI3  TLSW3MI3    -        1.00000   WWRF3                 .43660
    RLSW3MI3  DREQ3 .              1.00000
    QLSW3WL3  AVAILSW3             1.00000   WLREQ3               1.00000
    PLSW3AG2  AVAILSW3             1.00000   AGREQ2               1.00000
    PLSW3AG2  AGRFSW2               .50770   AGRFGW2               .15000
    PLSW3AG2  DREQ3                1.00000
    PLSW3SW4  TLSW3SW4             1.00000
    QLSW3SW4  COST                 4.00000   TLSW3SW4             1.00000
    PLSW3SW4  DREQ3                1.00000   TLSW3SW4     -       1.00000
    RLSW3SW4  AVAILSW3             1.00000   AVAILSW4     -       1.00000
    RLSW3SW4  DREQ4       -        1.00000
    QAG3LSW3  AVAILSW3    -        1.00000   AGEXC3               1.00000
    PLSW4AG4  TLSW4AG4             1.00000
    QLSW4AG4  COST                 6.00000   TLSW4AG4             1.00000
    PLSW4AG4  AVAILSW4             1.00000   AGREQ4               1.00000
    RLSW4AG4  TLSW4AG4    -        1.00000   AGRFSW4               .46090
    PLSW4AG4  AGRFGW4               .15000   DREQ4                1.00000
    PLSW4MI4  TLSW4MI4             1.00000.
    QLSW4MI4  COST                43.00000   TLSW4MI4             1.00000
    RLSW4MI4  AVAILSW4             1.00000   MIREQ4               1.00000
    RLSW4MI4  TLSW4MI4    -        1.00000   WWRF4                 .68890
    RLSW4MI4  DREQ4                1.00000
    QLSW4WL4  AVAILSW4             1.00000   WLREQ4               1.00000
    QLSW4SW5  COST                 5.00000   AVAILSW4             1.25000
    QLSW4SW5  AVAILSW5    -        1.00000   DREQ4                1.25000
    QLSW4SW5  DREQ5       -        1.00000
    QAG4LSW4  AVAILSW4    -        1.00000   AGEXC4               1.00000
    PLSW5AG5  TLSW5AG5             1.00000
    QLSW5AG5  COST                 5.00000   TLSW5AG5             1.00000
    RLSW5AG5  AVAILSW5             1.00000   AGREQ5               1.00000
    RLSW5AG5  TLSW5AG5    -        1.00000   AGRFSW5               .52500
    RLSW5AG5  AGRFGW5               .15000   DREQ5                1.00000
    PLSW5MI5  TLSW5MI5             1.00000
    QLSW5MI5  COST                36.00000   TLSW5MI5             1.00000
    RLSW5MI5  AVAILSW5             1.00000   MIREQ5               1.00000
    RLSW5MI5  TLSW5MI5    -        1.00000   WWRF5                 .45880
    RLSW5MI5  DREQ5                1.00000
    QLSW5WL5  AVAILSW5             1.00000   WLREQ5               1.00000
    QLSW5SW6  COST                 4.00000   AVAILSW5             1.00000
    QLSW5SW6  AVAILSW6    -        1.00000   DREQ5                1.00000
    QLSW5SW6  DREQ6       -        1.00000
    PLSW5AG9  AVAILSW5             1.00000   AGREQ9               1.00000
    PLSW5AG9  AGRFSW9               .80000   DREQ5                1.00000
    PLSW6AG6  TLSW6AG6             1.00000
    QLSW6AG6  COST                 5.00000   TLSW6AG6             1.00000
    RLSW6AG6  AVAILSW6             1.00000   AGREQ6               1.00000
    RLSW6AG6  TLSW6AG6    -        1.00000   AGRFSW6               .40000
    RLSW6AG6  AGRFGW6               .14470   DREQ6                1.00000
    PLSW6MI6  TLSW6MI6             1.00000
    QLSW6MI6  COST                36.00000   TLSW6MI6             1.00000
    RLSW6MI6  AVAILSW6             1.00000   MIREQ6               1.00000
    RLSW6MI6  TLSW6MI6    -        1.00000   WWRF6                 .69700
    RLSW6MI6  DREQ6                1.00000
    QLSW6WL6  AVAILSW6             1.00000   WLREQ6               1.00000
    PLSW7AG7  TLSW7AG7             1.00000
    QLSW7AG7  COST                 5.00000   TLSW7AG7             1.00000
    RLSW7AG7  LSWU7                1.00000   AGREQ7               1.00000
    RLSW7AG7  TLSW7AG7    -        1.00000   AGRFSW7               .47990
    RLSW7AG7  AGRFGW7               .15000   DREQ7                1.00000
    PLSW7MI7  TLSW7MI7             1.00000
    QLSW7MI7  COST                36.00000   TLSW7MI7             1.00000
    RLSW7MI7  LSWU7                1.00000   MIREQ7               1.00000
    RLSW7MI7  TLSW7MI7    -        1.00000   WWRF7                 .65000
    RLSW7MI7  DREQ7                1.00000
    QLSW7WL7  LSWU7                1.00000   WLREQ7               1.00000
    Q7LSW7    LSWU7       -        1.00000   AVAILSW7             1.00000
    PLSW7SW4  AVAILSW4    -        1.00000   AVAILSW7             1.00000
    PLSW7SW4  DREQ7                1.00000   DREQ4                1.00000
    PLSW8AG8  COST                  .00010   TLSW8AG8             1.00000
    QLSW8AG8  COST                 5.00000   TLSW8AG8             1.00000
    RLSW8AG8  LSWU8                1.00000   AGREQ8               1.00000
    RLSW8AG8  TLSW8AG8    -        1.00000   AGRFSW8               .52500
    RLSW8AG8  DREQ8                1.00000
    PLSW8MI8  TLSW8MI8             1.00000
    QLSW8MI8  COST                51.00000   TLSW8MI8             1.00000
    RLSW8MI8  LSWU8                1.00000   MIREQ8               1.00000
    RLSW8MI8  TLSW8MI8    -        1.00000   WWRF8                 .30000
    RLSW8MI8  DREQ8                1.00000
    QLSW8WL8  LSWU8                1.00000   WLREQ8               1.00000
    Q8LSW8    LSWU8       -        1.00000   AVAILSW8             1.00000
    PLSW8AG5  AVAILSW8             1.00000   AGREQ5               1.00000
    PLSW8AG5  AGRFSW5               .52500   AGRFGW5               .15000
    PLSW8AG5  DREQ8                1.00000
    QAG8LSW8  AVAILSW8    -        1.00000   AGEXC8               1.00000
    PLSW9AG9  TLSW9AG9             1.00000
    QLSW9AG9  COST                 5.00000   TLSW9AG9             1.00000
    RLSW9AG9  AVAILSW9             1.00000   AGREQ9               1.00000
    RLSW9AG9  TLSW9AG9    -        1.00000   AGRFSW9               .80000
    RLSW9AG9  DREQ9                1.00000
    PLSW9MI9  TLSW9MI9             1.00000
    QLSW9MI9  COST                43.00000   TLSW9MI9             1.00000
    RLSW9MI9  AVAILSW9             1.00000   MIREQ9               1.00000
    RLSW9MI9  TLSW9MI9    -        1.00000   WWRF9                 .25000
    RLSW9MI9  DREQ9                1.00000
    QLSW9WL9  AVAILSW9             1.00000   WLREQ9               1.00000
    PLSW0AG0  TLSW0AG0             1.00000
    QLSW0AG0  COST                 5.00000   TLSW0AG0             1.00000
    RLSW0AG0  AVAILSW0             1.00000   AGREQ0               1.00000
    RLSW0AG0  TLSW0AG0    -        1.00000   AGRFSW0               .50000
    RLSW0AG0  DREQ0                1.00000
    PLSW0MI0  TLSW0MI0             1.00000
    QLSW0MI0  COST                43.00000   TLSW0MI0             1.00000
    RLSW0MI0  AVAILSW0             1.00000   MIREQ0               1.00000
    RLSW0MI0  TLSW0MI0    -        1.00000   WWRF0                 .30000
    RLSW0MI0  DREQ0                1.00000
    QLSW0WL0  AVAILSW0             1.00000   WLREQ0               1.00000
    PLSW0SW6  TLSW0SW6             1.00000
    QLSW0SW6  COST                 4.00000   TLSW0SW6             1.00000
    RLSW0SW6  AVAILSW6    -        1.00000   AVAILSW0             1.00000
    RLSW0SW6  DREQ0                1.00000   TLSW0SW6             1.00000
    RLSW0SW6  DREQ6       -        1.00000
    PGW1AG1   TGW1AG1              1.00000
    QGW1AG1   COST                 4.90000   TGW1AG1              1.00000
    RGW1AG1   AVAILGW1             1.00000   AGREQ1               1.00000
    RGW1AG1   TGW1AG1     -        1.00000   AGRFSW1               .40000
    RGW1AG1   AGRFGW1               .12420
    PGW1MI1   TGW1MI1              1.00000
    QGW1MI1   COST                34.25000   TGW1MI1              1.00000
    RGW1MI1   AVAILGW1             1.00000   MIREQ1               1.00000
    RGW1MI1   TGW1MI1     -        1.00000   WWRF1                 .70000
    QFGW1WL1  AVAILGW1             1.00000   WLREQ1               1.00000
    QFGW1WL1  FGWAVWL1             1.00000
    QCGW1WL1  COST                 2.40000   AVAILGW1             1.00000
    QCGW1WL1  WLREQ1               1.00000
    PGW2AG2   TGW2AG2              1.00000
    QGW2AG2   COST                 5.60000   TGW2AG2              1.00000
    RGW2AG2   AVAILGW2             1.00000   AGREQ2               1.00000
    RGW2AG2   TGW2AG2     -        1.00000   AGRFSW2               .50770
    RGW2AG2   AGRFGW2               .15000
    PGW2MI2   TGW2MI2              1.00000
    QGW2MI2   COST                34.25000   TGW2MI2              1.00000
    RGW2MI2   AVAILGW2             1.00000   MIREQ2               1.00000
    RGW2MI2   TGW2MI2     -        1.00000   WWRF2                 .66000
    QFGW2WL2  FGWAVWL2             1.00000   AVAILGW2             1.00000
    QFGW2WL2  WLREQ2               1.00000
    QCGW2WL2  COST                 3.10000   AVAILGW2             1.00000
    QCGW2WL2  WLREQ2               1.00000
    PGW3AG3   TGW3AG3              1.00000
    QGW3AG3   COST                 6.70000   TGW3AG3              1.00000
    RGW3AG3   AVAILGW3             1.00000   AGREQ3               1.00000
    RGW3AG3   TGW3AG3     -        1.00000   AGRFSW3               .48330
    RGW3AG3   AGRFGW3               .15000
    PGW3MI3   TGW3MI3              1.00000
    QGW3MI3   COST                41.65000   TGW3MI3              1.00000
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Table B-2. Continued.

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RGW3MI3    AVAILGW3        1.00000   MIREQ3          1.00000
RGW3MI3    TGW3MI3    -    1.00000   WWRF3            .43660
QFGW3WL3   AVAILGW3        1.00000   WLREQ3          1.00000
QFGW3WL3   FGWAVWL3        1.00000
QCGW3WL3   COST            3.70000   AVAILGW3        1.00000
QCGW3WL3   WLREQ3          1.00000
QAG3GW3    AVAILGW3   -    1.00000   AGEXC3          1.00000
PGW4AG4    TGW4AG4         1.00000
QGW4AG4    COST            7.70000   TGW4AG4         1.00000
RGW4AG4    AVAILGW4        1.00000   AGREQ4          1.00000
RGW4AG4    TGW4AG4    -    1.00000   AGRFSW4          .46090
RGW4AG4    AGRFGW4          .15000
PGW4MI4    TGW4MI4         1.00000
QGW4MI4    COST           41.65000   TGW4MI4         1.00000
RGW4MI4    AVAILGW4        1.00000   MIREQ4          1.00000
RGW4MI4    TGW4MI4    -    1.00000   WWRF4            .58890
QFGW4WL4   AVAILGW4        1.00000   WLREQ4          1.00000
QFGW4WL4   FGWAVWL4        1.00000
QCGW4WL4   COST            4.70000   AVAILGW4        1.00000
QCGW4WL4   WLREQ4          1.00000
QAG4GW4    AVAILGW4   -    1.00000   AGEXC4          1.00000
PGW5AG5    TGW5AG5         1.00000
QGW5AG5    COST            5.80000   TGW5AG5         1.00000
RGW5AG5    AVAILGW5        1.00000   AGREQ5          1.00000
RGW5AG5    TGW5AG5    -    1.00000   AGRFSW5          .52500
RGW5AG5    AGRFGW5          .15000
PGW5MI5    TGW5MI5         1.00000
QGW5MI5    COST           34.25000   TGW5MI5         1.00000
RGW5MI5    AVAILGW5        1.00000   MIREQ5          1.00000
RGW5MI5    TGW5MI5    -    1.00000   WWRF5            .45880
QFGW5WL5   AVAILGW5        1.00000   WLREQ5          1.00000
QFGW5WL5   FGWAVWL5        1.00000
QCGW5WL5   COST            3.30000   AVAILGW5        1.00000
QCGW5WL5   WLREQ5          1.00000
PGW6AG6    TGW6AG6         1.00000
QGW6AG6    COST            6.40000   TGW6AG6         1.00000
RGW6AG6    AVAILGW6        1.00000   AGREQ6          1.00000
RGW6AG6    TGW6AG6    -    1.00000   AGRFSW6          .40000
RGW6AG6    AGRFGW6          .14470
PGW6MI6    TGW6MI6         1.00000
QGW6MI6    COST           34.25000   TGW6MI6         1.00000
RGW6MI6    AVAILGW6        1.00000   MIREQ6          1.00000
RGW6MI6    TGW6MI6    -    1.00000   WWRF6            .69700
QFGW6WL6   AVAILGW6        1.00000   WLREQ6          1.00000
QFGW6WL6   FGWAVWL6        1.00000
QCGW6WL6   COST            3.90000   AVAILGW6        1.00000
QCGW6WL6   WLREQ6          1.00000
PGW7AG7    TGW7AG7         1.00000
QGW7AG7    COST            4.60000   TGW7AG7         1.00000
RGW7AG7    AVAILGW7        1.00000   AGREQ7          1.00000
RGW7AG7    TGW7AG7    -    1.00000   AGRFSW7          .47880
RGW7AG7    AGRFGW7          .15000
PGW7MI7    TGW7MI7         1.00000
QGW7MI7    COST           34.25000   TGW7MI7         1.00000
RGW7MI7    AVAILGW7        1.00000   MIREQ7          1.00000
RGW7MI7    TGW7MI7    -    1.00000   WWRF7            .65000
QFGW7WL7   AVAILGW7        1.00000   WLREQ7          1.00000
QFGW7WL7   FGWAVWL7        1.00000
QCGW7WL7   COST            2.10000   AVAILGW7        1.00000
QCGW7WL7   WLREQ7          1.00000
PGW0AG0    TGW0AG0         1.00000
QGW0AG0    COST            4.80000   TGW0AG0         1.00000
RGW0AG0    AVAILGW0        1.00000   AGREQ0          1.00000
RGW0AG0    TGW0AG0    -    1.00000   AGRFSW0          .50000
PGW0MI0    TGW0MI0         1.00000
QGW0MI0    COST           34.10000   TGW0MI0         1.00000
RGW0MI0    AVAILGW0        1.00000   MIREQ0          1.00000
RGW0MI0    TGW0MI0    -    1.00000   WWRF0            .30000
QFGW0WL0   AVAILGW0        1.00000   WLREQ0          1.00000
QFGW0WL0   FGWAVWL0        1.00000
QCGW0WL0   COST            2.30000   AVAILGW0        1.00000
QCGW0WL0   WLREQ0          1.00000
QDREQ1     DREQ1      -    1.00000   GRID1     -    1.00000
SET1       'MARKER'                  'SEPORG'
D11        GRID1         123.00000
D12        GRID1           7.00000   LSW1ST1        10.00000
D13        GRID1          30.00000   LSW1ST1        80.00000
D14        GRID1          30.00000   LSW1ST1       190.00000
ENDSET1    'MARKER'                  'SEPEND'
PLSW1ST1   TST1            1.00000
QLSW1ST1   COST           11.00000   TST1            1.00000
RLSW1ST1   LSW1ST1    -    1.00000   EVLSW1           .07000
RLSW1ST1   TST1       -    1.00000
QDREQ2     DREQ2      -    1.00000   GRID2     -    1.00000
SET2       'MARKER'                  'SEPORG'
D21        GRID2         596.00000
D22        GRID2         138.00000   LSW2ST2       300.00000
D23        GRID2         137.00000   LSW2ST2       880.00000
D24        GRID2         138.00000   LSW2ST2      1140.00000
ENDSET2    'MARKER'                  'SEPEND'
PLSW2ST2   TST2            1.00000
QLSW2ST2   COST            4.70000   TST2            1.00000
RLSW2ST2   LSW2ST2    -    1.00000   EV2ST2    -    1.00000
RLSW2ST2   TST2       -    1.00000
QDREQ3     DREQ3      -    1.00000   GRID3     -    1.00000
SET3       'MARKER'                  'SEPORG'
D31        GRID3         435.00000
D32        GRID3          93.00000   LSW3ST3       240.00000
D33        GRID3          99.00000   LSW3ST3       690.00000
D34        GRID3          99.00000   LSW3ST3       870.00000
ENDSET3    'MARKER'                  'SEPEND'
PLSW3ST3   TST3            1.00000
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QLSW3ST3   COST           16.30000   TST3            1.00000
RLSW3ST3   LSW3ST3    -    1.00000   EVLSW3           .02300
RLSW3ST3   EVGW3            .02300   TST3      -    1.00000
QDREQ4     DREQ4      -    1.00000   GRID4     -    1.00000
SET4       'MARKER'                  'SEPORG'
D41        GRID4         382.00000
D42        GRID4          66.00000   LSW4ST4       130.00000
D43        GRID4          84.00000   LSW4ST4       340.00000
D44        GRID4          84.00000   LSW4ST4       710.00000
ENDSET4    'MARKER'                  'SEPEND'
PLSW4ST4   TST4            1.00000
QLSW4ST4   COST           13.00000   TST4            1.00000
RLSW4ST4   LSW4ST4    -    1.00000   EV4ST4    -    1.00000
RLSW4ST4   TST4       -    1.00000
QDREQ5     DREQ5      -    1.00000   GRID5     -    1.00000
SET5       'MARKER'                  'SEPORG'
D51        GRID5         262.00000
D52        GRID5          71.00000   LSW5ST5       220.00000
D53        GRID5          63.00000   LSW5ST5       430.00000
D54        GRID5          62.00000   LSW5ST5       510.00000
ENDSET5    'MARKER'                  'SEPEND'
PLSW5ST5   TST5            1.00000
QLSW5ST5   COST            8.60000   TST5            1.00000
RLSW5ST5   LSW5ST5    -    1.00000   EVLSW5           .09300
RLSW5ST5   EVGW5            .03100   TST5      -    1.00000
QDREQ6     DREQ6      -    1.00000   GRID6     -    1.00000
SET6       'MARKER'                  'SEPORG'
D61        GRID6          48.00000
D62        GRID6          16.00000   LSW6ST6        26.00000
D63        GRID6          12.00000   LSW6ST6        38.00000
D64        GRID6          12.00000   LSW6ST6        94.00000
ENDSET6    'MARKER'                  'SEPEND'
PLSW6ST6   TST6            1.00000
QLSW6ST6   COST           14.00000   TST6            1.00000
RLSW6ST6   LSW6ST6    -    1.00000   EVLSW6           .05250
RLSW6ST6   EVGW6            .01750   TST6      -    1.00000
QDREQ7     DREQ7      -    1.00000   GRID7     -    1.00000
SET7       'MARKER'                  'SEPORG'
D71        GRID7         870.00000
D72        GRID7         185.00000   LSW7ST7       320.00000
D73        GRID7         198.00000   LSW7ST7       600.00000
D74        GRID7         198.00000   LSW7ST7      1280.00000
ENDSET7    'MARKER'                  'SEPEND'
PLSW7ST7   TST7            1.00000
QLSW7ST7   COST           10.80000   TST7            1.00000
RLSW7ST7   LSW7ST7    -    1.00000   EVLSW7           .02600
RLSW7ST7   TST7       -    1.00000
QDREQ8     DREQ8      -    1.00000   GRID8     -    1.00000
SET8       'MARKER'                  'SEPORG'
D81        GRID8         394.00000
D82        GRID8         126.00000   LSW8ST8       200.00000
D83        GRID8          98.00000   LSW8ST8       300.00000
D84        GRID8          97.00000   LSW8ST8       710.00000
ENDSET8    'MARKER'                  'SEPEND'
PLSW8ST8   TST8            1.00000
QLSW8ST8   COST            7.20000   TST8            1.00000
RLSW8ST8   LSW8ST8    -    1.00000   EVLSW8           .04500
RLSW8ST8   TST8       -    1.00000
QDREQ9     DREQ9      -    1.00000   GRID9     -    1.00000
SET9       'MARKER'                  'SEPORG'
D91        GRID9         272.00000
D92        GRID9          72.00000   LSW9ST9       120.00000
D93        GRID9          65.00000   LSW9ST9       150.00000
D94        GRID9          64.00000   LSW9ST9       280.00000
ENDSET9    'MARKER'                  'SEPEND'
PLSW9ST9   TST9            1.00000
QLSW9ST9   COST           13.50000   TST9            1.00000
RLSW9ST9   LSW9ST9    -    1.00000   EVLSW9           .07000
RLSW9ST9   TST9       -    1.00000
QDREQ0     DREQ0      -    1.00000   GRID0     -    1.00000
SET0       'MARKER'                  'SEPORG'
D01        GRID0         160.00000
D02        GRID0          40.00000   LSW0ST0        75.00000
D03        GRID0          38.00000   LSW0ST0       100.00000
D04        GRID0          37.00000   LSW0ST0       285.00000
ENDSET0    'MARKER'                  'SEPEND'
PLSW0ST0   TST0            1.00000
QLSW0ST0   COST           14.30000   TST0            1.00000
RLSW0ST0   LSW0ST0    -    1.00000   EVLSW0           .07000
RLSW0ST0   TST0       -    1.00000
QLSW1EV1   AVAILSW1        1.00000   EVLSW1    -    1.00000
QLSW2EV2   AVAILSW2        1.00000   EVLSW2    -    1.00000
QLSW3EV3   AVAILSW3        1.00000   EVLSW3    -    1.00000
QLSW4EV4   AVAILSW4        1.00000   EVLSW4    -    1.00000
QLSW5EV5   AVAILSW5        1.00000   EVLSW5    -    1.00000
QLSW6EV6   AVAILSW6        1.00000   EVLSW6    -    1.00000
QLSW7EV7   AVAILSW7        1.00000   EVLSW7    -    1.00000
QLSW8EV8   AVAILSW8        1.00000   EVLSW8    -    1.00000
QLSW9EV9   AVAILSW9        1.00000   EVLSW9    -    1.00000
QLSW0EV0   AVAILSW0        1.00000   EVLSW0    -    1.00000
QGW1EV1    AVAILGW1        1.00000   EVGW1     -    1.00000
QGW2EV2    AVAILGW2        1.00000   EVGW2     -    1.00000
QGW3EV3    AVAILGW3        1.00000   EVGW3     -    1.00000
QGW4EV4    AVAILGW4        1.00000   EVGW4     -    1.00000
QGW5EV5    AVAILGW5        1.00000   EVGW5     -    1.00000
QGW6EV6    AVAILGW6        1.00000   EVGW6     -    1.00000
QGW7EV7    AVAILGW7        1.00000   EVGW7     -    1.00000
QGW0EV0    AVAILGW0        1.00000   EVGW0     -    1.00000
QEV2       EVLSW2           .50000   EVGW2            .50000
QEV2       EV2        -    1.00000
SET21      'MARKER'                  'SEPORG'
E21        EV2ST2        208.00000
```

Table B-2. Continued.

