AN INTERACTIVE RIVER BASIN WATER MANAGEMENT MODEL: SYNTHESIS AND APPLICATION

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ABSTRACT

AN INTERACTIVE RIVER BASIN WATER MANAGEMENT MODEL: SYNTHESIS AND APPLICATION

A computer model is presented for quantifying the impacts of multipurpose water management policy. The model is designed for the analysis of water availabilities throughout a river basin over extended time periods. It is capable of simulating the monthly storage, flow, and diversion of water in a complex river basin system. The prototype system is represented in the model by a network of interconnected nodes which characterize the reservoirs, tributary inflow points, and diversion points in the basin. Linkages between nodes represent the conveyance morphology of the basin.

The model, MODSIM, is synthesized from previously existing models. A base or core model is selected from these models, and further modified so as to better conform to the attributes and capabilities considered desirable for the model.

An advantage of the model is its optimizing capability with respect to reservoir operating rules. Also, MODSIM is able to simulate institutional dictates governing water allocation, such as water rights priorities. Conveyance losses and return flows resulting from irrigation practices can also be considered by MODSIM.

MODSIM is interfaced with an interactive conversational data management package. Conversational programming facilitates the rapid analysis of management alternatives, and promotes the successful transfer of this technology to water planners and managers with little background in computer programming.

Two case studies are presented which demonstrate the utility of MODSIM for aiding in the analysis of impacts of long-term changes in water resource management within a river basin. The Cache la Poudre River Basin in north-central Colorado is used for both case studies. The first case study involves the analysis of opportunities for including recreation in a multipurpose management framework for selected high mountain reservoirs. The second case study addresses the availability of a firm water supply for the proposed Rawhide coal-fired power generation facility.

Model calibration studies are undertaken for both analyses. The calibration studies clearly show the model is capable of accurately simulating the important physical and institutional aspects of water allocation in the basin. The methodologies for evaluating the impacts of the alternative management schemes for each case study are presented, followed by an extensive discussion of the results.

The case studies show that (1) in selected high mountain reservoirs recreation opportunities can be provided by maintaining satisfactory storage levels without causing injury to downstream water users, and (2) sufficient reusable effluent from the City of Fort Collins, Colorado, is available (given the hydrology considered) to meet power plant demand. Together, the case studies represent a viable demonstration of the capabilities of the model.

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CHAPTER I

INTRODUCTION

Water resources planners and managers are commissioned with the responsibility of developing water policy which provides an atmosphere of consistency and equitability in water administration. During the past decade certain *tools* have become available to the planner/manager which enable him to perform complex analyses of alternate management strategies otherwise impossible within a reasonable time frame. Hopefully, these *tools*, such as computer models and data management systems, provide the means to test the impact of various water resources policies with reasonable accuracy before these policies are actually implemented.

Many computer models exist for evaluating a wide range of water resources problems. Often, too much emphasis is placed on the development of new models, and not enough emphasis on the application of good models already available for actual water resources planning and management. Unfortunately, and for a variety of reasons, many of these models have not been employed to any large degree. Perhaps due to lack of consideration of the requirements and needs of those who will use the model, many efforts of model implementation have failed. However, through modern techniques of interactive conversational computer programming, a new group of potential users may be reached; indeed, a group of users more directly involved in water policy decision-making.

A. Objectives

There are two principal objectives of this study. The first is the synthesis of a computerized river basin water management model from currently *existing* models. The model is developed in an interactive conversational mode so that familiarity with computer programming is not essential for model usage. Only a rudimentary knowledge of the computer operating system on which the model is implemented is required for successful operation. The intended purpose of this model is to provide State and local water resources planners and managers with a comprehensive and useful tool for evaluating the impacts of alternate water management policies on water availabilities at various critical points in a river basin. Although MODSIM is in reality a long-term water management model, it could be used to evaluate several differing water planning alternatives; however, it has no inherent ability to select the best plan internally.

The second objective of this research is to demonstrate the application of the model through the comprehensive analysis of two specific case studies. The case study approach is an excellent method for introducing the model and its associated advantages and limitations, along with the underlying assumptions concerning its design. The case studies presented in this report are both realistic and varied. They provide potential users with insight into the types of problems that the model can aid in solving, and also, provide users with guidelines concerning problem formulation, data management, and interpretation of results.

B. Justification

The need for such a model is very much in evidence in many western States of the United States. Though this study will focus on Colorado water problems, this should by no means detract from the general applicability of the model. Colorado water resources planners and policy makers are facing increasingly challenging problems concerning allocation of the water resources of the State. Water is of critical economic, social, and environmental importance to Colorado. Unfortunately, only a finite raw water supply is made available each year from spring snowmelt in the Colorado Rockies. A portion of this annual supply is captured in a complex network of interconnected storage reservoirs, and then allocated for satisfaction of various competing demands within Colorado, as well as interstate compact agreements for water leaving the State. In years past, when demands placed on raw water supply were lower and the uses less diverse, this system of water collection and distribution was largely self-administering under the Colorado appropriative doctrine.

The Front Range of Colorado, in particular, is experiencing a steadily growing pressure on available water resources. This pressure originates from both direct and indirect influences on demand. For example, expanding urban centers require more water for domestic and industrial uses, which often is obtained through transfer of irrigation water rights. Irrigated agriculture is still the leading water user in Colorado, and greater attention should be focused on more efficient use of water diverted for agriculture. In-stream uses of water resources, as well as water-related recreation, are being given an increasingly higher priority. Finally, the prospect of large-scale energy development in Colorado presents perhaps the greatest challenge when considering some of the projected water requirements for this use. Such energy related endeavors will not only have considerable economic importance in Colorado, but national implications as well. Rationally, one can only expect that competition for waters originating in Colorado will greatly intensify.

A complex institutional framework has evolved within which this supply/demand cycle operates. Increased demand, however, has led to over-appropriation of waters along the Front Range. Additional diversion of western slope waters is being scrutinized, but this source is limited. In an effort to extend the supply as far as possible, formal arrangements for the reuse or secondary use of water are being pursued, although in practice such a policy has been in existence since the first diversion of water for irrigation purposes. Of the water applied to croplands, a certain portion not consumptively used finds its way back to the stream for subsequent reuse. As the irrigation season progresses, the amount of *return flow* accruing to the river can be significant, as is the case with the Cache la Poudre River Basin in north central Colorado.

W.D. Farr, Chairman of the City of Greeley, Colorado Water and Sewage Board, (1977) stated that:

> There is not very much more water that can be developed. The problem is to best manage and utilize our total water supplies not only on a day to day basis, but on a prudent plan for years ahead.

The use of modern systems analysis techniques coupled with high speed digital computers will go a long way in helping achieve effective and efficient water resources planning and management. The use of system analysis techniques in water resources planning and management has gained in acceptance in recent years. Due to the large-scale nature of most physical water resource systems, and the corresponding quantity and diversity of data, a systematic treatment of problems becomes somewhat mandatory if such problems are to remain tractable. By definition, the systems approach to problem solving specifies an orderly stepwise solution strategy for these complex problems. Such an endeavor aids the planner/manager in pinpointing data requirements and facilitates the rapid analysis of many management schemes. Also, a general modeling framework can be developed that is not basin specific. This allows the planner/manager the flexibility of analyzing problems occurring in different basins using the same model structure. Once this basic model structure has been developed, there is the added advantage of being able to systematically incorporate new data and information as they become available.

C. Contribution

This study provides a two-fold contribution to the body of knowledge pertaining to water resources engineering. Generally, the contribution is of both theoretical and practical significance. First, a new computerized water management model is synthesized from previously existing models. This, in itself, is of little practical importance in that new computer models are created with considerable regularity. However, a goodly portion of these new models cannot be used much beyond a small circle of developers and experienced computer programmers. It is the author's firm belief that for a computerized river basin model to have practical, *real world* problem solving potential, it must be capable of being comprehended and employed by those individuals who would benefit most from its use. These individuals are the local and State agency water planners and managers who must actually wrestle with the problems of water allocation. To this end, MODSIM was developed in an interactive conversational model which allows operation of the model without appreciable computer science training. A theoretically sound model with real practical advantages has been developed. There are few examples of the development and application of interactive river basin water management models, especially those developed in a conversational mode.

The types of problems which the model can be of aid in solving are varied. For instance, upon successful calibration, MODSIM can be used to perform impact analyses and determine sensitivites of:

1. potential critical period hydrologies
2. transfers of water use
3 variations in water rights structure within a river basin
4. changes in water demands
5. new or modified structural facilities such as reservoirs, canals, pipelines, etc.
6. availabilities and/or use of imported water
7. minimum streamflows as dictated by state and federal water quality regulations
8. water conservation and reuse measures.

Finally, it must be noted that computer modeling is an evolutionary process. Most models are in a constant state of flux as new technology becomes available and new theory is tested. As experience is gained through model application, changes are made to better reflect the aspirations of the user. In this way, a constantly improving product results. It is expected that MODSIM will undergo several changes in the future. Ultimately, an accepted and useful tool will emerge which extends the capability of planners and managers beyond that currently realized.

CHAPTER II

REVIEW OF SELECTED MODELS

As stated in the introduction, there are a considerable number of river basin computer models currently in existence. These models were developed to aid in the analyses of certain classes of water resource problems. All models are created for a particular purpose. Even within the same class of models (e.g., river basin models) the intended purpose may vary widely. For instance, within a group of river basin simulation models, there may be long-term planning models, real-time operational models, models designed for economic analyses, hydraulic or hydrologic models, surface water models, groundwater models, conjunctive use models, and so forth.

The principal objective of this study is to synthesize from these *existing* models, one model which is better suited for the analysis of water availabilities throughout a river basin resulting from alternate water management policies over long-term planning horizons. This model synthesis is undertaken with a specific user group in mind; State and local governmental water resources planners and managers. However, in order to accomplish this task, the attributes of the most realistically desirable model for the above stated purpose must first be set forth against which the existing models are evaluated and also against which the synthesized model is ultimately judged.

A. Attributes of the Desired River Basin Water Management Model

Basic to the assumption that a desirable model can be perceived is the premise that the model must be capable of simulating the operation of a complex river basin system (by monthly time increments) over a multi-year planning period. Monthly time increments are preferred because they usually provide sufficient accuracy over long time periods and are compatible with available data. Also, monthly time increments enable as detailed as possible analysis of water transfer without the consideration of the necessity for hydrologic routing of flow. In addition, a longer time increment, such as seasonal, does not provide for sufficient temporal resolution required to calibrate MODSIM as accurately as possible. The desirable model should also have the capability of considering the institutional framework within which the physical system functions. This extension beyond typical water accounting models makes it especailly useful for studying systems where existing or planned priorities among various beneficial uses of water must be preserved. Also, the model must be *presentable*; that is, it must not be so obscure in methodology and difficult in application to prevent its usage regardless of its ability to analyze the problem.

Thus, a realistic river basin water management model might include the following attributes:

1. An interactive, conversationally programmed input data file to facilitate ease of usage by the planner/manager.
2. Simulation of the water storage, transport, and distribution morphology of the system, including reservoir operation in monthly time increments. The model should have optimizing capability with

respect to reservoir operation and demand satisfaction, since searching among a myriad of possible operating rules can be extremely time consuming.

3. Consideration of non-beneficial consumptive losses such as reservoir evaporation and conveyance losses, though the latter may not actually be lost from the system.
4. Inclusion of the quantifiable aspects of institutional structures governing stream diversion and water storage.
5. Consideration of consumptive water use from municipal and agricultural sectors. Such consideration may range in detail from evapotranspiration prediction using climatic factors, to estimation of demand patterns from historical records.
6. Inclusion of possible imports to the basin from adjacent river basins.
7. Options for including the stochastic nature of inflows, perhaps using rainfall-runoff watershed models to predict virgin streamflows.
8. Flexibility to differentiate between energy consuming pumped pipeline flow and gravity channel flow.
9. Reasonably accurate consideration of irrigation return flows. A high degree of flexibility exists here in appropriate model detail necessary for stream-aquifer interactions within a long-term planning context.
10. Well documented and sufficiently demonstrated modeling procedures. Careful attention must be afforded balancing model detail with available data and study goals.

B. Selected River Basin Models

By no means was every river basin model in existence considered in the following review. Such a task would be all but impossible due to the large number available and the proprietary nature of some. Rather, the models reviewed in this report represent a cross-section of the types of models available which might prove useful in the synthesis of the desired model. The models selected for consideration along with their reference publication are:

1. POUDRE: R.G. Evans, "Hydrologic budget of the Poudre Valley," M.S. Thesis, Colorado State University, 1971.
2. HEC-3: U.S. Army Corps of Engineers, "HEC-3 reservoir system analysis for conservation--user's manual," Hydrologic Engineering Center, 723-030, July, 1974.
3. NW01: R.W. Ribbens, "Program NW01 river network program--user's manual," U.S. Bureau of Reclamation, Denver, Colorado, July, 1973.
4. MITSIM: R.L. Lenton and K.M. Strzepek, "Theoretical and practical characteristics of the MIT river basin simulation model," Ralph M. Parsons Laboratory, Report No. 225, Massachuestts Institute of Technology, August, 1977.
5. MITSIM-E: R.P. Schreiber, "A digital simulation model for conjunctive groundwater-surface water systems," M.S. Thesis, Massachusetts Institute of Technology, 1976.
6. SIMYLD: Texas Water Development Board, "Economic optimization and simulation techniques for management of regional water resource systems, river basin simulation model SIMYLD-II--

program description," Prepared by Systems Engineering Division, Austin, Texas, July, 1972.

7. WADIST: R.L. Thaemert, "Mathematical model of water allocation methods," Ph.D. Dissertation, Colorado State University, 1976.

8. WRMM: B. Wang, and others, "A water resource management model, Upper Jordan River Drainage, Utah," Utah Water Research Laboratory, Utah State University, March, 1973.

9. SSARR: U.S. Army Corps of Engineers, "Program description and user manual for SSARR model-streamflow synthesis and reservoir regulation," North Pacific Division, Program 724-KS-G0010, September, 1972.

Each model was reviewed with regard to determining its advantages and limitations with respect to those attributes deemed desirable for the synthesized model. All of the models have some similarities. For example, they all are oriented toward water allocation analyses instead of design problems. However, some of the models could be employed to analyze the impact of varying structural designs within a river basin. All are deterministic in the nature of inflow consideration. Monthly time increments are employed by the models except WADIST, which calculates a daily water delivery to irrigation systems throughout the season May through October. All of the surface water quantity aspects of the models use a fundamental mass-balance solution approach.

The above models differ widely in purpose and therefore have varying degrees of sophistication. For instance, NW01 is a surface flow and total dissolved solids accounting model which has limited simulation ability and considers flows only in 1000 acre-foot units. In comparison, SIMYLD is labeled a quasi-optimization model and provides highly detailed results. The models differ in data requirements and problem formulation. Some develop network configurations of the physical system, while POUDRE considers each canal system independently without preserving the morphology of the system.

While most of the models are designed for general application, some have received only hypothetical test considerations. Others, such as HEC-3, have received broad acceptance and usage throughout the United States. WADIST and POUDRE were developed for the legal system administered in Colorado, and even more specifically, for the Cache la Poudre River Basin, respectively. WRMM is the most hydrologically basic model considered, in that data requirements include temperature, precipitation, and snowmelt characteristics. However, WRMM is less favorable as the core model because it cannot consider water distribution complexities with sufficient detail, and has no optimizing capability. Several of the models (HEC-3, MITSIM, and MITSIM-E) also perform economic analyses as to benefits and costs to be expected from the operation of a system in some specified manner.

MITSIM-E (extended version of MITSIM) includes modeling of stream-aquifer interaction via a discretization of the groundwater basin into a network of irregular polygons. Finite-difference approximations are employed to solve the groundwater flow equations. Although MITSIM-E represents the most sophisticated modeling of groundwater-surface water interactions of these models, it does not have the capability of considering the quantifiable aspects of institutional dictates governing water distribution. In addition, the data necessary to execute MITSIM-E, such as groundwater head levels, storage coefficients, etc., are not always available on a basin-wide scale.

Some optimizing capability was considered extremely important in selecting the core model from which the synthesized model would evolve. Only SIMYLD offers such a feature. SIMYLD is capable of modeling a multi-reservoir river basin system, including the institutional framework. In the semi-arid western United States, water rights dictate, from a legal viewpoint, amounts of water that can physically be diverted for any purpose. Therefore, in order to realistically simulate the behavior of a river basin in this geographical region the water rights structure must, in some fashion, be included in the modeling effort. POUDRE and WADIST consider the legal framework of water allocation but lack the flexibility of considering the impacts of changes in the legal framework within a particular river basin. SIMYLD, however, through its general quasi-optimization capability allows for priorities or rankings of preferences of water diversion which may reflect the historical legal preferences existing or easily and quickly modified to reflect some new preferential scheme. It should also be noted that since SIMYLD calculates the transfer of water on a monthly volumetric basis and water rights priorities are established as flow (cfs), there has to be a lumping of priorities. Therefore, SIMYLD only approximates the water rights structure present in a river basin.

SIMYLD also provides high resolution of the distributional aspects of a river basin system. However, it does not have the capability of considering conveyance losses or irrigation return flows. Still, SIMYLD is considered as being the most appropriate base model for which suitable modifications can be added that further enhance its capability in regard to the overall model purpose. It has an optimizing capability which is an extremely important attribute of the desired model, and provides a detailed analysis of the distributional aspects of water transfers within a river basin. Also, SIMYLD can be readily adapted to an interactive, conversational mode. Simulation models must go through a trial and error process in order to determine reservoir releases that will meet downstream demands. The optimizing capability in SIMYLD uses an efficient network algorithm which can find strategies that meet demands, under given priorities, much more rapidly.

Tables II.1 through II.9 contain a complete analysis of each of these river basin models, including limitations of these models in comparison with the desired model. Chapter III further describes SIMYLD and the resulting synthesized model MODSIM.

Table II.1. MODEL: POUDRE

Model Purpose:	•Adjustment of various water flows throughout a river basin according to a set of weighted data to represent actual conditions in area
Problem Type:	•Hydrologic budget (allocation)
Type of Model:	•Accounting
Problem Formulation	•All inflows and outflows are determined for each canal system
Solution Approach:	•Mass balance on each irrigation portion of basin
Application:	•Specifically designed for Cache la Poudre River Basin, Colorado
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Monthly
Data Requirements:	•Extensive land use inventory •All inflows •Canal diversions •Consumptive loss coefficients •Root zone flows
Output:	•Detailed report of budget (including return flow, consumptive loss, etc.) for each canal system in basin
Major Assumptions:	•Constant crop acreages under each canal •Uniform application and runoff of irrigation water •All errors accumulated in groundwater flows
Advantages:	•Detailed consideration of irrigation sector •Considers mass balance for every irrigation canal in basin •Return flows
Limitations:	•Lacks flexibility of application to other river basins •Not designed for long-term planning studies •No detailed resolution of distributional aspects of river basin •All storage aggregated

Table II.2. MODEL: HEC-3

Model Purpose:	•Simulation of a multi-reservoir system for conservation purposes, includes economic analysis
Problem Type:	•Allocation
Type of Model:	•Simulation
Problem Formulation:	•Each system component designated as a control point with appropriate characteristics
Solution Approach:	•Mass balance by control point
Application:	•Wide acceptability and usage
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Variable (monthly recommended)
Data Requirements:	•Control point configuration •Reservoir characteristics •Power requirements •Hydrology •Economic factors •Evaporation •Desired diversions •Minimum diversions
Output:	•Detailed monthly conditions at each control point: inflow, outflow, storage, etc. •Results of economic analysis
Major Assumptions:	•All changes in system behavior can be accounted for at control points •Only one diversion per control point
Advantages:	•Hydropower •Economic analysis options •Comprehensive surface water simulation •General model
Limitations:	•No conveyance losses •Complex input format •No optimizing capability •No return flow calculation •No consideration of conditions between control points •Reservoir operating rules based on prescribed storage levels

Table II.3. MODEL: NW01

Model Purpose:	•Surface flow and TDS accounting model
Problem Type:	•Allocation
Type of Model:	•Accounting
Problem Formulation:	•Network
Solution Approach:	•Mass balance in downstream direction
Application:	•Used for some preliminary studies such as Cache la Poudre River, Colorado
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Monthly
Data Requirements:	•System configuration •Reservoir characteristics •Operating criteria •Imports/Exports •Water use information •Evaporation •Hydrology
Output:	•Monthly conditions at each node--flows, storages, etc.
Major Assumptions:	•Single downstream boundary •Tree type network
Advantages:	•Computes TDS at each node •Network provides detail between nodes •General model
Limitations	.Limited simulation ability •No optimization capability •1000 acre-foot units •No return flow calculation •No conveyance losses •Rough approximation of evaporation •Specified reservoir operating rules allow no flexibility •Only up to 5 reservoirs can be modeled

Table II.4. MODEL: MITSIM

Model Purpose:	•Hydroeconomic simulation of large-scale river basins
Problem Type:	•Allocation
Type of Model:	•Simulation
Problem Formulation:	•Node-Reach configuration
Solution Approach:	•Mass balance in downstream direction
Application:	•Vadar/Axios River Basin, Greece and Yugoslavia
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Monthly
Data Requirements:	•System configuration •Annual benefits •Loss coefficients •Annual costs •Diversion target flows •Power requirements •Evaporation •Hydrology
Output:	•Mean monthly performance for each node, ex. irrigation node, hydropower node, etc. •Statistical summary •Net economic benefits
Major Assumptions:	•Water allocated to users in upstream to downstream order
Advantages:	•Hydropower •Performs statistical analysis on results •Designed for large-scale long-term planning studies •Economic analysis •General model
Limitations:	•Limited flexibility in reservoir operating rules •No optimization capability •No conveyance losses

Table II.5. MODEL: MITSIM-E

Model Purpose:	•Conjunctive use of surface water and groundwater •Response of both artificial and natural aquifer recharge and discharge
Problem Type:	•Allocation
Type of Model:	•Simulation
Problem Formulation:	•Discretization of groundwater basin into network of irregular polygons
Solution Approach:	•Finite-difference approximation
Application:	•Hypothetical simplified test case
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Monthly
Data Requirements:	•Cellular structure of groundwater basin •Area of cell interfaces •Hydraulic conductivity •Storage coefficients •Initial head levels •Hydrology (infiltration, base flow)
Output:	•Groundwater availability •Distribution of groundwater and surface water contributing to demand
Major Assumptions:	•Constant percentage of applied water at each irrigation area goes to infiltration
Advantages:	•Three stream-aquifer interactions can be modeled: 1. base flow 2. groundwater recharge 3. streamflow infiltration
Limitations:	•Complex problem formulation •Not compatible with broad planning scope •Data requirements •Cannot consider complex surface water system

Table II.6. MODEL: SIMYLD

Model Purpose:	•Simulation of multi-reservoir river basin system with consideration of institutional framework
Problem Type:	•Allocation
Type of Model:	•Quasi-optimization
Problem Formulation:	•Capacitated Network (circulating)
Solution Approach:	•Out-of-kilter network optimization algorithm which preserves nodal mass balance
Application:	•Limited application on Texas river basins
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Monthly
Data Requirements:	•System configuration •Node characteristics •Operational priorities •Inflows, demands and evaporation rates
Output:	•Highly detailed output by node for each month of simulation •Summary report over entire simulation period
Major Assumptions:	•Unidirectional flow •All linkages bounded from above and below •All inflows, demands, and losses occur at nodes
Advantages:	•Quasi-optimization •High resolution of distributive aspects of river basins •General Model
Limitations:	•No conveyance losses •No return flow calculations

Table II.7. MODEL: WADIST

Model Purpose:	•Irrigation demand allocation
Problem Type:	•Allocation
Type of Model:	•Accounting
Problem Formulation:	•Control point concept
Solution Approach:	•Distribution of virgin flow according to prescribed entitlement
Application:	•Designed for Colorado water law •Test case: Poudre River Basin
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Daily
Data Requirements:	•Diversion data •Reservoir data •Daily flow data
Output:	•Summary output of transfers to each canal system including debits and credits and sources of supply
Major Assumptions:	•Constant water requirements •Constant loss factor •Surface return flow has one-day lag
Advantages:	•Conveyance losses considered •Crop water requirements approximated •Return flows calculated
Limitations:	•Distribution criteria must be predetermined •Cannot readily consider varying water rights structure •Daily time interval not suited for long-term planning studies •Specific to particular river basin •Constant demands for water

Table II.8. MODEL: WRMM

Model Purpose:	•Watershed hydrology simulation
Problem Type:	•Allocation
Type of Model:	•Watershed simulation with parameter optimization
Problem Formulation:	•Decomposes river system into subbasins with all activity in subbasin aggregated
Solution Approach:	•Mass balance from subbasin to subbasin
Application:	•Upper Jordan River Drainage, Utah
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Monthly
Data Requirements:	•Temperature, precipitation, groundwater inflows, gaged flows, reservoir characteristics, irrigation diversions, imports, exports
Output:	•Storage change, precipitation, snowmelt, and inflow & outflow for each subbasin
Major Assumptions:	•Subbasins are gaged at upstream and downstream boundaries
Advantages:	•Considers basic hydrologic inputs to system •Capable of considering very large river basin systems •Groundwater consideration
Limitations:	•Does not consider distributive complexities with any detail •No optimizing capability •No conveyance losses •Cannot consider complex channel morphology

Table II.9. MODEL: SSARR

Model Purpose:	•Streamflow synthesis and reservoir regulation model
Problem Type:	•Allocation
Type of Model:	•Mathematical hydrologic model of a river basin system which synthesizes streamflow from snowmelt and rainfall
Problem Formulation:	•Decomposes river basin system into relatively homogeneous hydrologic units. User then specifies upstream to downstream order of all watersheds, reservoirs and river reaches
Solution Approach:	•Modular operating procedure whereby watershed runoff modeling is followed by river system model for streamflow routing combined with reservoir regulation
Application:	•Columbia River Basin through the Cooperative Columbia River Forecasting Unit
Deterministic vs Stochastic:	•Deterministic
Time Period:	•Variable (daily)
Data Requirements	•Description of non-variable physical features •Current conditions of all watershed-runoff indices •Precipitation data, air temperatures, and thermal budget data •Job control and time control data
Output:	•Variable output format which includes listings and/or plotted information concerning simulated system behavior
Major Assumptions:	•Watersheds can be divided into homogeneous units •Linear storage-discharge relationships
Advantages:	•General model •Considers basic hydrologic inputs to system •Streamflow routing •High resolution of channel morphology •English or metric units
Limitations:	•No conveyance losses •No optimizing capability •Not as suitable for long-term management studies (i.e., daily time increments)

CHAPTER III

MODEL SYNTHESIS

This chapter describes in detail the synthesized model MODSIM. The core model is first presented followed by a discussion of modifications to the core model, SIMYLD, which result in the synthesized model MODSIM. Included in this chapter is an interpretation of various components of the network constructed and solved by MODSIM. The following chapter, Chapter IV, contains an in-depth user documentation of Program MODSIM.