```
E22       EV2ST2        103.00000   EV2           3.00000
E23       EV2ST2       1500.00000   EV2         105.00000
ENDSET21  'MARKER'                  'SEPEND'
QEV4      EVLSW4           .50000   EVGW4          .50000
QEV4      EV4      -      1.00000
SET41     'MARKER'                  'SEPORG'
E41       EV4ST4        220.00000
E42       EV4ST4        196.00000   EV4          25.50000
E43       EV4ST4       1500.00000   EV4         105.00000
ENDSET41  'MARKER'                  'SEPEND'
QAR1LSW1  AVAILSW1 -      1.00000   AGRFSW1  -    1.00000
QAR1LSW1  DREQ1    -       .20000
QAR2LSW2  AVAILSW2 -      1.00000   AGRFSW2  -    1.00000
QAR2LSW2  DREQ2    -       .80000
QAR3LSW3  AVAILSW3 -      1.00000   AGRFSW3  -    1.00000
QAR3LSW3  DREQ3    -       .50000
QAR4LSW4  AVAILSW4 -      1.00000   AGRFSW4  -    1.00000
QAR4LSW4  DREQ4    -       .70000
QAR5LSW5  AVAILSW5 -      1.00000   AGRFSW5  -    1.00000
QAR5LSW5  DREQ5    -       .80000
QAR6LSW6  AVAILSW6 -      1.00000   AGRFSW6  -    1.00000
QAR6LSW6  DREQ6    -       .60000
QAR7LSW7  LSWU7    -      1.00000   AGRFSW7  -    1.00000
QAR7LSW7  DREQ7    -       .30000
QAR8LSW8  LSWU8    -      1.00000   AGRFSW8  -    1.00000
QAR8LSW8  DREQ8    -       .20000
QAR9LSW9  AVAILSW9 -      1.00000   AGRFSW9  -    1.00000
QAR9LSW9  DREQ9    -       .20000
QAR0LSW0  AVAILSW0 -      1.00000   AGRFSW0  -    1.00000
QAR0LSW0  DREQ0    -       .30000
QAR1GW1   AVAILGW1 -      1.00000   AGRFGW1  -    1.00000
QAR1GW1   FGWAVWL1 -       .50000
QAR2GW2   AVAILGW2 -      1.00000   AGRFGW2  -    1.00000
QAR2GW2   FGWAVWL2 -       .50000
QAR3GW3   AVAILGW3 -      1.00000   AGRFGW3  -    1.00000
QAR3GW3   FGWAVWL3 -       .50000
QAR4GW4   AVAILGW4 -      1.00000   AGRFGW4  -    1.00000
QAR4GW4   FGWAVWL4 -       .50000
QAR5GW5   AVAILGW5 -      1.00000   AGRFGW5  -    1.00000
QAR5GW5   FGWAVWL5 -       .50000
QAR6GW6   AVAILGW6 -      1.00000   AGRFGW6  -    1.00000
QAR6GW6   FGWAVWL6 -       .50000
QAR7GW7   AVAILGW7 -      1.00000   AGRFGW7  -    1.00000
QAR7GW7   FGWAVWL7 -       .50000
QAR0GW0   AVAILGW0 -      1.00000   AGRFGW0  -    1.00000
QWW1LSW1  COST           26.00000   AVAILSW1 -    1.00000
QWW1LSW1  WWRF1    -      1.00000
QWW2LSW2  COST           26.00000   AVAILSW2 -    1.00000
QWW2LSW2  WWRF2    -      1.00000
QWW3LSW3  COST           26.00000   AVAILSW3 -    1.00000
QWW3LSW3  WWRF3    -      1.00000
QWW4LSW4  COST           26.00000   AVAILSW4 -    1.00000
QWW4LSW4  WWRF4    -      1.00000
QWW5LSW5  COST           26.00000   AVAILSW5 -    1.00000
QWW5LSW5  WWRF5    -      1.00000
QWW6LSW6  COST           26.00000   AVAILSW6 -    1.00000
QWW6LSW6  WWRF6    -      1.00000
QWW7LSW7  COST           26.00000   LSWU7    -    1.00000
QWW7LSW7  WWRF7    -      1.00000
QWW8LSW8  COST           26.00000   LSWU8    -    1.00000
QWW8LSW8  WWRF8    -      1.00000
QWW9LSW9  COST           26.00000   AVAILSW9 -    1.00000
QWW9LSW9  WWRF9    -      1.00000
QWW0LSW0  COST           26.00000   AVAILSW0 -    1.00000
QWW0LSW0  WWRF0    -      1.00000
QLSW1R1   COST           17.00000   AVAILSW1      1.00000
QLSW1R1   AVAILGW1 -      1.00000   GWRC1         1.00000
QLSW2R2   COST           17.00000   AVAILSW2      1.00000
QLSW2R2   AVAILGW2 -      1.00000   GWRC2         1.00000
QLSW3R3   COST           17.00000   AVAILSW3      1.00000
QLSW3R3   AVAILGW3 -      1.00000   GWRC3         1.00000
QLSW4R4   COST           17.00000   AVAILSW4      1.00000
QLSW4R4   AVAILGW4 -      1.00000   GWRC4         1.00000
QLSW4RU4  COST           23.00000   AVAILSW4      1.00000
QLSW4RU4  AVAILGW4 -      1.00000   GWRCU4        1.00000
QLSW5R5   COST           17.00000   AVAILSW5      1.00000
QLSW5R5   AVAILGW5 -      1.00000   GWRC5         1.00000
QLSW5RU5  COST           23.00000   AVAILSW5      1.00000
QLSW5RU5  AVAILGW5 -      1.00000   GWRCU5        1.00000
QLSW6R6   COST           17.00000   AVAILSW6      1.00000
QLSW6R6   AVAILGW6 -      1.00000   GWRC6         1.00000
QLSW7R7   COST           17.00000   LSWU7         1.00000
QLSW7R7   AVAILGW7 -      1.00000   GWRC7         1.00000
QLSW0R0   COST           17.00000   AVAILSW0      1.00000
QLSW0R0   AVAILGW0 -      1.00000   GWRC0         1.00000
QWW1R1    COST           29.00000   AVAILGW1 -    1.00000
QWW1R1    GWRC1           1.00000   WWRF1    -    1.00000
QWW2R2    COST           29.00000   AVAILGW2 -    1.00000
```

```
QWW2R2    GWRC2           1.00000   WWRF2    -    1.00000
QWW3R3    COST           29.00000   AVAILGW3 -    1.00000
QWW3R3    GWRC3           1.00000   WWRF3    -    1.00000
QWW4R4    COST           29.00000   AVAILGW4 -    1.00000
QWW4R4    GWRC4           1.00000   WWRF4    -    1.00000
QWW4RU4   COST           35.00000   AVAILGW4 -    1.00000
QWW4RU4   GWRCU4          1.00000   WWRF4    -    1.00000
QWW5R5    COST           29.00000   AVAILGW5 -    1.00000
QWW5R5    GWRC5           1.00000   WWRF5    -    1.00000
QWW5RU5   COST           35.00000   AVAILGW5 -    1.00000
QWW5RU5   GWRCU5          1.00000   WWRF5    -    1.00000
QWW6R6    COST           29.00000   AVAILGW6 -    1.00000
QWW6R6    GWRC6           1.00000   WWRF6    -    1.00000
QWW7R7    COST           29.00000   AVAILGW7 -    1.00000
QWW7R7    GWRC7           1.00000   WWRF7    -    1.00000
QWW0R0    COST           29.00000   AVAILGW0 -    1.00000
QWW0R0    GWRC0           1.00000   WWRF0    -    1.00000
QLSW1OF1  INFLOGSL        1.00000   AVAILSW1      1.00000
QLSW2OF2  INFLOGSL        1.00000   AVAILSW2      1.00000
QLSW3OF3  INFLOGSL        1.00000   AVAILSW3      1.00000
QLSW4OF4  INFLOGSL        1.00000   AVAILSW4      1.00000
QLSW5OF5  AVAILSW5        1.00000
QLSW6OF6  AVAILSW6        1.00000
QLSW7OF7  CROUT           1.00000   AVAILSW7      1.00000
QLSW8OF8  CROUT           1.00000   AVAILSW8      1.00000
QLSW9OF9  CROUT           1.00000   AVAILSW9      1.00000
QLSW0OF0  AVAILSW0        1.00000
QGW1OF1   INFLOGSL        1.00000   AVAILGW1      1.00000
QGW2OF2   INFLOGSL        1.00000   AVAILGW2      1.00000
QGW3OF3   INFLOGSL        1.00000   AVAILGW3      1.00000
QGW4OF4   INFLOGSL        1.00000   AVAILGW4      1.00000
QGW5OF5   AVAILGW5        1.00000
QGW6OF6   AVAILGW6        1.00000
QGW7OF7   CROUT           1.00000   AVAILGW7      1.00000
QGW0OF0   AVAILGW0        1.00000


RHS
    RHS       AVAILSW1        613.00000   AVAILSW2      941.50000
    RHS       AVAILSW3        789.20000   AVAILSW4      513.60000
    RHS       AVAILSW5        453.20000   AVAILSW6       80.00000
    RHS       AVAILSW7       1351.60000   AVAILSW8      650.00000
    RHS       AVAILSW9        430.00000   AVAILSW0      250.00000
    RHS       AVAILGW1        187.00000   AVAILGW2      103.50000
    RHS       AVAILGW3         94.90000   AVAILGW4      272.10000
    RHS       AVAILGW5        254.60000   AVAILGW6      130.00000
    RHS       AVAILGW7         40.00000   AVAILGW0       10.00000
    RHS       MIREQ1           10.00000   MIREQ2         44.00000
    RHS       MIREQ3           49.70000   MIREQ4        302.50000
    RHS       MIREQ5           17.00000   MIREQ6         13.00000
    RHS       MIREQ7           10.00000   MIREQ8          7.00000
    RHS       MIREQ9            6.80000   MIREQ0          1.50000
    RHS       AGREQ1          124.00000   AGREQ2       1034.00000
    RHS       AGREQ3          643.40000   AGREQ4        796.70000
    RHS       AGREQ5         1017.90000   AGREQ6        300.00000
    RHS       AGREQ7          789.10000   AGREQ8        303.00000
    RHS       AGREQ9          150.00000   AGREQ0         68.00000
    RHS       WLREQ1          715.00000   WLREQ2        240.00000
    RHS       WLREQ3          143.10000   WLREQ4        276.40000
    RHS       WLREQ5          332.60000   WLREQ6        130.00000
    RHS       WLREQ7          315.00000   WLREQ8         36.00000
    RHS       WLREQ9            8.00000   WLREQ0         19.00000
    RHS       FGWAVWL1        166.80000   FGWAVWL2      147.50000
    RHS       FGWAVWL3         51.80000   FGWAVWL4       96.00000
    RHS       FGWAVWL5        209.10000   FGWAVWL6       42.50000
    RHS       FGWAVWL7         59.20000   FGWAVWL0       10.00000
    RHS       GWRC2            60.00000   GWRC3         366.00000
    RHS       GWRC4           434.00000   GWRCU4        100.00000
    RHS       GWRC5            52.00000   GWRCU5         52.00000
    RHS       GWRC6            65.00000   CROUT         907.00000
    RHS       INFLOGSL        500.00000
    RHS2      MIREQ1            1.33000   MIREQ2         23.53000
    RHS2      MIREQ3           27.87000   MIREQ4         78.75000
    RHS2      MIREQ5            1.48000   MIREQ6          1.98000
    RHS2      MIREQ7           14.86000   MIREQ8          3.43000
    RHS2      MIREQ9           11.33000   MIREQ0           .71000
    RHS2      AGREQ1           19.76000   AGREQ2         39.43000
    RHS2      AGREQ3     -      5.45000   AGREQ4         11.31000
    RHS2      AGREQ5           24.62000   AGREQ6          8.79000
    RHS2      AGREQ7           29.09000   AGREQ8   -      2.93000
    RHS2      AGREQ0            4.00000   WLREQ1           .30000
    RHS2      WLREQ2            7.90000   WLREQ3           .60000
    RHS2      WLREQ4            6.70000   WLREQ5   -      1.70000
    RHS2      WLREQ6            1.00000   WLREQ7   -      1.70000
    RHS2      WLREQ8     -      1.30000   WLREQ9   -       .10000
    RHS2      WLREQ0     -      1.00000   AGEXC3          2.00000
    RHS2      AGEXC8            1.10000
```

Table B-2. Continued.

```
BOUNDS
 UP BOUNDX      QBULSW5        29.00000
 UP BOUNDX      QBUMPT        136.60000
 UP BOUNDX      QUILSW3        20.00000
 UP BOUNDX      QUILSW5        57.00000
 UP BOUNDX      QUIMPT        420.00000
 UP BOUNDX      QSALSW4        15.00000
 UP BOUNDX      QSAMPT         22.40000
 FX BOUNDX      PLSW1AG1      104.90000
 FX BOUNDX      PLSW1MI1        7.20000
 FX BOUNDX      PLSW1MI4       10.00000
 FX BOUNDX      PLSW2AG2      996.00000
 FX BOUNDX      PLSW2MI2       36.00000
 UP BOUNDX      QLSW2SW1       90.00000
 UP BOUNDX      QLSW2SW3      130.00000
 UP BOUNDX      PLSW3AG3      610.50000
 FX BOUNDX      PLSW3MI3       29.20000
 FX BOUNDX      PLSW3AG2       19.00000
 FX BOUNDX      PLSW3SW4       71.00000
 UP BOUNDX      QLSW3SW4      146.00000
 FX BOUNDX      PLSW4AG4      713.50000
 FX BOUNDX      PLSW4MI4      160.50000
 UP BOUNDX      QLSW4SW5       69.00000
 FX BOUNDX      PLSW5AG5      879.30000
 FX BOUNDX      PLSW5MI5        6.60000
 UP BOUNDX      QLSW5SW6       60.00000
 FX BOUNDX      PLSW5AG9        3.60000
 FX BOUNDX      PLSW6AG6      136.10000
 FX BOUNDX      PLSW6MI6       10.10000
 FX BOUNDX      PLSW7AG7      789.10000
 FX BOUNDX      PLSW7MI7       10.00000
 FX BOUNDX      PLSW7SW4      101.30000
 UP BOUNDX      PLSW8AG8      303.00000
 FX BOUNDX      PLSW8MI8        7.00000
 FX BOUNDX      PLSW8AG5       11.00000
 FX BOUNDX      PLSW9AG9      146.40000
 FX BOUNDX      PLSW9MI9        6.80000
 FX BOUNDX      PLSW0AG0       68.00000
 FX BOUNDX      PLSW0MI0        1.50000
 FX BOUNDX      PLSW0SW6        3.00000
 UP BOUNDX      QLSW0SW6       47.00000
 FX BOUNDX      PGW1AG1        19.10000
 FX BOUNDX      PGW1MI1         2.80000
 FX BOUNDX      PGW2AG2        19.00000
 FX BOUNDX      PGW2MI2         8.00000
 UP BOUNDX      PGW3AG3        32.90000
 FX BOUNDX      PGW3MI3        20.50000
 FX BOUNDX      PGW4AG4        83.20000
 FX BOUNDX      PGW4MI4       132.00000
 FX BOUNDX      PGW5AG5       127.60000
 FX BOUNDX      PGW5MI5        10.40000
 FX BOUNDX      PGW6AG6       163.90000
 FX BOUNDX      PGW6MI6         2.90000
 FX BOUNDX      PGW7AG7          .
 FX BOUNDX      PGW7MI7          .
 FX BOUNDX      PGW0AG0          .
 FX BOUNDX      PGW0MI0          .
 UP BOUNDX      D11             1.00000
 UP BOUNDX      D12             1.00000
 UP BOUNDX      D13             1.00000
 UP BOUNDX      D14             1.00000
 UP BOUNDX      PLSW1ST1       17.00000
 UP BOUNDX      QLSW1ST1       25.00000
 UP BOUNDX      D21             1.00000
 UP BOUNDX      D22             1.00000
 UP BOUNDX      D23             1.00000
 UP BOUNDX      D24             1.00000
 UP BOUNDX      PLSW2ST2      311.00000
 UP BOUNDX      QLSW2ST2     1200.00000
 UP BOUNDX      D31             1.00000
 UP BOUNDX      D32             1.00000
 UP BOUNDX      D33             1.00000
 UP BOUNDX      D34             1.00000
 UP BOUNDX      PLSW3ST3      578.00000
 UP BOUNDX      QLSW3ST3      125.00000
 UP BOUNDX      D41             1.00000
 UP BOUNDX      D42             1.00000
 UP BOUNDX      D43             1.00000
 UP BOUNDX      D44             1.00000
 UP BOUNDX      PLSW4ST4      416.00000
 UP BOUNDX      QLSW4ST4     1050.00000
 UP BOUNDX      D51             1.00000
 UP BOUNDX      D52             1.00000
 UP BOUNDX      D53             1.00000
 UP BOUNDX      D54             1.00000
 UP BOUNDX      PLSW5ST5      481.00000
 UP BOUNDX      QLSW5ST5      125.00000
 UP BOUNDX      D61             1.00000
 UP BOUNDX      D62             1.00000
 UP BOUNDX      D63             1.00000
 UP BOUNDX      D64             1.00000
 UP BOUNDX      PLSW6ST6       56.00000
 UP BOUNDX      QLSW6ST6      100.00000
 UP BOUNDX      D71             1.00000
 UP BOUNDX      D72             1.00000
 UP BOUNDX      D73             1.00000
 UP BOUNDX      D74             1.00000
 UP BOUNDX      PLSW7ST7      428.00000
 UP BOUNDX      QLSW7ST7     1500.00000
 UP BOUNDX      D81             1.00000
 UP BOUNDX      D82             1.00000
 UP BOUNDX      D83             1.00000
 UP BOUNDX      D84             1.00000
 UP BOUNDX      PLSW8ST8      199.00000
 UP BOUNDX      QLSW8ST8      285.00000
 UP BOUNDX      D91             1.00000
 UP BOUNDX      D92             1.00000
 UP BOUNDX      D93             1.00000
 UP BOUNDX      D94             1.00000
 UP BOUNDX      PLSW9ST9        1.00000
 UP BOUNDX      QLSW9ST9      140.00000
 UP BOUNDX      D01             1.00000
 UP BOUNDX      D02             1.00000
 UP BOUNDX      D03             1.00000
 UP BOUNDX      D04             1.00000
 UP BOUNDX      PLSW0ST0       14.00000
 UP BOUNDX      QLSW0ST0      280.00000
 UP BOUNDX      E21             1.00000
 UP BOUNDX      E22             1.00000
 UP BOUNDX      E23             1.00000
 UP BOUNDX      E41             1.00000
 UP BOUNDX      E42             1.00000
 UP BOUNDX      E43             1.00000
 LO BOUNDX      QLSW1OF1        7.00000
 LO BOUNDX      QLSW2OF2       50.00000
 LO BOUNDX      QLSW3OF3       50.00000
 LO BOUNDX      QLSW4OF4       50.00000
 LO BOUNDX      QLSW5OF5       13.70000
 LO BOUNDX      QLSW6OF6         .
 LO BOUNDX      QLSW7OF7      100.00000
 LO BOUNDX      QLSW8OF8      100.00000
 LO BOUNDX      QLSW9OF9      100.00000
 LO BOUNDX      QLSW0OF0      100.00000
 LO BOUNDX      QGW1OF1         6.00000
 LO BOUNDX      QGW2OF2         5.00000
 LO BOUNDX      QGW3OF3        25.00000
 LO BOUNDX      QGW4OF4         8.00000
 LO BOUNDX      QGW5OF5          .
 LO BOUNDX      QGW6OF6          .
 LO BOUNDX      QGW7OF7        40.00000
 LO BOUNDX      QGW0OF0          .
ENDATA
```

Table B-3. Print-out of the optimal solution.

```
                 EXECUTOR.      MPS/360 V2-M5

SOLUTION    (OPTIMAL)

TIME =    4.62 MINS. ITERATION NUMBER =     310

          ...NAME...      ...ACTIVITY...       DEFINED AS

          FUNCTIONAL         9722.44726        COST
          RESTRAINTS                           RHS
          BOUNDS....                           BOUNDX




SECTION 1 - ROWS

 NUMBER     ...ROW..  AT   ...ACTIVITY...  SLACK ACTIVITY  ..LOWER LIMIT.  ..UPPER LIMIT.  .DUAL ACTIVITY

        1   COST      BS     9722.44726        9722.44726-             NONE            NONE           1.00000
A       2   AVAILSW1  EQ      613.00000            .              613.00000       613.00000            .
A       3   AVAILSW2  EQ      941.50000            .              941.50000       941.50000            .
A       4   AVAILSW3  EQ      789.20000            .              789.20000       789.20000            .
A       5   AVAILSW4  EQ      513.60000            .              513.60000       513.60000            .
A       6   AVAILSW5  EQ      453.20000            .              453.20000       453.20000            .
        7   AVAILSW6  EQ       80.00000            .               80.00000        80.00000          14.00000
A       8   AVAILSW7  EQ     1351.60000            .             1351.60000      1351.60000            .
A       9   AVAILSW8  EQ      650.00000            .              650.00000       650.00000            .
A      10   AVAILSW9  EQ      430.00000            .              430.00000       430.00000            .
A      11   AVAILSW0  EQ      250.00000            .              250.00000       250.00000            .
A      12   LSWU7     EQ         .                 .                 .               .                 .
A      13   LSWU8     EQ         .                 .                 .               .                 .
A      14   AVAILGW1  EQ      187.00000            .              187.00000       187.00000            .
A      15   AVAILGW2  EQ      103.50000            .              103.50000       103.50000            .
A      16   AVAILGW3  EQ       94.90000            .               94.90000        94.90000            .
       17   AVAILGW4  EQ      272.10000            .              272.10000       272.10000           3.00000
       18   AVAILGW5  EQ      254.60000            .              254.60000       254.60000          17.00000
       19   AVAILGW6  EQ      130.00000            .              130.00000       130.00000          31.00000
       20   AVAILGW7  EQ       40.00000            .               40.00000        40.00000          66.66667
       21   AVAILGW0  EQ       10.00000            .               10.00000        10.00000           3.00000
       22   MIREQ1    BS       10.00000            .               10.00000            NONE            .
       23   MIREQ2    BS       44.00000            .               44.00000            NONE            .
       24   MIREQ3    BS       49.70000            .               49.70000            NONE            .
       25   MIREQ4    BS      302.50000            .              302.50000            NONE            .
       26   MIREQ5    BS       17.00000            .               17.00000            NONE            .
       27   MIREQ6    BS       13.00000            .               13.00000            NONE            .
       28   MIREQ7    LL       10.00000            .               10.00000            NONE          52.90000-
       29   MIREQ8    BS        7.00000            .                7.00000            NONE            .
       30   MIREQ9    BS        6.80000            .                6.80000            NONE            .
       31   MIREQ0    BS        1.50000            .                1.50000            NONE            .
       32   TLSW1MI1  EQ         .                 .                 .               .               18.20000
       33   TLSW2MI2  EQ         .                 .                 .               .               17.16000
       34   TLSW3MI3  EQ         .                 .                 .               .               11.35160
       35   TLSW4MI4  EQ         .                 .                 .               .               21.91140
       36   TLSW5MI5  EQ         .                 .                 .               .               15.50560
       37   TLSW6MI6  EQ         .                 .                 .               .               12.60600
       38   TLSW7MI7  EQ         .                 .                 .               .               36.00000-
       39   TLSW8MI8  EQ         .                 .                 .               .                7.80000
       40   TLSW9MI9  EQ         .                 .                 .               .                6.50000
       41   TLSW0MI0  EQ         .                 .                 .               .                7.80000
       42   TGW1MI1   EQ         .                 .                 .               .               18.20000
       43   TGW2MI2   EQ         .                 .                 .               .               17.16000
       44   TGW3MI3   EQ         .                 .                 .               .               11.35160
       45   TGW4MI4   EQ         .                 .                 .               .               20.91140
       46   TGW5MI5   EQ         .                 .                 .               .               22.50560
       47   TGW6MI6   EQ         .                 .                 .               .               29.60600
       48   TGW7MI7   EQ         .                 .                 .               .               30.66667
       49   TGW0MI0   EQ         .                 .                 .               .               34.10000-
       50   AGREQ1    BS      124.00000            .              124.00000            NONE            .
       51   AGREQ2    BS     1034.00000            .             1034.00000            NONE            .
       52   AGREQ3    LL      643.40000            .              643.40000            NONE            .
       53   AGREQ4    BS      796.70000            .              796.70000            NONE            .
       54   AGREQ5    BS     1017.90000            .             1017.90000            NONE            .
       55   AGREQ6    BS      300.00000            .              300.00000            NONE            .
       56   AGREQ7    BS      789.33333            .23333-        789.10000            NONE            .
       57   AGREQ8    LL      303.00000            .              303.00000            NONE           5.00000-
       58   AGREQ9    BS      150.00000            .              150.00000            NONE            .
       59   AGREQ0    BS       68.00000            .               68.00000            NONE            .
       60   TLSW1AG1  EQ         .                 .                 .               .                 .
       61   TLSW2AG2  EQ         .                 .                 .               .                 .
       62   TLSW3AG3  EQ         .                 .                 .               .                 .
       63   TLSW4AG4  EQ         .                 .                 .               .                2.48448
       64   TLSW5AG5  EQ         .                 .                 .               .                4.52500
       65   TLSW6AG6  EQ         .                 .                 .               .                5.14425
       66   TLSW7AG7  EQ         .                 .                 .               .                5.00000-
       67   TLSW8AG8  EQ         .                 .                 .               .                5.00000-
       68   TLSW9AG9  EQ         .                 .                 .               .                 .
       69   TLSW0AG0  EQ         .                 .                 .               .                 .
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Table B-3. Continued.

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 NUMBER  ...ROW..  AT ...ACTIVITY...  SLACK ACTIVITY ..LOWER LIMIT.  ..UPPER LIMIT. .DUAL ACTIVITY

A   70  TGW1AG1   EQ        .              .              .              .              .
A   71  TGW2AG2   EQ        .              .              .              .              .
A   72  TGW3AG3   EQ        .              .              .              .              .
    73  TGW4AG4   EQ        .              .              .              .             1.48448
    74  TGW5AG5   EQ        .              .              .              .            11.52500
    75  TGW6AG6   EQ        .              .              .              .            22.14425
    76  TGW7AG7   BS        .              .              .              .              .
    77  TGW0AG0   BS        .              .              .              .              .
    78  AGEXC3    BS        .              .              .              .              .
    79  AGEXC4    EQ        .              .              .              .             3.00000
    80  AGEXC8    BS        .              .              .              .              .
A   81  WLREQ1    EQ     715.00000         .           715.00000      715.00000         .
A   82  WLREQ2    EQ     240.00000         .           240.00000      240.00000         .
A   83  WLREQ3    EQ     143.10000         .           143.10000      143.10000         .
A   84  WLREQ4    EQ     276.40000         .           276.40000      276.40000         .
A   85  WLREQ5    EQ     332.60000         .           332.60000      332.60000         .
    86  WLREQ6    EQ     130.00000         .           130.00000      130.00000       14.00000-
A   87  WLREQ7    EQ     315.00000         .           315.00000      315.00000         .
A   88  WLREQ8    EQ      36.00000         .            36.00000       36.00000         .
A   89  WLREQ9    EQ       8.00000         .             8.00000        8.00000         .
A   90  WLREQ0    EQ      19.00000         .            19.00000       19.00000         .
A   91  DREQ1     EQ        .              .              .              .              .
A   92  DREQ2     EQ        .              .              .              .              .
A   93  DREQ3     EQ        .              .              .              .              .
    94  DREQ4     EQ        .              .              .              .             4.00000
    95  DREQ5     EQ        .              .              .              .            10.00000
A   96  DREQ6     EQ        .              .              .              .              .
A   97  DREQ7     EQ        .              .              .              .              .
A   98  DREQ8     EQ        .              .              .              .              .
A   99  DREQ9     EQ        .              .              .              .              .
A  100  DREQ0     EQ        .              .              .              .              .
A  101  GRID1     EQ        .              .              .              .              .
A  102  LSW1ST1   EQ        .              .              .              .              .
A  103  GRID2     EQ        .              .              .              .              .
A  104  LSW2ST2   EQ        .              .              .              .              .
A  105  GRID3     EQ        .              .              .              .              .
A  106  LSW3ST3   EQ        .              .              .              .              .
   107  GRID4     EQ        .              .              .              .             4.00000-
   108  LSW4ST4   EQ        .              .              .              .              .93924
   109  GRID5     EQ        .              .              .              .            10.00000-
   110  LSW5ST5   EQ        .              .              .              .             1.46512
A  111  GRID6     EQ        .              .              .              .              .
   112  LSW6ST6   BS        .              .              .              .              .
A  113  GRID7     EQ        .              .              .              .              .
   114  LSW7ST7   BS        .              .              .              .              .
A  115  GRID8     EQ        .              .              .              .              .
   116  LSW8ST8   BS        .              .              .              .              .
A  117  GRID9     EQ        .              .              .              .              .
   118  LSW9ST9   BS        .              .              .              .              .
A  119  GRID0     EQ        .              .              .              .              .
A  120  LSW0ST0   EQ        .              .              .              .              .
A  121  TST1      EQ        .              .              .              .              .
A  122  TST2      EQ        .              .              .              .              .
A  123  TST3      EQ        .              .              .              .              .
   124  TST4      EQ        .              .              .              .              .83324-
   125  TST5      EQ        .              .              .              .              .93812-
A  126  TST6      EQ        .              .              .              .              .
A  127  TST7      EQ        .              .              .              .              .
A  128  TST8      EQ        .              .              .              .              .
A  129  TST9      EQ        .              .              .              .              .
A  130  TST0      EQ        .              .              .              .              .
A  131  EVLSW1    EQ        .              .              .              .              .
A  132  EVLSW2    EQ        .              .              .              .              .
A  133  EVLSW3    EQ        .              .              .              .              .
A  134  EVLSW4    EQ        .              .              .              .              .
A  135  EVLSW5    EQ        .              .              .              .              .
   136  EVLSW6    EQ        .              .              .              .            10.33333-
   137  EVLSW7    BS        .              .              .              .              .
   138  EVLSW8    BS        .              .              .              .              .
A  139  EVLSW9    EQ        .              .              .              .              .
A  140  EVLSW0    EQ        .              .              .              .              .
   141  EVGW1     BS        .              .              .              .              .
   142  EVGW2     BS        .              .              .              .              .
A  143  EVGW3     EQ        .              .              .              .              .
   144  EVGW4     EQ        .              .              .              .             3.00000
   145  EVGW5     EQ        .              .              .              .            17.00000
   146  EVGW6     EQ        .              .              .              .            31.00000
   147  EVGW7     BS        .              .              .              .              .
   148  EVGW0     BS        .              .              .              .              .
A  149  EV2ST2    EQ        .              .              .              .              .
A  150  EV2       EQ        .              .              .              .              .
   151  EV4ST4    EQ        .              .              .              .              .10500-
   152  EV4       EQ        .              .              .              .             1.50000
   153  WWRF1     EQ        .              .              .              .            26.00000
   154  WWRF2     EQ        .              .              .              .            26.00000
   155  WWRF3     EQ        .              .              .              .            26.00000
   156  WWRF4     EQ        .              .              .              .            26.00000
   157  WWRF5     EQ        .              .              .              .            12.00000
   158  WWRF6     EQ        .              .              .              .             2.00000-
   159  WWRF7     EQ        .              .              .              .            26.00000
   160  WWRF8     EQ        .              .              .              .            26.00000
   161  WWRF9     EQ        .              .              .              .            26.00000
   162  WWRF0     EQ        .              .              .              .            26.00000
A  163  AGRFSW1   EQ        .              .              .              .              .
A  164  AGRFSW2   EQ        .              .              .              .              .
A  165  AGRFSW3   EQ        .              .              .              .              .
   166  AGRFSW4   EQ        .              .              .              .             2.80000-
   167  AGRFSW5   EQ        .              .              .              .             8.00000-
   168  AGRFSW6   EQ        .              .              .              .            14.00000-
A  169  AGRFSW7   EQ        .              .              .              .              .
A  170  AGRFSW8   EQ        .              .              .              .              .
A  171  AGRFSW9   EQ        .              .              .              .              .
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Table B-3. Continued.

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NUMBER    ...ROW..  AT  ...ACTIVITY...   SLACK ACTIVITY   ..LOWER LIMIT.   ..UPPER LIMIT.  .DUAL ACTIVITY
A   172  AGRFSWO   EQ           .                .                .                .                .
A   173  AGRFGW1   EQ           .                .                .                .                .
A   174  AGRFGW2   EQ           .                .                .                .                .
A   175  AGRFGW3   EQ           .                .                .                .                .
    176  AGRFGW4   EQ           .                .                .                .               1.50000-
    177  AGPFGW5   EQ           .                .                .                .               8.50000-
    178  AGRFGW6   EQ           .                .                .                .              22.50000-
    179  AGRFGW7   EQ           .                .                .                .              33.33333-
    180  AGRFGW0   EQ           .                .                .                .               3.00000-
A   181  FGWAVWL1  EQ        166.80000           .             166.80000        166.80000           .
A   182  FGWAVWL2  EQ        147.50000           .             147.50000        147.50000           .
A   183  FGWAVWL3  EQ         51.80000           .              51.80000         51.80000           .
    184  FGWAVWL4  EQ         96.00000           .              96.00000         96.00000          3.00000-
    185  FGWAVWL5  EQ        209.10000           .             209.10000        209.10000         17.00000-
    186  FGWAVWL6  EQ         42.50000           .              42.50000         42.50000         17.00000-
    187  FGWAVWL7  EQ         59.20000           .              59.20000         59.20000         66.66667-
    188  FGWAVWL0  EQ         10.00000           .              10.00000         10.00000          3.00000-
    189  GWRC1     BS           .                .                  NONE           .                .
    190  GWRC2     BS           .              60.00000             NONE         60.00000           .
    191  GWRC3     BS           .             366.00000             NONE        366.00000           .
    192  GWRC4     BS           .09750        433.90250             NONE        434.00000           .
    193  GWRCU4    BS           .             100.00000             NONE        100.00000           .
    194  GWRC5     BS         31.06850         20.93150             NONE         52.00000           .
    195  GWRCU5    BS           .              52.00000             NONE         52.00000           .
    196  GWRC6     BS         57.59500          7.40500             NONE         65.00000           .
    197  GWRC7     UL           .                .                  NONE           .              63.66667
    198  GWRC0     BS           .                .                  NONE           .                .
A   199  BUMPT     EQ           .                .                .                .                .
A   200  UIMPT     EQ           .                .                .                .                .
    201  SAMPT     EQ           .                .                .                .               6.00000
    202  TLSW3SW4  EQ           .                .                .                .               4.00000-
    203  TLSW0SW6  EQ           .                .                .                .              14.00000-
    204  INFLOGSL  BS       1017.30580       517.30580-      500.00000             NONE           .
    205  CROUT     BS       1506.78329       599.78328-      907.00000             NONE           .

SECTION 2 - COLUMNS
NUMBER    .COLUMN.  AT  ...ACTIVITY...   ..INPUT COST..   ..LOWER LIMIT.   ..UPPER LIMIT.  .REDUCED COST.

    206  QBULSW4   LL           .               7.00000           .                 NONE          3.00000
    207  QBULSW5   BS         19.67295         10.00000           .              29.00000           .
    208  QBUMPT    BS         24.59119           .                .             136.60000           .
    209  QUILSW3   LL           .              10.00000           .              20.00000         10.00000
    210  QUILSW4   LL           .              10.00000           .                 NONE          6.00000
    211  QUILSW5   LL           .              13.00000           .              57.00000          3.00000
    212  QUIMPT    BS           .                .                .             420.00000           .
    213  QSALSW4   LL           .               8.00000           .              15.00000         10.00000
    214  QSALSW5   BS         22.40000          4.00000           .                 NONE           .
    215  QSAMPT    UL         22.40000           .                .              22.40000          6.00000-
    216  PLSW1AG1  EQ        104.90000           .             104.90000        104.90000           .
    217  QLSW1AG1  LL           .               5.00000           .                 NONE          5.00000
    218  RLSW1AG1  BS        104.90000           .                .                 NONE           .
    219  PLSW1MI1  EQ          7.20000           .               7.20000          7.20000         18.20000
    220  QLSW1MI1  LL           .              31.00000           .                 NONE         49.20000
    221  RLSW1MI1  BS          7.20000           .                .                 NONE           .
    222  QLSW1WL1  BS        540.49960           .                .                 NONE           .
    223  PLSW1MI4  EQ         10.00000           .              10.00000         10.00000         17.91140
A   224  PLSW2AG2  EQ        996.00000           .             996.00000        996.00000           .
    225  QLSW2AG2  LL           .               5.00000           .                 NONE          5.00000
    226  RLSW2AG2  BS        996.00000           .                .                 NONE           .
    227  PLSW2MI2  EQ         36.00000           .              36.00000         36.00000         17.16000
    228  QLSW2MI2  LL           .              32.00000           .                 NONE         49.16000
    229  RLSW2MI2  BS         36.00000           .                .                 NONE           .
    230  QLSW2WL2  BS         14.95000           .                .                 NONE           .
    231  QLSW2SW1  LL           .               4.00000           .              90.00000          4.00000
    232  QLSW2SW3  LL           .               4.00000           .             130.00000          4.00000
    233  PLSW3AG3  BS        610.50000           .                .             610.50000           .
    234  QLSW3AG3  LL           .               6.00000           .                 NONE          6.00000
    235  RLSW3AG3  BS        610.50000           .                .                 NONE           .
    236  PLSW3MI3  EQ         29.20000           .              29.20000         29.20000         11.35160
    237  QLSW3MI3  LL           .              43.00000           .                 NONE         54.35160
    238  RLSW3MI3  BS         29.20000           .                .                 NONE           .
    239  QLSW3WL3  BS         43.04500           .                .                 NONE           .
A   240  PLSW3AG2  EQ         19.00000           .              19.00000         19.00000           .
    241  PLSW3SW4  EQ         71.00000           .              71.00000         71.00000          4.00000-
A   242  QLSW3SW4  LL           .               4.00000           .             146.00000           .
    243  PLSW3SW4  BS         71.00000           .                .                 NONE           .
A   244  QAG3LSW3  LL           .                .                .                 NONE           .
    245  PLSW4AG4  EQ        713.50000           .             713.50000        713.50000          2.48448
    246  QLSW4AG4  LL           .               6.00000           .                 NONE          8.48448
    247  RLSW4AG4  BS        713.50000           .                .                 NONE           .
    248  PLSW4MI4  EQ        160.50000           .             160.50000        160.50000         21.91140
    249  QLSW4MI4  LL           .              43.00000           .                 NONE         64.91140
    250  RLSW4MI4  BS        160.50000           .                .                 NONE           .
    251  QLSW4WL4  BS        120.64750           .                .                 NONE           .
    252  QLSW4SW5  BS         59.19852          5.00000           .              69.00000           .
    253  QAG4LSW4  LL           .                .                .                 NONE          3.00000
    254  PLSW5AG5  EQ        879.30000           .             879.30000        879.30000          4.52500
    255  QLSW5AG5  LL           .               5.00000           .                 NONE          9.52500
    256  RLSW5AG5  BS        879.30000           .                .                 NONE           .
    257  PLSW5MI5  EQ          6.60000           .               6.60000          6.60000         15.50560
    258  QLSW5MI5  LL           .              36.00000           .                 NONE         51.50560
    259  RLSW5MI5  BS          6.60000           .                .                 NONE           .
    260  QLSW5WL5  BS         47.15750           .                .                 NONE           .
    261  QLSW5SW6  BS         10.52900          4.00000           .              60.00000           .
    262  PLSW5AG9  EQ          3.60000           .               3.60000          3.60000         10.00000
    263  PLSW6AG6  EQ        136.10000           .             136.10000        136.10000          5.14425
    264  QLSW6AG6  LL           .               5.00000           .                 NONE         10.14425
    265  RLSW6AG6  BS        136.10000           .                .                 NONE           .
    266  PLSW6MI6  EQ         10.10000           .              10.10000         10.10000         12.60600
    267  QLSW6MI6  LL           .              36.00000           .                 NONE         48.60600
    268  RLSW6MI6  BS         10.10000           .                .                 NONE           .
    269  QLSW6WL6  BS         65.79500           .                .                 NONE           .
    270  PLSW7AG7  EQ        789.10000           .             789.10000        789.10000          5.00000-
    271  QLSW7AG7  BS           .23333          5.00000           .                 NONE           .
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Table B-3. Continued.

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   NUMBER  .COLUMN.  AT ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
   272  RLSW7AG7  BS    789.33333          .               .                   NONE          .
   273  PLSW7MI7  EQ     10.00000          .             10.00000        10.00000        36.00000-
   274  QLSW7MI7  BS       .             36.00000          .                   NONE          .
   275  RLSW7MI7  BS     10.00000          .               .                   NONE          .
   276  QLSW7WL7  BS    196.60000          .               .                   NONE          .
   277  Q7LSW7    BS    611.50053          .               .                   NONE          .
   278  PLSW7SW4  EQ    101.30000          .            101.30000       101.30000         4.00000-
   279  PLSW8AG8  UL    303.00000        .00010            .           303.00000         4.99990-
   280  QLSW8AG8  BS       .              5.00000          .                   NONE          .
   281  RLSW8AG8  BS    303.00000          .               .                   NONE          .
   282  PLSW8MI8  EQ      7.00000          .              7.00000         7.00000         7.80000
   283  QLSW8MI8  LL       .             51.00000          .                   NONE        58.80000
   284  RLSW8MI8  BS      7.00000          .               .                   NONE          .
   285  QLSW8WL8  BS     36.00000          .               .                   NONE          .
   286  Q8LSW8    BS    154.52500          .               .                   NONE          .
   287  PLSW8AG5  EQ     11.00000          .             11.00000        11.00000         5.47500-
A  288  QAG8LSW8  LL       .               .               .                   NONE          .
A  289  PLSW9AG9  EQ    146.40000          .            146.40000       146.40000          .
   290  QLSW9AG9  LL       .              5.00000          .                   NONE         5.00000
   291  RLSW9AG9  BS    146.40000          .               .                   NONE          .
   292  PLSW9MI9  EQ      6.80000          .              6.80000         6.80000         6.50000
   293  QLSW9MI9  LL       .             43.00000          .                   NONE        49.50000
   294  RLSW9MI9  BS      6.80000          .               .                   NONE          .
   295  QLSW9WL9  BS      8.00000          .               .                   NONE          .
A  296  PLSW0AG0  EQ     68.00000          .             68.00000        68.00000          .
   297  QLSW0AG0  LL       .              5.00000          .                   NONE         5.00000
   298  RLSW0AG0  BS     68.00000          .               .                   NONE          .
   299  PLSW0MI0  EQ      1.50000          .              1.50000         1.50000         7.80000
   300  QLSW0MI0  LL       .             43.00000          .                   NONE        50.80000
   301  RLSW0MI0  BS      1.50000          .               .                   NONE          .
   302  QLSW0WL0  BS      9.00000          .               .                   NONE          .
   303  PLSW0SW6  EQ      3.00000          .              3.00000         3.00000        14.00000-
   304  QLSW0SW6  UL     47.00000         4.00000          .            47.00000        10.00000-
   305  RLSW0SW6  BS     50.00000          .               .                   NONE          .
A  306  PGW1AG1   EQ     19.10000          .             19.10000        19.10000          .
   307  QGW1AG1   LL       .              4.90000          .                   NONE         4.90000
   308  RGW1AG1   BS     19.10000          .               .                   NONE          .
   309  PGW1MI1   EQ      2.80000          .              2.80000         2.80000        18.20000
   310  QGW1MI1   LL       .             34.25000          .                   NONE        52.45000
   311  RGW1MI1   BS      2.80000          .               .                   NONE          .
   312  QFGW1WL1  BS    174.50040          .               .                   NONE          .
   313  QCGW1WL1  LL       .              2.40000          .                   NONE         2.40000
A  314  PGW2AG2   EQ     19.00000          .             19.00000        19.00000          .
   315  QGW2AG2   LL       .              5.60000          .                   NONE         5.60000
   316  RGW2AG2   BS     19.00000          .               .                   NONE          .
   317  PGW2MI2   EQ      8.00000          .              8.00000         8.00000        17.16000
   318  QGW2MI2   LL       .             34.25000          .                   NONE        51.41000
   319  RGW2MI2   BS      8.00000          .               .                   NONE          .
   320  QFGW2WL2  BS    225.05000          .               .                   NONE          .
   321  QCGW2WL2  LL       .              3.10000          .                   NONE         3.10000
A  322  PGW3AG3   UL     32.90000          .               .            32.90000          .
   323  QGW3AG3   LL       .              6.70000          .                   NONE         6.70000
   324  RGW3AG3   BS     32.90000          .               .                   NONE          .
   325  PGW3MI3   EQ     20.50000          .             20.50000        20.50000        11.35160
   326  QGW3MI3   LL       .             41.65000          .                   NONE        53.00160
   327  RGW3MI3   BS     20.50000          .               .                   NONE          .
   328  QFGW3WL3  BS    100.05500          .               .                   NONE          .
   329  QCGW3WL3  LL       .              3.70000          .                   NONE         3.70000
A  330  QAG3GW3   LL       .               .               .                   NONE          .
   331  PGW4AG4   EQ     83.20000          .             83.20000        83.20000         1.43448
   332  QGW4AG4   LL       .              7.70000          .                   NONE         9.13448
   333  RGW4AG4   BS     83.20000          .               .                   NONE          .
   334  PGW4MI4   EQ    132.00000          .            132.00000       132.00000        20.91140
   335  QGW4MI4   LL       .             41.65000          .                   NONE        62.56140
   336  RGW4MI4   BS    132.00000          .               .                   NONE          .
   337  QFGW4WL4  BS    155.75250          .               .                   NONE          .
   338  QCGW4WL4  LL       .              4.70000          .                   NONE         7.70000
   339  QAG4GW4   BS       .               .               .                   NONE          .
   340  PGW5AG5   EQ    127.60000          .            127.60000       127.60000        11.52500
   341  QGW5AG5   LL       .              5.80000          .                   NONE        17.32500
   342  RGW5AG5   BS    127.60000          .               .                   NONE          .
   343  PGW5MI5   EQ     10.40000          .             10.40000        10.40000        22.50560
   344  QGW5MI5   LL       .             34.25000          .                   NONE        56.75560
   345  RGW5MI5   BS     10.40000          .               .                   NONE          .
   346  QFGW5WL5  BS    285.44250          .               .                   NONE          .
   347  QCGW5WL5  LL       .              3.30000          .                   NONE        20.30000
   348  PGW6AG6   EQ    163.90000          .            163.90000       163.90000        22.14425
   349  QGW6AG6   LL       .              6.40000          .                   NONE        28.54425
   350  RGW6AG6   BS    163.90000          .               .                   NONE          .
   351  PGW6MI6   EQ      2.90000          .              2.90000         2.90000        29.60600
   352  QGW6MI6   LL       .             34.25000          .                   NONE        63.85600
   353  RGW6MI6   BS      2.90000          .               .                   NONE          .
   354  QFGW6WL6  BS     64.20500          .               .                   NONE          .
   355  QCGW6WL6  LL       .              3.90000          .                   NONE        20.90000
A  356  PGW7AG7   EQ       .               .               .               .               .
   357  QGW7AG7   LL       .              4.60000          .                   NONE         4.60000
   358  RGW7AG7   LL       .               .               .                   NONE        61.65667
   359  PGW7MI7   EQ       .               .               .               .              30.65667
   360  QGW7MI7   LL       .             34.25000          .                   NONE        64.91667
   361  RGW7MI7   BS       .               .               .                   NONE          .
   362  QFGW7WL7  BS    118.40000          .               .                   NONE          .
   363  QCGW7WL7  LL       .              2.10000          .                   NONE        68.75667
A  364  PGW0AG0   EQ       .               .               .               .               .
   365  QGW0AG0   LL       .              4.80000          .                   NONE         4.80000
   366  RGW0AG0   LL       .               .               .                   NONE         3.00000
   367  PGW0MI0   EQ       .               .               .               .              34.10000-
   368  QGW0MI0   BS       .             34.10000          .                   NONE          .
   369  RGW0MI0   LL       .               .               .                   NONE        44.90000
   370  QFGW0WL0  BS     10.00000          .               .                   NONE          .
   371  QCGW0WL0  LL       .              2.30000          .                   NONE         5.30000
   372  QDREQ1    BS    112.18000          .               .                   NONE          .
   373  D11       BS       .91203          .               .             1.00000          .
A  374  D12       LL       .               .               .             1.00000          .
A  375  D13       LL       .               .               .             1.00000          .
A  376  D14       LL       .               .               .             1.00000          .
```

Table B-3. Continued.