A. The Core Model: SIMYLD

A.1 Background to core model selection

Selection of the base or core model, from the specific models reviewed in Chapter II, was contingent upon certain objective criteria including:

1. flexibility in application
2. capability of simulating a large river basin system over a period of several years
3. detail of model output provided
4. input data requirements
5. rapid-access computer core memory requirements
6. central processor time required for a typical run.

In addition to these qualifications, an intuitive feel of those aspects of the core model which would provide a measure of trust for the user was considered. The program methodology must not be so obscure as to prohibit even a rudimentary understanding of its assumptions, approximations, capabilities, and limitations. Also, the core model selection was, in part, based on a comparison of the capabilities of the reviewed models with the capabilities deemed *desirable* for the model. Of these models, Program SIMYLD (Texas Water Development Board, Systems Engineering Division, 1972) was selected as the most appropriate core model, based on the above discussion.

A.2 Program description

The computer program SIMYLD employs the *Out-of-Kilter-Method* (OKM) (Bazaraa and Jarvis, 1977; Clasen, 1968; Durbin and Kroenke, 1967; Ford and Fulkerson, 1962; Fulkerson, 1961) to minimize the total *cost* of flows in a network of interconnected reservoirs, river reaches, pump canals, and gravity flow canals. SIMYLD is capable of indirectly preserving water diversion and storage priorities established by water rights in the basin. This capability is achieved through a ranking procedure which is translated into *pseudo-costs* of water transfer. Using this ranking procedure, SIMYLD apportions available water for storage in various reservoirs and diversion of flow from the river according to their priority. If pump canals are included, the actual energy costs can be used. Otherwise, the costs used in the model are for ranking priorities for water use only. Other more informal institutional structures, such as water exchange agreements (i.e., the diversion of water out of priority as long as downstream senior direct flow rights are satisfied through reservoir releases) can be included.

A.3 Program methodology

The underlying principle of the operation of SIMYLD is that most physical water resources systems can be represented as capacitated flow networks. The *real* components of the system are represented in the network as nodes (storage and non-storage points) and links (canals, pipelines, river reaches). Reservoirs, demand points, canal diversions, and river confluences are represented as nodes, while river reaches, canals, and closed conduits are node to node linkages. In order to consider demands, inflows, and desired reservoir operating rules, several artificial nodes and linkages must be created. These additional nodes and linkages also insure the circulating nature of the network, which is a necessary condition if the Out-of-Kilter Algorithm is to be employed. A discussion of these artificial arcs is included in the final section of this chapter.

Basic assumptions associated with the core model include:

1. All storage nodes and linkages must be bounded from above and below (i.e., minimum and maximum storages and flows must be given).
2. Each linkage must be unidirectional with respect to flow.
3. All inflows, demands, and losses must occur at nodes.
4. An import node can be designated for water entering the system from across system boundaries.
5. Each reservoir can be designated as a spill node for losses from the system proper.
6. Spills from the system are the most expensive type of water transfer, in the sense that the model seeks to minimize unnecessary spill.

7. Reservoir operating policies are provided by the user as desired in-storage volume for each reservoir at the end of each month throughout the simulation period.

Within the confines of mass balance throughout the network, SIMYLD sequentially solves the following linear optimization problem via the Out-of-Kilter Algorithm.

$$\text{minimize} \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij}\, q_{ij} \qquad \text{(III.1)}$$

subject to:

$$\sum_{i=1}^{N} q_{ij} - \sum_{i=1}^{N} q_{ji} = 0 \quad ; \quad j=1,\ldots,N \qquad \text{(III.2)}$$

$$\ell_{ij} \leq q_{ij} \leq u_{ij} \quad ; \quad \text{for } i,j=1,\ldots,N \qquad \text{(III.3)}$$

$$\ell_{ij} \geq 0$$

where

q_{ij} = integer valued flow from node i to node j

w_{ij} = weighting or priority factor per unit of flow for node i to node j

ℓ_{ij} = lower bound on flow in the linkage connecting node i to node j

u_{ij} = upper bound on flow in the linkage connecting node i to node j

Equation III.2 insures that the flow into any one node is equal to the flow out of that node. The OKM is an extremely efficient primal-dual simplex algorithm that takes advantage of the special structure of a network-type problem. Appendix A contains an in-depth presentation of the out-of-kilter method, including an example problem which has been solved using hand calculations.

The reasoning behind labeling SIMYLD and subsequently MODSIM as *quasi-optimization* models stems from the fact that the global optimum is not actively sought. The network flow problem, however, is solved *successively* time period by time period.

B. Advantages of Network Approach to River Basin Modeling

There are certain real advantages of employing modern network theory to the solution of large-scale river basin problems. Hamdan (1974) lists these advantages rather succinctly.

1. A network formulation of a system provides a physical picture revealing the morphology of the system, which is readily recognizable.
2. Network optimization techniques (particularly the Out-of-Kilter Algorithm) are efficient solution techniques.
3. If the OKM is used, computation may begin with *any* solution, regardless of feasibility.
4. Extremely large (in terms of network components) problems can be solved.
5. Changes in some system components can be easily incorporated by manipulation of the previously constructed network.

C. MODSIM Synthesis

The core model, SIMYLD, was extensively modified so as to better conform to the proposed desired model. This section describes those modifications which resulted in the synthesized river basin planning model MODSIM. Chapter IV contains the discussion of the interactive, conversational aspects of data file organization which is interfaced with MODSIM.

C.1 Modifications to core model

The following extended capabilities were added to SIMYLD which resulted in the synthesized model MODSIM being more representative of the desired model.

Target Storage Levels: SIMYLD computes a hydrologic state on a monthly basis by considering current reservoir storage levels and inflows to these reservoirs. Associated with each of these states (average, dry, wet) is a corresponding set of operating rules with ranking priorities. These three hydrologic states are computed by selecting all or some of the reservoirs within the system (user preference) and performing the following analysis:

$$R = \sum_{i=1}^{N} S_{it} + \sum_{i=1}^{N} I_{i,t+1} \qquad \text{(III.4)}$$

$$W = \sum_{i=1}^{N} S_{imax} \qquad \text{(III.5)}$$

where:

N = number of reservoirs in the system

t = current month of operation

S_{it} = end of month t storage in reservoir i

S_{imax} = storage capacity for reservoir i, which may be less than the actual maximum capacity due to dam stability and safety considerations.

The user also specifies the upper and lower bounds of the average state as fractions of the total subsystem storage capacity:

$$LB = x_1 W \tag{III.6}$$

$$UB = x_2 W \tag{III.7}$$

where:

LB = lower bound of average state

UB = upper bound of average state

x_1 = percentage which defines lower limit of average state

x_2 = percentage which defines upper limit of average state

Subsequently, the hydrologic states are defined as:

Dry: $R < LB$

Average: $LB \leq R \leq UB$

Wet: $R > UB$

With the above method of calculating target operating rules, for a long period of analysis, only three target storage levels can be used for any one reservoir. However, the option has been included in MODSIM whereby the user can input separate target storage levels for each reservoir and for each month throughout the *entire* analysis.

Varying Priorities: In the core model, only three differing priorities for any node (storage and/or demand) can be included. Again, these priorities correspond to wet, average, or dry conditions calculated by the model. An additional option has been included which enables the user to input a separate priority for any node for each year of the analysis. This expanded capability means that instead of a maximum of three priorities associated with a wet, average, or dry state, a varying priority can be input for each year of analysis.

Import Nodes: SIMYLD will consider only one import node (i.e., flow originating outside the network). The modified code includes a variable number of possible import nodes.

Area-Capacity Points: Eighteen data points relating reservoir capacity to reservoir surface area are originally required. This means that zero filled entries must be made if, for instance, data are such that only 12 pairs of points are available. This leads to computing inefficiency and increased input time to read the remaining pairs of zeros. The revised code will accept a variable number of area-capacity data points up to a maximum of 18.

Variable Upper Bound on Links: All physical links in the network must be bounded from above. However, as SIMYLD is designed, only one upper bound for each link can be considered in the analysis. For some cases (Case Study #2) this limitation may not be realistic. MODSIM includes the additional capability of allowing the user to input (as originally designed) only one bound per link, or 12 varying monthly maximum flow limits per link.

Flow Through Demand: Demand satisfaction for SIMYLD, as originally designed, does not provide for demands for water which are not terminal; i.e., demands which flow *through* the demand node and remain in the network for subsequent diversion. All water contributing to demand satisfaction in the core model is lost from the network. These are termed *terminal demands*. However, MODSIM will consider both *terminal demands* and *flow-through demands*.

Variable Linkage Cost: The core model prices river reaches to 1 and pump canals to 2, automatically. Once again, for certain problems, this situation may not reflect actual cost variations within the problem. In order to more realistically consider variable water transfer costs throughout a network, MODSIM provides the option of inputing a varying cost for each linkage in the network.

Output Options: The original code outputs results in three reports: (1) echo print of input data, (2) monthly summaries of results for each year of analysis, and (3) a summary report (quite lengthy, for long planning periods) by node and year. The user now has the option of suppressing any or all of these reports according to his computational objectives.

Local File Creation: In order to facilitate additional analyses, all link flows (every link, every month) are read onto a local file which can be saved as a permanent file and read by subsequent user developed programs for further analysis.

Channel Losses: A significant addition to SIMYLD is the capability of including channel losses directly. A loss coefficient for each reach must be included in data input. This coefficient represents the fraction of the total flow in the link that would be lost. For example, some of the earthlined irrigation ditches in the Cache la Poudre River Basin in north central Colorado have estimated loss coefficients from 20 percent to 33 percent of the flow in the ditch. Subroutine CHANLS was added to the code to calculate the expected channel losses for each month. The procedure is as follows: first, network flows are solved via the Out-of-Kilter Algorithm with no losses. Initially, all flows are set to zero, or the lower bound if greater than zero. The losses in each link are computed by multiplying the loss coefficient by the calculated flows. This loss is established as a demand at the downstream node for each link. The Out-of-Kilter Algorithm is solved again with the increased demand. However, the initial feasible solution is now set equal to the previous optimum solution. New link losses are then computed and the procedure is repeated until acceptable convergence has occurred.

Return Flows: One of the most important modifications to the core model is the inclusion of the capability of determining irrigation return flows. Several options as to the methodology for including return flows in MODSIM were considered. Classical groundwater theory used to develop a finite element or finite difference approach to stream-aquifer interaction was disregarded due to the nature of the purpose of MODSIM. Such an approach would have necessitated extensive data gathering exercises and would not have been compatible with the general context of this planning model. However, for real-time management models, where a smaller (perhaps daily) time increment is employed, such an approach may be required. Also, in many cases, data concerning groundwater head levels, storage coefficients, etc. are not readily available for large-scale river basin studies.

A methodology for including return flows in MODSIM calculations, which would remain consistent with the broad, general nature of a planning model, was developed using an approach similar to one taken by Hodgson (1978). Hodgson (1978) uses multiple linear regression to simulate groundwater level responses. Since return flows are dependent upon the amount of water applied to irrigation, which is a function of the volume of water diverted to irrigation, the development of a predictive equation for return flows based on ditch diversions also has validity.

The number of monthly lags and the components (independent variables) included in the regression equation must be determined off-line. However, once the regression coefficients have been determined, MODSIM has the capability of considering up to 10 different return flow multiple linear regression equations with up to a maximum six-month lag. The following step-by-step procedure is recommended for use of this option.

1. Determine the number of return flow estimates necessary per month, based on the network design and the nature of the problem.
2. Determine which nodal diversions contribute to each return flow estimate.
3. Determine to which node in the network each monthly return flow estimate will accrue.
4. Using monthly historical data (ditch diversions and return flows), perform statistical correlation studies to determine the appropriate number of monthly lags.
5. Construct multiple linear regression equation based on the results of the above exercise.
6. Solve for regression coefficients for each return flow equation.

According to user input, MODSIM calculates monthly return flows, iterating over demand satisfaction, until acceptable convergence is achieved. Subroutine RTFLOW has been added to MODSIM for this purpose. A detailed example of the procedure with accompanying results is provided in Chapter VI.

C.2 MODSIM network interpretation

As previously mentioned, MODSIM solves a capacitated network of real and artificial nodes and arcs. For each real network, a series of artificial nodes and linkages is automatically appended to this network to guarantee circulation and Equation III.1 is solved for the entire network. Therefore, these artificial nodes and arcs are necessary so that ultimately some of the q_{ij} can be interpreted as demands and storages. This section describes these additional artificial arcs and the calculations of the bounds and costs for these arcs. Figure III.1 displays the total linkage configuration for MODSIM. All of the arcs shown in this diagram are artificial.

Artificial Inflow Arcs: Inflow arcs link each real node (storage and non-stroage) with an artificial initial storage and inflow node. The lower bound is set equal to the upper bound which is in turn set equal to the volumetric inflow to each particular real node. In this manner, the model is constrained to accept the particular nodal inflows input. The unit costs (w_{ij} in Equation III.1) are set equal to zero.

Artificial Demand Arcs: Demand arcs link each real node (storage and non-storage) with an artificial demand node. The lower bound on these arcs is set equal to zero, while the upper bound is set equal to the demand associated with each real node. The cost placed on each artificial demand arc is calculated by the following equation:

$$(w_{i,d})_t = - [1000 - (DEMR_{i,t} \cdot 10)] \qquad (III.8)$$

where:

$(w_{i,d})_t$ = cost of transporting one unit of water from real node i to artificial demand node d during month t

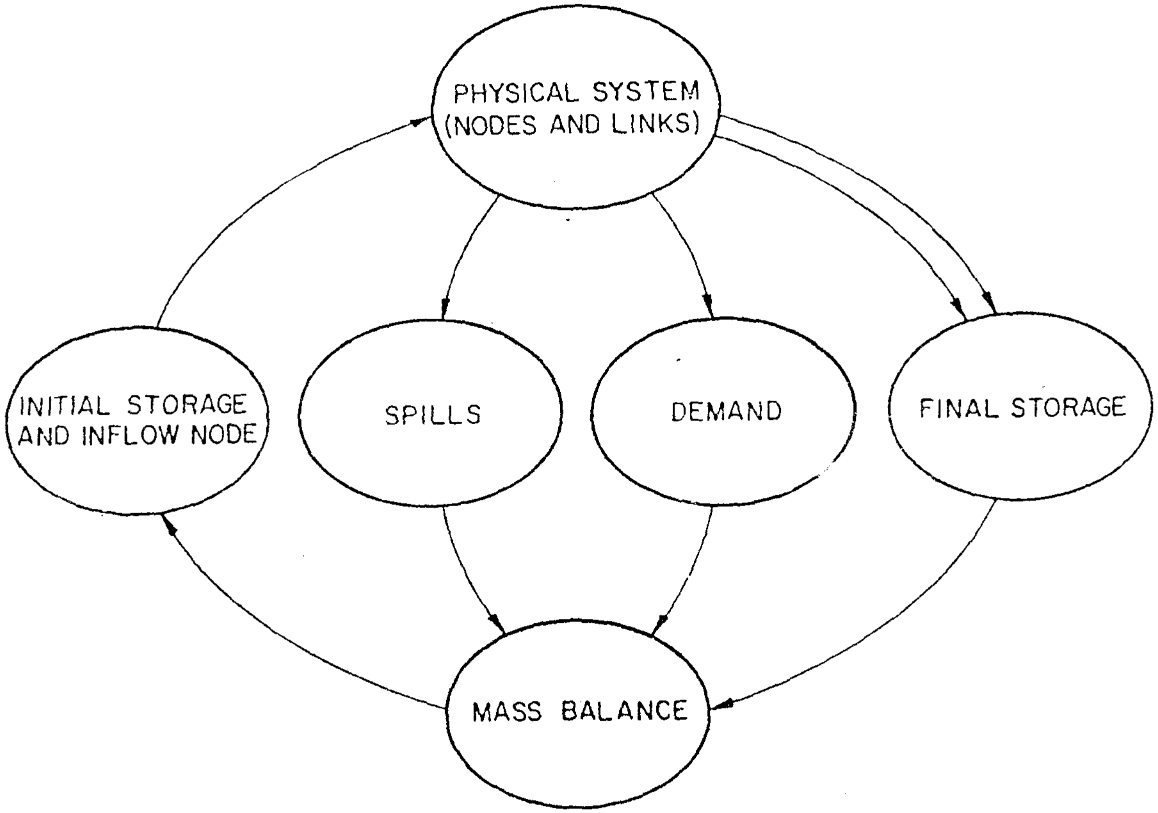


Figure III.1. Schematic diagram of linkage configuration for MODSIM.

$DEMR_{i,t}$ = user input priority for meeting demand at node i during month t

d = artificial demand node

i = real node

t = month

As the priority placed on demand satisfaction at node i $(DEMR_i)_t$ increases, i.e. ($DEMR_{i,t}$ actually *decreases*) the cost of transporting water via the artificial arc (i,d) decreases, making the transport of water through this arc more advantageous in relation to other linkages assuming all other costs remain constant. In this manner, the priorities placed on demand satisfaction at each demand node can be used to simulate the institutional framework (water rights priorities) or operational preferences present in all developed river basins in the semi-arid western United States. Again, a lower value of $DEMR_{i,t}$ means a higher priority.

Artificial Desired Storage Arcs and Artificial Final Storage Arcs: In order to provide capacitance in the network, another artificial node is established with linkage to all real nodes. The flows in these linkages or arcs are interpreted as storage volumes in the final results for the current month. For each real node, there are two artificial arcs connecting it with the artificial storage node. One arc is the *desired* storage arc, and the other is the *final* storage arc. The lower bound on desired storage arcs is set at the reservoir minimum capacity plus an estimate of the expected evaporation which would occur if the reservoir went from its current state to the minimum pool. However, if the lower bound of the artificial inflow arc to the reservoir in question is less than the lower bound on the desired storage arc, the lower bound on the desired storage arc is replaced by the lower bound on the corresponding inflow arc. This condition is necessary to insure network feasibility and subsequently that mass balance is maintained. The upper bound placed on desired storage arcs is the target storage level plus an estimate of the evaporation which would occur if the reservoir went from the current state to the target storage level. The cost associated with transferring one unit of water along the desired storage arc is calculated using an equation identical to Equation III.8 for demand arcs.

$$(w_{i,ds})_t = -\,[1000 - (OPRP_{i,t} \cdot 10)] \qquad \text{(III.9)}$$

where:

$(w_{i,ds})_t$ = cost of transporting one unit of water from real node i to artificial storage node ds during month t

$OPRP_{i,t}$ = user input priority for meeting the target storage level at node i during month t

ds = artificial storage node

i = real node

t = month

The cost $w_{i,ds}$ is interpreted in exactly the same manner as the previously discussed $w_{i,d}$ (Equation III.8). Such a procedure gives MODSIM the added advantage of being able to consider preferences among various reservoir storage levels in relation to various demands throughout the network. A final storage arc must also be employed to compensate for situations when (due to the nature of inflows and priorities) the reservoir storage must exceed the target level. The final storage arc connects each reservoir with the artificial storage node in the same manner as the desired storage arc. However, its lower bound equals zero and its cost equals zero. The upper bound is set equal to the difference between the maximum storage capacity and the target storage level, minus an estimate of evaporation for this case. The *real* node calculated storage volume becomes the sum of the flow in both of these arcs upon solution of the Out-of-Kilter Algorithm.

Artificial Spill Arcs: MODSIM also employs artificial spill arcs which help to maintain feasibility in the network solution. These arcs have the highest unit cost of all arcs associated with them. Each real storage node is linked with the artificial spill node by one artificial arc. The lower bound equals zero while the upper bound equals the total capacity of all reservoirs. The unit cost associated with the transfer of water through a spill arc is 10,000 multiplied by its preferential order.

Mass Balance Arcs: Finally, to assure that a circulating network is constructed, and also to insure mass balance throughout the system, an artificial mass balance node is included with arcs from the artificial demand, storage, and spill nodes leading to it, and one arc from it leading to the artificial inflow node. The costs associated with these mass balance arcs are zero along with the lower bounds (except the lower bound on the inflow mass balance arc), while the upper bounds on these arcs are the summation of the upper bounds on the arcs leading to the particular artificial node (demand, storage, spill).

Figure III.2 shows a simplified network which includes all artificial nodes and arcs as they would be constructed by MODSIM. Only nodes one and two represent the real network. The remaining nodes enhance MODSIM capability according to the above discussion. The user

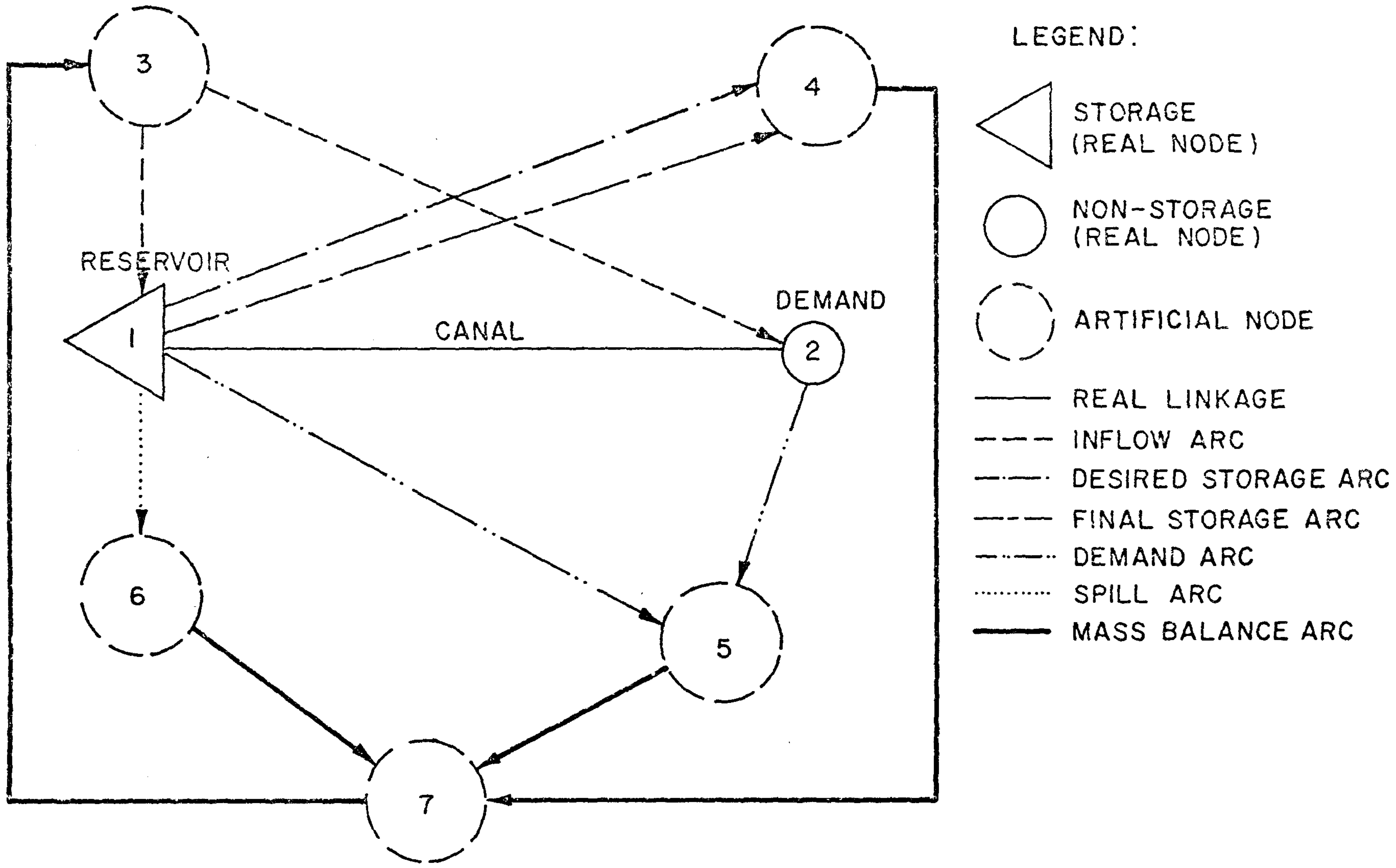


Figure III.2. Simplified network with artificial nodes and arcs included.

should note that, although he need be concerned only with his real network (MODSIM constructs the total network), the true size of his network (the one solved via the OKM) will be considerably larger than the real network. The total number of nodes in the total network will be only five larger than the real network. However, the total number of arcs will be:

$$\#ARCS = N_L + 4N_D + N_S + N_B$$

where

N_L = number of physical links (river reaches, canals, etc.)

N_D = number of nodes (storage and non-storage)

N_S = number of spill nodes

N_B = number of mass balance arcs = 4.

CHAPTER IV

MODSIM USER DOCUMENTATION

This chapter presents a practical guide for the actual execution of the simulation package. Input requirements are listed and a detailed demonstration of the interactive, conversational mode of data organization is included. Figures displaying the content of output reports are also provided. A complete, but very elementary, example exercise is presented, followed by a discussion of varying approaches by which the model can be used to aid in the analysis of important tradeoffs among in-stream, storage, and consumptive uses of water.

A. Data Requirements

The information necessary to successfully use Program MODSIM includes:

1. physical description of the system to be simulated
2. operational criteria
3. model control parameters
4. monthly unregulated inflows
5. monthly demands
6. monthly evaporation rates.

Two separate files must be created containing the above data. A binary file has to be created which contains monthly unregulated inflows, monthly demands, and monthly evaporation rates. A coded file (card images) contains all network morphology, operational criteria, and model control parameters. The coded file is divided into several records. The following offers a description of the information required for each record:

Record #1: Control options

1. channel loss option
2. echo print of input data option
3. summary output option
4. priority options (discussed in previous chapter)
5. return flow option

Record #2: Title or heading for simulation

Record #3: Network morphology parameters

1. number of nodes
2. number of reservoirs
3. number of links
4. number of river reaches
5. number of years in simulation
6. number of demand nodes
7. number of spill nodes
8. first calendar year of simulation
9. number of import nodes
10. from-to years for detailed output

Record #4: System nodes (storage nodes must precede all non-storage nodes)

1. node name
2. maximum capacity
3. minimum capacity
4. starting storage

Record #5: Spill reservoirs in order of preference

Record #6: Reservoir area-capacity tables

Record #7: Demand nodes

1. priority or ranking
2. node to which flow through accrues (if necessary)

Record #8: Import nodes

1. annual import
2. monthly distribution as percentage of total amount

Record #9: Calculation of hydrologic states (optional)

Record #10: Conversion factors (optional)

Record #11: Reservoir operational criteria

1. priority or ranking
2. desired storage levels, percentage of maximum capacity

Record #12: System configuration

1. number of variable capacity links
2. origin node for each link
3. termination node for each link
4. minimum capacity
5. maximum capacity
6. linkage loss coefficient
7. linkage unit cost

Record #13: Return flow (optional)

1. number of separate return flow equations
2. number of monthly lags
3. regression coefficients
4. nodes contributing to return flow

5. node accepting return flow
6. observed data for zero minus number of monthly lags

Usually, data files for computer models of this nature are punched on computer cards. This can be an exhausting and frustrating experience, especially if one is not familiar with the particular computer language used and consequently does not completely understand the data formatting. It is the author's opinion that many good simulation models have gone without use for this very reason. Those individuals who would have benefited most from their use did not have the time, patience, and/or computing expertise to follow through with the often long and tedious job of organizing the data in a form suitable for input. However, with Program MODSIM, the capability exists for developing a complete data file, ready for input, without manually punching a single computer card or knowing a single FORTRAN programming statement. This added capability is the result of interactive, conversational programming.

Conversational programming allows the user to execute a FORTRAN code, written in this mode, which queries him concerning the nature of the simulation and, based on his responses, constructs a data file which corresponds exactly to the input format for Program MODSIM. This file is then saved as a system permanent file which is attached to Program MODSIM for execution. Also, the data organization program checks periodically for inconsistencies in the input file which may lead to job abortion.

B. Data Management Program ORGANZ

The program designed to construct the coded data file for Program MODSIM is called ORGANZ. The most appropriate manner in which to present a program of this nature is through demonstration. Figure IV.1 contains a very simple network of four nodes (two reservoirs, two non-storage nodes, three links, and one import node). Node #4 is the demand node, and Reservoir #1 has an unregulated inflow. For the sake of demonstration, it is also assumed that Node #3 has a demand associated with it which only contributes to return flows at Node #4. Capacities and loss coefficients are as displayed. Operational criteria are dependent upon the nature of the problem being analyzed. In demonstrating Program ORGANZ, these criteria will be assumed, however, they are discussed in the section concerning use of program MODSIM to evaluate tradeoffs among varying water uses.

Program ORGANZ must be executed via a *procedure file* which has the form:

```
CLEAR.                        (readies system for new job)
GET,ORGANZ.                   (attaches file to job)
FTN,I=ORGANZ,L=0.             (compiles FORTRAN program)
LGO.                          (executes program)
REWIND,A.                     (writes new job control language)
CALL,A.                       (executes new job controls)
```

The above procedure file is compatible with CDC172 time-sharing software packages. For other time-sharing systems a different (depending on control language) but similar procedure file must be created. Also, depending on the particular FORTRAN compiler used, the free format statements may require modification. The results of the application of Program ORGANZ to the construction of

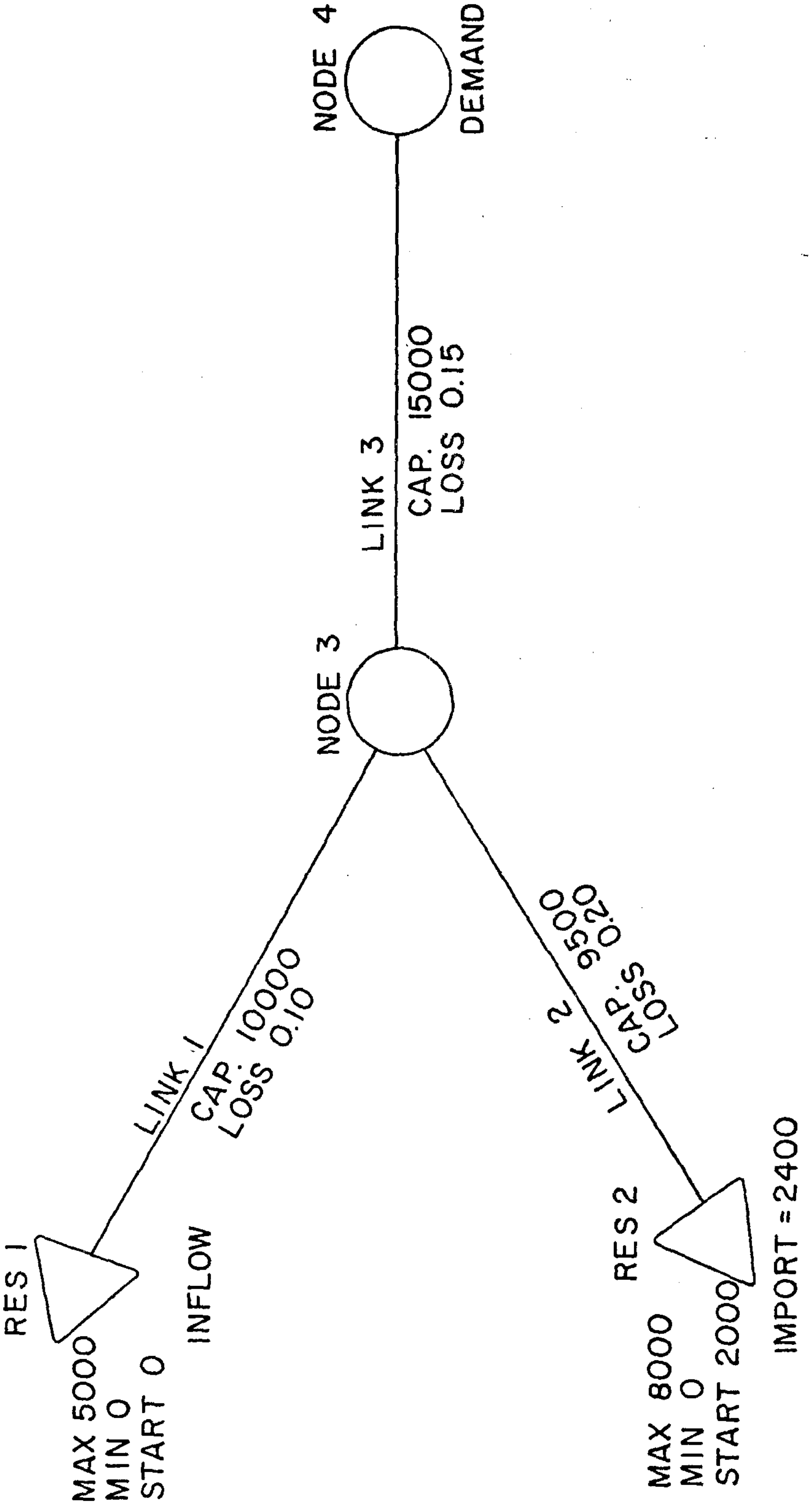


Figure IV.1. Simplified example network.

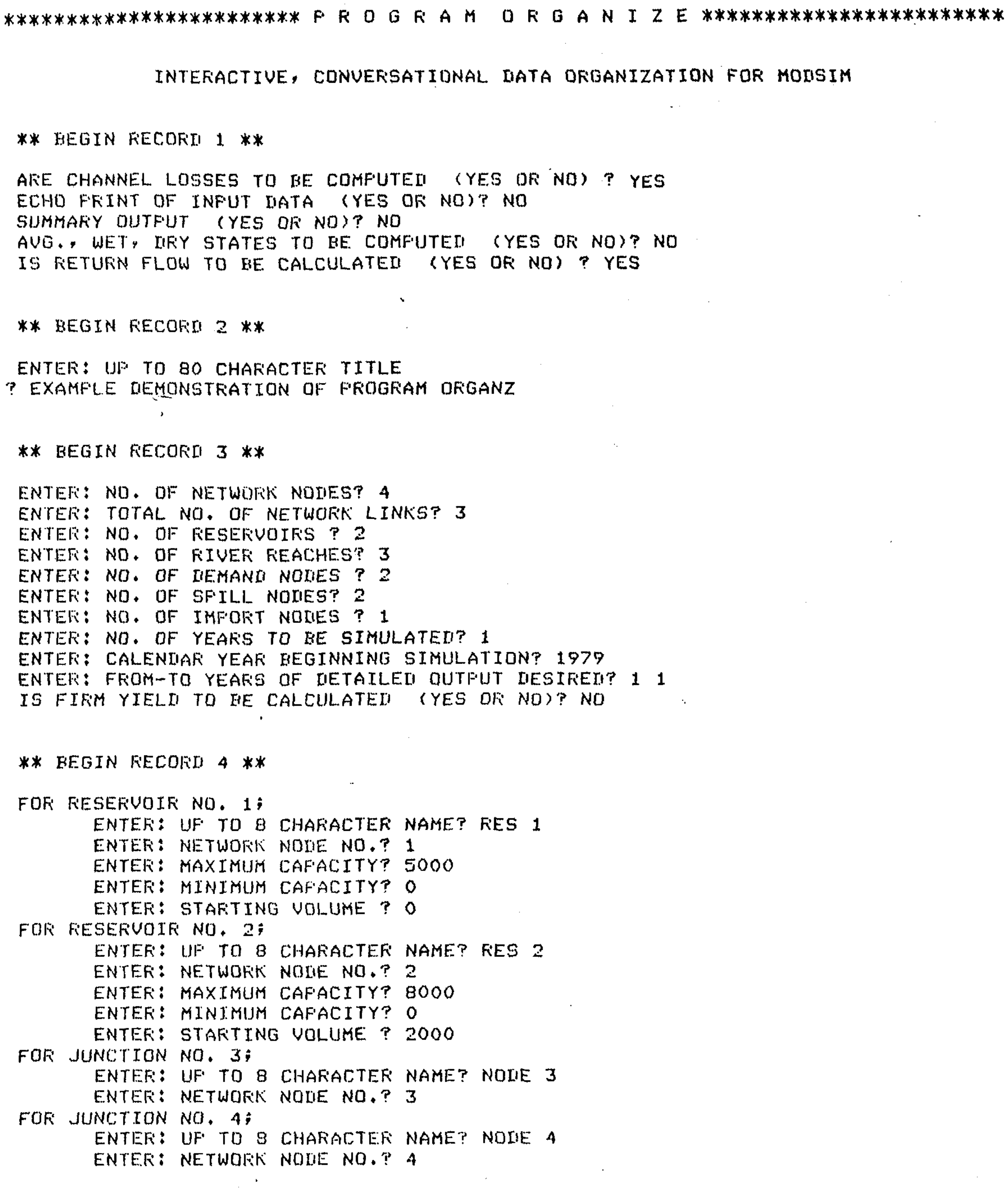
a data file for the network in Figure IV.1 is displayed in Figure IV.2. Appendix B of this report contains a listing of the FORTRAN IV source listing for Program ORGANZ. Figure IV.3 shows a listing of the resulting coded data file which Program ORGANZ produces for this hypothetical example problem. This file is in exact Program MODSIM format and can either be attached directly to Program MODSIM for execution or sent to system card punching hardware to be punched on 80 column computer cards which can subsequently be read via card reader hardware and executed by Program MODSIM.

C. Binary Data File Creation

As mentioned previously, it is necessary to create a binary file containing all nodal inflows, demands, and evaporation rates, which also is attached to Program MODSIM prior to execution. To accomplish this task, interactive, conversational Program ADATA was written. Program ADATA is executed in exactly the same manner as Program ORGANZ, from a *procedure file* like (or similar to) the following:

```
CLEAR.
GET,ADATA.
FTN,I=ADATA,L=0.
LGO.
REWIND,B.
CALL,B.
```

Figure IV.4 displays an example of the execution of Program ADATA for the demonstration network in Figure IV.1. The binary data file is saved as a permanent file for subsequent attachment to Program MODSIM.



```
************************ P R O G R A M   O R G A N I Z E ************************

           INTERACTIVE, CONVERSATIONAL DATA ORGANIZATION FOR MODSIM

 ** BEGIN RECORD 1 **

 ARE CHANNEL LOSSES TO BE COMPUTED  (YES OR NO) ? YES
 ECHO PRINT OF INPUT DATA  (YES OR NO)? NO
 SUMMARY OUTPUT  (YES OR NO)? NO
 AVG., WET, DRY STATES TO BE COMPUTED  (YES OR NO)? NO
 IS RETURN FLOW TO BE CALCULATED  (YES OR NO) ? YES


 ** BEGIN RECORD 2 **

 ENTER: UP TO 80 CHARACTER TITLE
? EXAMPLE DEMONSTRATION OF PROGRAM ORGANZ


 ** BEGIN RECORD 3 **

 ENTER: NO. OF NETWORK NODES? 4
 ENTER: TOTAL NO. OF NETWORK LINKS? 3
 ENTER: NO. OF RESERVOIRS ? 2
 ENTER: NO. OF RIVER REACHES? 3
 ENTER: NO. OF DEMAND NODES ? 2
 ENTER: NO. OF SPILL NODES? 2
 ENTER: NO. OF IMPORT NODES ? 1
 ENTER: NO. OF YEARS TO BE SIMULATED? 1
 ENTER: CALENDAR YEAR BEGINNING SIMULATION? 1979
 ENTER: FROM-TO YEARS OF DETAILED OUTPUT DESIRED? 1 1
 IS FIRM YIELD TO BE CALCULATED  (YES OR NO)? NO


 ** BEGIN RECORD 4 **

 FOR RESERVOIR NO. 1;
       ENTER: UP TO 8 CHARACTER NAME? RES 1
       ENTER: NETWORK NODE NO.? 1
       ENTER: MAXIMUM CAPACITY? 5000
       ENTER: MINIMUM CAPACITY? 0
       ENTER: STARTING VOLUME ? 0
 FOR RESERVOIR NO. 2;
       ENTER: UP TO 8 CHARACTER NAME? RES 2
       ENTER: NETWORK NODE NO.? 2
       ENTER: MAXIMUM CAPACITY? 8000
       ENTER: MINIMUM CAPACITY? 0
       ENTER: STARTING VOLUME ? 2000
 FOR JUNCTION NO. 3;
       ENTER: UP TO 8 CHARACTER NAME? NODE 3
       ENTER: NETWORK NODE NO.? 3
 FOR JUNCTION NO. 4;
       ENTER: UP TO 8 CHARACTER NAME? NODE 4
       ENTER: NETWORK NODE NO.? 4
```

Figure IV.2. Demonstration of Program ORGANZ for simplified network in Figure IV.1.

```
 ** BEGIN RECORD 5 **

 ENTER: 2 SPILL NODE(S) IN ORDER OF PREFERENCE? 2 1


 ** BEGIN RECORD 6 **

 ENTER: NO. OF AREA-CAPACITY POINTS PER RES.? 4
 FOR RESERVOIR NO. 1;
       ENTER: POINT 1 [AREA-CAPACITY] ? 0 0
       ENTER: POINT 2 [AREA-CAPACITY] ? 20 1250
       ENTER: POINT 3 [AREA-CAPACITY] ? 70 3500
       ENTER: POINT 4 [AREA-CAPACITY] ? 100 5000
 FOR RESERVOIR NO. 2;
       ENTER: POINT 1 [AREA-CAPACITY] ? 0 0
       ENTER: POINT 2 [AREA-CAPACITY] ? 70 2000
       ENTER: POINT 3 [AREA-CAPACITY] ? 150 5000
       ENTER: POINT 4 [AREA-CAPACITY] ? 200 8000


 ** BEGIN RECORD 7 **

 PRIORITY FOR EACH YEAR OF SIMULATION WILL BE INPUT
 FOR DEMAND NODE NO. 1;
       ENTER: NETWORK NODE NO.? 3
       IS THIS A FLOW THRU DEMAND  (YES OR NO)? NO
       ENTER: PRIORITY FOR SIMULATION YEAR 1? 25
       IS MONTHLY DEMAND TO BE INPUT VIA DATA FILE  (YES OR NO) ? YES
 FOR DEMAND NODE NO. 2;
       ENTER: NETWORK NODE NO.? 4
       IS THIS A FLOW THRU DEMAND  (YES OR NO)? NO
       ENTER: PRIORITY FOR SIMULATION YEAR 1? 35
       IS MONTHLY DEMAND TO BE INPUT VIA DATA FILE  (YES OR NO) ? YES


 ** BEGIN RECORD 8 **

 FOR IMPORT NODE NO. 1;
       ENTER: NETWORK NODE NO.? 2
 FOR SIMULATION YEAR NO. 1
       ENTER: TOTAL ANNUAL IMPORT ? 2400
       ENTER: MONTHLY DISTRIBUTION
? .083 .083 .083 .083 .083 .083 .083 .083 .083 .083 .083 .083


 ** BEGIN RECORD 10 **

 ARE CONVERSION FACTORS NECESSARY  (YES OR NO)? NO


 ** BEGIN RECORD 11 **

 FOR RESERVOIR NO. 1;
       ENTER: PRIORITY FOR SIMULATION YEAR 1? 15
       ENTER: MONTHLY DESIRED DISTRIBUTION
? 1 1 1 1 1 1 .8 .6 .4 .6 .8 1
 FOR RESERVOIR NO. 2;
       ENTER: PRIORITY FOR SIMULATION YEAR 1? 40
       ENTER: MONTHLY DESIRED DISTRIBUTION
? 0 0 0 0 0 0 0 .3 .6 .9 1 1
```

Figure IV.2. Continued.

```
** BEGIN RECORD 12 **

ENTER: NO. OF LINKS WITH VARIABLE CAPACITY ? 0
ENTER REMAINING LINKAGE
ENTER: NETWORK LINK NO.? 1
       ENTER: MAXIMUM CAPACITY? 10000
       ENTER: MINIMUM CAPACITY? 0
       ENTER: ORIGIN NODE NO. ? 1
       ENTER: TERMINATION NODE NO.? 3
       ENTER: LOSS COEFFICIENT? 0.10
       ENTER: UNIT COST ? 0
ENTER: NETWORK LINK NO.? 2
       ENTER: MAXIMUM CAPACITY? 9500
       ENTER: MINIMUM CAPACITY? 0
       ENTER: ORIGIN NODE NO. ? 2
       ENTER: TERMINATION NODE NO.? 3
       ENTER: LOSS COEFFICIENT? 0.20
       ENTER: UNIT COST ? 10
ENTER: NETWORK LINK NO.? 3
       ENTER: MAXIMUM CAPACITY? 15000
       ENTER: MINIMUM CAPACITY? 0
       ENTER: ORIGIN NODE NO. ? 3
       ENTER: TERMINATION NODE NO.? 4
       ENTER: LOSS COEFFICIENT? 0.15
       ENTER: UNIT COST ? 5


** BEGIN RECORD 13 **

ENTER: NO. OF RETURN FLOW EQUATIONS? 1
ENTER: NO. OF TIME PERIODS TO BE LAGGED? 1
FOR RETURN FLOW EQU. NO. 1;
       ENTER: NO. OF NODES CONTRIBUTING TO RTFLOW ? 1
       ENTER: NODE NO. WHERE FLOW RETURNS ? 4
       ENTER: NODES WHICH CONTRIBUTE TO RTFLOW? 3
       ENTER: REGRESSION COEF. BEGINNING WITH
              THE CONSTANT TERM, FOLLOWED BY DITCH
              DIVERSIONS, FOLLOWED BY RETURN FLOWS
              EXAMPLE FOR 1 MONTH LAG
              A1+A2*D(T)+A3*D(T-1)+A4*R(T-1)
? 789 .157 .0482 .6589


       FOR INITIAL CALCULATIONS ENTER:
       TOTAL DITCH DIVERSION AND TOTAL RETURN
       FLOW OBSERVED FOR TIME PERIOD ZERO MINUS
       1; ? 200 85


SAVE FILE AS PERMANENT FILE  (YES OR NO) ? YES
ENTER: UP TO 7 CHARACTER FILE NAME ? CODATA
IS A LISTING REQUIRED  (YES OR NO) ? YES
```

Figure IV.2. Continued

```
CONTROL OPTIONS    1    0    0    1    1
EXAMPLE DEMONSTRATION OF PROGRAM ORGANZ
PARAMETERS    4    2    3    3    1    2    2 1979    1    0    1    1     10.000
RES 1         1      5000         0         0
RES 2         2      8000         0      2000
NODE 3        3         0         0         0
NODE 4        4         0         0         0
SPILLS        2    1
NO. PAIRS     4
AREA-CAP      1         0         0        20      1250        70      3500
                      100      5000
AREA-CAP      2         0         0        70      2000       150      5000
                      200      8000
DEMAND   3  0       0         0.000.000.000.000.000.000.000.000.000.000.000.00
RANK          3   25
DEMAND   4  0       0         0.000.000.000.000.000.000.000.000.000.000.000.00
RANK          4   35
IMPORT        2
YEAR   1                  2400.083.083.083.083.083.083.083.083.083.083.083.083
FACTORS        0.000     0.000     0.000
ANNUAL OPR    1             151.001.001.001.001.001.00 .80 .60 .40 .60 .801.00
ANNUAL OPR    2             400.000.000.000.000.000.000.00 .30 .60 .901.001.00
NVARLKS       0
LINK          1    1    3     10000         0 .10000000    0
LINK          2    2    3      9500         0 .20000000   10
LINK          3    3    4     15000         0 .15000000    5
NEQU,NLAGS    1    1
 789.0     .1570     .4820E-01 .6589
EQU      1    4
EQU      3
LAGS    200    85
```

Figure IV.3. Example coded data file created by Program ORGANZ.

```
************************** P R O G R A M  A D A T A ***************************

          BINARY INFLOW, DEMAND, AND EVAP. FILE CREATION FOR MODSIM

 ENTER: TOTAL NO. OF NODES? 4
 ENTER: TOTAL NO. OF RESERVOIRS ? 2
 ENTER: NO. OF YEARS TO BE SIMULATED? 1

 ENTER: NO. OF DEMAND NODES ? 2
 ENTER: NODE NO. OF EACH DEMAND NODE
? 3 4

 ENTER: NO. OF NODES WHERE UNREGULATED INFLOW OCCURS? 1
 ENTER: NODE NO. OF EACH UNREG. INFLOW NODE
? 1

 ENTER: NO. OF RESERVOIRS WITH EVAP. > 0? 2
 ENTER: NODE NO. OF RESERVOIRS WITH EVAP. > 0
? 1 2
 ENTER: MONTHLY INFLOWS FOR NODE 1 YEAR 1
? 1000 2000 2000 2000 750 500 0 0 500 500 1000 1500

 ENTER: MONTHLY EVAP. RATES FOR RES. NO. 1 YEAR 1
? -.05 -.02 .01 .04 .14 .22 .27 .35 .28 .17 .06 .01

 ENTER: MONTHLY EVAP. RATES FOR RES. NO. 2 YEAR 1
? -.01 -.07 -.10 -.03 .06 .11 .21 .27 .23 .15 .09 .02

 ENTER: MONTHLY DEMANDS FOR NODE 3 YEAR 1
? 100 200 300 400 500 500 500 400 300 200 100 100

 ENTER: MONTHLY DEMANDS FOR NODE 4 YEAR 1
? 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000 5000

 ENTER: UP TO 7 CHARACTER PFN FOR BINARY FILE ? BINDATA
 SAVE COPY OF CODED DATA FILE ALSO  (YES OR NO) ? NO


 JOB SUCCESSFULLY COMPLETED.
 PRINT-OUT OF DATA FILE  (YES OR NO)? NO
```

Figure IV.4. Demonstration of Program ADATA for simplified network in Figure IV.1.