```
   NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
    377  PLSW1ST1  BS             .              .              .        17.00000               .
    378  QLSW1ST1  LL             .       11.00000              .        25.00000        11.00000
    379  RLSW1ST1  BS             .              .              .            NONE               .
    380  QDREQ2    BS     612.03056              .              .            NONE               .
A   381  D21       UL       1.00000              .              .         1.00000               .
    382  D22       BS        .11616              .              .         1.00000               .
A   383  D23       LL             .              .              .         1.00000               .
A   384  D24       LL             .              .              .         1.00000               .
    385  PLSW2ST2  BS      34.84904              .              .       311.00000               .
    386  QLSW2ST2  LL             .        4.70000              .      1200.00000         4.70000
    387  RLSW2ST2  BS      34.84904              .              .            NONE               .
    388  QDREQ3    BS     574.22239              .              .            NONE               .
A   389  D31       UL       1.00000              .              .         1.00000               .
A   390  D32       UL       1.00000              .              .         1.00000               .
    391  D33       BS        .46689              .              .         1.00000               .
A   392  D34       LL             .              .              .         1.00000               .
    393  PLSW3ST3  BS     562.15605              .              .       578.00000               .
    394  QLSW3ST3  LL             .       16.30000              .       125.00000        16.30000
    395  RLSW3ST3  BS     562.15605              .              .            NONE               .
    396  QDREQ4    BS     518.65882              .              .            NONE               .
    397  D41       UL       1.00000              .              .         1.00000     1528.00000-
    398  D42       UL       1.00000              .              .         1.00000      135.52941-
    399  D43       BS        .84118              .              .         1.00000               .
    400  D44       LL             .              .              .         1.00000       365.64706
    401  PLSW4ST4  UL     416.00000              .              .       416.00000         .88324-
    402  QLSW4ST4  LL             .       13.00000              .      1050.00000        12.11676
    403  PLSW4ST4  BS     416.00000              .              .            NONE               .
    404  QDREQ5    BS     371.23953              .              .            NONE               .
    405  D51       UL       1.00000              .              .         1.00000     2620.00000-
    406  D52       UL       1.00000              .              .         1.00000      387.67442-
    407  D53       BS        .60698              .              .         1.00000               .
    408  D54       LL             .              .              .         1.00000       127.20930
    409  PLSW5ST5  UL     481.00000              .              .       481.00000         .93812-
    410  QLSW5ST5  LL             .        8.60000              .       125.00000         7.66188
    411  RLSW5ST5  BS     481.00000              .              .            NONE               .
    412  QDREQ6    BS      13.67100              .              .            NONE               .
    413  D61       BS        .28481              .              .         1.00000               .
A   414  D62       LL             .              .              .         1.00000               .
A   415  D63       LL             .              .              .         1.00000               .
A   416  D64       LL             .              .              .         1.00000               .
    417  PLSW6ST6  BS             .              .              .        56.00000               .
    418  QLSW6ST6  LL             .       14.00000              .       100.00000        14.00000
    419  RLSW6ST6  BS             .              .              .            NONE               .
    420  QDREQ7    BS     811.84468              .              .            NONE               .
    421  D71       BS        .93315              .              .         1.00000               .
A   422  D72       LL             .              .              .         1.00000               .
A   423  D73       LL             .              .              .         1.00000               .
A   424  D74       LL             .              .              .         1.00000               .
    425  PLSW7ST7  BS             .              .              .       428.00000               .
    426  QLSW7ST7  LL             .       10.80000              .      1500.00000        10.80000
A   427  RLSW7ST7  LL             .              .              .            NONE               .
    428  QDREQ8    BS     305.52500              .              .            NONE               .
    429  D81       BS        .77544              .              .         1.00000               .
A   430  D82       LL             .              .              .         1.00000               .
A   431  D83       LL             .              .              .         1.00000               .
A   432  D84       LL             .              .              .         1.00000               .
    433  PLSW8ST8  BS             .              .              .       199.00000               .
    434  QLSW8ST8  LL             .        7.20000              .       285.00000         7.20000
A   435  RLSW8ST8  LL             .              .              .            NONE               .
    436  QDREQ9    BS     129.20000              .              .            NONE               .
    437  D91       BS        .47500              .              .         1.00000               .
A   438  D92       LL             .              .              .         1.00000               .
A   439  D93       LL             .              .              .         1.00000               .
A   440  D94       LL             .              .              .         1.00000               .
    441  PLSW9ST9  BS             .              .              .         1.00000               .
    442  QLSW9ST9  LL             .       13.50000              .       140.00000        13.50000
    443  PLSW9ST9  BS             .              .              .            NONE               .
    444  QDREQ0    BS     109.30000              .              .            NONE               .
    445  D01       BS        .68313              .              .         1.00000               .
A   446  D02       LL             .              .              .         1.00000               .
A   447  D03       LL             .              .              .         1.00000               .
A   448  D04       LL             .              .              .         1.00000               .
    449  PLSW0ST0  BS             .              .              .        14.00000               .
    450  QLSW0ST0  LL             .       14.30000              .       280.00000        14.30000
    451  RLSW0ST0  BS             .              .              .            NONE               .
    452  QLSW1EV1  BS             .              .              .            NONE               .
    453  QLSW2EV2  BS             .              .              .            NONE               .
    454  QLSW3EV3  BS      12.92959              .              .            NONE               .
    455  QLSW4EV4  BS      12.75000              .              .            NONE               .
    456  QLSW5EV5  BS      44.73300              .              .            NONE               .
    457  QLSW6EV6  LL             .              .              .            NONE        24.33333
A   458  QLSW7EV7  LL             .              .              .            NONE               .
A   459  QLSW8EV8  LL             .              .              .            NONE               .
A   460  QLSW9EV9  LL             .              .              .            NONE               .
    461  QLSW0EV0  BS             .              .              .            NONE               .
A   462  QGW1EV1   LL             .              .              .            NONE               .
A   463  QGW2EV2   LL             .              .              .            NONE               .
    464  QGW3EV3   BS      12.92959              .              .            NONE               .
    465  QGW4EV4   BS      12.75000              .              .            NONE               .
    466  QGW5EV5   BS      14.91100              .              .            NONE               .
    467  QGW6EV6   BS             .              .              .            NONE               .
    468  QGW7EV7   LL             .              .              .            NONE        66.66667
    469  QGW0EV0   LL             .              .              .            NONE         3.00000
    470  QEV2      BS             .              .              .            NONE               .
    471  E21       BS        .16754              .              .         1.00000               .
A   472  E22       LL             .              .              .         1.00000               .
A   473  E23       LL             .              .              .         1.00000               .
    474  QEV4      BS      25.50000              .              .            NONE               .
    475  E41       UL       1.00000              .              .         1.00000       23.10000-
    476  E42       UL       1.00000              .              .         1.00000        17.67000
    477  E43       BS             .              .              .         1.00000               .
    478  QAR1LSW1  BS      49.60000              .              .            NONE               .
    479  QAR2LSW2  BS     524.96180              .              .            NONE               .
    480  QAR3LSW3  BS     310.95522              .              .            NONE               .
    481  QAR4LSW4  BS     367.19903              .              .            NONE               .
```

Table B-3. Continued.

```
NUMBER  .COLUMN.  AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  ..UPPER LIMIT.  .REDUCED COST.
   482  QAR5LSW5  BS       534.39750          .               .                 NONE          .
   483  QAR6LSW6  BS       120.00000          .               .                 NONE          .
   484  QAR7LSW7  BS       377.93280          .               .                 NONE          .
   485  QAR8LSW8  BS       189.37500          .               .                 NONE          .
   486  QAR9LSW9  BS       120.00000          .               .                 NONE          .
   487  QAR0LSW0  BS        34.00000          .               .                 NONE          .
   488  QAR1GW1   BS        15.40080          .               .                 NONE          .
   489  QAR2GW2   BS       155.10000          .               .                 NONE          .
   490  QAR3GW3   BS        96.51000          .               .                 NONE          .
   491  QAR4GW4   BS       119.50500          .               .                 NONE          .
   492  QAR5GW5   BS       152.68500          .               .                 NONE          .
   493  QAR6GW6   BS        43.41000          .               .                 NONE          .
   494  QAR7GW7   BS       118.40000          .               .                 NONE          .
   495  QAR0GW0   BS          .               .               .                 NONE          .
   496  QWW1LSW1  BS         7.00000        26.00000          .                 NONE          .
   497  QWW2LSW2  BS        29.04000        26.00000          .                 NONE          .
   498  QWW3LSW3  BS        21.69902        26.00000          .                 NONE          .
   499  QWW4LSW4  BS       208.29475        26.00000          .                 NONE          .
   500  QWW5LSW5  LL          .             26.00000          .                 NONE        14.00000
   501  QWW6LSW6  LL          .             26.00000          .                 NONE        14.00000
   502  QWW7LSW7  BS         6.50000        26.00000          .                 NONE          .
   503  QWW8LSW8  BS         2.10000        26.00000          .                 NONE          .
   504  QWW9LSW9  BS         1.70000        26.00000          .                 NONE          .
   505  QWW0LSW0  BS          .45000        26.00000          .                 NONE          .
   506  QLSW1R1   LL          .             17.00000          .                 NONE        17.00000
   507  QLSW2R2   LL          .             17.00000          .                 NONE        17.00000
   508  QLSW3R3   LL          .             17.00000          .                 NONE        17.00000
   509  QLSW4R4   LL          .             17.00000          .                 NONE        14.00000
   510  QLSW4RU4  LL          .             23.00000          .                 NONE        20.00000
   511  QLSW5R5   BS        23.26890        17.00000          .                 NONE          .
   512  QLSW5RU5  LL          .             23.00000          .                 NONE         6.00000
   513  QLSW6R6   BS        48.53400        17.00000          .                 NONE          .
   514  QLSW7R7   LL          .             17.00000          .                 NONE        14.00000
   515  QLSW0R0   LL          .             17.00000          .                 NONE        14.00000
   516  QWW1R1    LL          .             29.00000          .                 NONE         3.00000
   517  QWW2R2    LL          .             29.00000          .                 NONE         3.00000
   518  QWW3R3    LL          .             29.00000          .                 NONE         3.00000
   519  QWW4R4    BS          .09750        29.00000          .                 NONE          .
   520  QWW4RU4   LL          .             35.00000          .                 NONE         6.00000
   521  QWW5R5    BS         7.79960        29.00000          .                 NONE          .
   522  QWW5RU5   LL          .             35.00000          .                 NONE         6.00000
   523  QWW6R6    BS         9.06100        29.00000          .                 NONE          .
   524  QWW7R7    BS          .             29.00000          .                 NONE          .
   525  QWW0R0    BS          .             29.00000          .                 NONE          .
   526  QLSW1OF1  BS         7.00040          .              7.00000            NONE          .
   527  QLSW2OF2  BS       448.55180          .             50.00000            NONE          .
   528  QLSW3OF3  BS       336.17965          .             50.00000            NONE          .
   529  QLSW4OF4  BS       179.99814          .             50.00000            NONE          .
   530  QLSW5OF5  BS        73.68057          .             13.70000            NONE          .
   531  QLSW6OF6  LL          .               .               .                 NONE        14.00000
   532  QLSW7OF7  BS       614.20828          .            100.00000            NONE          .
   533  QLSW8OF8  BS       462.07500          .            100.00000            NONE          .
   534  QLSW9OF9  BS       390.50000          .            100.00000            NONE          .
   535  QLSW0OF0  BS       155.95000          .            100.00000            NONE          .
   536  QGW1OF1   BS         6.00040          .              6.00000            NONE          .
   537  QGW2OF2   BS         6.55000          .              5.00000            NONE          .
   538  QGW3OF3   BS        25.02541          .             25.00000            NONE          .
   539  QGW4OF4   LL         8.00000          .              8.00000            NONE         3.00000
   540  QGW5OF5   LL          .               .               .                 NONE        17.00000
   541  QGW6OF6   LL          .               .               .                 NONE        31.00000
   542  QGW7OF7   LL        40.00000          .             40.00000            NONE        66.66667
   543  QGW0OF0   LL          .               .               .                 NONE         3.00000
```

Table B-4. Print-out of the sensitivity analysis. (First page of each section only.)

```
SECTION 1 - ROWS AT LIMIT LEVEL

NUMBER  ...ROW..  AT  ...ACTIVITY...  SLACK ACTIVITY  ..LOWER LIMIT.  LOWER ACTIVITY  ...UNIT COST..  ..UPPER COST..  LIMITING  AT
                                                      ..UPPER LIMIT.  UPPER ACTIVITY  ...UNIT COST..  ..LOWER COST..  PROCESS.  AT

     2  AVAILSW1  EQ      613.00000         .              613.00000       612.99960         .                         QLSW1OF1  LL
                                                          613.00000        INFINITY         .                             NONE

     3  AVAILSW2  EQ      941.50000         .              941.50000       542.94824         .                         QLSW2OF2  LL
                                                          941.50000        INFINITY         .                             NONE

     4  AVAILSW3  EQ      789.19995         .              789.19995       503.02051         .                         QLSW3OF3  LL
                                                          789.19995        INFINITY         .                             NONE

     5  AVAILSW4  EQ      513.59985         .              513.59985       383.60173         .                         QLSW4OF4  LL
                                                          513.59985        INFINITY         .                             NONE

     6  AVAILSW5  EQ      453.19995         .              453.19995       393.21939         .                         QLSW5OF5  LL
                                                          453.19995        INFINITY         .                             NONE

     7  AVAILSW6  EQ       80.00000         .               80.00000        70.67295        14.00000                   QBULSW5   UL
                                                           80.00000        90.52900        14.00000-                  QLSW5SW6  LL

     8  AVAILSW7  EQ     1351.59985         .             1351.59985       837.39160         .                         QLSW7OF7  LL
                                                         1351.59985        INFINITY         .                             NONE

     9  AVAILSW8  EQ      650.00000         .              650.00000       287.92505         .                         QLSW8OF8  LL
                                                          650.00000        INFINITY         .                             NONE

    10  AVAILSW9  EQ      430.00000         .              430.00000       139.50024         .                         QLSW9OF9  LL
                                                          430.00000        INFINITY         .                             NONE

    11  AVAILSW0  EQ      250.00000         .              250.00000       194.05000         .                         QLSW0OF0  LL
                                                          250.00000        INFINITY         .                             NONE

    12  LSWU7     EQ          .             .                  .           514.20825-        .                         QLSW7OF7  LL
                                                              .            611.50049         .                         Q7LSW7    LL

    13  LSWU8     EQ          .             .                  .           362.07495-        .                         QLSW8OF8  LL
                                                              .            154.52499         .                         Q8LSW8    LL

    14  AVAILGW1  EQ      187.00000         .              187.00000       186.99960         .                         QGW1OF1   LL
                                                          187.00000        INFINITY         .                             NONE

    15  AVAILGW2  EQ      103.50000         .              103.50000       101.95000         .                         QGW2OF2   LL
                                                          103.50000        INFINITY         .                             NONE

    16  AVAILGW3  EQ       94.89999         .               94.89999        94.87458         .                         QGW3OF3   LL
                                                           94.89999        INFINITY         .                             NONE

    17  AVAILGW4  EQ      272.09985         .              272.09985       142.10173         3.00000                   QLSW4OF4  LL
                                                          272.09985       272.19735         3.00000-                  QWW4R4    LL

    18  AVAILGW5  EQ      254.59999         .              254.59999       233.66850        17.00000                   GWRC5     UL
                                                          254.59999       277.86888        17.00000-                  QLSW5R5   LL

    19  AVAILGW6  EQ      130.00000         .              130.00000       122.59500        31.00000                   GWRC6     UL
                                                          130.00000       140.52900        31.00000-                  QLSW5SW6  LL

    20  AVAILGW7  EQ       40.00000         .               40.00000        34.90676        66.66666                   D71       UL
                                                           40.00000        40.01750        66.66666-                  AGREQ7    LL

    21  AVAILGW0  EQ       10.00000         .               10.00000        10.00000         3.00000                   GWRC0     UL
                                                           10.00000        10.00000         3.00000-                  QWWOR0    LL

    28  MIREQ7    LL       10.00000         .               10.00000        10.00000        52.89999-                  QLSW7MI7  LL
                                                               NONE        68.15532        52.89999                   D71       UL

    32  TLSW1MI1  EQ          .             .                  .              .00133-      18.20000                   QLSW1OF1  LL
                                                              .               .            18.20000-                  MIREQ1    LL

    33  TLSW2MI2  EQ          .             .                  .            79.64943-      17.15999                   E21       UL
                                                              .               .            17.15999-                  MIREQ2    LL

    34  TLSW3MI3  EQ          .             .                  .              .15852-      11.35160                   QGW3OF3   LL
                                                              .               .            11.35160-                  MIREQ3    LL

    35  TLSW4MI4  EQ          .             .                  .            11.65881-      21.91139                   QBULSW5   UL
                                                              .               .            21.91139-                  MIREQ4    LL

    36  TLSW5MI5  EQ          .             .                  .             9.32705-      15.50560                   QBULSW5   UL
                                                              .               .            15.50560-                  MIREQ5    LL

    37  TLSW6MI6  EQ          .             .                  .            30.78233-      12.60600                   QBULSW5   UL
                                                              .               .            12.60600-                  MIREQ6    LL

    38  TLSW7MI7  EQ          .             .                  .              .            36.00000-                  QLSW7MI7  LL
                                                              .            INFINITY        36.00000                       NONE

    39  TLSW8MI8  EQ          .             .                  .            88.47501-       7.80000                   D81       UL
                                                              .               .             7.80000-                  MIREQ8    LL

    40  TLSW9MI9  EQ          .             .                  .           142.80000-       6.50000                   D91       UL
                                                              .               .             6.50000-                  MIREQ9    LL

    41  TLSW0MI0  EQ          .             .                  .            50.69998-       7.80000                   D01       UL
                                                              .               .             7.80000-                  MIREQ0    LL

    42  TGW1MI1   EQ          .             .                  .              .00040-      18.20000                   QGW1OF1   LL
                                                              .               .            18.20000-                  MIREQ1    LL

    43  TGW2MI2   EQ          .             .                  .             1.55000-      17.15999                   QGW2OF2   LL
                                                              .               .            17.15999-                  MIREQ2    LL
```

Table B-4. Continued.

```
SECTION 2 - COLUMNS AT LIMIT LEVEL

NUMBER  .COLUMN.   AT  ...ACTIVITY...  ..INPUT COST..  ..LOWER LIMIT.  LOWER ACTIVITY  ...UNIT COST..  ..UPPER COST..  LIMITING  AT
                                                       ..UPPER LIMIT.  UPPER ACTIVITY  ...UNIT COST..  ..LOWER COST..  PROCESS.  AT

   206  QBULSW4    LL          .              7.00000          .             11.65881-        3.00000-       INFINITY  QBULSW5   UL
                                                                 NONE        12.25186         3.00000         4.00000  QLSW4SW5  UL

   209  QUILSW3    LL          .             10.00000          .               .             10.00000-       INFINITY  QUIMPT    LL
                                                             20.00000        46.22236        10.00000          .       D33       LL

   210  QUILSW4    LL          .             10.00000          .               .              6.00000-       INFINITY  QUIMPT    LL
                                                                 NONE        12.25186         6.00000         4.00000  QLSW4SW5  UL

   211  QUILSW5    LL          .             13.00000          .               .              3.00000-       INFINITY  QUIMPT    LL
                                                             56.99999        19.67294         3.00000        10.00000  QBULSW5   LL

   213  QSALSW4    LL          .              8.00000          .             73.99813-       10.00000-       INFINITY  QLSW4SW5  LL
                                                             15.00000        12.25186        10.00000         2.00000- QLSW4SW5  UL

   215  QSAMPT     UL        22.40000          .               .             13.07295         6.00000         6.00000  QBULSW5   UL
                                                             22.40000        42.07294         6.00000-       INFINITY- QBULSW5   LL

   216  PLSW1AG1   EQ       104.89999          .            104.89999       104.89999          .             INFINITY  AGREQ1    LL
                                                            104.89999       104.90074          .             INFINITY- QLSW1CF1  LL

   217  QLSW1AG1   LL          .              5.00000          .               .              5.00000-       INFINITY  AGREQ1    LL
                                                                 NONE          .00074         5.00000          .       QLSW1CF1  LL

   219  PLSW1MI1   EQ         7.20000          .              7.20000         7.20000        18.20000-       INFINITY  MIREQ1    LL
                                                              7.20000         7.20133        18.20000        13.20000- QLSW1CF1  LL

   220  QLSW1MI1   LL          .             31.00000          .               .             49.20000-       INFINITY  MIREQ1    LL
                                                                 NONE          .00133        49.20000        18.20000- QLSW1CF1  LL

   223  PLSW1MI4   EQ        10.00000          .             10.00000        10.00000        17.91139-       INFINITY  MIREQ4    LL
                                                             10.00000        10.00040        17.91139        17.91139- QLSW1DF1  LL

   224  PLSW2AG2   EQ       996.00000          .            996.00000       996.00000          .             INFINITY  AGREQ2    LL
                                                            996.00000      1130.12608          .             INFINITY- E21       UL

   225  QLSW2AG2   LL          .              5.00000          .               .              5.00000-       INFINITY  AGREQ2    LL
                                                                 NONE       134.12608         5.00000          .       E21       UL

   227  PLSW2MI2   EQ        36.00000          .             36.00000        36.00000        17.15999-       INFINITY  MIREQ2    LL
                                                             36.00000       115.64943        17.15999        17.15999- E21       UL

   228  QLSW2MI2   LL          .             32.00000          .               .             49.15999-       INFINITY  MIREQ2    LL
                                                                 NONE        79.64943        49.15999        17.15999- E21       UL

   231  QLSW2SW1   LL          .              4.00000          .               .00040-        4.00000-       INFINITY  QLSW1CF1  LL
                                                             90.00000        79.64943         4.00000          .       E21       UL

   232  QLSW2SW3   LL          .              4.00000          .               .15852-        4.00000-       INFINITY  QGW3CF3   LL
                                                            129.99989        46.22233         4.00000          .       D33       LL

   234  QLSW3AG3   LL          .              6.00000          .             INFINITY-        6.00000-       INFINITY    NONE
                                                                 NONE       610.50000         6.00000          .       PLSW3AG3  LL

   236  PLSW3MI3   EQ        29.20000          .             29.20000        29.20000        11.35160-       INFINITY  MIREQ3    LL
                                                             29.20000        29.35851        11.35160        11.35160- QGW3DF3   LL

   237  QLSW3MI3   LL          .             43.00000          .               .             54.35159-       INFINITY  MIREQ3    LL
                                                                 NONE          .15852        54.35159        11.35159- QGW3DF3   LL

   240  PLSW3AG2   EQ        19.00000          .             19.00000        19.00000          .             INFINITY  AGREQ2    LL
                                                             19.00000        19.15852          .             INFINITY- QGW3DF3   LL

   241  PLSW3SW4   EQ        71.00000          .             71.00000        59.34118         4.00000         4.00000  QBULSW5   UL
                                                             71.00000        71.15852         4.00000-       INFINITY- QGW3DF3   LL

   242  QLSW3SW4   LL          .              4.00000          .             11.65881-         .             INFINITY  QBULSW5   UL
                                                            145.99992          .15852          .              4.00000  QGW3DF3   LL

   244  QAG3LSW3   LL          .               .               .               .               .             INFINITY  AGEXC3    UL
                                                                 NONE          .               .               .       AGEXC3    UL

   245  PLSW4AG4   EQ       713.50000          .            713.50000       713.50000         2.48448-       INFINITY  AGREQ4    LL
                                                            713.50000       714.80000         2.48448         2.48448- QWW4R4    LL

   246  QLSW4AG4   LL          .              6.00000          .               .              8.48448-       INFINITY  AGREQ4    LL
                                                                 NONE         1.30000         8.48448         2.48448- QWW4R4    LL

   248  PLSW4MI4   EQ       160.50000          .            160.50000       160.50000        21.91139-       INFINITY  MIREQ4    LL
                                                            160.50000       172.15882        21.91139        21.91139- QBULSW5   UL

   249  QLSW4MI4   LL          .             43.00000          .               .             64.91139-       INFINITY  MIREQ4    LL
                                                                 NONE        11.65882        64.91139        21.91139- QBULSW5   UL

   253  QAG4LSW4   LL          .               .               .               .09750-        3.00000-       INFINITY  QWW4R4    LL
                                                                 NONE          .              3.00000         3.00000- QAG4GW4   LL

   254  PLSW5AG5   EQ       879.29980          .            879.29980       879.29980         4.52500-       INFINITY  AGREQ5    LL
                                                            879.29980       895.38092         4.52500         4.52500- QBULSW5   UL

   255  QLSW5AG5   LL          .              5.00000          .               .              9.52500-       INFINITY  AGREQ5    LL
                                                                 NONE        16.08112         9.52500         4.52500- QBULSW5   UL