D. Output of Results

The user has the option of obtaining one or more of three possible output reports. These include:

1. an echo of the input data pertaining to the system configuration
2. a detailed *monthly* report providing entire nodal and linkage conditions such as:
    a. Storage node:
        - initial storage
        - unregulated inflows
        - upstream spills
        - demand
        - surface area
        - evaporation loss
        - downstream spills
        - shortages
        - system loss
        - water pumped into a node
        - water pumped from a node
        - end-of-month storage (actual)
        - end-of-month storage (desired)

    b. Non-storage demand node:
        - demand
        - shortages

    c. Linkage:
        - total monthly flow as volume
        - loss as volume
        - yearly mean flow
        - return flow
3. node by node annual summaries for the entire simulation period plus maximum linkage flows and simulation period average flows in each linkage.

Figure IV.5 shows the detailed monthly report for the analysis performed on the example network, as dictated by the data files created by Program ORGANZ and Program ADATA.

E. Discussion

In order to properly operate Program MODSIM, a *submit file* must be created which attaches the appropriate files, executes the program, and disposes the output to a line printer. The submit file has the following form for the CDC 172, NOS Operating System:

```
/JOB
<Job Card>
<User Card>
ROUTE,OUTPUT,DC=PR,UN=AD,DEF.  (routes output to line printer)
ATTACH,MODSIM.
FTN,I=MODSIM,L=0,OPT.
GET,TAPE5=<coded data file>.
GET,TAPE10=<binary data file>.
LDSET,PRESET=ZERO.             (initially sets computer core storage
                                to zero)
LGO,TAPE5,OUTPUT.
/EOF
```

The user should be careful to note that Program MODSIM has been specifically designed to operate with the computer core storage initialized to zero. Also, other system control options may be included in the submit file. The above example represents only the control logic essential to the successful execution of the simulation package.

To this point, no mention has been made of the selection of operating criteria for evaluation by the model. However, the selection

```
                  EXAMPLE DEMONSTRATION OF PROGRAM ORGANZ

SIMULATION YEAR  1     CALENDAR YEAR 1979

                   RESERVOIR NO  1  RES 1        MAX. CAPACITY    5000  MIN. OPERATING POOL        0
         INITIAL      UREG   UPSTRM             SURFACE  EVAP    EVAP  DWNSTRM              PUMPED      PUMPED    SYSTEM END MO.     OPER.
MONTH   STORAGE    INFLOWS   SPILLS    DEMAND      AREA  RATE    LOSS   SPILLS SHORTAGE      INTO         OUT    LOSS  CONTENT      RULE
  1           0      1000        0         0         8  -.05       0        0        0         0           0       0     1000      5000
  2        1000      2000        0         0        37  -.02       0        0        0         0           0       0     3000      5000
  3        3000      2000        0         0        80   .01       1        0        0         0           0       0     4999      5000
  4        4999      2000        0         0       100   .04       4     1796        0         0           0       0     5000      5000
  5        5000       750        0         0       100   .14      14      663        0         0           0       0     5000      5000
  6        5000       500        0         0       100   .22      22      431        0         0           0       0     5000      5000
  7        5000         0        0         0        90   .27      24      879        0         0           0       0     4000      4000
  8        4000         0        0         0        70   .35      24      879        0         0           0       0     3000      3000
  9        3000       500        0         0        48   .28      13     1339        0         0           0       0     2000      2000
 10        2000       500        0         0        42   .17       7        0        0         0           0       0     2493      3000
 11        2493      1000        0         0        59   .06       4        0        0         0           0       0     3489      4000
 12        3489      1500        0         0        85   .01       1        0        0         0           0       0     4988      5000

  YEAR TOTALS,      11750        0         0                       114     5987        0         0           0       0

                   RESERVOIR NO  2  RES 2        MAX. CAPACITY    8000  MIN. OPERATING POOL        0
         INITIAL      UREG   UPSTRM             SURFACE  EVAP    EVAP  DWNSTRM              PUMPED      PUMPED    SYSTEM END MO.     OPER.
MONTH   STORAGE    INFLOWS   SPILLS    DEMAND      AREA  RATE    LOSS   SPILLS SHORTAGE      INTO         OUT    LOSS  CONTENT      RULE
  1        2000       199        0         0        35  -.01       0     1763        0         0           0       0        0         0
  2           0       199        0         0         0  -.07       0      160        0         0           0       0        0         0
  3           0       199        0         0         0  -.10       0      160        0         0           0       0        0         0
  4           0       199        0         0         0  -.03       0      190        0         0           0       0        0         0
  5           0       199        0         0         0   .06       0      180        0         0           0       0        0         0
  6           0       199        0         0         0   .11       0      160        0         0           0       0        0         0
  7           0       199        0         0         0   .21       0      160        0         0           0       0        0         0
  8           0       199        0         0         0   .27       0      160        0         0           0       0        0      2400
  9           0       199        0         0         0   .23       0      160        0         0           0       0        0      4800
 10           0       199        0         0         0   .15       0      160        0         0           0       0        0      7200
 11           0       199        0         0         0   .08       0      160        0         0           0       0        0      8000
 12           0       199        0         0         0   .02       0      160        0         0           0       0        0      8000

  YEAR TOTALS,       2388        0         0                         0     3620        0         0           0       0
```

Figure IV.5. Example output from Program MODSIM.

```
DEMAND NODE  3  NODE 3

MONTH          DEMAND       SHORTAGE
  1               100              0
  2               200             40
  3               300            140
  4               400              0
  5               500              0
  6               500              0
  7               500              0
  8               400              0
  9               300              0
 10               200             40
 11               100              0
 12               100              0
YEAR TOTALS      3600            220

DEMAND NODE  4  NODE 4

MONTH          DEMAND       SHORTAGE
  1              5000           2651
  2              5000           3537
  3              5000           3208
  4              5000           1599
  5              5000           2441
  6              5000           2508
  7              5000           2035
  8              5000           1902
  9              5000           1408
 10              5000           2463
 11              5000           2459
 12              5000           2493
YEAR TOTALS     60000          28704
```

Figure IV.5. Continued

```
                                    * VOLUMETRIC FLOW IN LINK *

SEASON         1       2       3       4       5       6       7       8       9      10      11      12      AVERG
LINK NO.
   1           0       0       0    1796     663     431     879     879    1339       0       0       0      499
    LOSS       0.      0.      0.    200.     74.     48.     98.     98.    149.      0.      0.      0.

   2        1760     160     160     160     160     160     160     160     160     160     160     160      293
    LOSS     440.     40.     40.     40.     40.     40.     40.     40.     40.     40.     40.     40.

   3        1411       0       0    1323     275      78     459     544    1020       0      51      51      434
    LOSS     249.      0.      0.    233.     48.     14.     81.     96.    180.      0.      9.      9.


RETURN FLOWS CALCULATED

RETURN FLOW EQUATION NO.:  1     RETURNS TO NODE NO.:  4

SEASON         1       2       3       4       5       6       7       8       9      10      11      12

             938    1463    1792    2078    2284    2414    2506    2554    2572    2537    2490    2456
```

Figure IV.5. Continued.

of the appropriate operational criteria is paramount to the success of the particular analysis. Indeed, the right answer to the wrong problem can be potentially more harmful than no answer at all. Specific attention must be afforded the development of operating rules to insure that the problem perceived is the problem analyzed.

The nature and generality of the model provides the user with a high degree of flexibility in the analyses which can be performed. For instance, if instream uses, such as low flow augmentation, are of concern, minimum channel capacities can be established which reflect the desire to maintain appropriate levels of flow. By varying the priorities placed on demands and storages, the critical time periods when it may be difficult to sustain minimum flow levels can be determined. Certain tradeoffs between the sacrifice of water held in storage and the minimum required flow can be determined.

Tradeoffs among more traditional water uses can easily be analyzed; for example, irrigation demands competing with municipal/industrial demands for a limited water supply. By varying the priorities associated with these demands one may test alternate schemes for minimizing the shortage to both sectors, or evaluate management alternatives which distribute expected shortages in some equitable manner. Further, MODSIM is capable of evaluating tradeoffs among in-storage uses of water in differing reservoirs. Flood control pool maintenance versus holding water in storage for recreational usage is a prime example. The reservoir operating rules input to Program MODSIM may reflect either the desire to maintain storage levels at some point below maximum capacity during certain months (flood control) or maintain levels as high as possible to enhance recreation opportunities. By manipulating the priorities placed on achieving the target storage levels, different operational schemes designed to accomplish these goals can be analyzed over long time periods. Finally, perhaps the greatest advantage of MODSIM is the capability (for large-scale river basins) of simultaneously considering all of the above water usages in a single execution of the code.

CHAPTER V

PRESENTATION OF CASE STUDIES

A. Introduction

Two case studies were undertaken to fully demonstrate the capability and utility of MODSIM for aiding in the analysis of changes in water resources policy within a river basin. In addition, it is hoped that these case studies will provide the potential user with insight into the formulation of his problem in such a manner that can be readily analyzed by MODSIM. Considerable thought was devoted to the selection of appropriate case studies that were relevant, timely, and provided potential for the actual use of the results. Therefore, several water resources planning and/or management problems currently concerning area (Northern Colorado Front Range) decision-makers were evaluated. These perceived problems were judged according to such factors as complexity, information requirements, potential cost (time and money), urgency as related to other water allocation problems, and the degree of professional interest expected in the study.

The two case studies presented in this report differ completely in objectives; however, they are both located in the same river basin (the Cache la Poudre River Basin) in north-central Colorado (Figure V.1). Even though two entirely different problem formulations are necessary, much of the information requirements remain the same (evaporation rates, gaged inflow records, area-capacity relationships, demands, etc.).

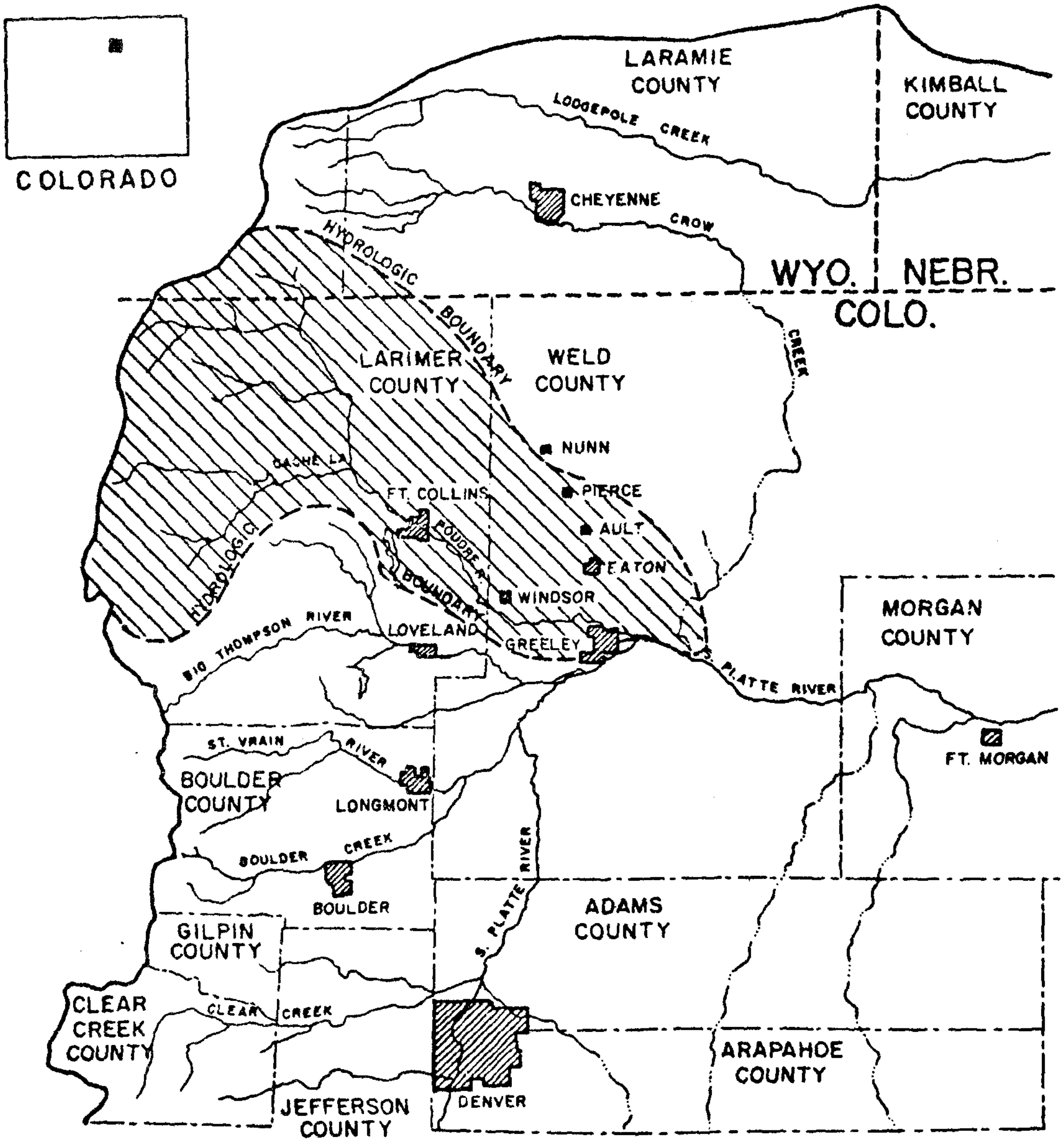


Figure V.1. Location of Cache la Poudre River Basin.

In other words, within the same hydrology and institutional framework many varying problems coexist.

As part of Water Division 1, District 3, the Cache la Poudre River Basin has as complex a system of interrelated water storage and distribution structures and regulations as anywhere along the Front Range. District 3 is also one of the most productive agricultural areas in Colorado. Consequently, irrigated agriculture has dominated the water use in the area. The Cache la Poudre River Basin is also favorable as a study area since there has been much previous modeling work done, although not related to the case studies presented here. However, much information can and has been extracted from these previously completed studies. Also, since water in the Cache la Poudre River on an average annual basis is highly over-appropriated, it affords the challenge of modeling a system in great need of comprehensive planning studies.

B. Background Information

B.1 Physical description of the study area

The extremes in elevation in the basin differ by about 7550 vertical feet. The agricultural portion of the valley represents almost 50 percent of the entire basin area and ranges in elevation from roughly 4650 feet above MSL to 5800 feet. The western boundary of the Cache la Poudre River Basin is the Continental Divide, with a maximum elevation of 12,200 feet above MSL (Evans, 1971).

The natural surface water supply is composed of spring snowmelt and direct precipitation. Additional supply is realized from various transbasin diversions. The Colorado-Big Thompson (CBT) Project is the most significant of these diversion projects and adds substantial flow to lower reaches of the Cache la Poudre River during irrigation seasons. Table V.1 lists sources of water supply to the basin and their corresponding percentage.

Table V.1. Sources of Water Supply for the Cache la Poudre River Basin (Evans, 1971)

SOURCE	Percentage (%)
Natural Inflows (Snowmelt, Precipitation)	44
Pumped Groundwater	33
CBT	17
Other Imported Waters (Transbasin Diversions)	6
	100

Within the Cache la Poudre system there are more than 30 major storage reservoirs located on the plains, plus an additional nine high country reservoirs with significant storage. These reservoirs are owned for the most part by established irrigation companies throughout the basin. For example, the North Poudre Irrigation Company has an elaborate system of canals and interconnected reservoirs and plays an important role in the local economy due to an extensive involvement in an exchange system which has developed in the basin. Figure V.2 displays the major features of the Cache la Poudre River Basin.

As mentioned previously, the average annual natural flow in the Cache la Poudre River has long been over-appropriated. Therefore, to augment this natural supply, a series of transbasin diversions have been established. This importation of western slope water is limited, however, by a number of legally binding obligations. These obligations include the

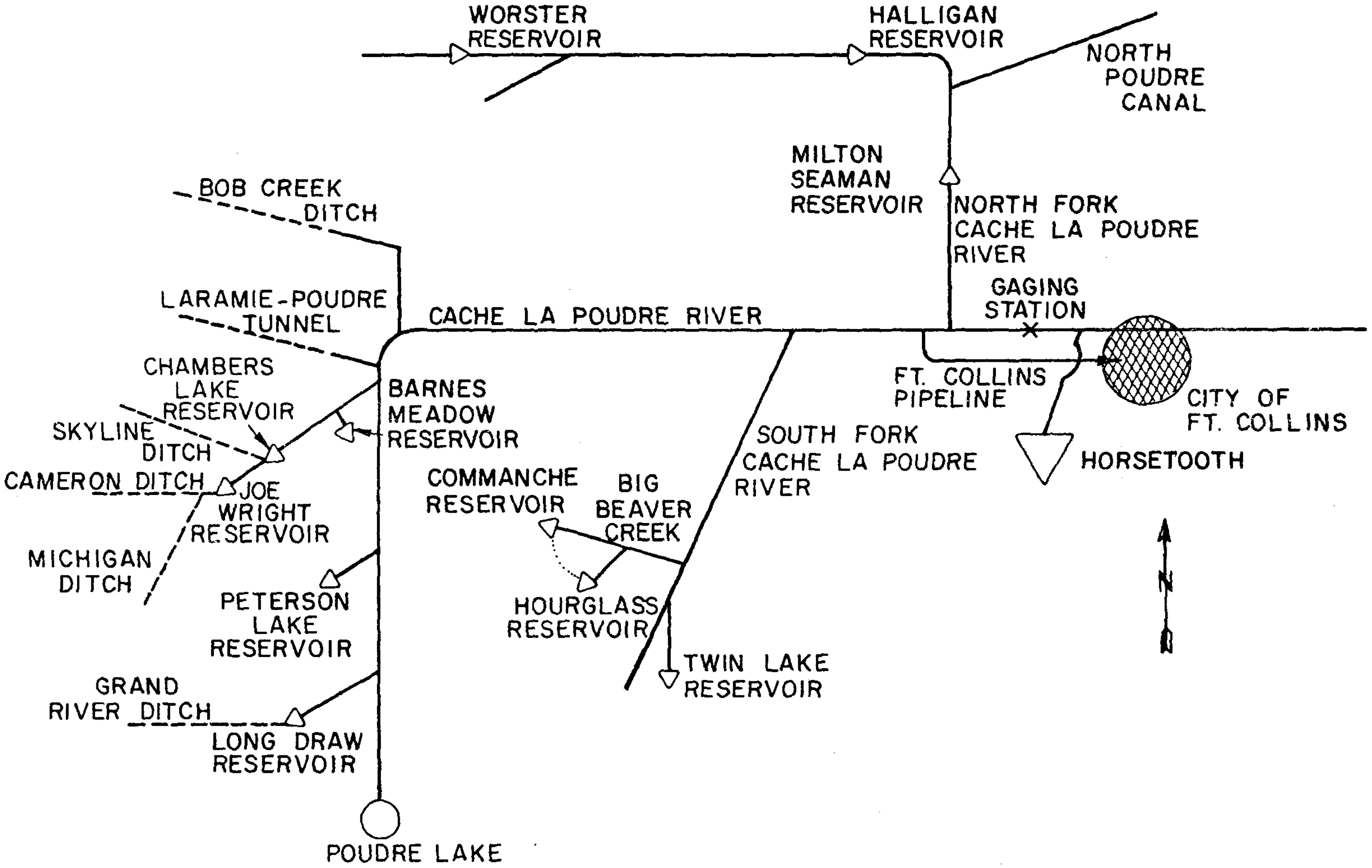


Figure V.2. Schematic diagram of major components of Cache la Poudre River Basin.

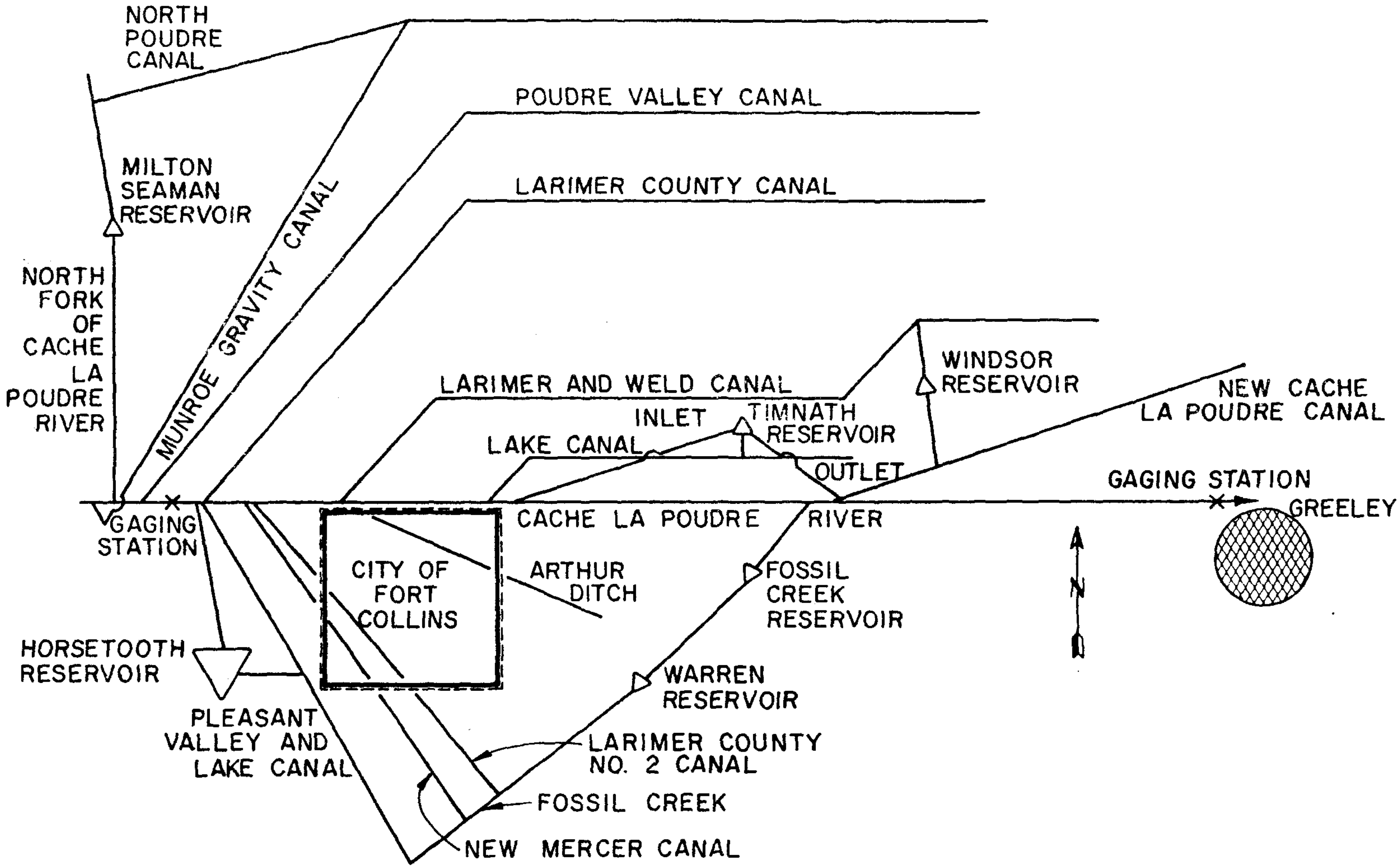


Figure V.2. Continued.

Laramie River Decree, the Colorado River Compact, and the North Platte River Decree. The largest transmountain diversion of water is the CBT Project. Originally, CBT water was intended solely for supplemental irrigation water. Municipalities (including Fort Collins) have subsequently acquired more than 23 percent of CBT water. Historically, high mountain transbasin diversions other than CBT have contributed, on the average, 45,000 acre-feet of water annually to the basin (Evans, 1971).