   257  PLSW5MI5   EQ         6.60000          .              6.60000         6.60000        15.50560-       INFINITY  MIREQ5    LL
                                                              6.60000        15.92705        15.50560        15.50560- QBULSW5   UL

   258  QLSW5MI5   LL          .             36.00000          .               .             51.50560-       INFINITY  MIREQ5    LL
                                                                 NONE         9.32705        51.50560        15.50560- QBULSW5   UL
```

Table B-4. Continued.

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          EXECUTOR.     MPS/360 V2-M5

SECTION 3 - ROWS AT INTERMEDIATE LEVEL

NUMBER  ...ROW..  AT  ...ACTIVITY...  SLACK ACTIVITY  ..LOWER LIMIT.  LOWER ACTIVITY  ...UNIT COST..  ..UPPER COST..  LIMITING  AT
                                                      ..UPPER LIMIT.  UPPER ACTIVITY  ...UNIT COST..  ..LOWER COST..  PROCESS.  AT

    22  MIREQ1    BS        10.00000               .        10.00000        10.00000        INFINITY                      NONE
                                                                NONE        10.00133        49.20000                  QLSW1MI1  LL

    23  MIREQ2    BS        44.00000               .        44.00000        44.00000        INFINITY                      NONE
                                                                NONE       123.64941        49.15999                  QLSW2MI2  LL

    24  MIREQ3    BS        49.70000               .        49.70000        49.70000        INFINITY                      NONE
                                                                NONE        49.72541        53.00159                  QGW3MI3   LL

    25  MIREQ4    BS       302.50000               .       302.50000       302.50000        INFINITY                      NONE
                                                                NONE       720.36572        62.56139                  QGW4MI4   LL

    26  MIREQ5    BS        17.00000               .        17.00000        17.00000        INFINITY                      NONE
                                                                NONE        26.32705        51.50560                  QLSW5MI5  LL

    27  MIREQ6    BS        13.00000               .        13.00000        13.00000        INFINITY                      NONE
                                                                NONE        43.78233        48.60599                  QLSW6MI6  LL

    29  MIREQ8    BS         7.00000               .         7.00000         7.00000        INFINITY                      NONE
                                                                NONE        95.47501        58.79999                  QLSW8MI8  LL

    30  MIREQ9    BS         6.80000               .         6.80000         6.80000        INFINITY                      NONE
                                                                NONE       149.59999        49.49998                  QLSW9MI9  LL

    31  MIREQ0    BS         1.50000               .         1.50000         1.50000        INFINITY                      NONE
                                                                NONE         1.50000        44.89999                  RGW0MI0   LL

    50  AGREQ1    BS       124.00000               .       124.00000       124.00000        INFINITY                      NONE
                                                                NONE       124.00043         4.90000                  QGW1AG1   LL

    51  AGREQ2    BS      1034.00000               .      1034.00000      1034.00000        INFINITY                      NONE
                                                                NONE      1168.12607         5.00000                  QLSW2AG2  LL

    53  AGREQ4    BS       796.69995               .       796.69995       796.69995        INFINITY                      NONE
                                                                NONE       797.99995         8.48448                  QLSW4AG4  LL

    54  AGREQ5    BS      1017.89990               .      1017.89990      1017.89990        INFINITY                      NONE
                                                                NONE      1033.98100         9.52500                  QLSW5AG5  LL

    55  AGREQ6    BS       300.00000               .       300.00000       300.00000        INFINITY                      NONE
                                                                NONE       320.48549        10.14425                  QLSW6AG6  LL

    56  AGREQ7    BS       789.33319         .23333-       789.09985       789.33319        INFINITY                      NONE
                                                                NONE       789.33319         4.62500                  RGW7AG7   LL

    58  AGREQ9    BS       150.00000               .       150.00000       150.00000        INFINITY                      NONE
                                                                NONE       319.99998         5.00000                  QLSW9AG9  LL

    59  AGREQ0    BS        68.00000               .        68.00000        68.00000        INFINITY                      NONE
                                                                NONE        68.00000         3.00000                  RGW0AG0   LL

    76  TGW7AG7   BS               .               .               .        5.58213-        61.66666                  RGW7AG7
                                                                   .        INFINITY        4.60000-                  QGW7AG7   LL

    77  TGW0AG0   BS               .               .               .               .         3.00000                  RGW0AG0   LL
                                                                   .        INFINITY         4.80000                  QGW0AG0   LL

    78  AGEXC3    BS               .               .               .               .        INFINITY                      NONE
                                                                   .        INFINITY               .                  QAG3LSW3  LL

    80  AGEXC8    BS               .               .               .               .        INFINITY                      NONE
                                                                   .        INFINITY               .                  QAG8LSW8  LL

   112  LSW6ST6   BS               .               .               .       55.99995-         1.27750                  QLSW6EV6  LL
                                                                   .       107.08948               .                  D64       LL

   114  LSW7ST7   BS               .               .               .               .               .                  RLSW7ST7  LL
                                                                   .      5248.28516               .                  D74       LL

   116  LSW8ST8   BS               .               .               .               .               .                  RLSW8ST8  LL
                                                                   .      2236.31567               .                  D84       LL

   118  LSW9ST9   BS               .               .               .        1.00000-               .                  QLSW9EV9  LL
                                                                   .       565.24951               .                  D94       LL

   137  EVLSW7    BS               .               .               .      514.20825-               .                  QLSW7EV7  LL
                                                                   .               .               .                  RLSW7ST7  LL

   138  EVLSW8    BS               .               .               .      362.07495-               .                  QLSW8EV8  LL
                                                                   .               .               .                  RLSW8ST8  LL

   141  EVGW1     BS               .               .               .         .00040-               .                  QGW1EV1   LL
                                                                   .               .        INFINITY                      NONE

   142  EVGW2     BS               .               .               .        1.55000-               .                  QGW2EV2   LL
                                                                   .         1.21972               .                  E23       LL

   147  EVGW7     BS               .               .               .        5.09325-        66.66666                  QGW7EV7   LL
                                                                   .               .        INFINITY                      NONE

   148  EVGW0     BS               .               .               .               .         3.00000                  QGW0EV0   LL
                                                                   .               .        INFINITY                      NONE

   189  GWRC1     BS               .               .            NONE               .        INFINITY                      NONE
                                                                   .          .00040         3.00000                  QWW1B1    LL

   190  GWRC2     BS               .        60.00000            NONE               .        INFINITY                      NONE
                                                            60.00000        29.03999         3.00000                  QWW2R2    LL
```

Table B-4. Continued.

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                 EXECUTOR.     MPS/360 V2-M5

SECTION 4 - COLUMNS AT INTERMEDIATE LEVEL

NUMBER  .COLUMN.  AT  ...ACTIVITY... ..INPUT COST..  ..LOWER LIMIT. LOWER ACTIVITY  ...UNIT COST..  ..UPPER COST..  LIMITING  AT
                                                     ..UPPER LIMIT. UPPER ACTIVITY  ...UNIT COST..  ..LOWER COST..  PROCESS.  AT

   207  QBULSW5   BS       19.67294        10.00000               .        19.54613               .        10.00000   QLSW3SW4  LL
                                                           28.99999        19.67294         4.46875         5.53125   PLSW4ST4  UL

   208  QBUMPT    BS       24.59118               .               .        24.43266               .               .   QLSW3SW4  LL
                                                          136.59997        24.59118         3.57500         3.57500-  PLSW4ST4  UL

   212  QUIMPT    BS              .               .               .               .        INFINITY        INFINITY       NONE
                                                          419.99995        24.59117         2.40000         2.40000-  QUILSW5   LL

   214  QSALSW5   BS       22.39999         4.00000               .        13.07294         6.00000        10.00000   QSAMPT    UL
                                                               NONE        22.39999        INFINITY        INFINITY-      NONE

   218  RLSW1AG1  BS      104.89999               .               .       104.89999        INFINITY        INFINITY       NONE
                                                               NONE       104.90074         5.00000         5.00000-  QLSW1AG1  LL

   221  RLSW1MI1  BS        7.20000               .               .         7.20000        INFINITY        INFINITY       NONE
                                                               NONE         7.20133        49.20000        49.20000-  QLSW1MI1  LL

   222  QLSW1WL1  BS      540.49951               .               .       540.49911         2.40000         2.40000   QCGW1WL1  LL
                                                               NONE       540.49951        INFINITY        INFINITY-      NONE

   226  RLSW2AG2  BS      995.99976               .               .       995.99976        INFINITY        INFINITY       NONE
                                                               NONE      1130.12582         5.00000         5.00000-  QLSW2AG2  LL

   229  RLSW2MI2  BS       35.99998               .               .        35.99998        INFINITY        INFINITY       NONE
                                                               NONE       115.64940        49.15999        49.15999-  QLSW2MI2  LL

   230  QLSW2WL2  BS       14.95000               .               .        13.40000         3.10000         3.10000   QCGW2WL2  LL
                                                               NONE        14.95000        INFINITY        INFINITY-      NONE

   233  PLSW3AG3  BS      610.49997               .               .        INFINITY-        6.00000         6.00000   QLSW3AG3  LL
                                                          610.50000       611.04567               .               .   AGREQ3    LL

   235  RLSW3AG3  BS      610.49976               .               .       610.46949         6.70000         6.70000   QGW3AG3   LL
                                                               NONE       611.04545               .               .   AGREQ3    LL

   238  RLSW3MI3  BS       29.20000               .               .        29.20000        INFINITY        INFINITY       NONE
                                                               NONE        29.35851        54.35159        54.35159-  QLSW3MI3  LL

   239  QLSW3WL3  BS       43.04500               .               .        43.00407               .               .   AGREQ3    LL
                                                               NONE        43.04500        INFINITY        INFINITY-      NONE

   243  RLSW3SW4  BS       70.99998               .               .        70.99998        INFINITY        INFINITY       NONE
                                                               NONE        71.15850               .               .   QLSW3SW4  LL

   247  RLSW4AG4  BS      713.49976               .               .       713.49976        INFINITY        INFINITY       NONE
                                                               NONE       714.79975         8.48448         8.48448-  QLSW4AG4  LL

   250  RLSW4MI4  BS      160.49998               .               .       160.49998        INFINITY        INFINITY       NONE
                                                               NONE       172.15880        64.91139        64.91139-  QLSW4MI4  LL

   251  QLSW4WL4  BS      120.64749               .               .        87.64723-        7.70000         7.70000   QCGW4WL4  LL
                                                               NONE       120.64749        INFINITY        INFINITY-      NONE

   252  QLSW4SW5  BS       59.19850         5.00000               .        59.19850         4.46875         9.46875   PLSW4ST4  UL
                                                           68.99999        59.32532               .         5.00000   QLSW3SW4  LL

   256  RLSW5AG5  BS      879.29980               .               .       879.29980        INFINITY        INFINITY       NONE
                                                               NONE       895.38091         9.52500         9.52500-  QLSW5AG5  LL

   259  RLSW5MI5  BS        6.60000               .               .         6.60000        INFINITY        INFINITY       NONE
                                                               NONE        15.92705        51.50560        51.50560-  QLSW5MI5  LL

   260  QLSW5WL5  BS       47.15749               .               .        26.22601        20.29999        20.29999   QCGW5WL5  LL
                                                               NONE        47.15749        INFINITY        INFINITY-      NONE

   261  QLSW5SW6  BS       10.52900         4.00000               .        10.52900        INFINITY        INFINITY       NONE
                                                           60.00000        19.85604        10.00000         6.00000-  QLSW0SW6  UL

   265  RLSW6AG6  BS      136.09999               .               .       136.09999        INFINITY        INFINITY       NONE
                                                               NONE       156.58548        10.14425        10.14425-  QLSW6AG6  LL

   268  RLSW6MI6  BS       10.10000               .               .        10.10000        INFINITY        INFINITY       NONE
                                                               NONE        40.88233        48.60599        48.60599-  QLSW6MI6  LL

   269  QLSW6WL6  BS       65.79500               .               .        58.39000        20.89999        20.89999   QCGW6WL6  LL
                                                               NONE        65.79500        INFINITY        INFINITY-      NONE

   271  QLSW7AG7  BS         .23333         5.00000               .          .23333        INFINITY        INFINITY       NONE
                                                               NONE          .23333         4.77500          .22500   GWRC7     UL

   272  RLSW7AG7  BS      789.33325               .               .       789.33325        INFINITY        INFINITY       NONE
                                                               NONE       789.33325         4.77500         4.77500-  GWRC7     UL

   274  QLSW7MI7  BS                       36.00000               .         5.58213-       64.91666       100.91666   QGW7MI7   LL
                                                               NONE        58.15530        52.89999        16.89999-  MIREQ7    LL

   275  RLSW7MI7  BS       10.00000               .               .        10.00000        64.91666        64.91666   QGW7MI7   LL
                                                               NONE        68.15530        52.89999        52.89999-  MIREQ7    LL

   276  QLSW7WL7  BS      196.59999               .               .       186.41350        34.39335        34.38335   QCGW7WL7  LL
                                                               NONE       196.59999        INFINITY        INFINITY-      NONE

   277  Q7LSW7    BS      611.50049               .               .       611.50049        INFINITY        INFINITY       NONE
                                                               NONE       611.50049        11.20574        11.20574-  QGW7EV7   LL