B.2 Exchange system

Early in the evolution of the current irrigation scheme in the Poudre Valley, it was realized by the administrators of water in the basin that greater efficiency in water use could be achieved by creating an exchange system. Though Colorado constitutionally supports the appropriation doctrine and senior water right holders must receive their direct flow appropriation first, an exchange system has been developed which allows junior water right holders to receive water through development of additional storage. The important point is that this storage need not be available upstream of their point of diversion.

A maximum mean monthly natural flow of 1769 cfs in the Cache la Poudre River occurs in June. Unfortunately, it can be shown from a review of direct flow rights on the river that most major canals could not operate in June (highest flow month) without the use of some kind of exchange system. Most canals have undergone several expansions, each time filing for an additional decree with a priority date based on the time of the new construction. Through such action, the river has become over-appropriated to the point where as of 1970, for example, only two years in 35 could the Greeley No. 2 Canal exercise its entire right (priorities 37, 44, 72, 83). The river has approximately 200 formal rights filed for its water. It is unlikely that Larimer and Weld Canal or North Poudre Canal would ever receive any water.

Exchanges of stored and direct flow water between ditch companies occur in conjunction with the reservoirs throughout the basin. Few reservoirs are located such that they can directly service the acreage of the owner. Subsequently, through the exchange system, it is of little significance whether or not a reservoir is located above or below the ditch system of its owner. With the addition of CBT water, which is capable of delivery via the river at any point below the Poudre Valley Canal, the exchange of water throughout the basin becomes even more attractive from an efficiency viewpoint. This system of exchanges has an important bearing on the management strategies which are to be analyzed as part of this case study (for additional information, see Evans, 1971, pp. 115-118).

B.3 Fort Collins water system

Fort Collins raw water supply is derived from four sources: (1) CBT water, (2) shares in Water Supply and Storage Company, (3) shares in North Poudre Irrigation Company, and (4) direct flow rights. Table V.2 lists the annual amounts of these supply sources.

Table V.2. Fort Collins Water Supply (Wengert, 1975)

Source	Mean Annual Supply (acre-feet)
CBT	7,203
Water Supply & Storage Co.	833
North Poudre Irrigation Co.	4,190
Direct Flow	12,293*
	24,519

*Includes recent acquisitions subsequent to Wengert

The City has two water treatment plants with a combined capacity of approximately 44 mgd. Treatment Plant 1 is located 11 miles northwest of Fort Collins on the Cache la Poudre River and has a capacity of 20 mgd. The second plant is situated at the base of Horsetooth Reservoir Spring Canyon Dam and has a capacity of 24 mgd. The capacity of Plant 2 is scheduled for a 10 mgd expansion by 1980 (Wengert, 1975).

West Fort Collins Water District serves an area to the northwest of Fort Collins. The District purchases treated water from the City and exchanges one acre-foot of CBT water for every unit of treated water the City supplies the District. It is assumed that two percent (2%) of the total gross water supply to the City is diverted to West Fort Collins Water District. Furthermore, no return of this diversion is realized at the City's waste treatment facilities. In other words, Fort Collins does not recover any of the water it supplies West Fort Collins.

M.W. Bittinger and Associates, Inc. (1975) conducted a study in which a detailed analysis of the consumptive use of treated water within the City of Fort Collins was undertaken. Consumptively used water and percentage of adjusted (minus West Fort Collins Water District) total inflow are provided on a monthly basis for 1974. Table V.3 lists the results. The Bittinger report states:

> As long as the uses of City water remain in the approximate proportions that existed in 1974, the percentages...should be acceptable for determining the amount of City effluent available for a succession of uses without harming other water rights on the river.

Due to varying microclimatic conditions and changes in land use, these percentages (Table V.3) may fluctuate somewhat.

Table V.3. Consumptive Water Use Fort Collins - 1974 (Bittinger, 1975)

Month	Adjusted Inflow (acre-feet)	Total Consumptive Use (acre-feet)	Percent
JAN	626.7	6.8	1.1
FEB	577.6	6.8	1.2
MAR	679.5	10.9	1.7
APR	881.8	378.9	42.9
MAY	2029.3	1231.5	60.7
JUN	2251.8	1239.0	55.0
JUL	2855.9	1163.0	45.5
AUG	2353.1	1094.6	46.5
SEP	1541.6	541.7	35.1
OCT	1166.6	254.0	21.8
NOV	844.9	13.6	1.6
DEC	798.0	10.9	1.4

At the wastewater treatment end of the City's system there are two options for treated effluent release. The effluent can either be returned to the river or diverted to Fossil Creek Reservoir.

C. Case Study 1: High Mountain Reservoir Recreation Study

C.1 Problem statement

As stated previously, several high mountain reservoirs are located within the basin boundaries. In the past, these reservoirs have been operated exclusively for the provision of a late season irrigation water supply. Such a policy has often resulted in the complete emptying of these reservoirs toward the end of the irrigation season. Attention has been focused on the inclusion of recreation in a multipurpose framework for some of these reservoirs.

The City of Greeley, Colorado, owns and operates six high mountain reservoirs in the Cache la Poudre River Basin. Of these six reservoirs, water stored in five is sold on a seasonal basis to the North Poudre Irrigation Company and water stored in the sixth (Milton Seaman) is used for exchange purposes and municipal supply. The five high mountain Greeley-owned reservoirs are Peterson, Barnes Meadow, Commanche, Twin Lake, and Big Beaver. These reservoirs, along with the North Poudre Irrigation Company reservoir and canal system, form an autonomous unit in that all water originating in the Greeley reservoirs is delivered to the North Poudre system.

The five high mountain reservoirs were evaluated according to their perceived public recreation potential by outdoor recreation specialists assuming that stable pool elevations could be maintained at or near maximum levels. The analysis included such considerations as fisheries potential, scenic beauty, private versus public ownership of riparian lands, ease of access, etc. The results showed that Barnes Meadow and Twin Lake reservoirs have the highest recreation potential of the five. Commanche Reservoir and Peterson Reservoir were believed to have limited recreation potential while Big Beaver Reservoir was declared to have no recreation potential whatsoever due to private ownership of riparian lands (Aukerman, et al, 1977). The problem in this case study is one of determining if it would be possible, from a hydrologic and legal standpoint, to maintain a stable pool elevation, at or near maximum, in one or more of these reservoirs according to the preferences outlined above. This problem is not as straightforward as it may first appear in that such a change in the operating policy of these reservoirs would, to some extent, alter the traditional hydrology of the basin. This alteration must occur in such a manner that the North Poudre Irrigation Company demands for Greeley reservoir water are satisfied, no injury to downstream water right holders is incurred, and that appreciable changes in the flow regime of the river do not result.

C.2 Study objective

The objective of this case study is to investigate opportunities to operate the high mountain reservoirs in such a manner that would allow the maintenance of storages at or near capacity while meeting the North Poudre Irrigation Company demands from other reservoirs owned and operated by the company. The North Poudre Irrigation Company owns and operates many plains reservoirs with storage capacities significantly greater than those of the high mountain reservoirs under consideration. Halligan, Park Creek, and North Poudre No. 15 plains reservoirs have traditionally held large carry-over storages from season to season. These reservoirs have virtually no recreation potential. Therefore, if in the management of the Greeley-North Poudre system as a whole, the severe late season drawdown in the selected high mountain reservoirs could be curtailed while allowing storage levels in the plains reservoirs to more widely fluctuate, enhanced mountain reservoir recreation may be provided.

The approach taken in investigating this problem is to isolate the Greeley high mountain reservoir subsystem and the North Poudre Irrigation Company subsystem. In this manner only water released from the high mountain reservoirs along with other reservoir water controlled by North Poudre needs to be considered. This allows analysis of changes in the operating policies of the reservoirs without considering direct flow rights along the river or other reservoir water not directly involved with the study.

C.3 System configuration and decomposition

Due to the interdependence of system components, management of the high mountain reservoirs cannot be analyzed without proper consideration of the demand points for their stored water. However, once the reservoirs to be studied are identified, along with the various distribution and use subsystems to which they contribute water, a spatial decomposition isolates this subsystem of water supply, distribution, and use for further analysis. As long as all sources and sinks of *reservoir* water in the subsystem are considered, a meaningful study of the decomposed system can be conducted even though the entire system is no longer under investigation. This approach allows the problem to remain tractable without great sacrifice in accuracy and detail. Figure V.3 shows the decomposed Greeley-North Poudre subsystem for this case study.

Only the demand for intrabasin high mountain reservoir water is of interest for this problem. Accordingly, imported water is ignored along with direct flow of river water to satisfy irrigation requirements. Since the origin of the reservoir water contributing to demand satisfaction is the only concern, its final destination can be considered a single demand center without introducing any error into the analysis. All of the individual North Poudre Irrigation Company plains reservoirs (N.P. No. 1 and those to the east) provide water to turnouts for application to fields. Of interest to this study is the *total* monthly volume of mountain reservoir water supplied to these plains reservoirs.

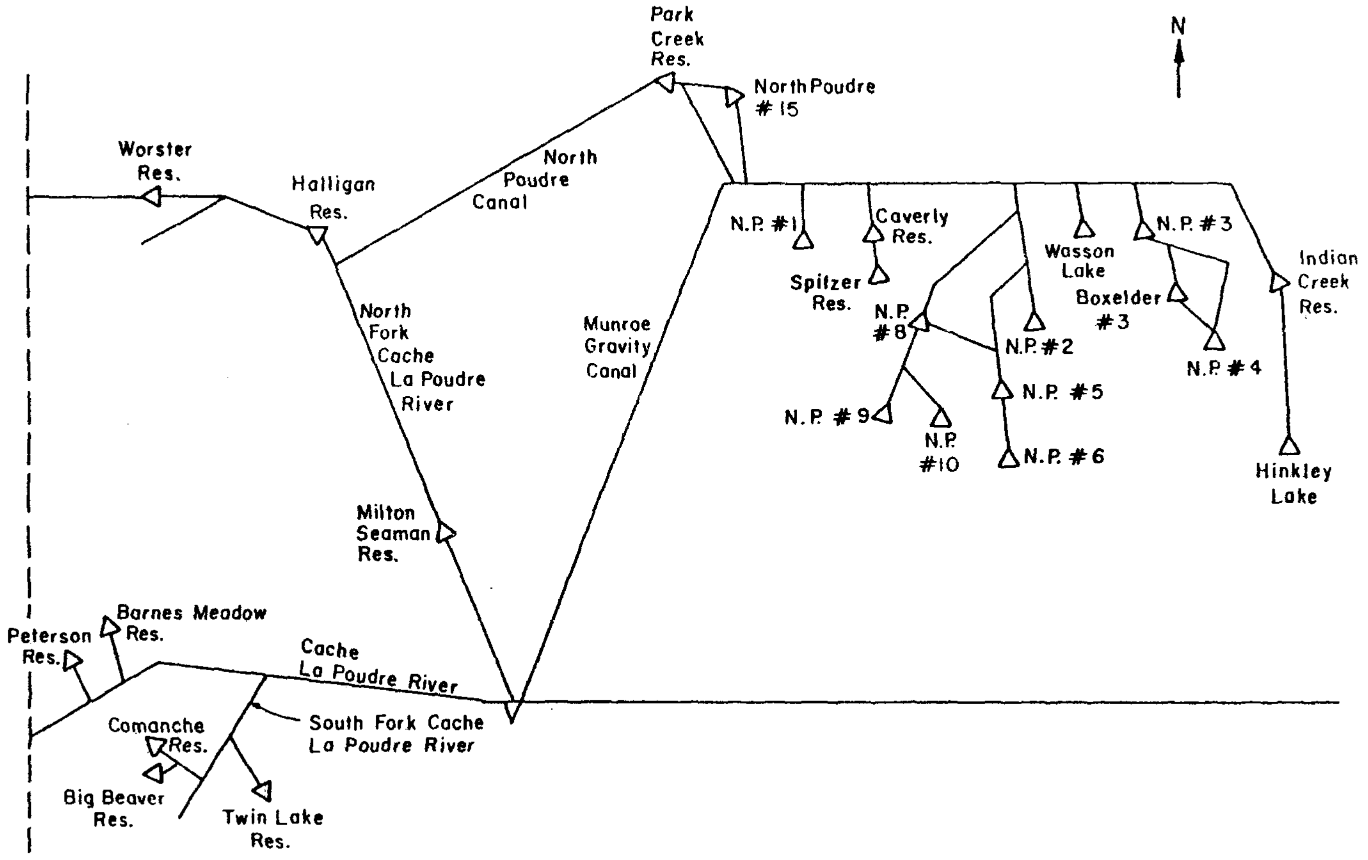


Figure V.3. Decomposed case study reservoir and canal subsystem.

Therefore, the North Poudre plains reservoirs are aggregated into one large plains reservoir whose surface area and storage volume are equal to the sums of the surface acreages and volumes of the individual plains reservoirs. This maneuver allows the total monthly demand for water from the high mountain reservoirs to be lumped together at one demand center (Figure V.4).

Once the physical system has been isolated, and all important components identified, it must be translated into a corresponding graphical network of nodal points and linkages. Care must be exercised during this translation to insure that the essence of the physical system is captured in its entirety. All nodes and links are then labeled numerically. Reservoirs must be labeled first, followed by non-storage nodes. Figure V.5 displays the network configuration for this case study.

D. Case Study 2: Rawhide Project

D.1 Problem statement

The problem selected for the second case study addresses itself to the availability of water for cooling purposes and other in-plant uses for the proposed *Rawhide Project*. The Rawhide Project is a coal-fired electric generation plant to be located approximately 20 miles north of Fort Collins, Colorado. The project is designed to augment projected power demands of the municipalities of Estes Park, Fort Collins, Longmont, and Loveland, Colorado. The first 230 megawatt unit should be in operation by 1985. Such facilities require adequate supplies of water. The Platte River Power Authority (PRPA) is negotiating with various potential water suppliers, including the City of Fort Collins.

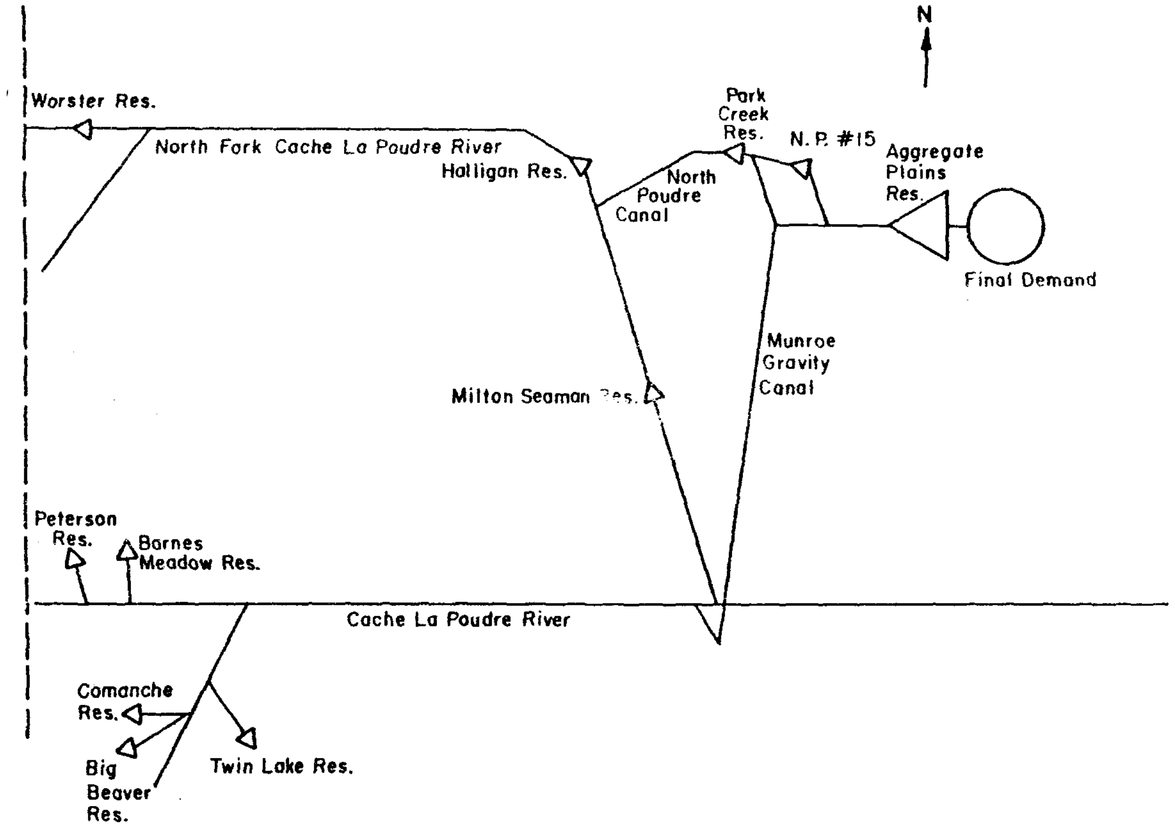


Figure V.4. Decomposed subsystem with aggregated plains reservoirs.

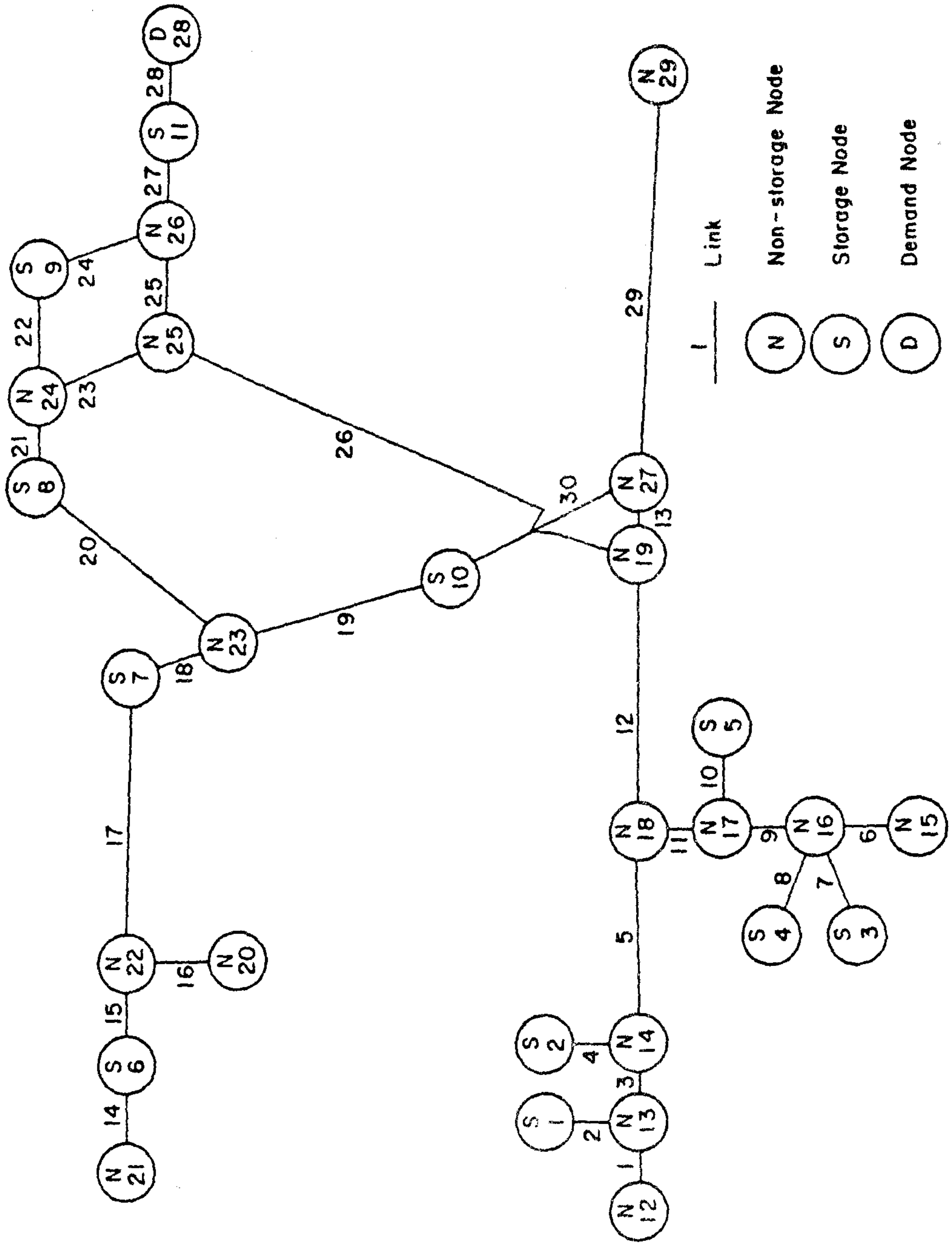


Figure V.5. Network configuration for case study subsystem.

A preliminary contract has been made between Fort Collins, PRPA, and the Water Supply and Storage Irrigation Company outlining a scheme whereby the water requirements of the Rawhide Project could possibly be met. However, before any of the parties enter into a formal agreement, the potential effect of such a scheme on those parties directly and indirectly involved or impacted must be ascertained.

The project calls for the construction of a 13,000 acre-foot reservoir from which waters can be circulated through the power plant for cooling and additional purposes. The Rawhide Project is scheduled for commencement of operation in 1985. However, the Rawhide Reservoir must be full prior to the beginning of power generation. To accomplish this requirement, the agreement between the parties concerned states that filling must begin in 1981. Upon filling the reservoir, the Rawhide Project will require no less than 4200 acre-feet of firm water annually and a stable reservoir elevation within two or three feet.

To accomplish the above tasks, Fort Collins is to provide the Rawhide Project with the opportunity to utilize sewer effluent attributable to newly developed or imported water first used by the City. Imported or foreign water is water which originates outside of the Cache la Poudre River Basin and is diverted from some basin other than the Poudre Basin. The significance of *newly developed* refers to the fact that changing the diversion of the City's effluent attributable to *old foreign water* may result in possible *injury* to those users who have historically come to rely on its availability. In contrast, *new* foreign water is that which only recently or in the future is imported into the Cache la Poudre River Basin in excess of waters which constitute old foreign water.

New foreign waters for Fort Collins originate in the adjacent North Platte River drainage and are diverted across the basin divide via the Michigan Ditch. These waters are then placed in Joe Wright Creek, tributary to the Poudre River. At this point, the water can be used directly or stored in the expanded capacity of Joe Wright Reservoir.

Joe Wright Reservoir is owned and operated by Fort Collins and is being enlarged by the City from 800 acre-feet of water to approximately 8,000 acre-feet. Historic diversions through the Michigan Ditch have been estimated by the parties involved as 1,000 acre-feet per year. Accordingly, the reuse of the first 1,000 acre-feet annually diverted through the Michigan Ditch is, in effect, prohibited. This is not to say that the Rawhide Project cannot divert the effluent from the City's first use of the initial 1,000 acre-feet. However, if such an action takes place, the City must release from other sources the amount of water that would have existed if the 1,000 acre-feet were used by the City and the corresponding return flow was not diverted to the power plant.

New foreign water diverted into the basin via the Grand River Ditch is also available for reuse by the Rawhide Project after first use by Fort Collins. This water can be stored, upon importation, in Long Draw Reservoir which is owned by the Water Supply and Storage Company. However, only 6,000 acre-feet of storage space in this reservoir is to be made available to Fort Collins for storage of Grand River Ditch imports.*

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*Maximum capacity of Long Draw Reservoir is approximately 10,500 acre-feet.

D.2 Study objective

The objective of this case study is to determine, first, if the cooling pond could be filled prior to the beginning of power generation in 1985, and, second, if a minimum of 4,200 acre-feet of reusable water can be provided at a uniform rate thereafter. For this case study all water that becomes available in the basin must be considered. This includes direct flow river water, Colorado-Big Thompson Project water, intrabasin reservoir water, and, of course, the transbasin diversions via Michigan and Grand River ditches. This objective has many ramifications. Injury to water users downstream from the pipeline intake must not occur or must be compensated. A *borrowing* arrangement must be made in order to maintain uniformity in delivery of reused water to the pipeline. A stable pool elevation in the cooling pond must be maintained. The preference of the City's direct flow right over other sources of water must be preserved. Finally, spills from Joe Wright Reservoir and Long Draw Reservoir must be considered. However, as in Case Study #1, the total river basin system can be decomposed into a subsystem of the specific components necessary to analyze this problem.

D.3 System configuration and decomposition

As previously discussed, the Poudre River system is extremely complex in both composition and operation. Fortunately, the system has two control points situated in advantageous positions. The State of Colorado has two gaging states located on the Poudre River. The upstream gage is situated near the mounth of Poudre Canyon before most of the ditch diversions occur, while the downstream gage is located on the Poudre at the confluence of the South Platte River.

Due to the size of the system (number of interrelated components) it would be all but impossible to model the entire system. Therefore, the complete system is decomposed to a point where the key components of the case study are individually considered, but the remainder of the system is aggregated in various ways. In this manner, the integrity of the system as a whole is preserved while only certain components are *directly* modeled.