   280  QLSW8AG8  BS                        5.00000               .               .        INFINITY        INFINITY       NONE
                                                               NONE       302.99976         4.99990          .00010   PLSW8AG8  UL
```
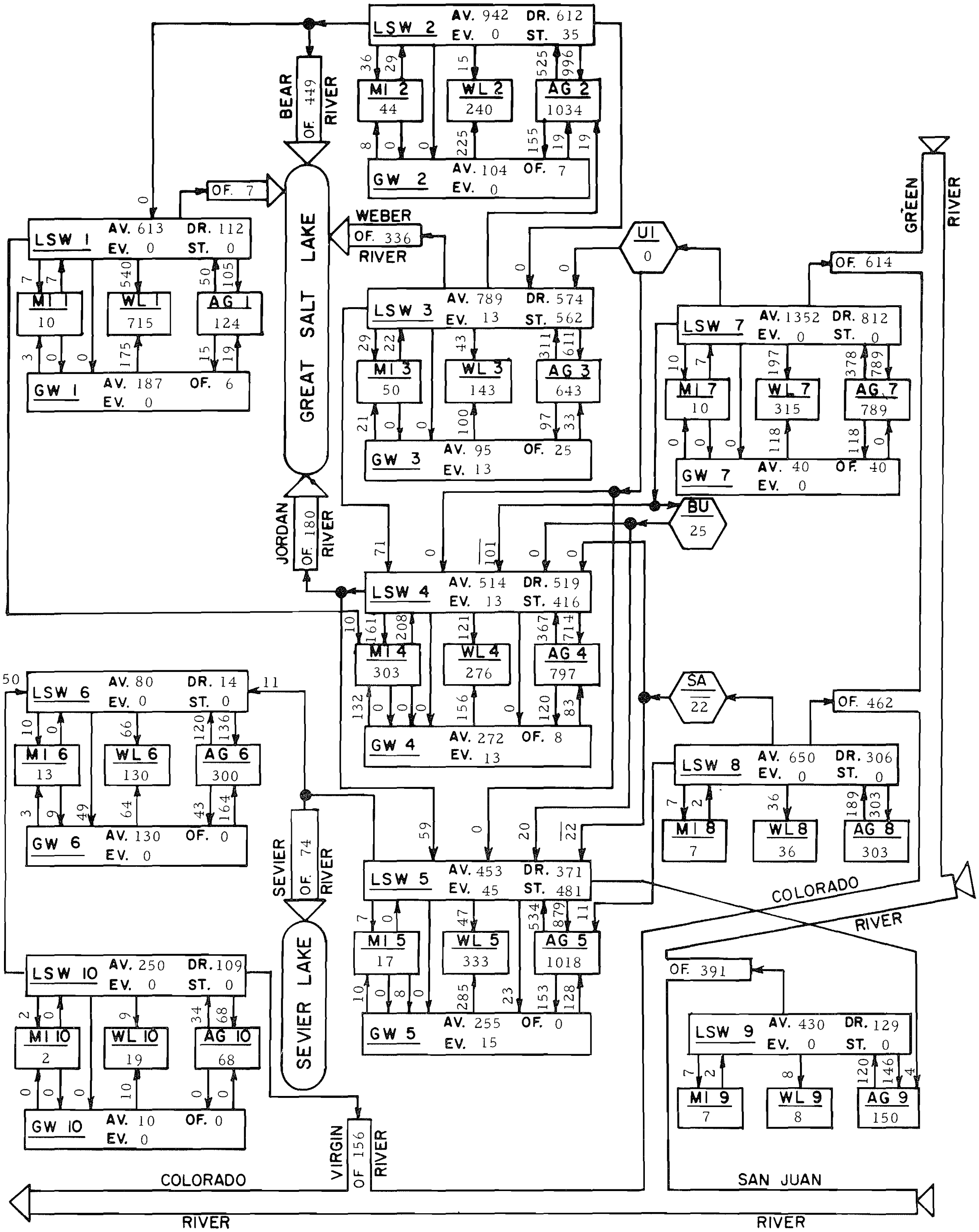

APPENDIX C

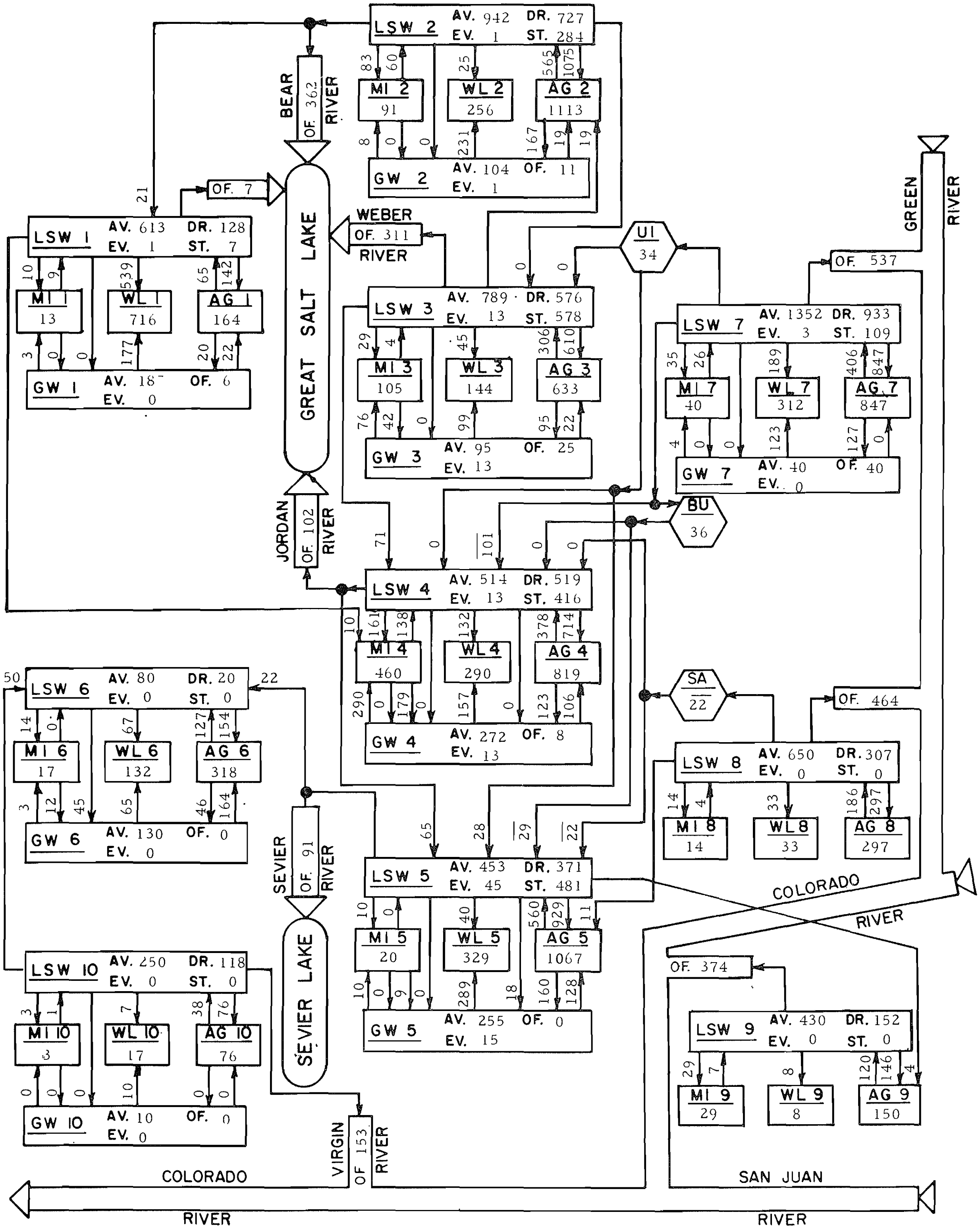
FLOW DIAGRAMS FOR ALLOCATION MODELS



FLOW DIAGRAM FOR ALLOCATION MODEL

(a) Theta = 0 (Time = 1965)

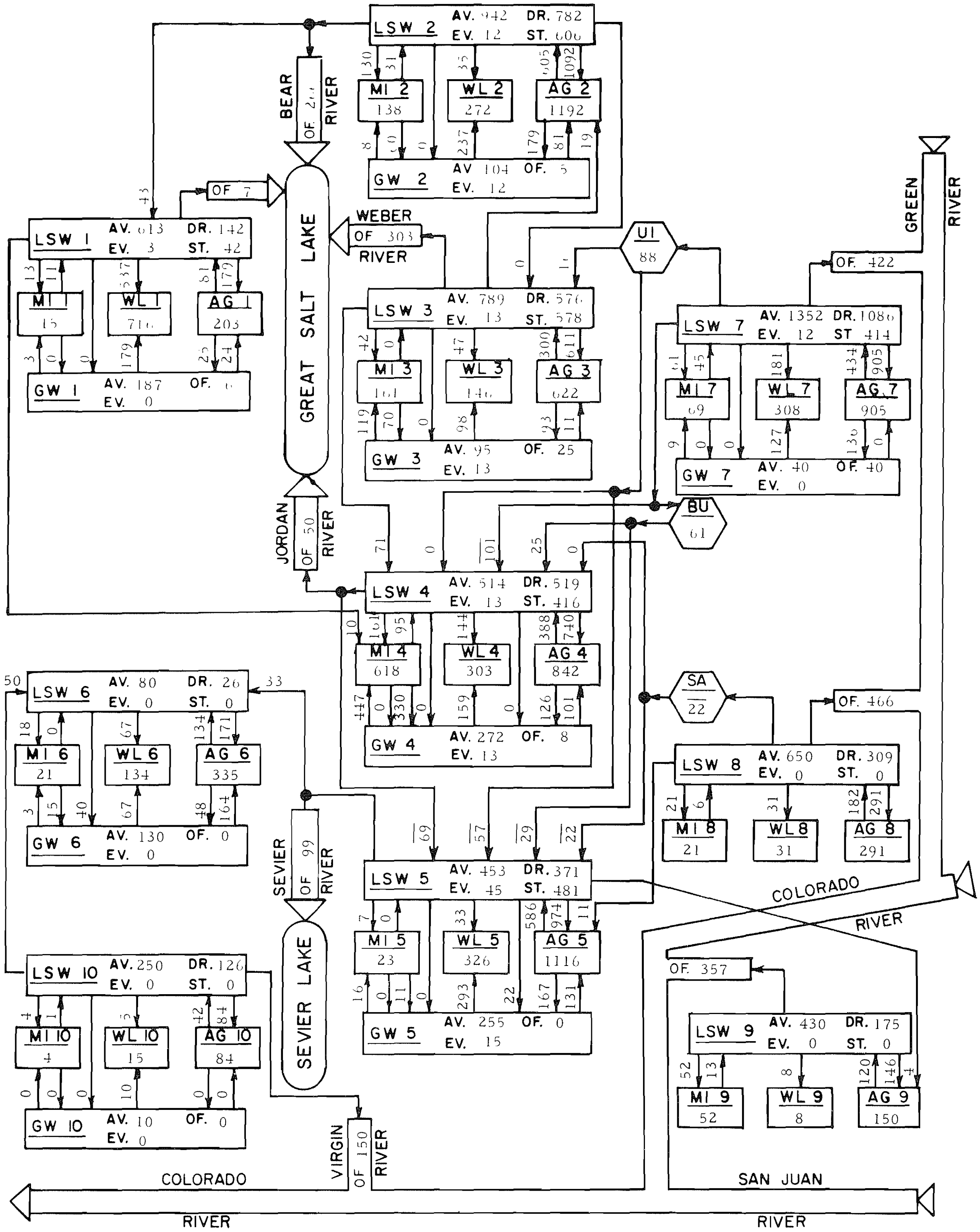
Figure C-1. Basic model.



FLOW DIAGRAM FOR ALLOCATION MODEL

(b) Theta = 2 (Time = 1976)

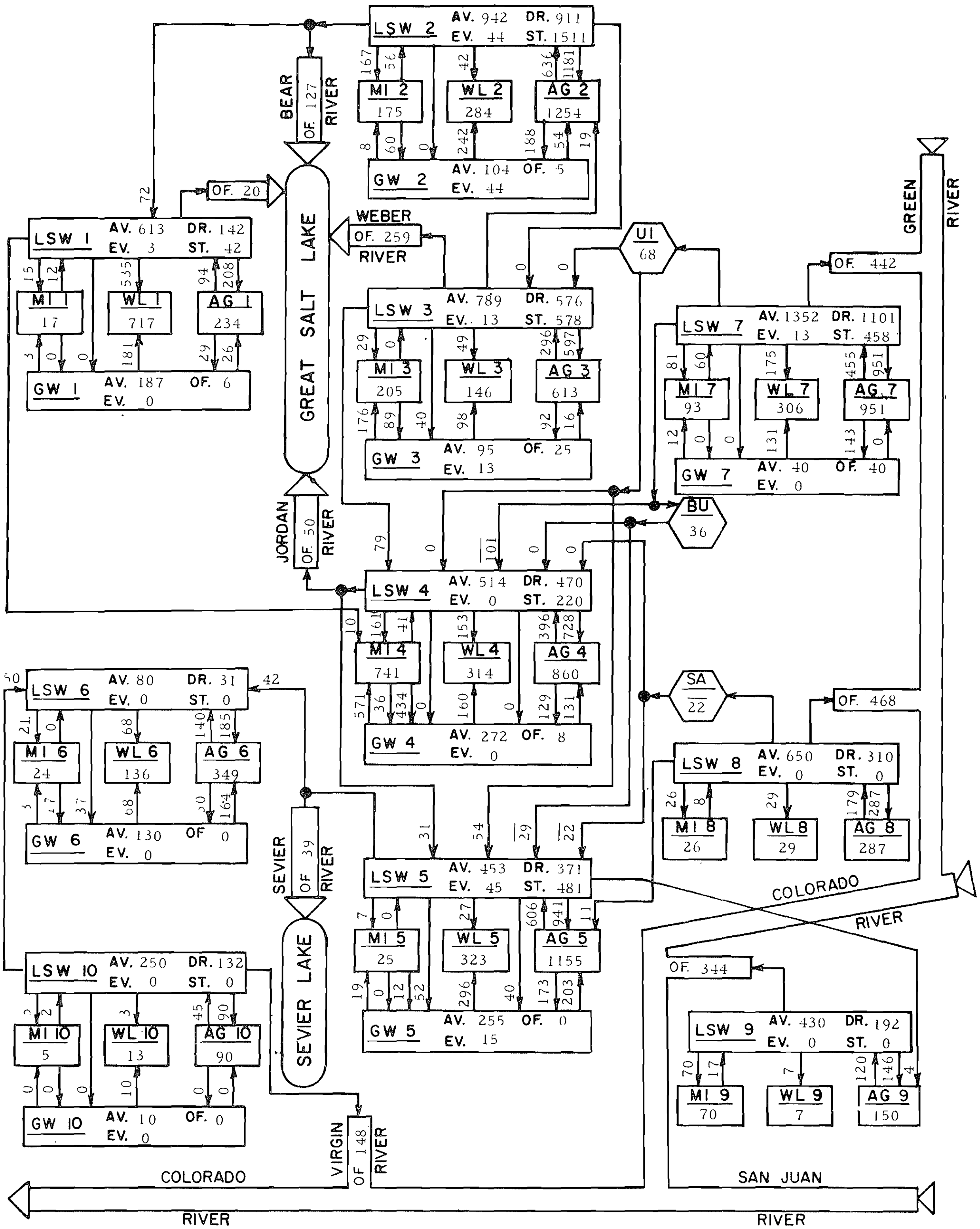
Figure C-1. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(c) Theta = 4 (Time = 1987)

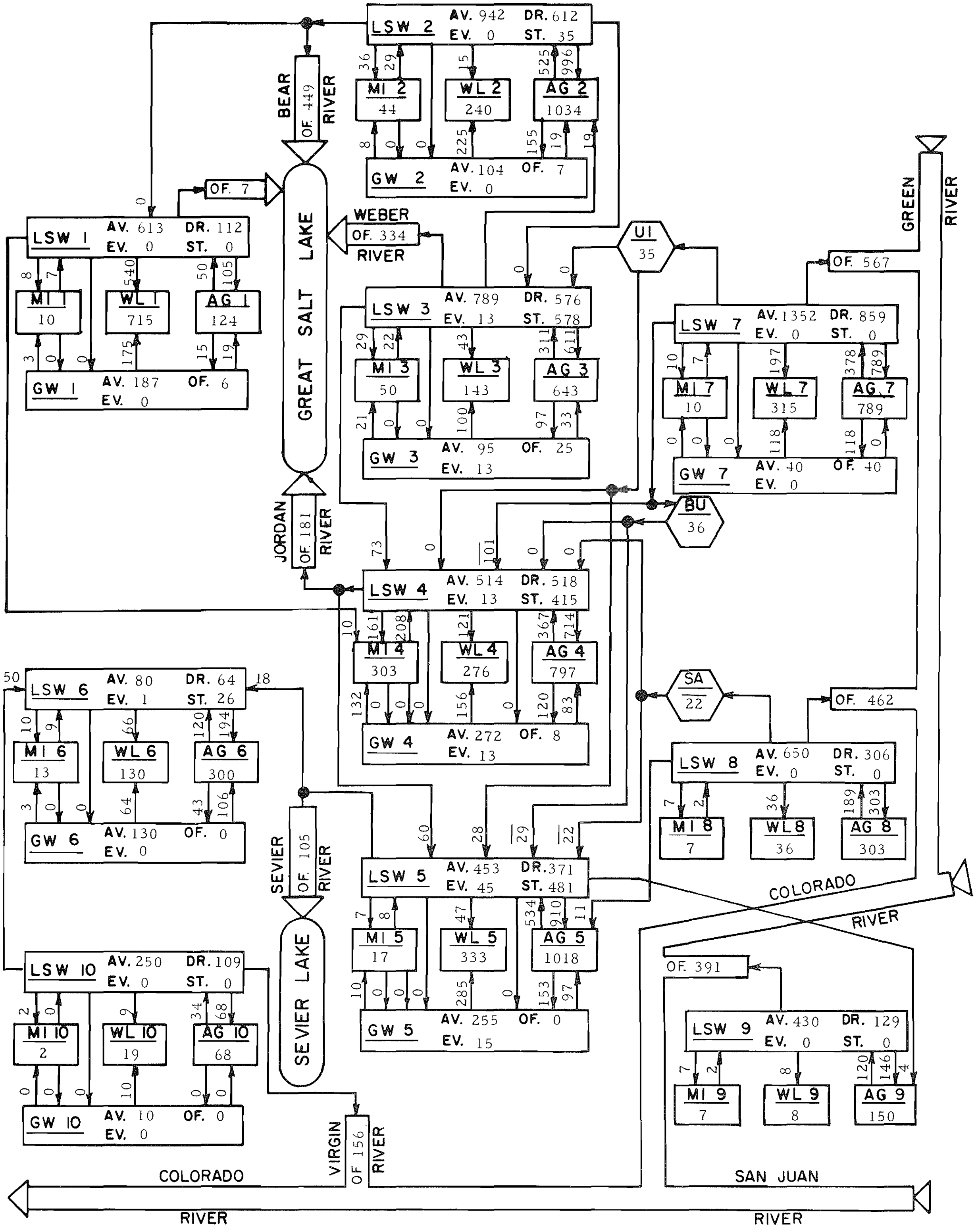
Figure C-1. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(d) Theta = 5.57104 (Time = 1996)

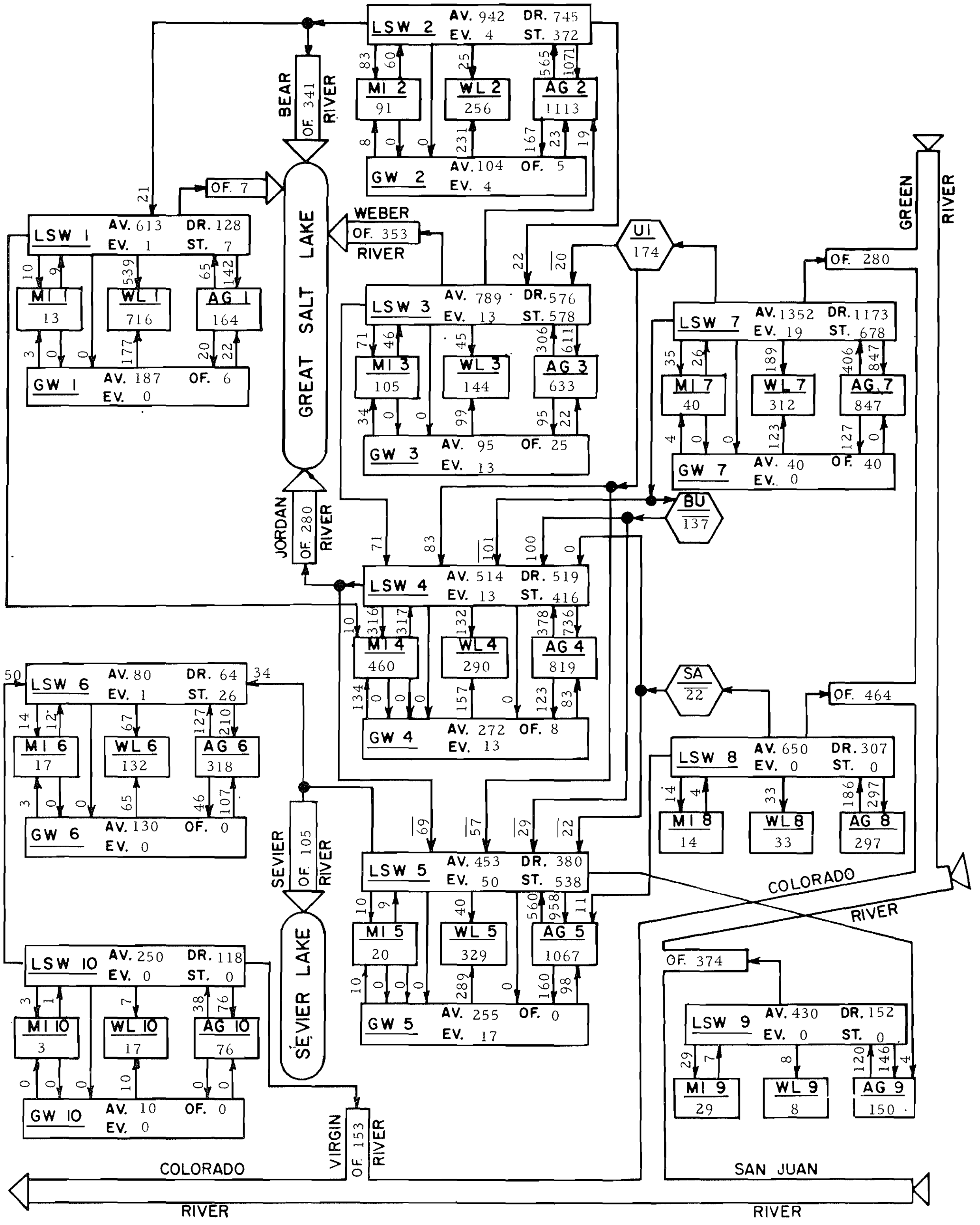
Figure C-1. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(a) Theta = 0 (Time = 1965)

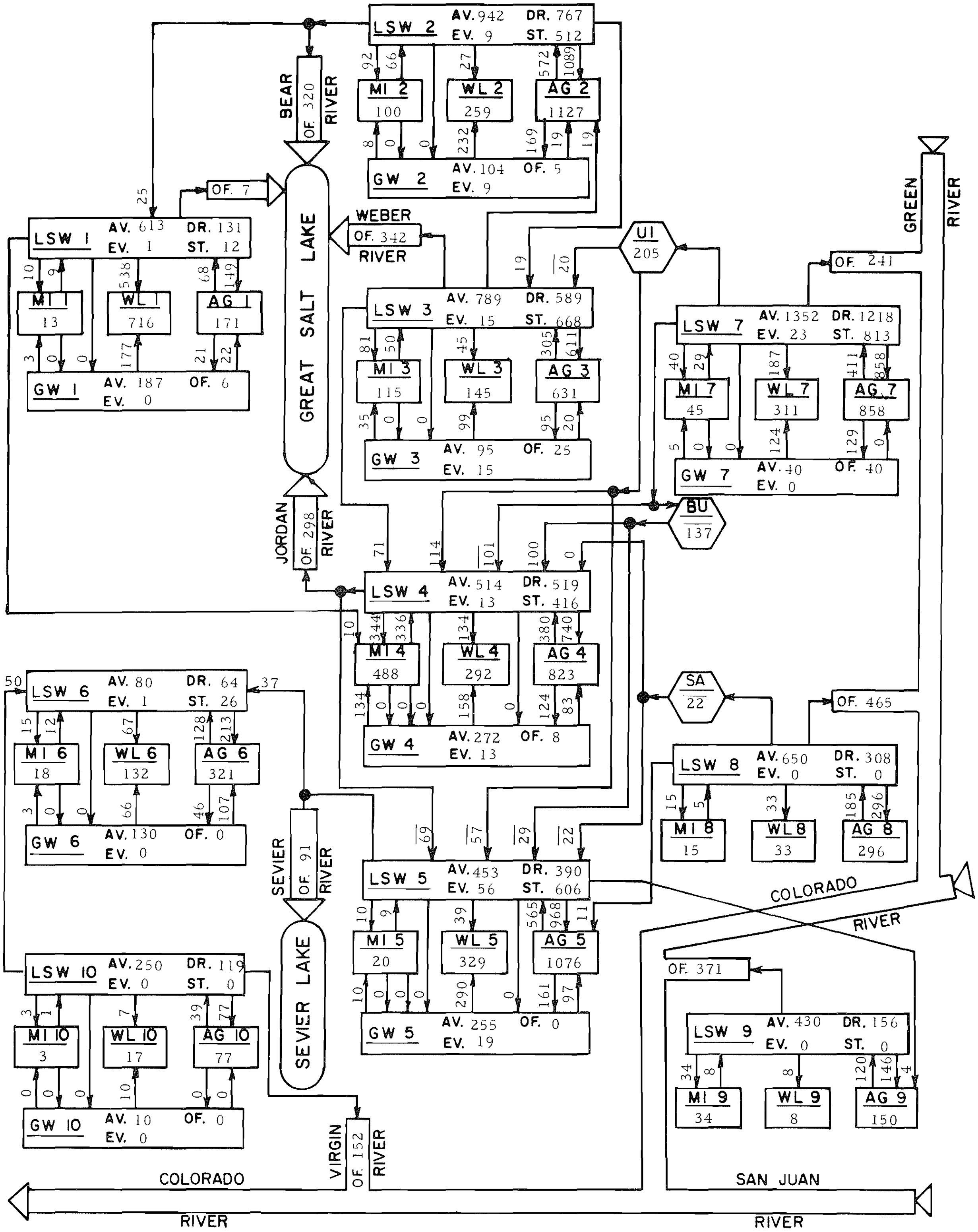
Figure C-2. No groundwater recharge model.



FLOW DIAGRAM FOR ALLOCATION MODEL

(b) Theta = 2 (Time = 1976)