The components of the decomposed system pertaining to the Rawhide Project are listed in Table V.4. The system can be defined in this manner as a result of the placement of the aforementioned gaging stations. Flow adjustments are made between gages, as well as from the upstream gage to the headwaters of the Poudre River. The effect of varying diversion schemes on the aggregated systems components can be determined *a posteriori*. Figure V.6 is a schematic diagram depicting the major components of the decomposed system.

Table V.4. Rawhide Project Subsystem Components

Reservoirs	Irrigation Ditches	Other Conveyances
Long Draw	Munroe Gravity Canal	Ft. Collins Pipeline
Joe Wright	Larimer & Weld Canal	Charles Hansen Canal
Chambers Lake	Lake Canal	Timnath Reservoir Inlet
Horsetooth	New Cache la Poudre Canal	Rawhide Pipeline
North Poudre No. 6		
Windsor	Imports	
Timnath	Michigan Ditch	
Fossil Creek	Grand River Ditch	
Rawhide Cooling Pond		

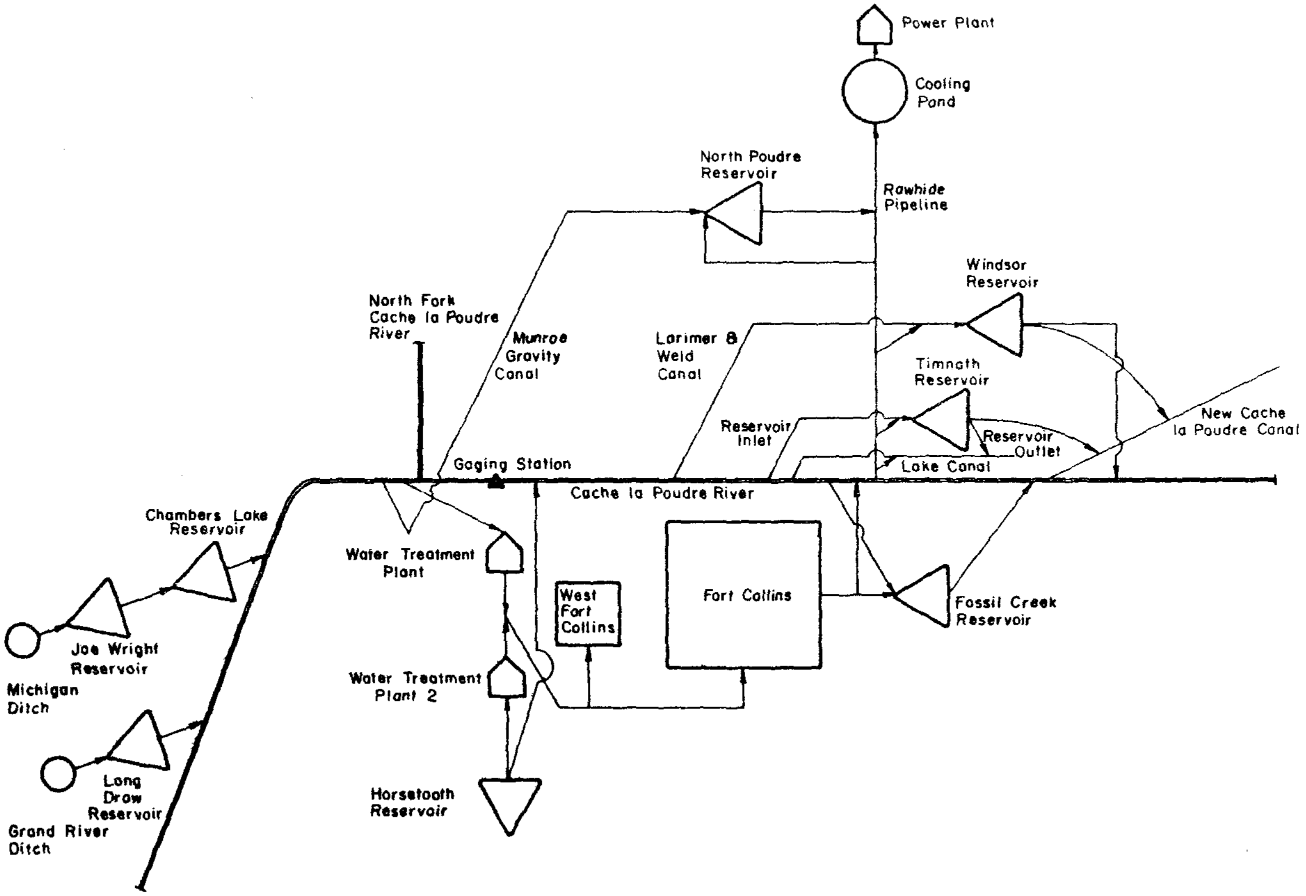

Figure V.6. Major components of decomposed subsystem for Rawhide Project.

Once the physical system to be modeled has been delineated, it must be translated into a node-link network configuration. Particular attention must again be afforded this phase of any study to insure that the essence of the system remains intact. Figure V.7 shows the network system for which the model is calibrated. Table V.5 lists the names of the nodes and the flow capacity of each link. Notice that the Fort Collins water treatment plants have been represented as links instead of nodes. The upper bound on each link corresponds to the respective monthly treatment capacity of each plant. To effectively model the decomposed system, 35 nodes and 47 links are required to represent the physical system, plus additional artificial nodes and arcs.

E. Data Organization

Since both case studies involve the same river basin, commonalities in data requirements exist. The same hydrologic, climatic, structural, and institutional characteristics are encountered in each case study. This section identifies the agencies and individuals who have made available the information needed to conduct the case studies. Also, this section contains the method of calculation of the evaporation rates used throughout the analysis. Channel characteristics and reservoir characteristics are also presented, along with other necessary data common to both studies. Information which is specific to one case study is introduced later in the appropriate section of this report. All data must be compatible, therefore, units are selected as follows: (1) flows--acre-feet/month, (2) storage--acre-feet, (3) surface area--acres, (4) net evaporation rate--feet, and (5) demands--acre-feet.

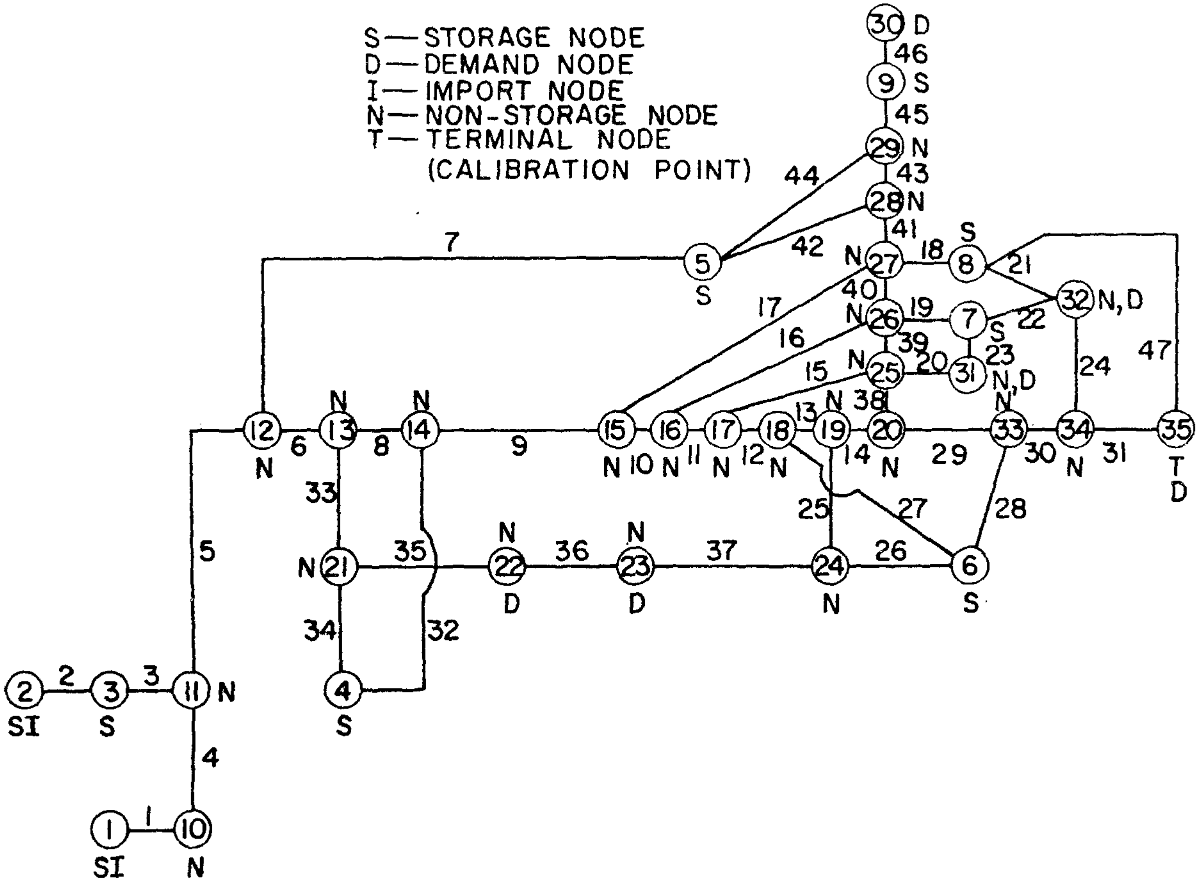

Figure V.7. Network configuration for Rawhide Project.

Table V.5. Rawhide Project Network Components Description

Node #	Name
1	Long Draw Reservoir
2	Joe Wright Reservoir
3	Chambers Lake Reservoir
4	Horsetooth Reservoir
5	North Poudre No. 6 Reservoir
6	Fossil Creek Reservoir
7	Timnath Reservoir
8	Windsor Reservoir
9	Rawhide Cooling Pond
10	Upper Stem Poudre River
11	"
12	Munroe Canal Diversion
13	Ft. Collins Pipeline Diversion
14	Confluence N. Fork Poudre River
15	Larimer & Weld Canal Diversion
16	Timnath Reservoir Inlet
17	Lake Canal Diversion
18	Fossil Creek Reservoir Inlet
19	Ft. Collins Return Flow
20	Rawhide Pipeline Diversion
21	Ft. Collins Inflow
22	West Ft. Collins
23	Consumptive Loss
24	Dummy
25	Rawhide Pipeline
26	"
27	"
28	"
29	"
30	Rawhide Power Plant
31	Lake Canal
32	New Cache la Poudre Canal
33	Release from Fossil Creek
34	New Cache la Poudre Canal Diversion
35	Terminal

Link #	Maximum Flow (ac-ft/mo)
1	15000
2	15000
3	15000
4	300000
5	300000
6	300000
7	15000
8	300000
9	300000
10	300000
11	300000
12	300000
13	300000
14	300000
15	158
16	10070
17	60667
18	60667
91	10070
20	158
21	17689
22	10070
23	10070
24	35490
25	4026
26	4026
27	11100
28	11100
29	300000
30	300000
31	300000
32	91000
33	1779
34	2247
35	4026
36	4026
37	4026
38	0
39	0
40	0
41	0
42	0
43	0
44	0
45	0
46	0
47	17689

E.1 Sources of information

Data requirements for performance of the case studies were met from the following sources.

1. The Water Commissioner, District 3, provided data concerning both reservoir and channel characteristics. Also, the commissioner provided valuable assistance in interpreting the water rights structure of the Cache la Poudre River Basin.
2. Information concerning the allocation of Horsetooth Reservoir water via the Colorado-Big Thompson Project was made available by the Northern Colorado Water Conservancy District offices located in Loveland, Colorado.
3. Detailed daily diversion data for all structures in Water District 3 were obtained from the Colorado Water Data Bank through the Division of Water Resources, State Engineer's Office.
4. The United States Bureau of Reclamation, Denver Office, provided information concerning evaporation rates from reservoir surfaces. These data were refined by accounting for precipitation taken from records compiled by the State Climatologist.

E.2 Evaporation rates

Representative estimates of the expected evaporation rates were difficult to obtain because of a lack of information specific to the area of interest. The rates obtained from the Bureau of Reclamation (USBR) were not oriented toward this particular geographic region. However, the monthly distribution of the annual total was considered acceptable for irrigation years 1973-1975 (Shafer and Labadie, 1977). Two gross evaporation rates were necessary to differentiate between the plains reservoirs (5000 to 6000 feet above MSL) and the high mountain reservoirs (8000 to 9000+ feet above MSL). An adjustment of the monthly distribution of the total annual value for the mountain reservoirs was made to reflect periods of ice and snow cover on the surface during winter months and differences in vapor pressure and wind velocities during summer. Figure V.8 shows these monthly percentages of the total annual evaporation. Annual summaries of climatological data obtained from the Office of the State Climatologist were used to calculate the net evaporation rates for each month during the three-year period. Mean annual corrected pan evaporation at Grand Lake (elevation 8288 ft) and Fort Collins (elevation 5001 ft) were divided into corresponding monthly values according to the distribution in Figure V.8. The observed monthly precipitation for stations at Red Feather Lakes (elevation 8237 ft) and Fort Collins were subtracted from these gross monthly rates to derive a representative net monthly evaporation rate for the plains reservoirs and high country reservoirs (Figure V.9).

E.3 Channel characteristics

Since each physical arc must be bounded from above (lower bound equals zero) actual channel capacities were obtained from the CWDB and personal interviews with John W. Neutze, Commissioner, District 3. Typical capacities, along with loss coefficients where appropriate, are provided in Table V.6.

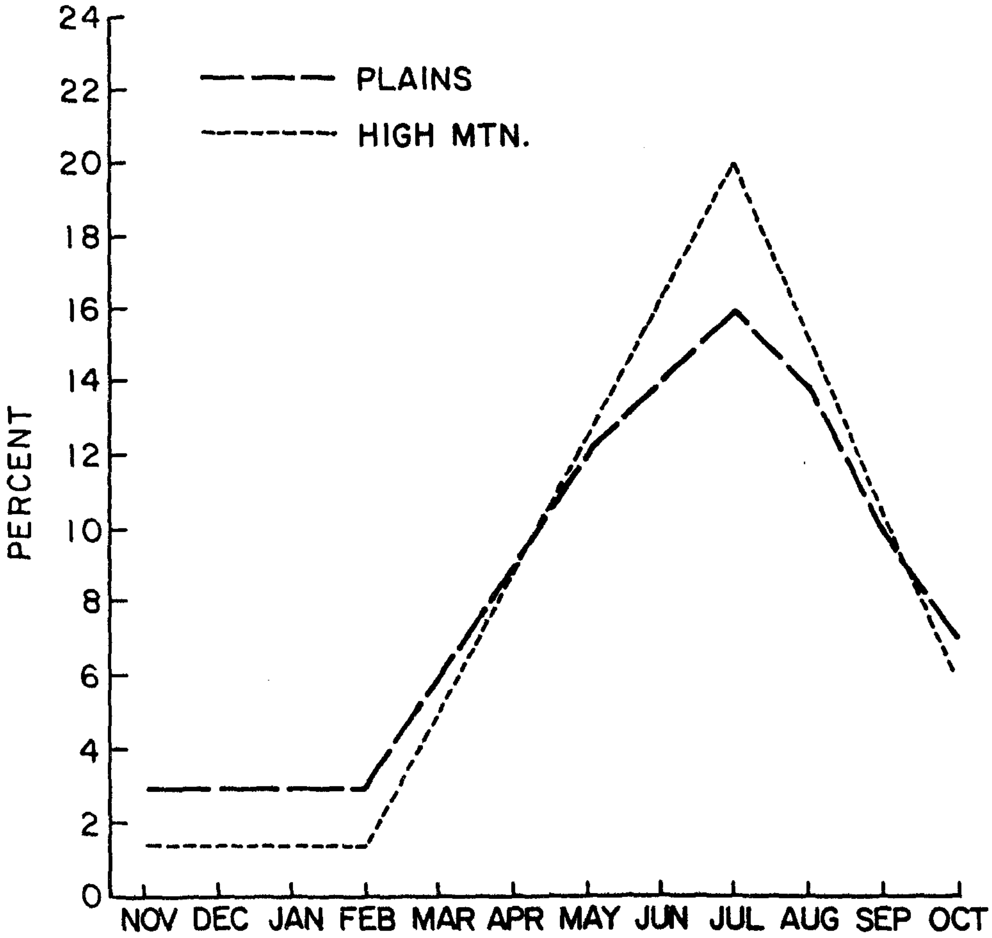

Figure V.8. Monthly distribution of evaporation as percentage of gross annual rate.

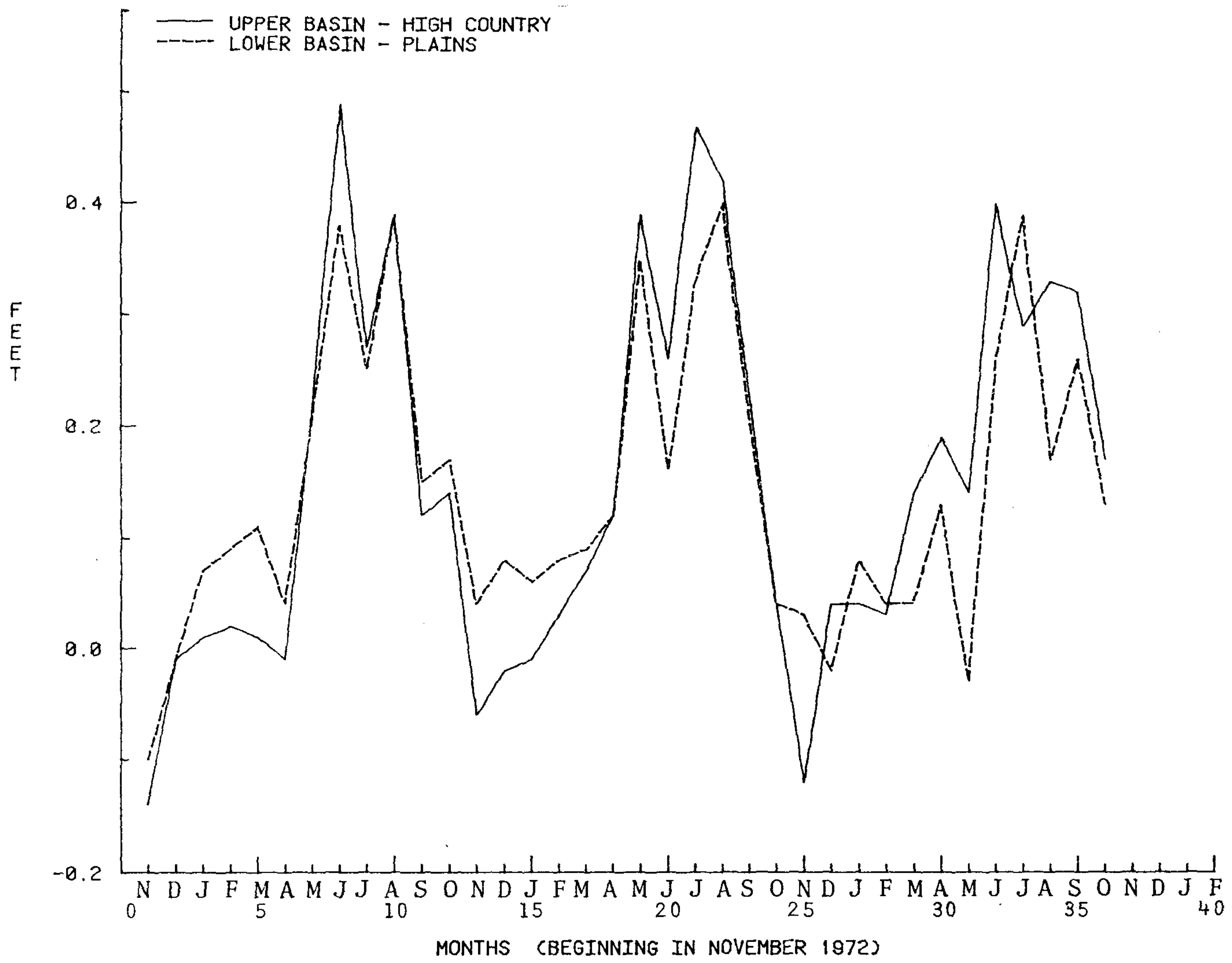

Figure V.9. Net evaporation rate for high country and plains.

Table V.6. Typical Channel Capacities and Loss Coefficients

Capacities	Capacity (acre-feet/month)	Loss (Percentage of Flow)
Mainstream Cache la Poudre	300,000	5.0
Munroe Gravity Canal	15,000	20.0-33.0
Hansen Supply Canal	91,000	---
Larimer and Weld Canal	60,667	20.0-33.0
Timnath Inlet	10,070	20.0-33.0
Lake Canal	9,100	20.0-33.0
New Cache la Poudre Canal	35,297	20.0-33.0

E.4 Reservoir characteristics

MODSIM uses a linear interpolation procedure to determine surface area from tables of volume versus surface area points for each reservoir. From an estimate of average surface area during any particular month, the amount of evaporation (net of precipitation) occurring from the water surface can be calculated. The model will accept up to 18 pairs of volume-surface area points for each reservoir. These points were calculated by solving a series of exponential equations relating volume and surface area to gage height (Thaemert, 1976). An interactive conversational computer program was written to calculate these tables, allowing zero or one discontinuity in each curve. Table V.7 contains an example calculation of area-capacity points. Horsetooth Reservoir is not included for reasons which are discussed in the following chapter.

Table V.7. Example Area-Capacity Relationships

Point	Timnath Reservoir			Fossil Creek Reservoir			Long Draw Reservoir		
	Gage Ht (ft)	Area (ac)	Vol. (ac/ft)	Gage Ht (ft)	Area (ac)	Vol. (ac/ft)	Gage Ht (ft)	Area (ac)	Vol. (ac/ft)
1	0.	0	0	0.	0	0	0.	0	0
2	3.778	70	196	4.000	8	40	8.889	69	772
3	5.667	89	345	6.000	28	241	13.33	91	1335
4	6.556	106	517	8.000	54	170	17.78	112	1969
5	9.444	131	776	10.00	80	318	22.22	131	2661
6	11.33	163	1110	12.44	112	530	26.67	149	3403
7	13.22	196	1522	14.00	147	817	31.11	166	4191
8	15.11	230	1988	16.00	188	1188	35.56	182	5019
9	17.00	265	2517	18.00	232	1652	40.00	198	5884
10	18.89	301	3107	20.00	281	2219	44.44	213	6783
11	20.78	337	3760	22.00	333	2897	48.89	228	7715
12	22.67	374	4475	24.00	390	3697	53.33	242	8676
13	24.56	412	5251	26.00	450	4626	57.78	256	9667
14	26.44	451	6090	28.00	515	5692	62.22	270	10519
15	28.33	490	6992	30.00	583	6906			
16	30.22	529	7955	32.00	655	8273			
17	32.11	569	8981	34.00	730	9804			
18	34.00	609	10070	36.00	810	11100			

F. Comparison of Case Studies

There are marked differences in these case studies which help to demonstrate the utility of MODSIM for water policy analysis. The high mountain reservoir recreation study is a straightforward analysis of the ability to alter the operating policies of several reservoirs to achieve the same end result as far as demand satisfaction is concerned, while enhancing recreation opportunities on certain reservoirs. Only the water normally contributed to the irrigation system by these reservoirs is important. Once the model has been satisfactorily calibrated, the study becomes a matter of adjusting reservoir priorities in such a manner that allows one to determine the effect of differing operating rules on the decomposed system. No further interpretation of the results produced by MODSIM is necessary, and the outcome of many varying operating policies can be determined quickly. The institutional framework within which the system operates is only marginally involved (by design) in this analysis. As long as the final demand for reservoir water is met, no injury to the North Poudre Irrigation Company will occur. Also, there should be no injury to water users downstream of the Munroe Gravity Canal.

In comparison, the second case study (Rawhide Project) is a much more sophisticated problem. Here, the hydrology is important, but of equal importance is the legal system. For instance, Fort Collins must first exercise its monthly direct flow right before drawing any reservoir water. Since all water in the basin is being considered, as opposed to only reservoir water in the first case study, model calibration must not only include reservoir storages, but also river flows.

There is much more flexibility in system operation due to the added complexity of the second case study. This flexibility must be taken into consideration when adjusting priorities throughout the network.

The primary goal of the high mountain reservoir study is one of determining to what degree the operating policy of the plains reservoirs can be traded with that of the high mountain reservoirs. Demands are given the highest priority and the model does the best it can to achieve target storage levels once the demand has been satisfied. The Rawhide Project, however, not only has certain demands which must be met, but qualifications on how they are met. These qualifications or constraints vary widely from month to month and are dependent upon both the hydrologic and institutional conditions present in any one month. Where the output of results by MODSIM for the first case study is adequate enough to draw particular conclusions about the problem, certain parts of the results provided by MODSIM for the Rawhide Project must be further analyzed to arrive at a conclusion.

CHAPTER VI

MODEL CALIBRATION

A. Introduction

Model calibration for these case studies is defined as the adjustment of certain model parameters until the model *reasonably duplicates* available historical records for some prescribed time period. Calibration is an extremely important task to be accomplished in river basin studies such as these. Without successful model calibration, there can be no assurance of reliability in subsequent management alternative analyses. *Success* for these cases is defined such that little or no further improvement in model results, in relation to the historical records, can be achieved by continued parameter adjustment. Insufficient data were available at the time of the study for performing a model verification; e.g., splitting the data, calibrating over one portion, and verifying model consistency over the remaining part.

The goal of model calibration is to manipulate the priorities placed on individual reservoir storage and demand satisfaction until:

1. the calculated end-of-month reservoir storage volumes *reasonably duplicate* the historically observed end-of-month storage volumes
2. shortages in calculated water diverted to meet demand are minimized.

Since each case study was calibrated independently, the calibration exercise for each study is discussed separately. However, the same three-year period (1973-1975), and much of the same information is used to calibrate both cases. As mentioned earlier, the Poudre River Basin is an extremely complex water resource system. Many water exchanges are not documented, since they originate in verbal agreements. Parameters such as channel loss coefficients are only estimates. These values are , however, the best judgements made by persons involved with the river system for many, many years. Also, the Out-of-Kilter Algorithm necessitates the conversion of real values to integer values, which introduces round-off errors. For these reasons, the term *reasonably duplicates* is employed. There is no substitute for good judgement and thorough knowledge of the system when evaluating the results of the calibration phase.

This chapter presents the results of the calibration phase of the two case studies. A brief discussion of the procedure for calibration of MODSIM for the reservoir recreation study is included with the results of this case study. However, a detailed, step by step, outline of the procedure for calibrating MODSIM for the Rawhide Project is provided which not only describes the calibration methodology but also should give potential users insight into data organization for model operation.

B. MODSIM Calibration for the High Mountain Reservoir Recreation Study

The approach used to calibrate MODSIM for the subsequent analysis of reservoir recreational potential is straightforward. All inflows which accrue to the decomposed system components are isolated. Evaporation rates are input along with the historical end-of-month reservoir storage volumes. The total monthly demand for reservoir water by the North Poudre Irrigation Company is also input for the three-year period. Finally, appropriate channel loss coefficients are included. An initial set of downstream demand ($DEMR_{i,t}$) and reservoir storage ($OPRP_{i,t}$) priorities, from which the values of the w_{ij} are calculated according to Equations III.8 and III.9, are selected and the model is operated to determine the distribution of storage based on the degree of demand satisfaction throughout the network. All other parameters, such as evaporation and channel loss coefficients, are fixed. The model results are compared with the historical records for the same three-year period, priority factors are adjusted according to the deviation of model results from historical values, and MODSIM is rerun. The above procedure is repeated until an acceptable deviation is reached or no further improvement can be made. In the latter case, if no further improvement can be made while results remain unacceptable, other model parameters, such as evaporation or channel loss coefficients, must be reviewed, perhaps leading to a redesign of the network or even a reconceptualization of the problem.

A complete summary of MODSIM calibration results for the high country reservoir recreation analysis can be found in Shafer and Labadie (1977; Table 5, pp. 187-189). The mean monthly deviation of calculated storage from historical storage for all the reservoirs (except Milton Seamon Reservoir and the aggregate plains reservoirs) is 2.16 percent. The highest monthly deviation recorded is 100 percent for Twin Lake Reservoir in May, 1975. However, the absolute values of calculated storage versus historical storage for Twin Lake in this month are zero acre-feet and 17 acre-feet, respectively. Even though the deviation is 100 percent, the difference in actual storage levels is not significant. The final storage priorities for the calibration phase are presented in Table VI.1. Decreasing values mean higher priorities, which reflect the implicit priorities that governed the historical management of the system.

Table VI.1. Implicit Historical Reservoir Storage Priorities for High Mountain Reservoir Recreation Study ($OPRP_{i,t}$)*

Reservoir (i)	1973	1974	1975
Peterson	50	50	48
Barnes Meadow	50	55	45
Big Beaver	50	50	59
Commanche	55	50	59
Twin Lake	50	50	59
Worster	70	46	48
Halligan	60	60	48
Park Creek	70	70	48
N.P. #15	80	80	47

*Referring to Equation III.9, a lower value for $OPRP_{i,t}$ implies a higher priority since it results in a more negative value for the corresponding w_{ii}. Because MODSIM performs a minimizing operation, this means that a more negative value would encourage the model to retain more water in storage during a given month t, i.e., transfer more water to the artificial storage node.

Milton Seamon Reservoir has special consideration in the analysis, in that, although it is owned and operated by the City of Greeley, it does not directly contribute to the North Poudre Irrigation Company system. Also, Seaman Reservoir has little or no recreational potential. This reservoir, however, does contribute slightly to the irrigation system in an indirect fashion through the exchange process. In this analysis, Milton Seaman Reservoir is viewed as an equalizing reservoir and is not allowed to influence the operation of the subsystem. Historically, Seaman Reservoir has a beginning period storage of 2460 acre-feet. This is set equal to zero in the study and no unregulated flows into it were considered. In this manner, Seaman Reservoir cannot unduly influence system performance. The small contribution made by this reservoir toward demand satisfaction for reservoir water is subtracted from the total demand, thereby eliminating the error of overestimating the demand. Finally, its ending storage was allowed to go to zero.

The difference between total historical ending storage volume (excluding Milton Seaman) and total calculated ending storage volume for the calibration exercise is approximately 1875 acre-feet (historical greater than calculated). Although this value is not significant, it does indicate some data inconsistencies. Subsequently, MODSIM was rerun with the above priorities; however, evaporation rates were set equal to zero. For this case, the calculated ending storage was greater than the historically observed ending storage. The above result tends to lend support to the suggestion that evaporative losses are not entirely reflected in the historical records of observed storage in some of the reservoirs. Likewise, it is also ture that the evaporation rates used for these analyses are probably somewhat overestimated, which could explain the lower ending storage. It was suspected that the so-called *observed* storages may not have been observed at all because records showed no change in storage in some cases even though there were no inflows or outflows with evaporation still occurring. In spite of inconsistencies in the observed data and uncertainties with regard to evaporation rates, it was decided that the model could be trusted for purposes of the high mountain recreation analysis.

C. MODSIM Calibration for the Rawhide Project

C.1 Procedure

The following step by step procedure was used to calibrate MODSIM for the Rawhide Project.

1. Set the lower and upper bounds equal to zero for all links representing the Rawhide Pipeline.
2. Set desired monthly ending storage for Joe Wright Reservoir to zero for all months. Joe Wright was inactive during the calibration period.
3. Obtain initial storage volumes (November 1, 1972) (Table VI.2).
4. Set desired or target end-of-month storage values as historically observed end-of-month storage divided by reservoir maximum capacity (except Horsetooth Reservoir) (Table VI.3).
5. Determine unregulated and spurious inflows:
    i. Inflow to node 14 (confluence of North Fork Cache la Poudre River) equals monthly release from Milton Seaman Reservoir.
    ii. Inflow to node 10 equals Fort Collins gaged flow plus diversions to Fort Collins Pipeline and Munroe Gravity Canal, minus releases from Chambers Lake, Long Draw Reservoir, and Milton

Table VI.2. Initial Storage Levels
(November 1, 1972)

Reservoir	Water in Storage (Acre-Feet)
Long Draw	1174
Chambers Lake	2192
North Poudre No. 6	6224
Fossil Creek	5837
Timnath	5455
Windsor	9805
Horsetooth	0

Table VI.3. Storage Targets % of Full

1973	CAP	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Long Draw Res.	10519	.112	.128	.128	.126	.129	.134	.000	.000	.000	.000	.000	.000
Chambers Lake	8824	.371	.399	.476	.501	.534	.580	.844	1.00	1.00	.546	.115	.225
No. Poudre #6	9968	.624	.624	.624	.624	.624	.624	.659	.703	.582	.495	.286	.503
Fossil Creek	11100	.652	.765	.759	.791	.843	.927	.797	.935	.892	.573	.658	.658
Timnath Res.	10070	.612	.774	.774	.774	.808	.928	.910	1.00	.973	.471	.449	.612
Windsor Res.	17689	.659	.680	.708	.734	.791	.888	.781	.697	.847	.466	.493	.500
1974													
No. Poudre #6	9968	.511	.511	.511	.530	.558	.534	.495	.484	.447	.407	.404	.659
Windsor Res.	17689	.550	.573	.607	.629	.646	.776	.720	.857	.421	.417	.236	.504
Timnath Res.	10070	.715	.715	.715	.741	.830	.836	.887	1.00	.628	.140	0.00	.434
Fossil Creek	11100	.658	.664	.664	.670	.850	.864	.772	.792	.658	.330	.525	.623
Long Draw Res.	10519	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chambers Lake	8824	.261	.317	.373	.399	.370	4.90	.875	.976	.927	.700	.136	.208
1975													
Long Draw Res.	10519	.018	.018	.018	.018	.018	.018	.062	.993	.993	1.00	.811	.829
Chambers Lake	8824	.257	.293	.369	.369	.401	.440	.297	.962	.962	.281	0.00	.110
No. Poudre #6	9968	.659	.659	.681	.681	.681	.690	.676	.672	.522	.320	.286	.432
Fossil Creek	11100	.676	.685	.595	.595	.700	.617	.374	.857	.687	.353	.056	.079
Timnath Res.	10070	.662	.662	.662	.662	.662	.662	.436	.678	.569	.152	.271	.273
Windsor Res.	17689	.547	.547	.607	.607	.650	.715	.477	.939	.554	.178	.335	.431

Seaman Reservoir, plus five percent to compensate for channel losses. This result is the gross amount of water available for subsequent diversion in each month from the headwaters of the Poudre River. It is also net of diversions to Poudre Valley Canal and assumes historical operation of high mountain reservoirs not directly modeled.

iii. For purposes of this study, Horsetooth Reservoir is considered an equalizing reservoir. The reservoir operates on a seasonal basis. In all but a few cases the reservoir only releases water between the first of April and the end of October. Its waters service the entire valley with supplemental irrigation water and also augment the supply of several municipalities, including Fort Collins. To avoid allowing more Horsetooth water to the system than actually is available, the Northern Colorado Water Conservancy District (NCWCD) records were used to delineate only those waters that are delivered to the river and also supplied to the City of Fort Collins. These monthly releases are then summed and entered as inflow to the reservoir in April. The reservoir level is allowed to freely fluctuate except that the storage has to go to zero in October. Evaporation is not deducted from the storage pool due to the fact the adjusted inflow is the net delivery to the City.

iv. Historical inflows to Long Draw Reservoir and Chambers Lake Reservoir are input monthly.

v. Additional inflows to certain plains reservoirs are included as a result of ditch transfers that do not originate from diversions on the main stem of the river and non-stream inflows.

Table VI.4 lists the primary inflows to various nodes throughout the system for the calibration period.

6. Net added flow to the river is also calculated. Due to irrigation activity in the valley, there is significant return flow accruing to the Poudre River between Fort Collins and Greeley. Also, tributary inflow, precipitation on the channel, and channel seepage are occurring throughout the year. This net additional inflow to the river can be reasonably estimated. The gaged Poudre River flow at Greeley (confluence with South Platte River), the gaged river flow at Fort Collins, and the monthly diversions and releases between these stations are used to determine the net added flow. Working upstream, diversions and releases to the river are added and subtracted from the gaged record at Greeley. This results in a calculated flow at the Fort Collins gage. Comparing this calculated flow with the observed flow at Fort Collins reveals that in each month the calculated flow at Fort Collins is greater than the observed, as expected. The difference between these values is assumed to be net return flow to the river. Figure VI.1 shows the Fort Collins gaged flow and the net added flow between Fort Collins and Greeley. These monthly values of net added flow are input to the model at node 15. Though the lumping of total return flow at this point is somewhat erroneous, the nature of the aggregated demand for water downstream of the system boundary (as well as other ditches within the system not explicitly included in the model), does not seriously detract from reality.

Table VI.4. Unregulated Inflows (Acre-Feet)

Month	Node 14 Release from Milton Seaman Res.	Node 10 Fort Collins Adjusted Gage Record	Node 4 Horse-tooth Res.	Node 1 Longdraw Res.	Node 3 Chambers Lake Res.
Nov 72	133	3274	0	0	1081
Dec	0	2409	0	150	248
Jan 73	0	2278	0	0	730
Feb	148	2068	0	0	230
Mar	50	2843	114	28	299
Apr	0	4175	66874	53	404
May	3950	92672	0	346	2547
Jun	0	144424	0	0	1584
Jul	184	83659	0	0	0
Aug	1647	26996	0	0	0
Sep	1059	7615	0	0	0
Oct	0	6512	0	0	993
Nov	1879	5576	0	0	345
Dec	154	3719	0	0	493
Jan 74	0	3188	0	0	489
Feb	0	3702	0	0	238
Mar	4	6702	0	0	339
Apr	661	7860	107189	0	461
May	3881	87129	0	0	3396
Jun	400	126667	0	0	1103
Jul	0	54024	0	0	0
Aug	1204	19390	0	0	0
Sep	287	8471	0	0	127
Oct	2208	7298	0	0	630
Nov	28	3715	0	0	434
Dec	170	2106	0	0	319
Jan 75	590	1094	0	0	303
Feb	129	1433	0	0	363
Mar	0	2010	64	0	291
Apr	0	3106	87210	0	343
May	3942	20168	0	1002	449
Jun	0	98256	0	9801	5869
Jul	0	94907	0	0	0
Aug	1449	25328	0	69	0
Sep	1119	10156	0	73	0
Oct	1190	3508	0	194	974

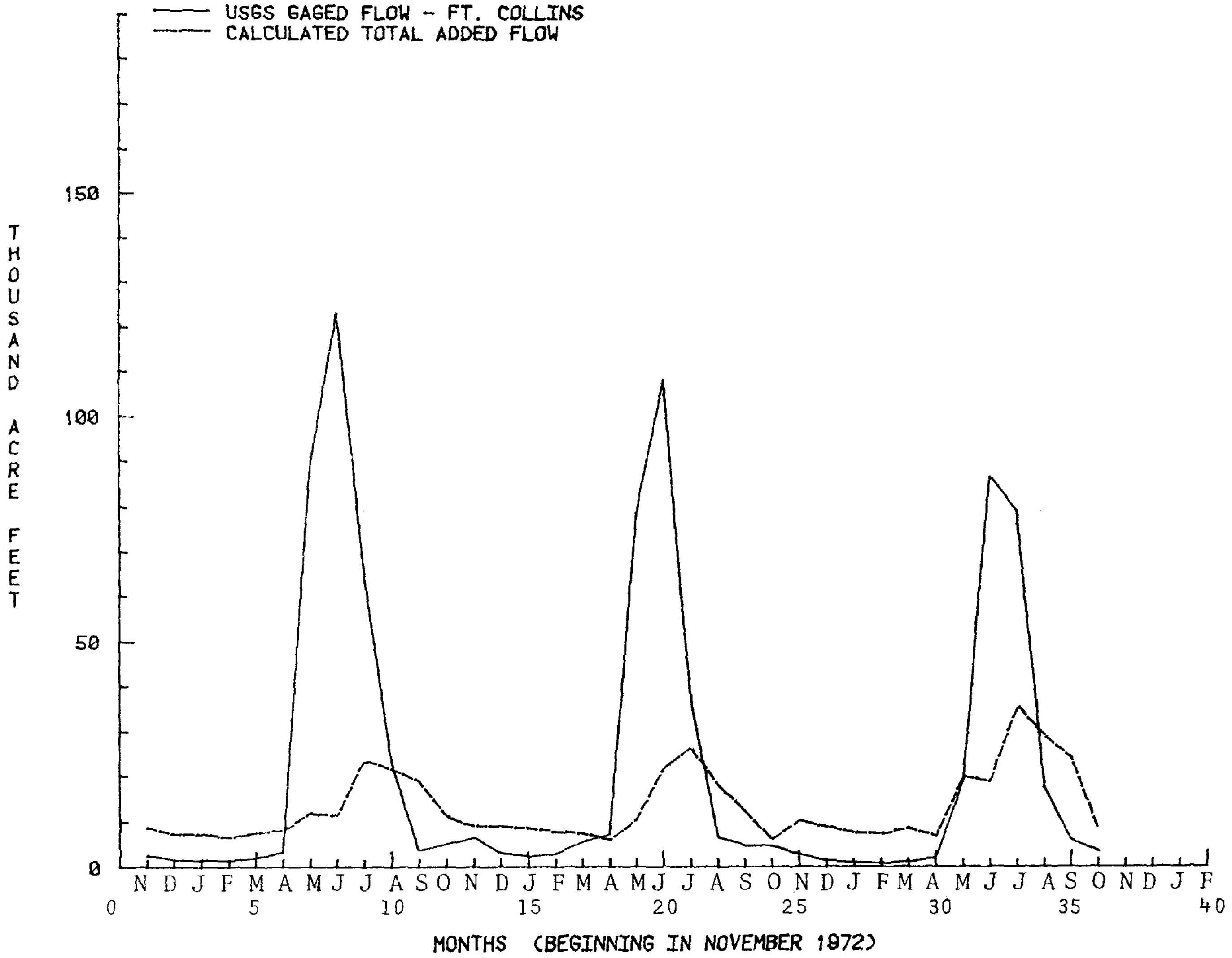

Figure VI.1. Fort Collins gaged flow and net added flow between Fort Collins and Greeley.

7. Determine historical demands:

   i. The demand for raw water by the City of Fort Collins has been discussed previously. Using the aforementioned consumptive loss percentages and a two percent diversion of treated water to West Fort Collins Water District, the resulting estimated losses are specified as model demands. Tables VI.5 through VI.7 display the monthly values for diversions to the Fort Collins treatment plants and associated consumptive losses.

   ii. The historical river to ditch diversions (including Horsetooth water) as compiled from generated reports from the CWDB are input as demands for the specific canal systems modeled.

   iii. To insure that the remainder of the system not explicitly modeled is realistically considered, a demand is established at the terminal node which takes into account all ditch diversions not directly analyzed. To do this, the flow normally passing the downstream case study boundary is calculated for the historical period in much the same fashion as the added flow. Beginning with the recorded streamflow of the Greeley gage, canal diversions are added (moving upstream) until the historical flow of the study boundary is calculated. To these monthly values are added the monthly diversions to ditches not directly modeled between the boundary and the Fort Collins stream gage. These total monthly figures are then input as the monthly demand at the terminal node. In this manner, the total historical requirement for river water in this reach is considered (Table VI.8).

Table VI.5. 1973 Demands at Fort Collins (Acre-Feet)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
River Diversion to Pipeline	621	704	710	668	708	506	748	1335	1396	1416	1010	920	10,742
Horsetooth					114	280	630	991	569	757	257	90	3,688
TOTAL (Demand at 21)	621	704	710	668	822	786	1378	2326	1965	2173	1267	1010	14,430
2% to West Ft. Collins (Demand at 22)	12	14	14	13	16	16	28	47	39	43	25	20	287
Available at Ft. Collins	609	690	696	655	806	770	1350	2279	1926	2130	1242	990	14,143
% Consumptive Loss	1.6	1.4	1.1	1.2	1.6	42.9	60.7	55.0	46.0	46.5	35.1	21.8	
Consumptive Loss (Demand at 23)	10	10	8	8	13	330	819	1253	886	990	436	216	4,979

Table VI.6. 1974 Demands at Fort Collins (Acre-Feet)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
River Diversion to Pipeline	826	796	636	586	587	877	1447	1611	1693	1731	1279	1184	13,353
Horsetooth	36	18	3	3	6	22	623	686	914	669	293	6	3,279
TOTAL (Demand at 21)	862	814	639	589	693	899	2070	2297	2607	2400	1572	1190	16,632
2% to West Ft. Collins (Demand at 22)	17	16	13	12	14	18	41	46	52	48	31	24	332
Available at Ft. Collins	845	798	626	577	679	881	2029	2251	2255	2352	1541	1166	16,300
% Consumptive Loss	1.6	1.4	1.1	1.2	1.6	42.9	60.7	55.0	46.0	46.5	35.1	21.8	
Consumptive Loss (Demand at 23)	14	11	7	7	11	379	1231	1238	1176	1095	542	254	5,965

Table VI.7. 1975 Demands at Fort Collins (Acre-Feet)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
River Diversion to Pipeline	776	796	816	750	748	834	1105	966	1196	1178	1034	1028	11,227
	50		6	4	16	26	69				238	178	587
											109		109
Transbasin							10		65	174	91		340
TOTAL	826	796	822	754	764	858	1184	966	1261	1352	1472	1206	12,263
Horsetooth					64	2	332	528	1077	738	483	173	3,397
TOTAL (Demand at 21)	826	796	822	754	828	860	1516	1494	2338	2090	1955	1379	15,660
2% to West Ft. Collins (Demand at 22)	17	16	16	15	17	17	30	30	47	42	39	28	314
Available at Ft. Collins	809	780	806	739	811	843	1486	1464	2291	2048	1916	1351	15,346
% Consumptive Loss	1.6	1.4	1.1	1.2	1.6	42.9	60.7	55.0	46.0	46.5	35.1	21.8	
Consumptive Loss (Demand at 23)	13	11	9	9	13	362	902	805	1054	952	672	294	5,096

Table VI.8. Calculation of Adjusted Demand at Terminal Node - 1974 (Acre-Feet)

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Annual
Calculated Flow at Terminal Node	13350	10380	9420	9060	7360	7476	13528	41842	20718	16807	8667	8568	167,176
Ditches Not in Analysis													
Boxelder							1744	1378	2265	1719	659	121	7,886
Chaffee							105	141	125	117			488
Coy						14	283	303	376	297	248	46	1,567
Arthur							1340	1169	1881	729	86		5,205
Larimer Co.#2							3429	3424	1307	1650	555		10,365
New Mercer							2482	1820	1627	1077	240		7,246
Little Cache La Poudre		1071	921	832	1154	719	3619	3289	3859	1184	545	89	17,282
Jackson							2170	1934	1632	988	376		7,100
Larimer Co. Canal	362				319	2109	20608	18970	23170	16490	4496	3838	90,362
Pleasant Valley and Lake							4536	4617	3357	3046	2481	818	18,857
Greeley Pipeline	760	719	709	630	739	744	251		1468	1702	1462	1303	10,487
TOTAL	14472	12170	11050	10522	9572	11062	54095	78889	61785	45806	19815	14783	344,021
Seeley Lake Release		125		59		166				311		82	743
Total Adjusted Demand at Terminal Node	14472	12045	11050	10463	9572	10896	54095	78889	61785	45495	19815	14701	343,278

C.2 Results

The aggregate demand is given the lowest priority among demand nodes to insure that all shortages occur at the terminal node. The water requirement at this node is a conservative estimate of the actual aggregate due to the inclusion of reservoir to reservoir transfers of water that are impossible to separate from the data. Shortages which occur at the boundary should be limited to the non-irrigation months of the year when such transfers take place. This condition is exactly the response one finds from model runs with these data.

The criteria for acceptable model calibration was met after successive adjustment of model priorities. The final priorities or ranks are presented in Table VI.9. Reservoir storages calculated by the model correspond surprisingly well with observed data. In every case (except Windsor Reservoir) the calculated storage identically matches observed, or varies by a few acre-feet. The model calculates storage volumes for Windsor Reservoir in 1975 which are below observed, except for May when the calculated equals observed. This significant deviation may be attributed to an underestimate of either non-stream inflow to Windsor Reservoir or failure to consider transfers within the ditch system itself to the reservoir, or both.

The results of the model calibration are presented in Figures VI.2 through VI.7. Clearly, good correlation between calculated and observed flows at the Fort Collins gage exists. Deviation between the calculated water available at the case study boundary and the historical requirement are only a small percentage of the total requirement, and occur in off-season months. All other demands throughout the system were totally satisfied.

Table VI.9. Final Rankings for Rawhide Project Calibration*

	Name	Network Node No.	1973	1974	1975
Demand	N. Poudre No. 6 Res.	5	10	10	10
	Munroe Gravity Canal	12	10	10	10
	Larimer & Weld Canal	15	10	28	10
	Fort Collins Pipeline	21	10	40	10
	West Fort Collins	22	10	42	10
	Fort Collins (consumptive loss)	23	10	44	10
	Lake Canal	31	10	48	10
	New Cache la Poudre Canal	32	10	50	10
	System Boundary	35	18	55	15
Storage	Long Draw Res.	1	13	500	13
	Joe Wright Res.	2	500	500	500
	Chambers Lake Res.	3	3	3	3
	Horsetooth Res.	4	50	60	50
	N. Poudre No. 6 Res.	5	1	30	1
	Fossil Creek Res.	6	5	5	5
	Timnath Res.	7	13	3	13
	Windsor Res.	8	17	10	20
	Cooling Pond	9	100	100	100

*Rankings are translated into *pseudo-costs* of moving a unit of water from storage to demand satisfaction. For example, the rank of 1 in 1973 for holding water in N. Poudre Reservoir No. 6 takes precedence over all other storages and demands in 1973.