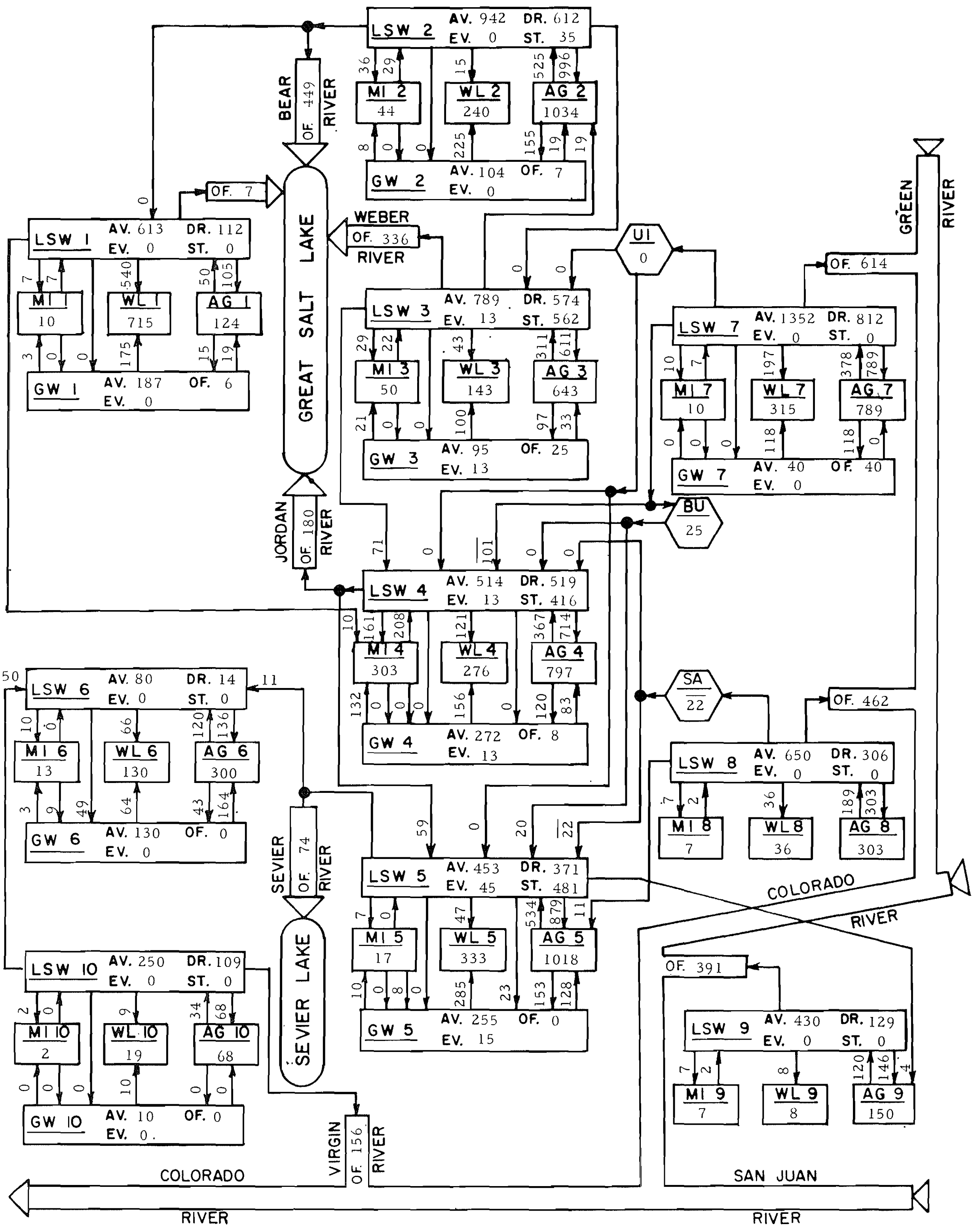
Figure C-2. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(c) Theta = 2.36025 (Time = 1978)

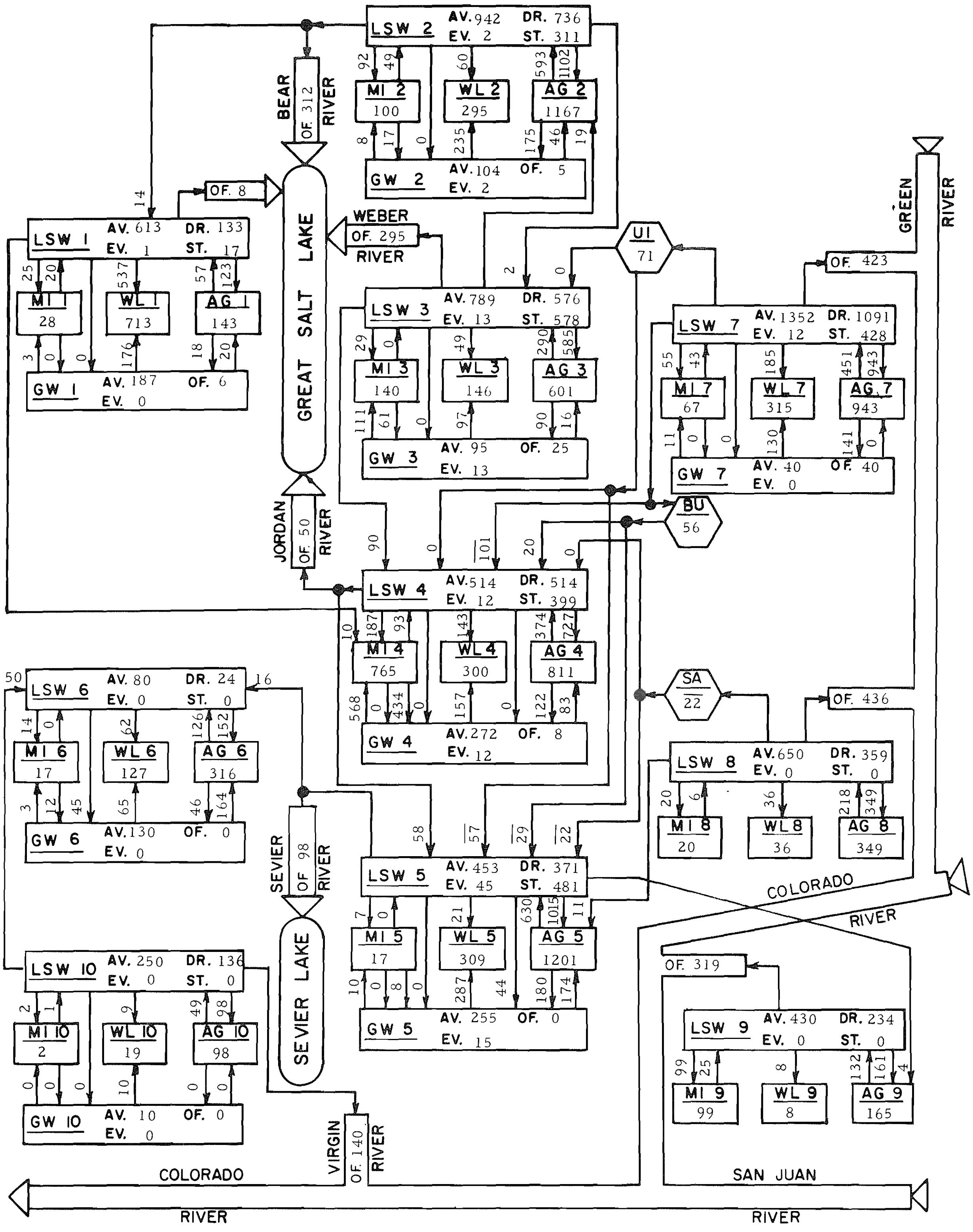
Figure C-2. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(a) Theta = 0 (Time = 1965)

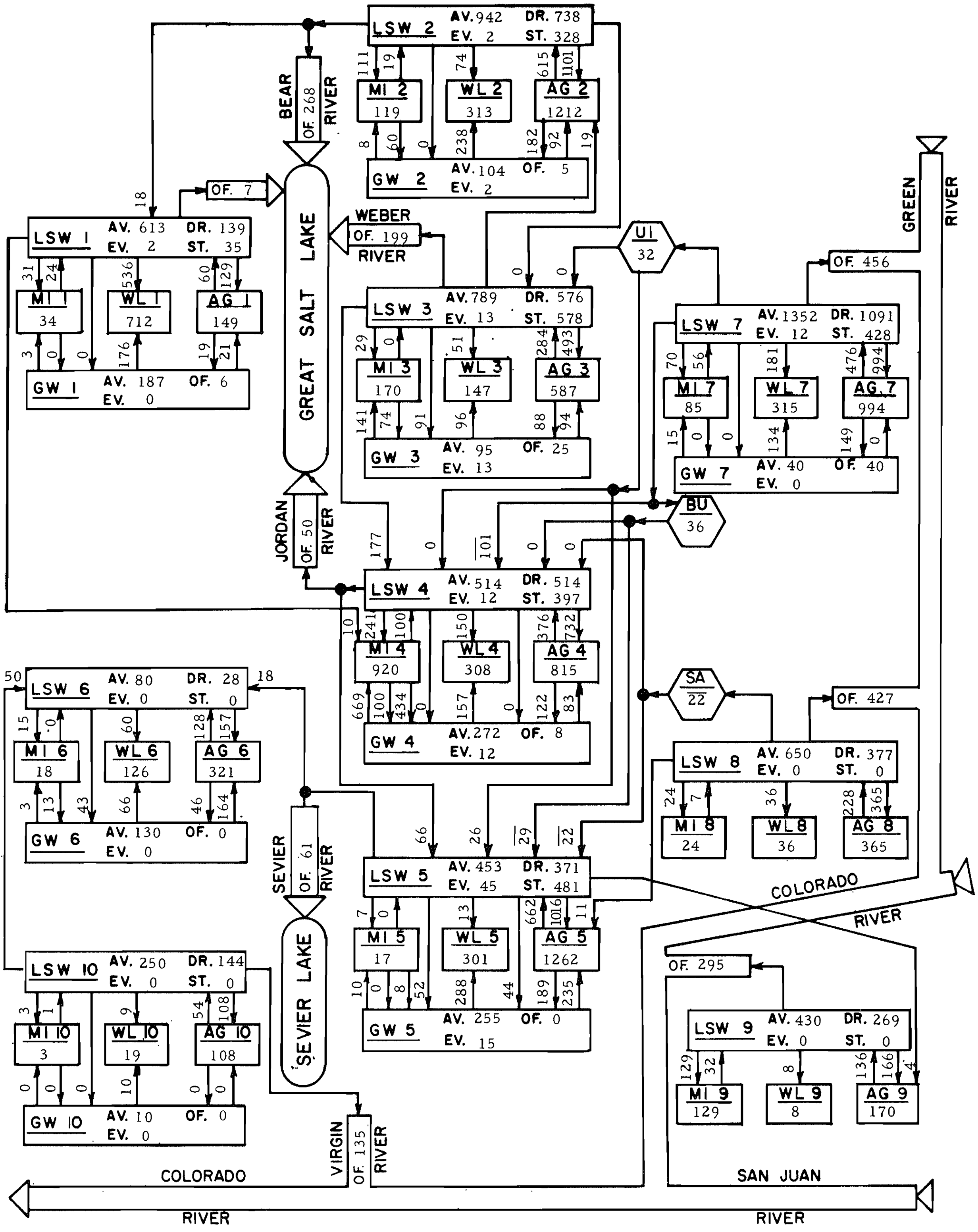
Figure C-3. No further groundwater development model.



FLOW DIAGRAM FOR ALLOCATION MODEL

(d) Theta = 6 (Time = 1998)

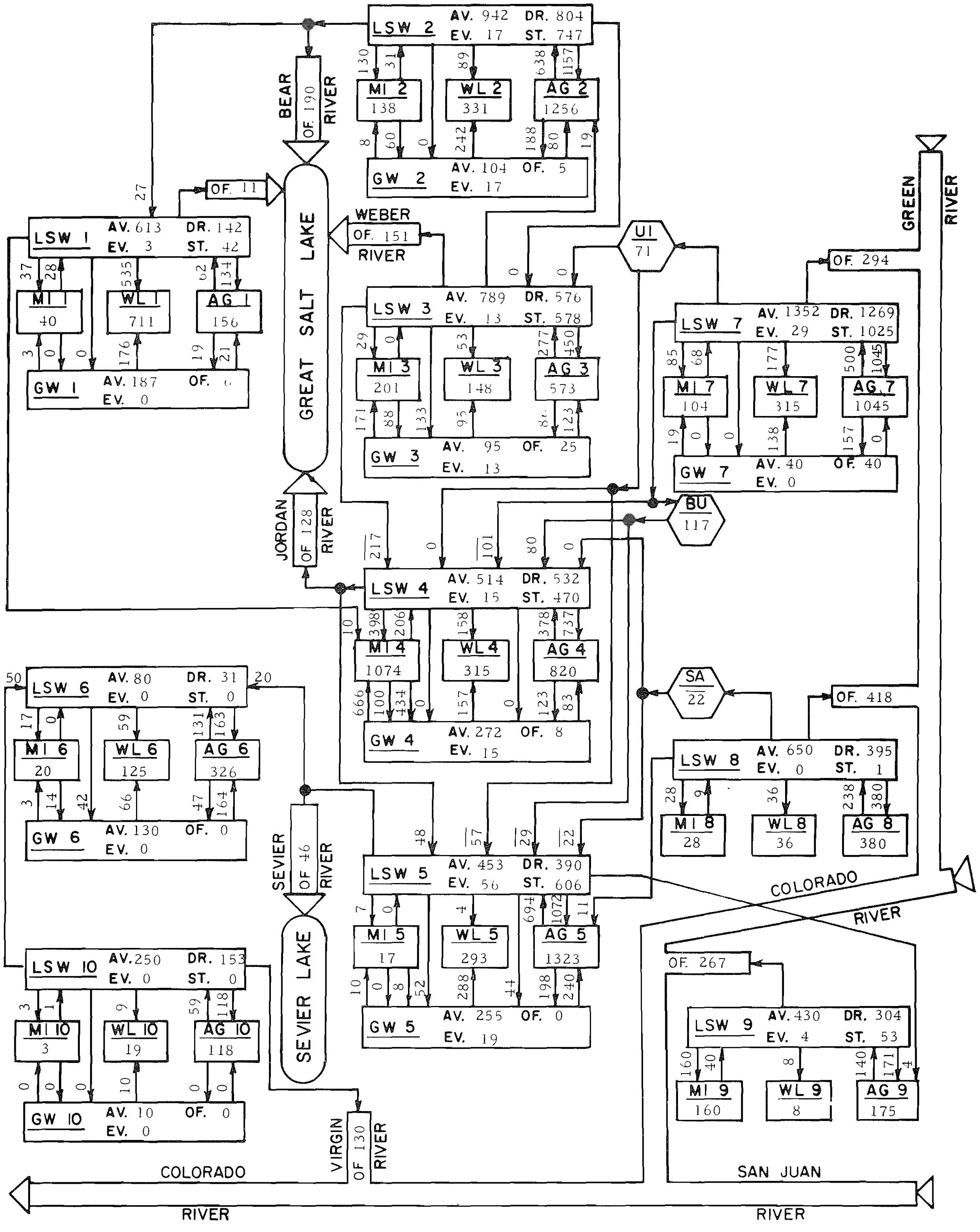
Figure C-5. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(e) Theta = 8 (Time = 2009)

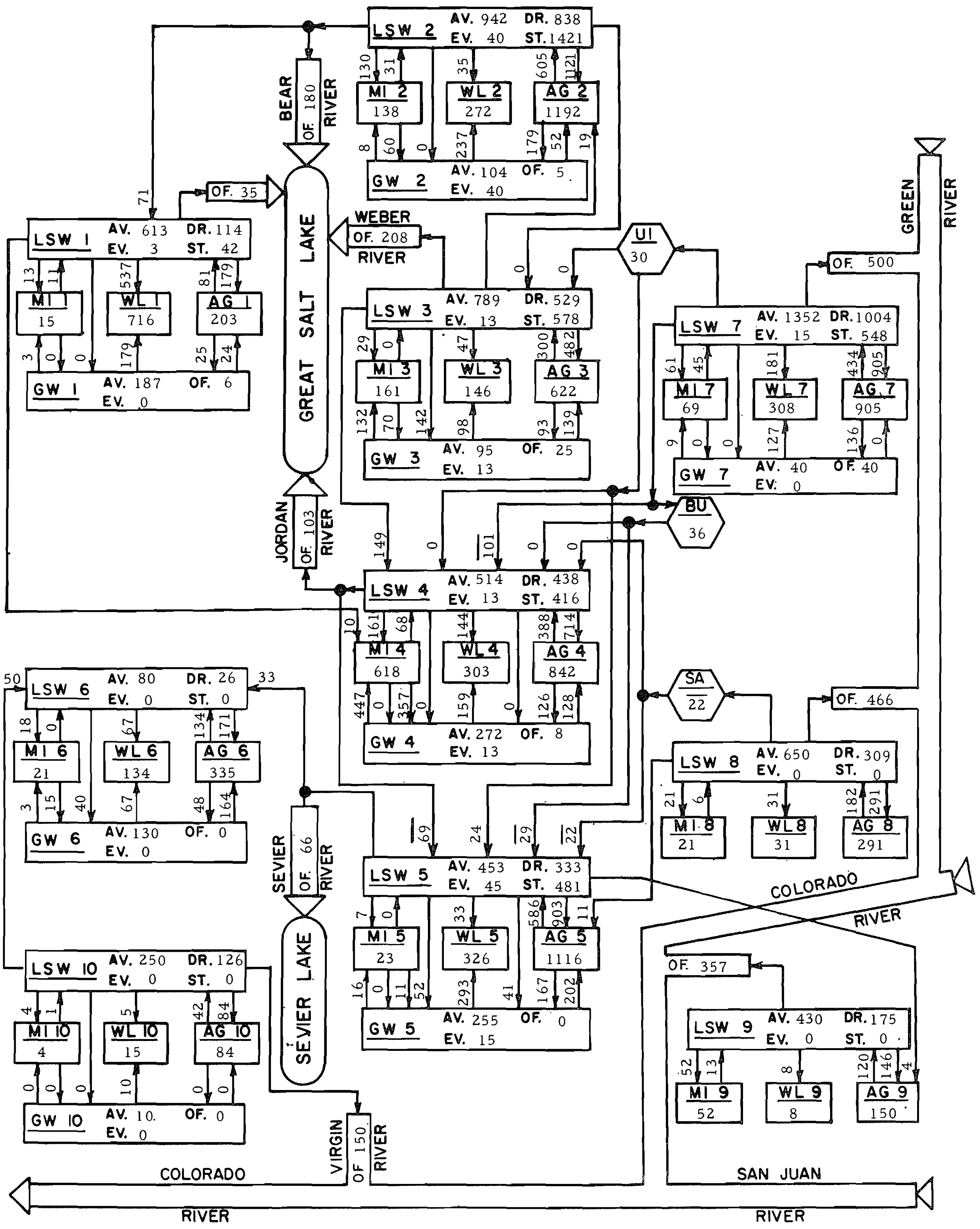
Figure C-5. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(f) Theta = 10 (Time = 2020)

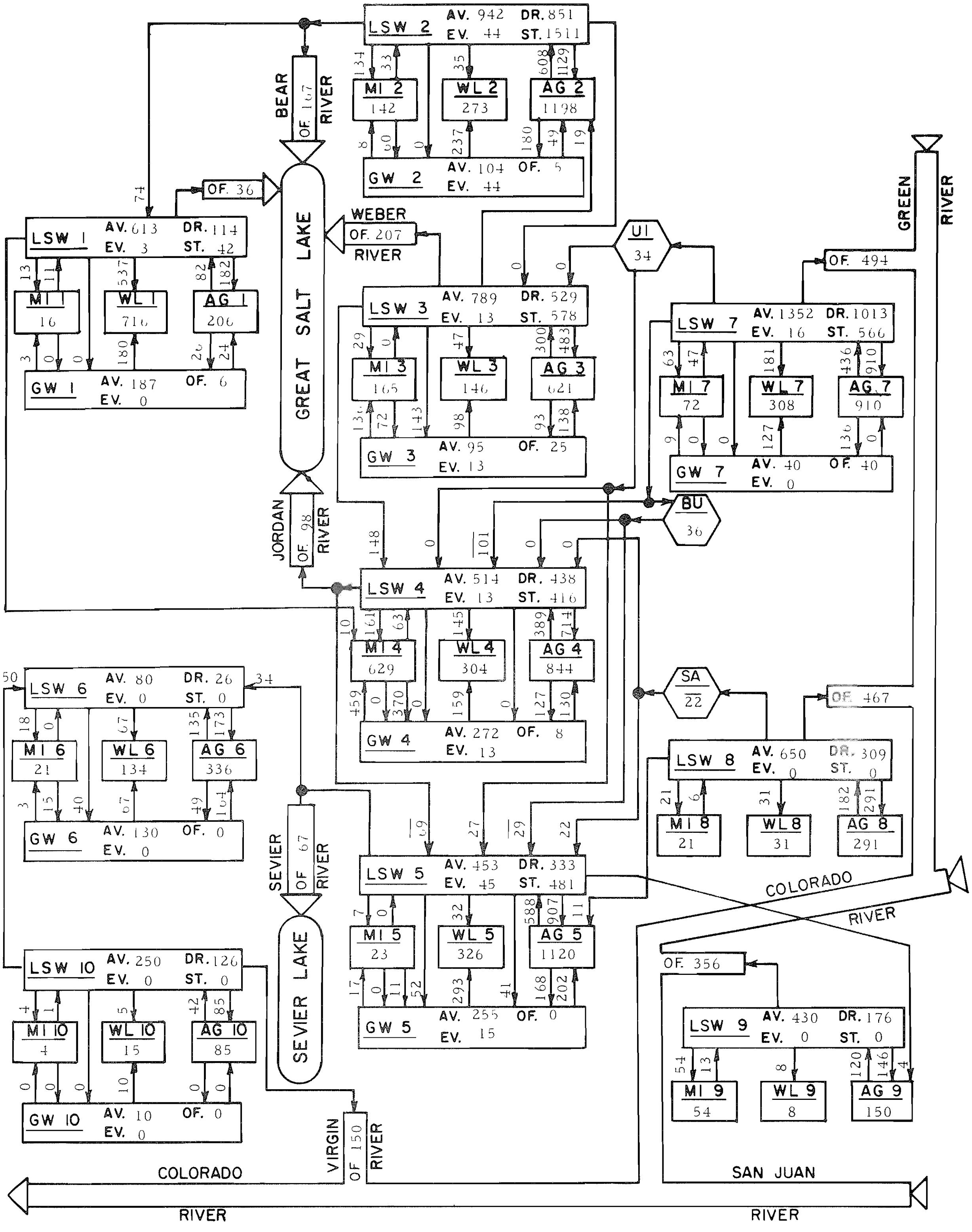
Figure C-5. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(c) Theta = 4 (Time = 1987)

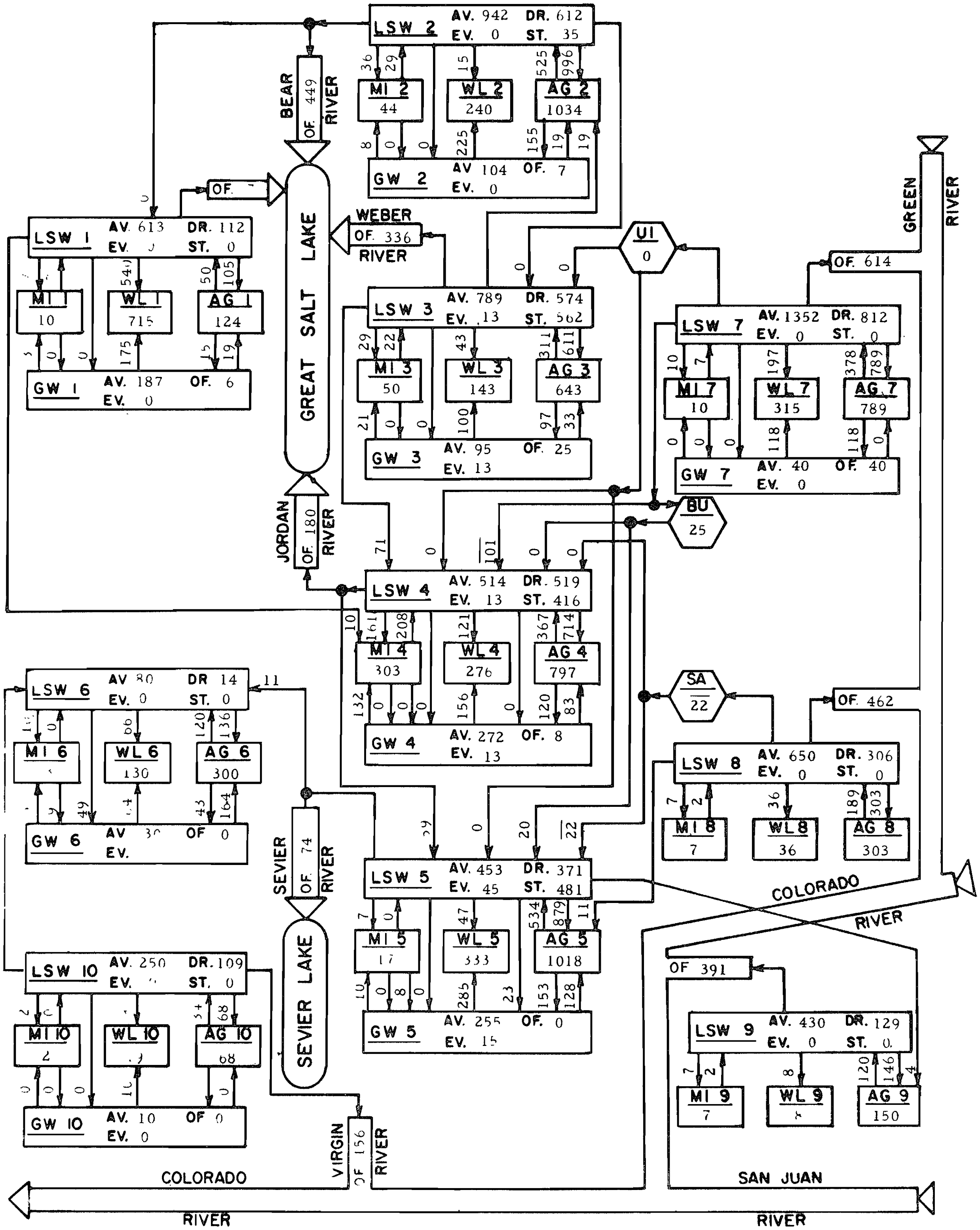
Figure C-7. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(d) Theta = 4.14770 (Time = 1988)

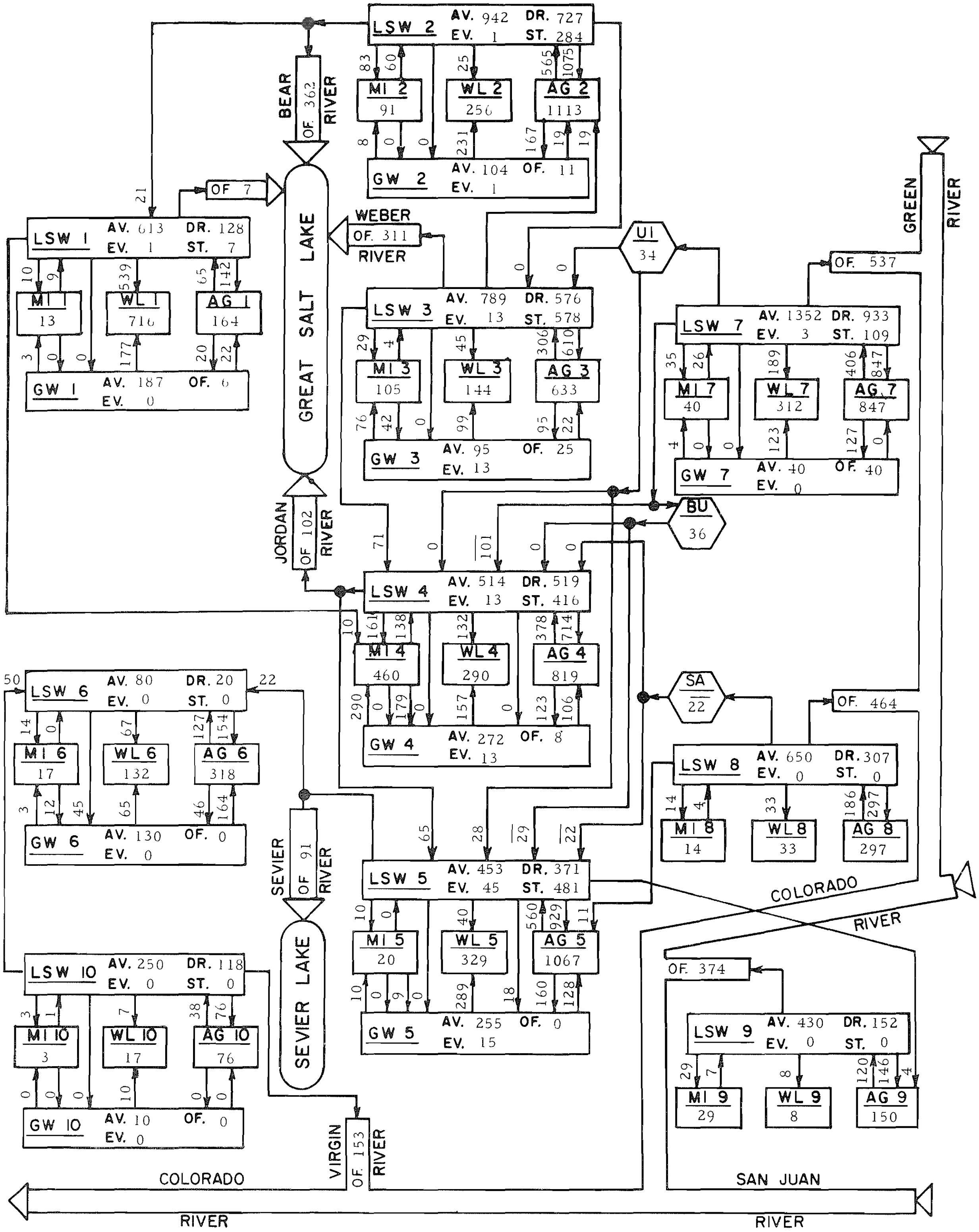
Figure C-7. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(a) Theta = 0 (Time = 1965)

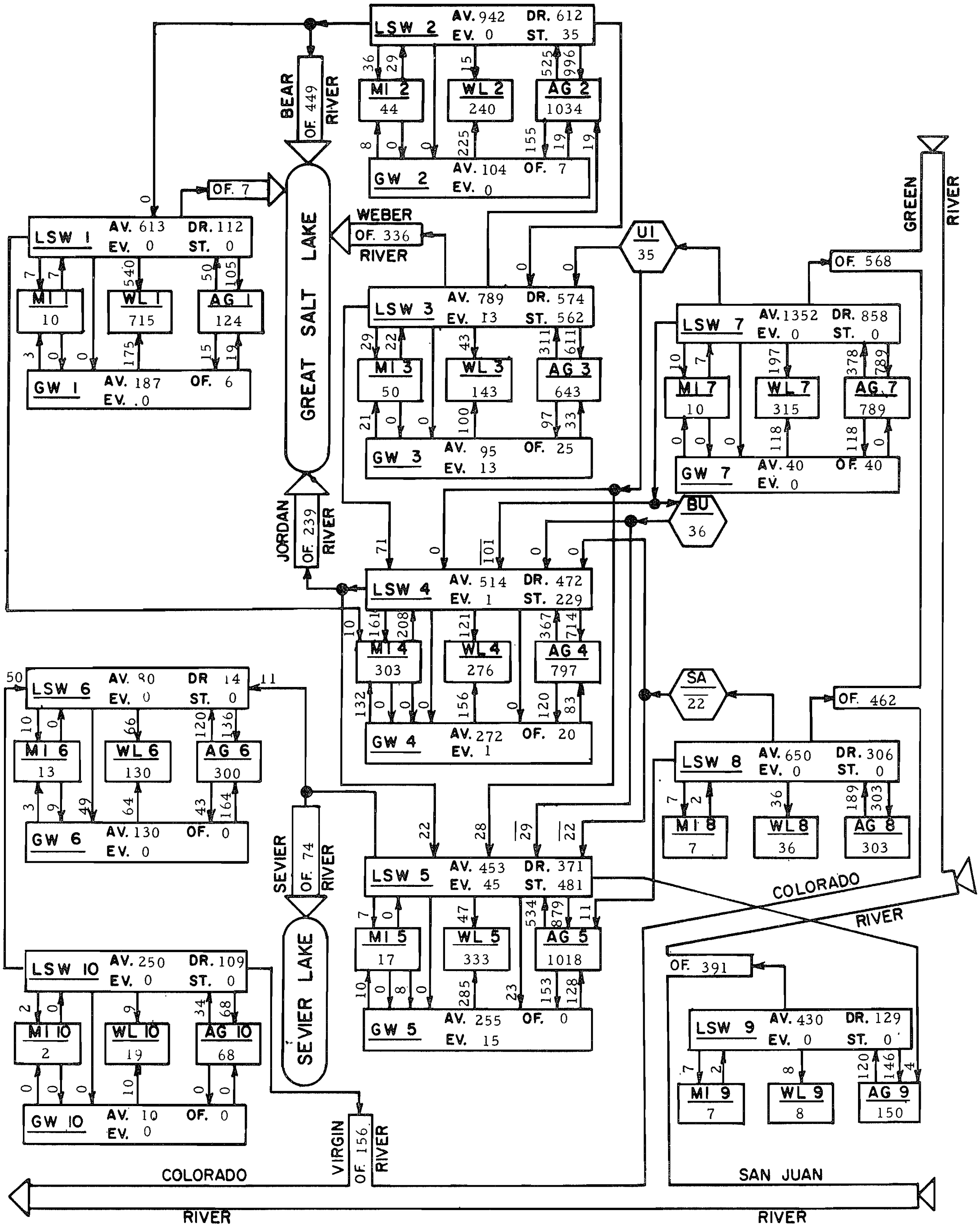
Figure C-8. Inflow to Great Salt Lake ≥ 800,000 ac-ft/yr model.



FLOW DIAGRAM FOR ALLOCATION MODEL

(b) Theta = 2 (Time = 1976)

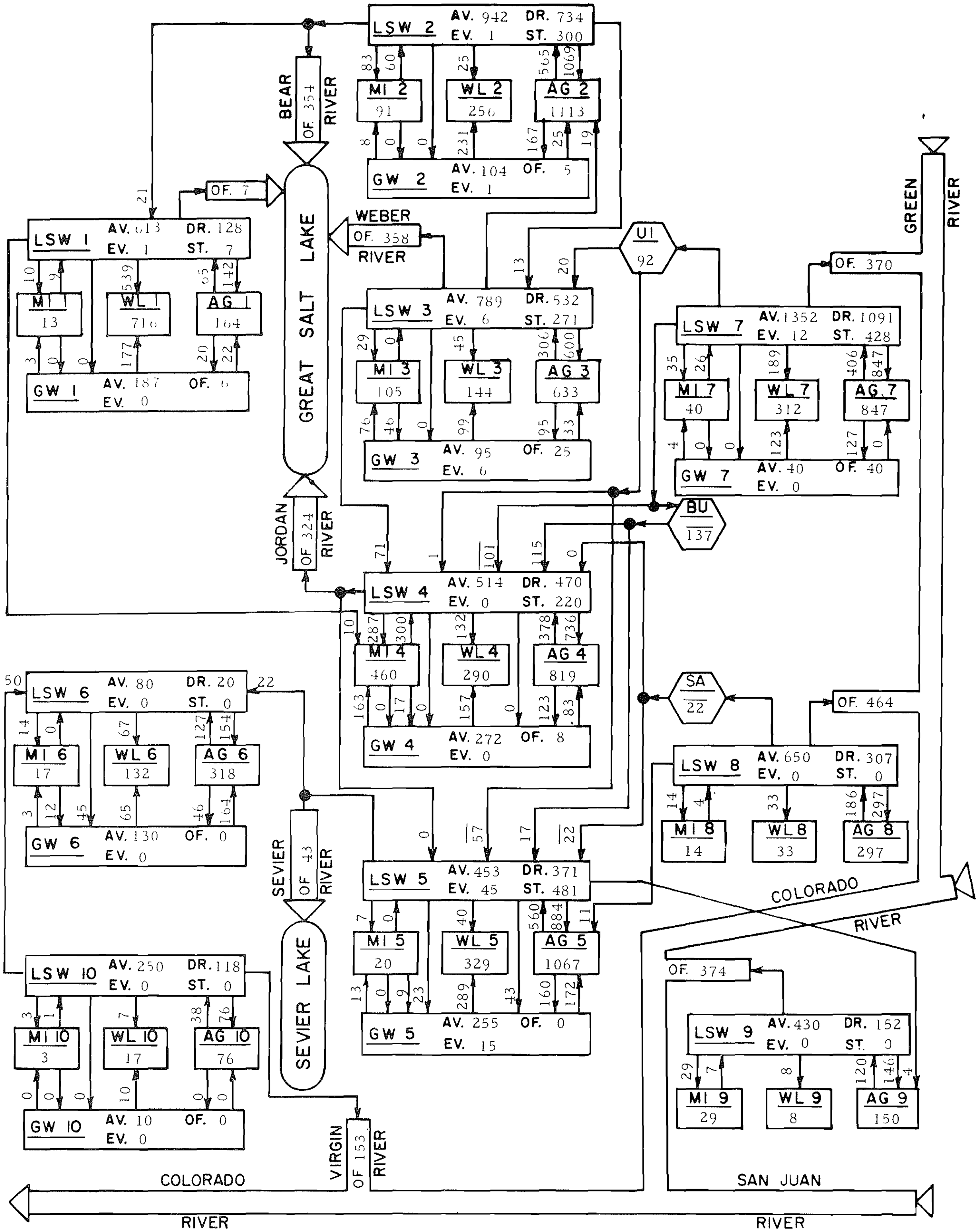
Figure C-8. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(a) Theta = 0 (Time = 1965)

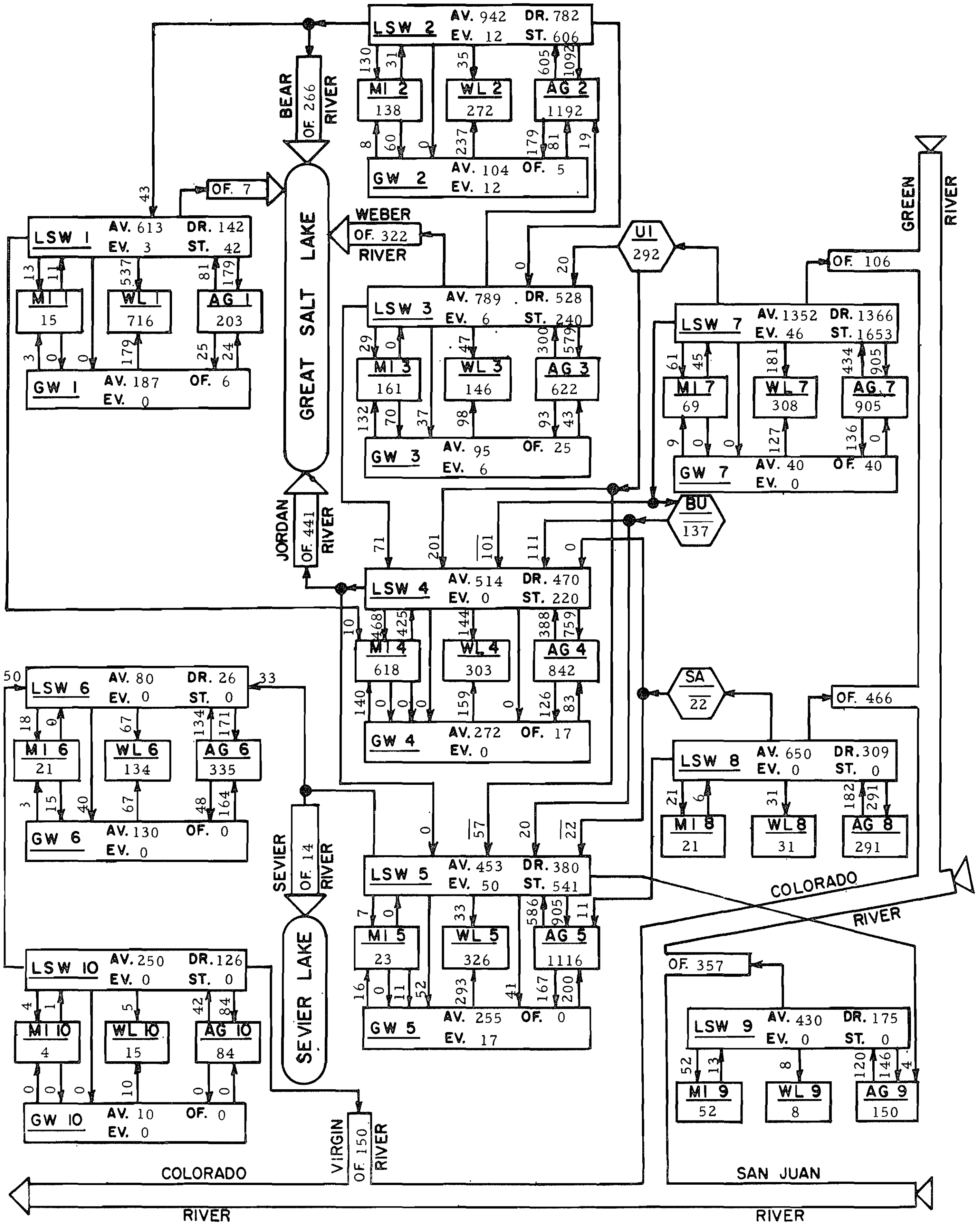
Figure C-9. Inflow to Great Salt Lake ≥ 1,088,000 ac-ft/yr model.



FLOW DIAGRAM FOR ALLOCATION MODEL

(b) Theta = 2 (Time = 1976)

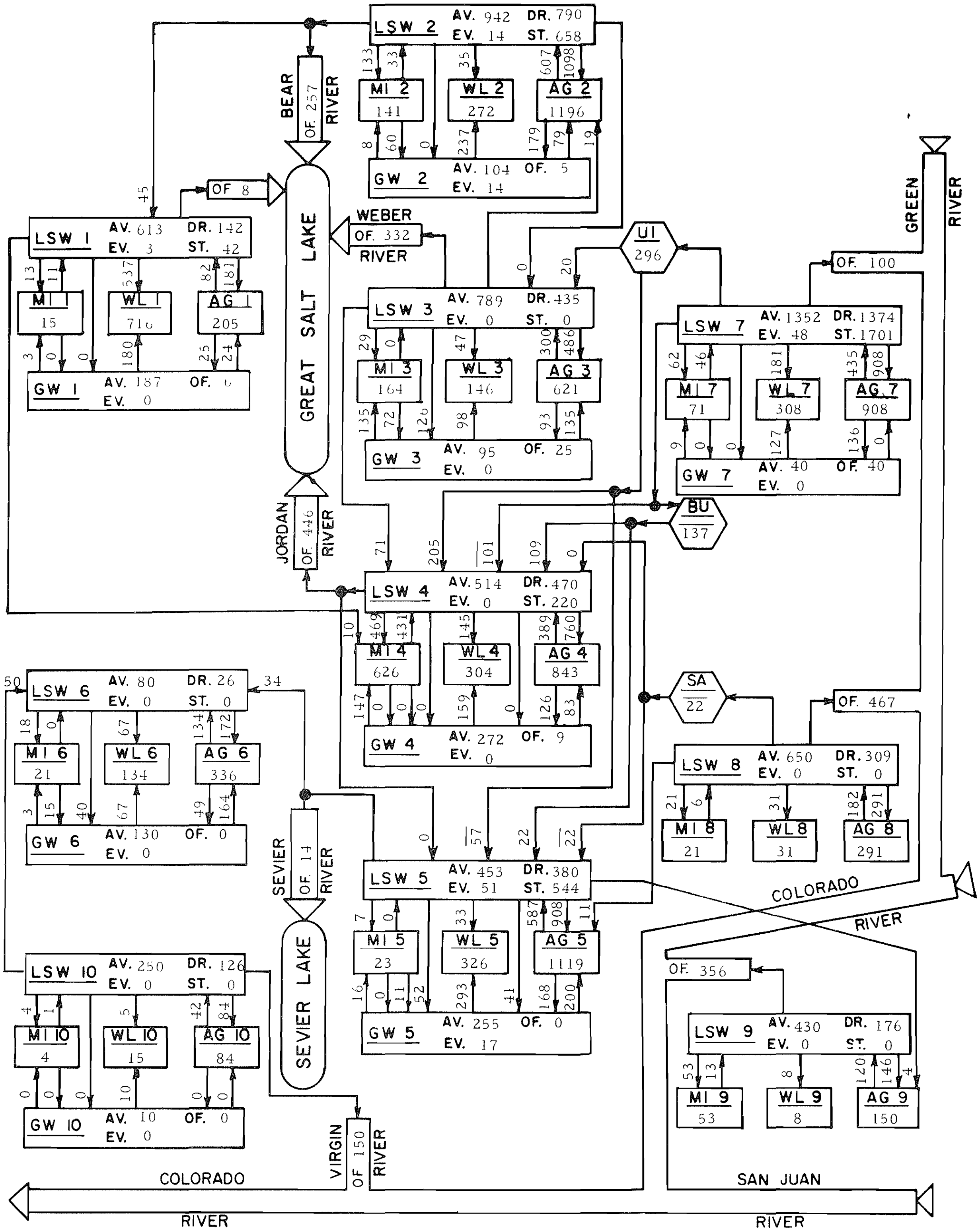
Figure C-9. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(c) Theta = 4 (Time = 1987)

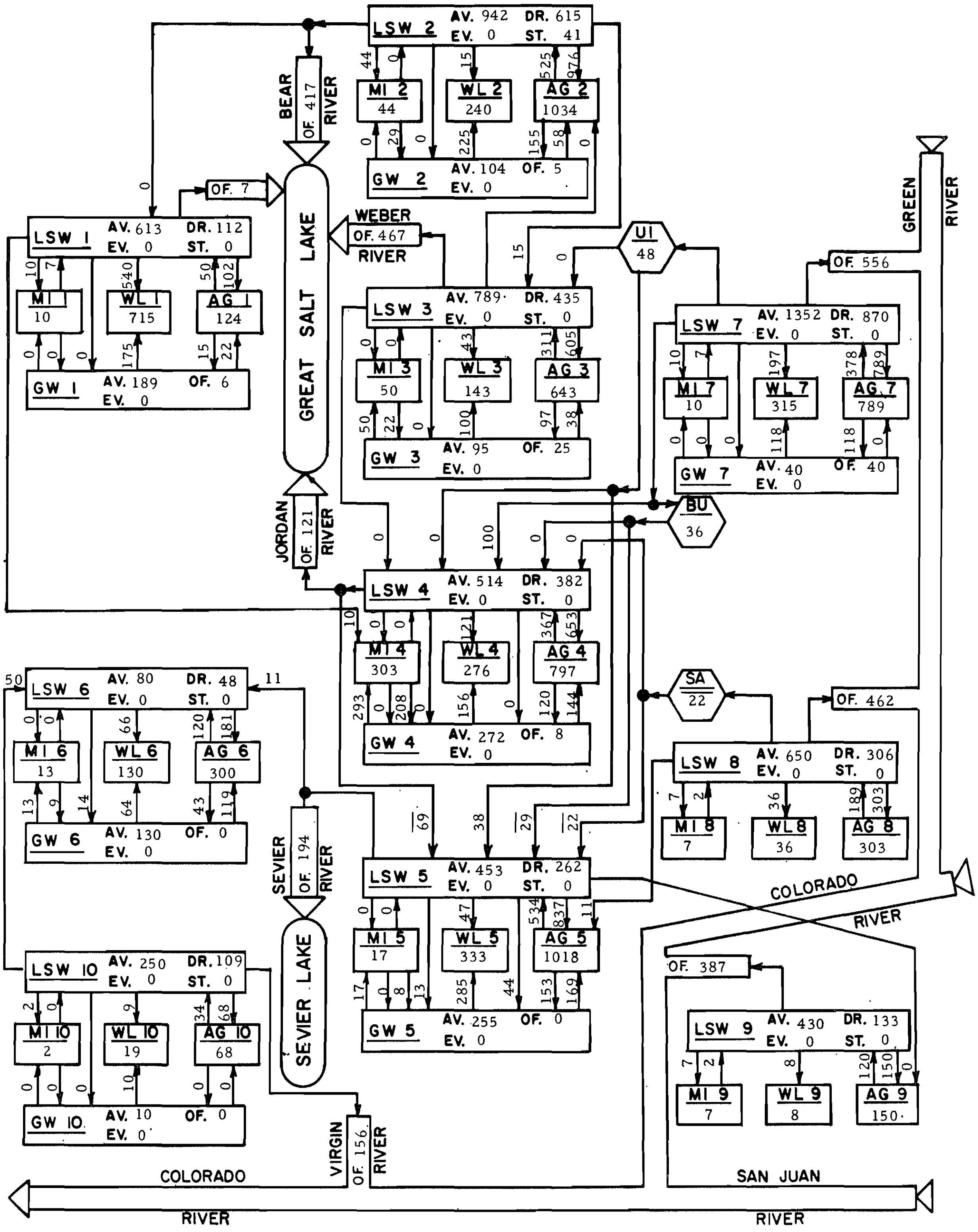
Figure C-9. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(d) Theta = 4.10232 (Time = 1988)

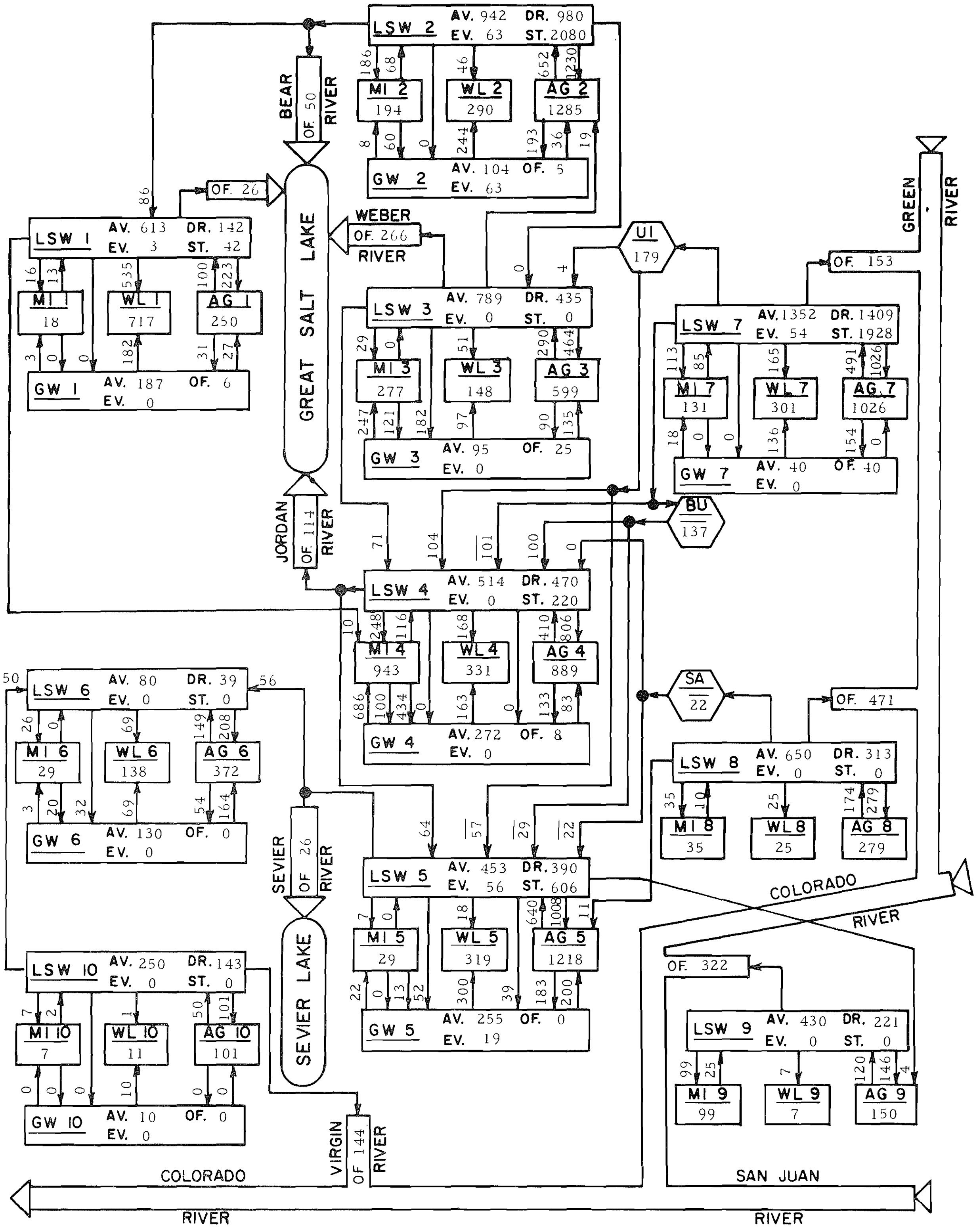
Figure C-9. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(a) Theta = 0 (Time = 1965)

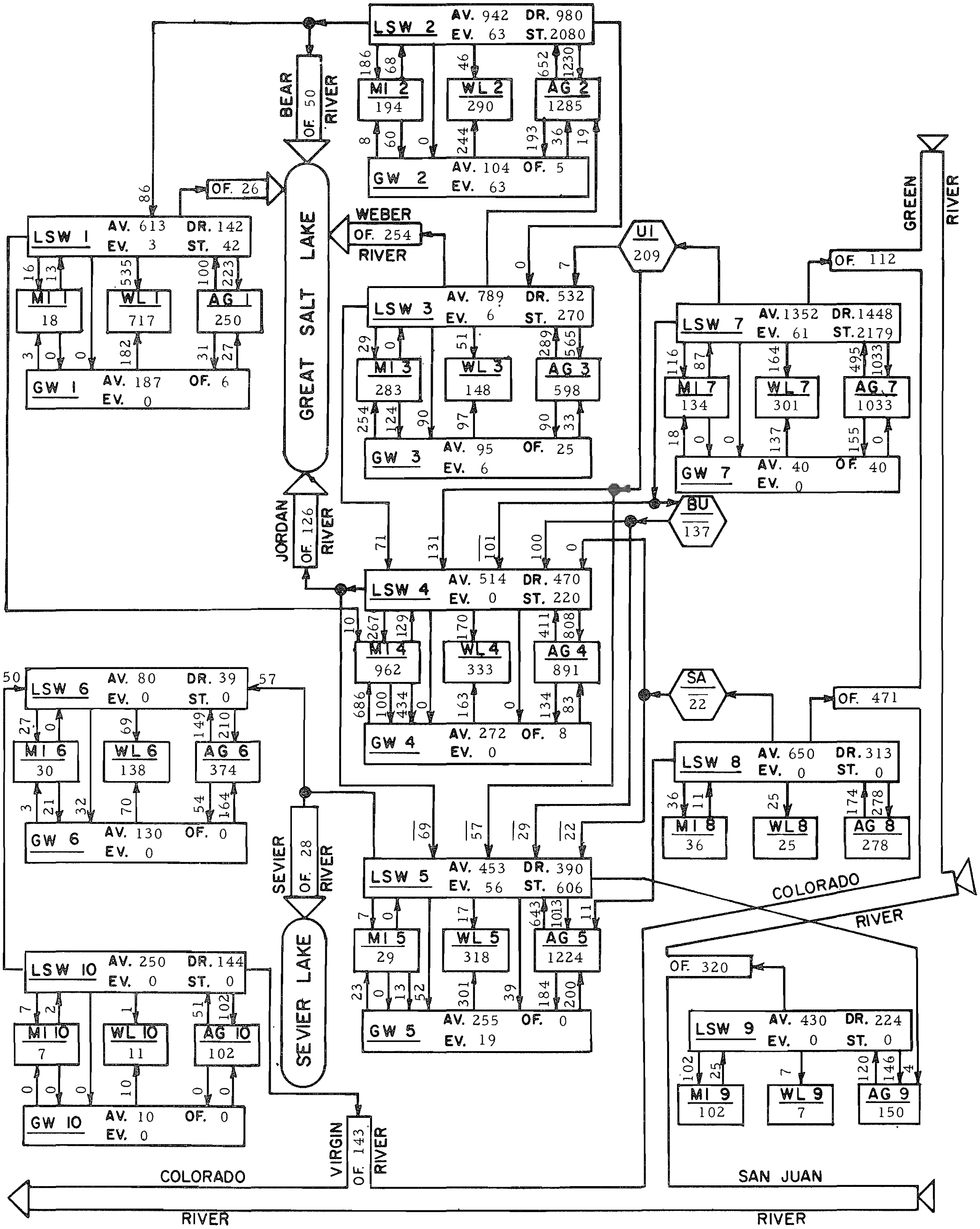
Figure C-10. No previous development model.



FLOW DIAGRAM FOR ALLOCATION MODEL

(h) Theta = 8.13826 (Time = 2010)

Figure C-11. Continued.



FLOW DIAGRAM FOR ALLOCATION MODEL

(i) Theta = 8.37806 (Time = 2011)

Figure C-11. Continued.