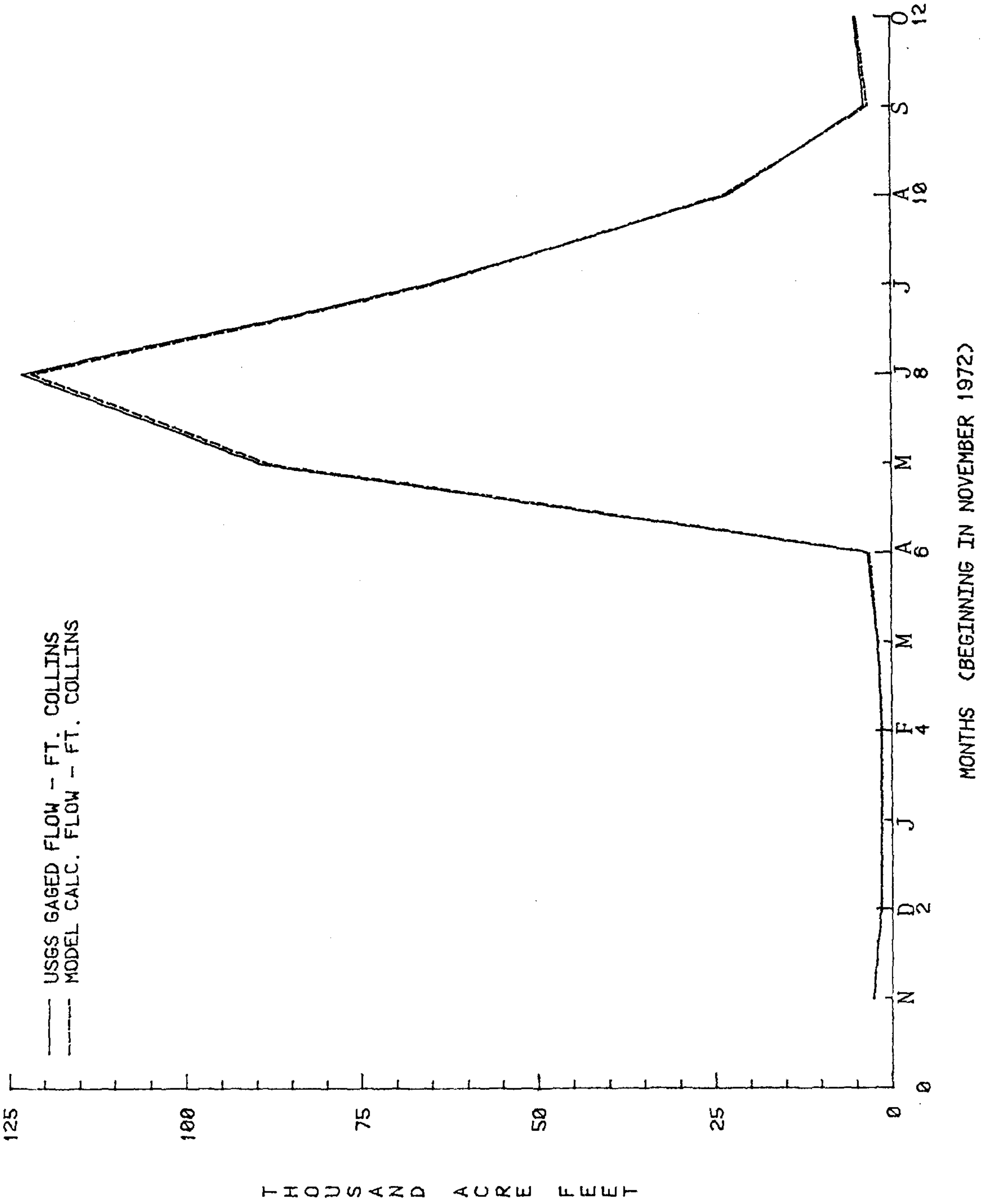

Figure VI.2. Calibration for Rawhide Project irrigation year 1973.

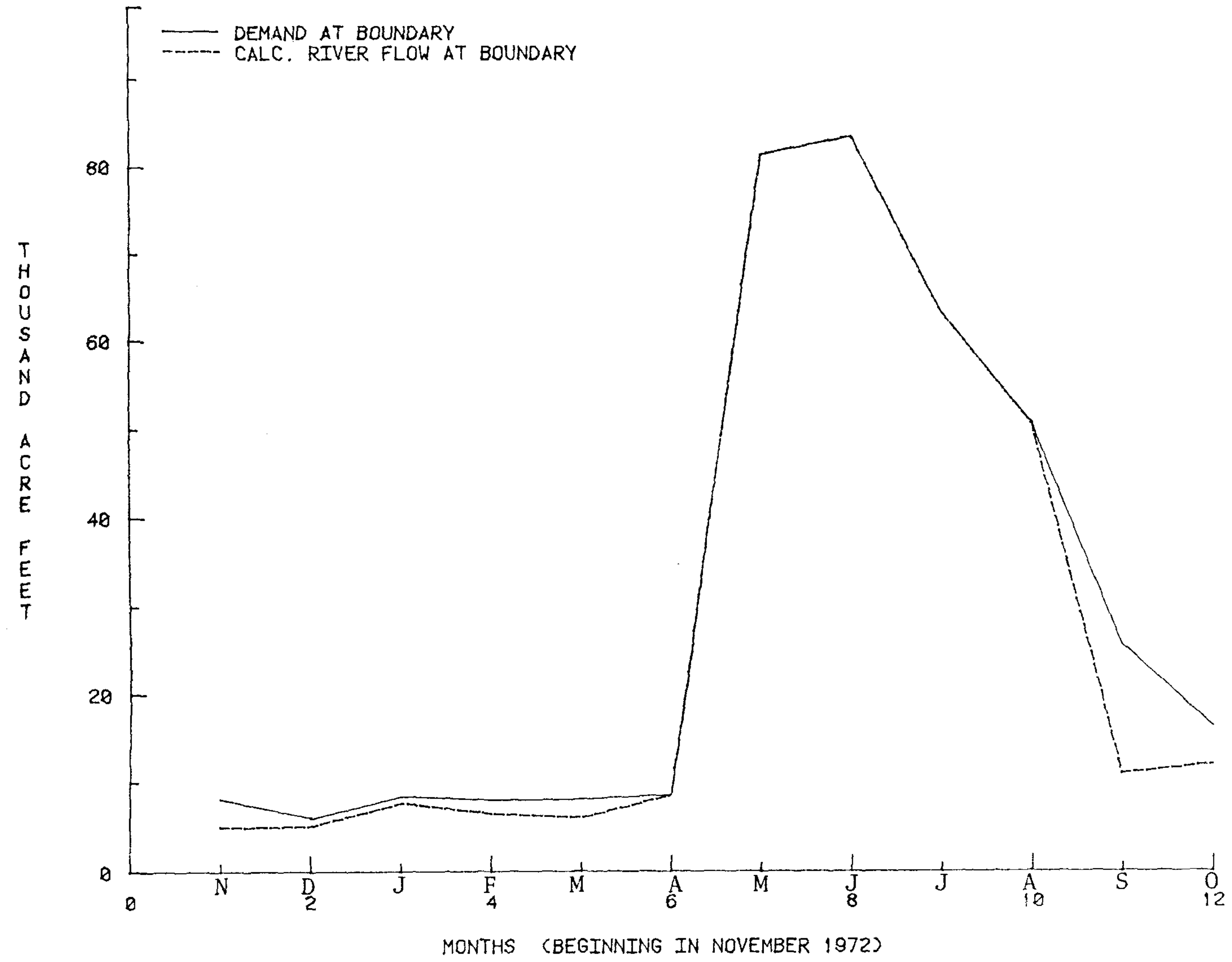

Figure VI.3. Calibration for Rawhide Project irrigation year 1973.

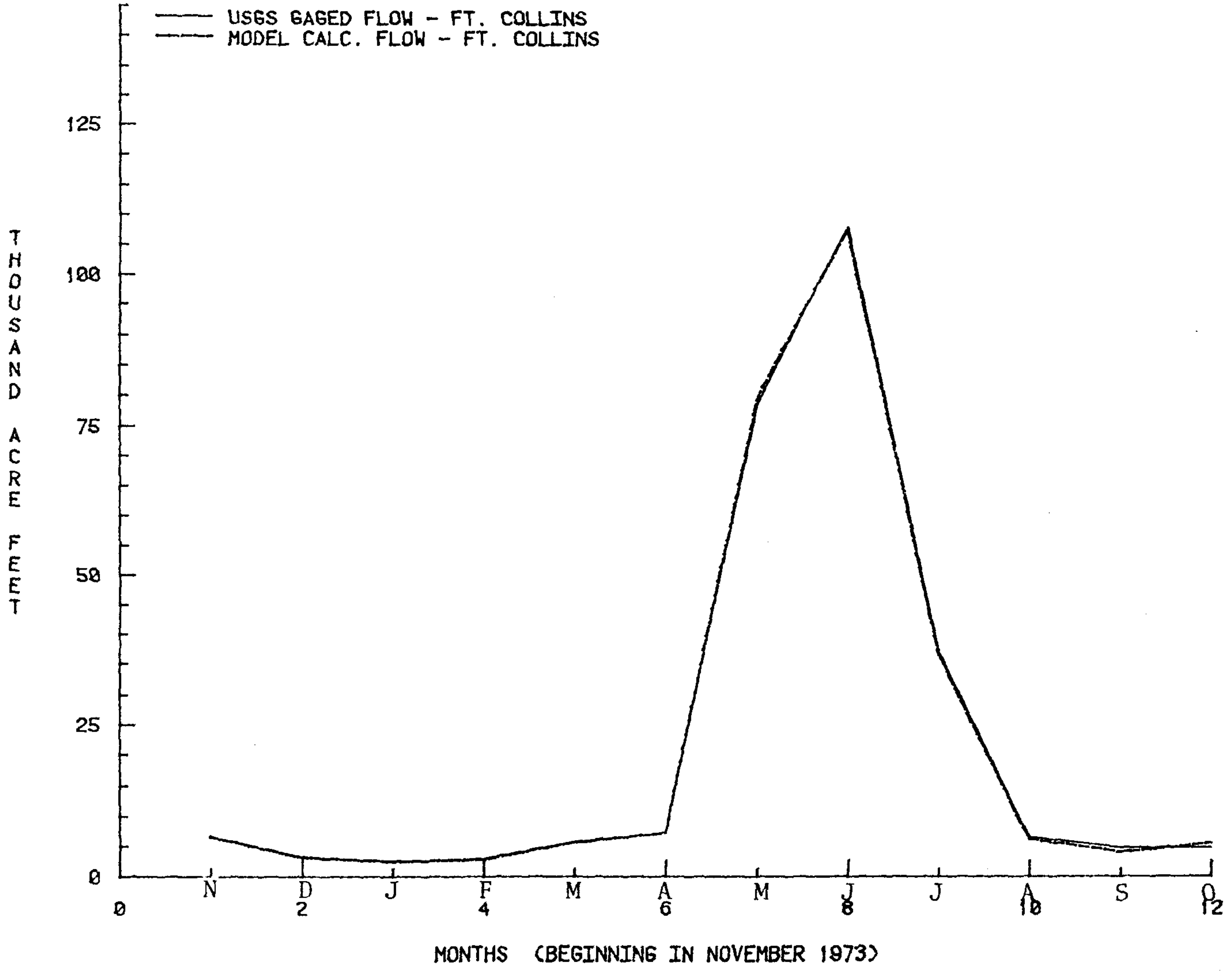

Figure VI.4. Calibration for Rawhide Project irrigation year 1974.

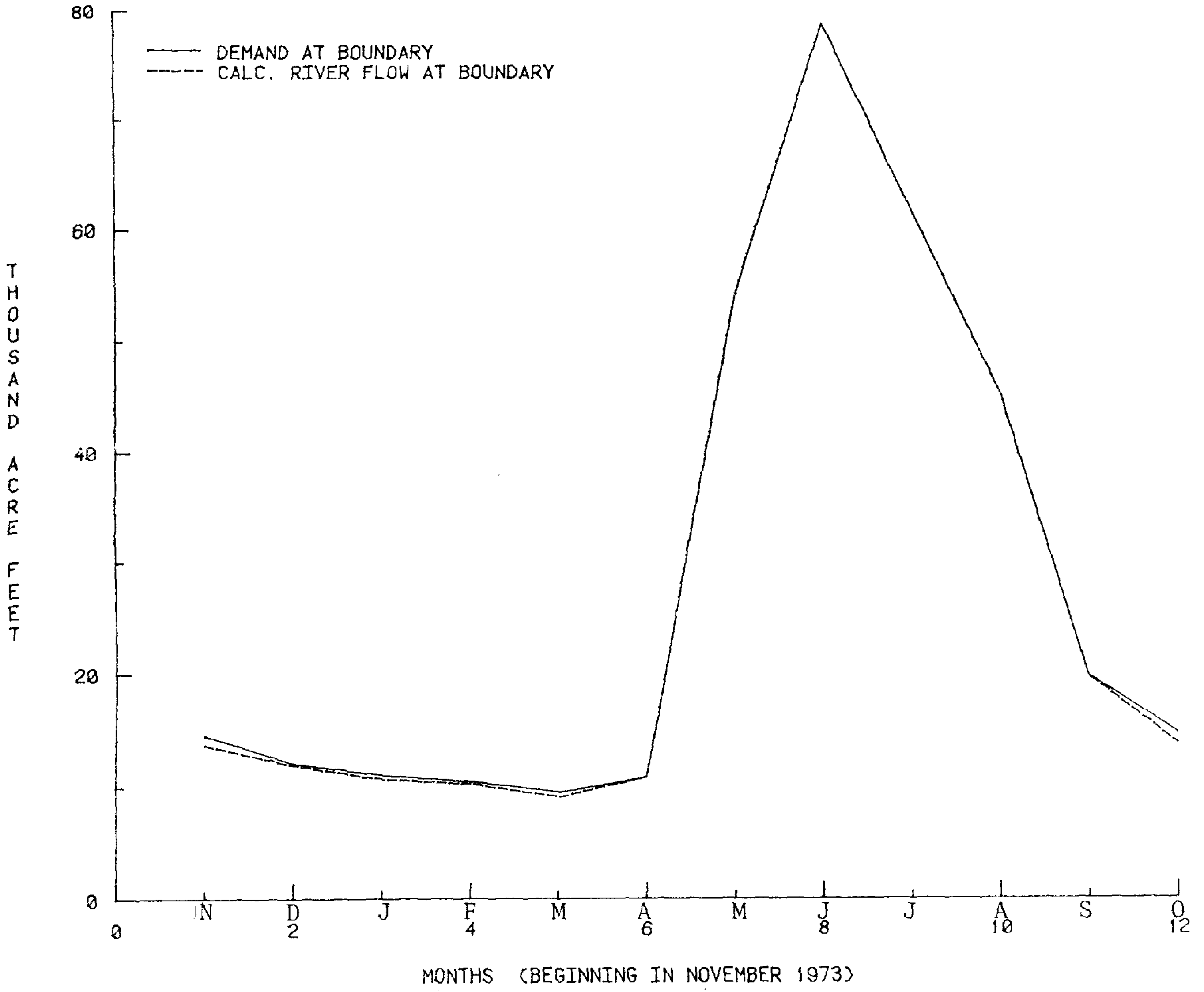

Figure VI.5. Calibration for Rawhide Project irrigation year 1974.

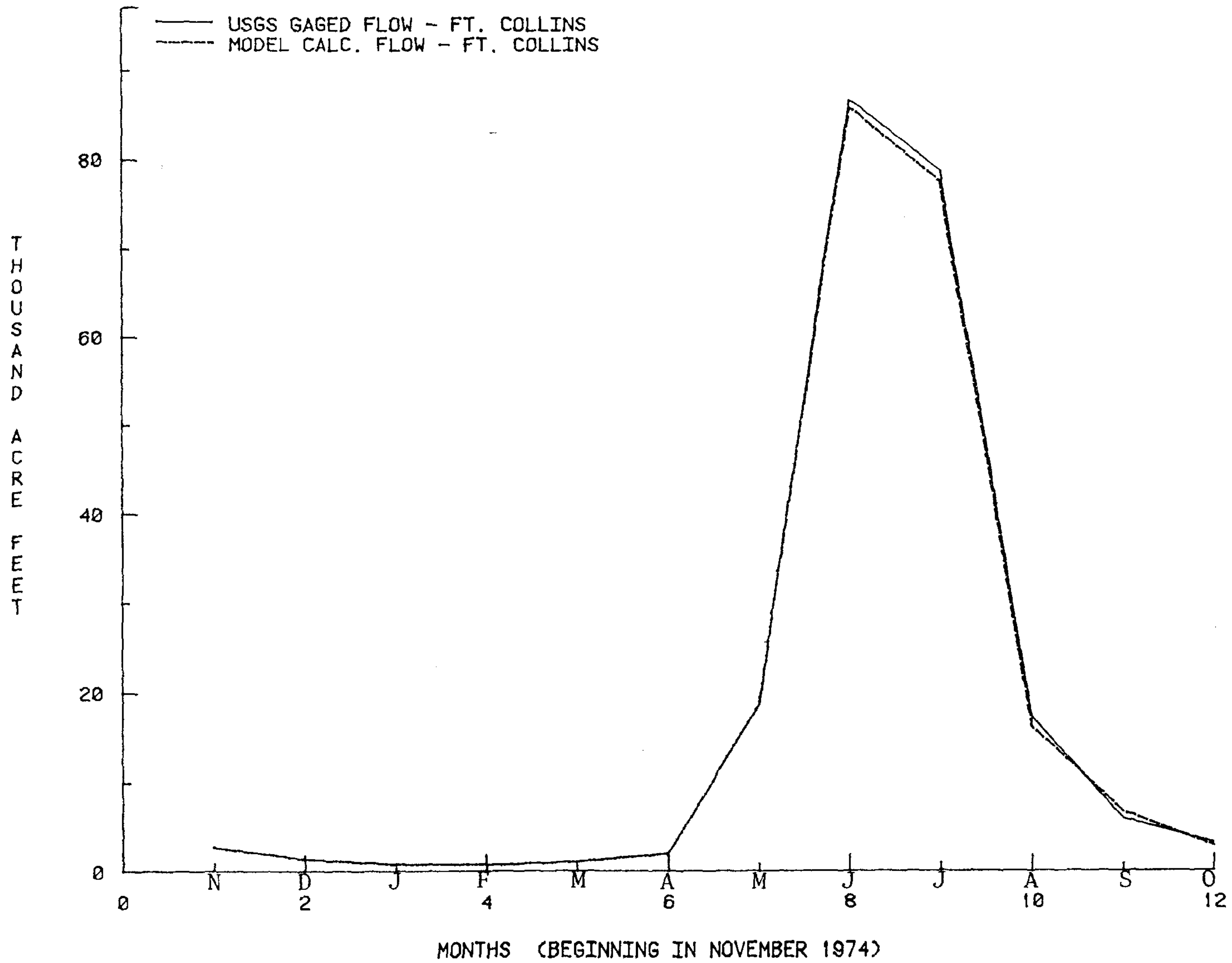

Figure VI.6. Calibration for Rawhide Project irrigation year 1975.

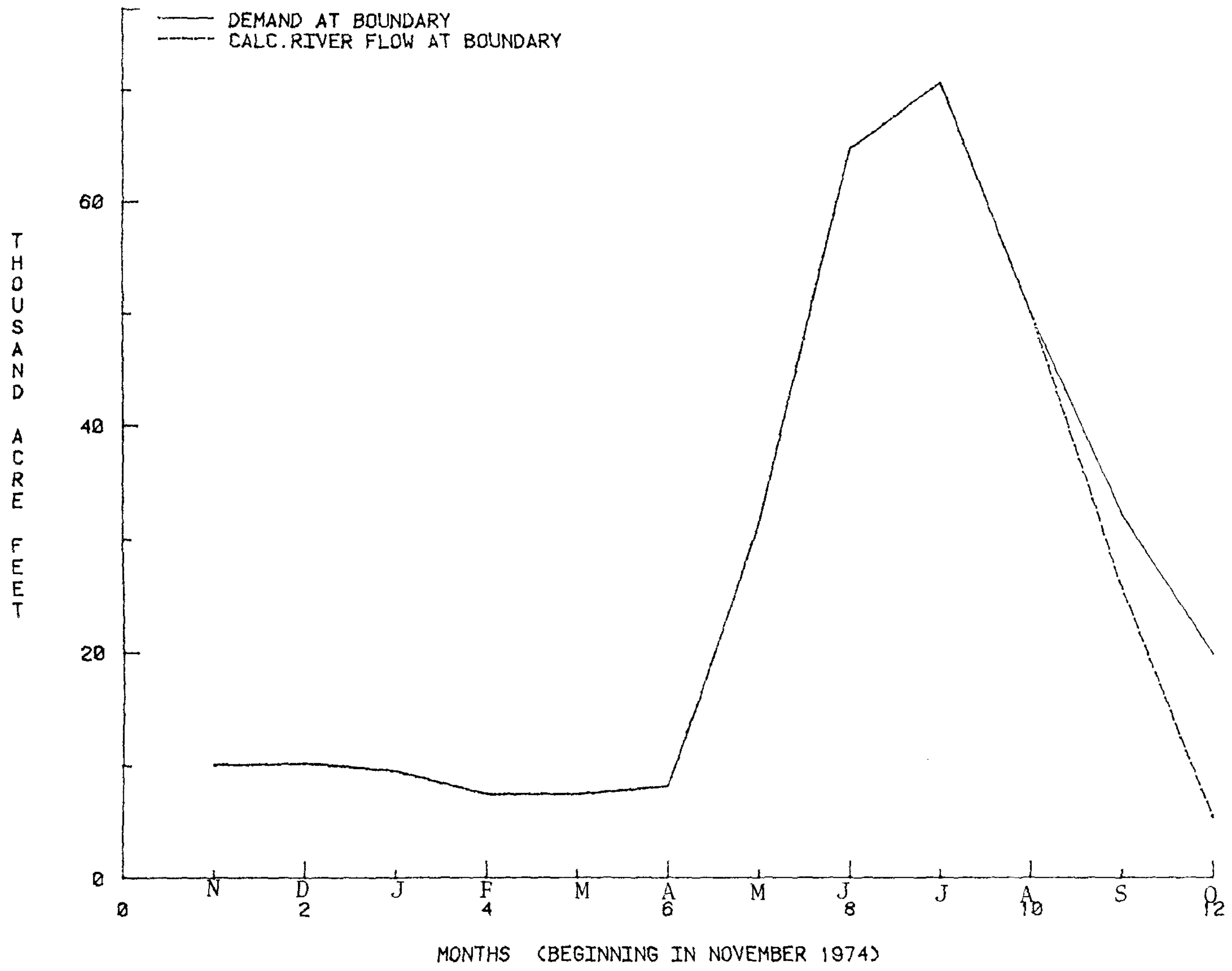

Figure VI.7. Calibration for Rawhide Project irrigation year 1975.

To summarize, the calibration of MODSIM for the Rawhide Project did include the use of some historical data. Historical return flows accruing to the river were input, thus eliminating groundwater considerations from the calibration exercise. As a result, only surface water conditions were attempted to be duplicated during calibration. The $DEMR_{i,t}$ and $OPRP_{i,t}$ of Equations III.8 and III.9 were adjusted until no better fit of calculated storage volumes, gaged river flows, and demand satisfaction with the historically observed values could be gained.

C.3 Return flow calculation option

For purposes of this case study, actual monthly return flows (net added flows) are calculated and input to the model. However, as discussed in Chapter III, return flows may be calculated via a multiple linear regression equation whose coefficients are MODSIM input. This section demonstrates the use of this option.

To begin, both a multi-lag autocorrelation of 18 years of monthly return flow values and a multi-lag cross-correlation of ditch diversions with return flows for the same 18 years is performed to determine the significant number of monthly lags to be included in the regression equation. For both correlation exercises a 95 percent confidence interval is used to test for significance of the correlation coefficients. The 18 years of return flow data are calculated in exactly the same manner as the net added flow discussed in the previous section.

The results of the correlation exercises are presented in Tables VI.10 and VI.11.

Table VI.10. Results of Autocorrelation of 18 Years of Monthly Return Flows at 95% Confidence Interval

Lag (K)	Conf. Int. (1)	Correlation R(K)	Conf. Int. (2)
1	- .133	.688	.133
2	- .133	.383	.133
3	- .133	.028	.133

Table VI.11. Results of Cross-Correlation of 18 years of Monthly Ditch Diversions with Return Flows at 95% Confidence Interval

Lag (K)	Conf. Int. (1)	Correlation R(K)	Conf. Int. (2)
0	- .133	.776	.133
1	- .133	.728	.133
2	- .133	.443	.133
3	- .133	.057	.133

From these two tables, the appropriate number of monthly lags which need to be included in the regression equation is determined to be two for both return flows and ditch diversions. Beyond two months there is insignificant (at 95% confidence interval) correlation to warrant expansion of the regression equation to include additional terms.

The confidence interval is used to test for significance of correlation coefficients in the following manner. The hypothesis is formulated which states that all return flow and ditch diversion values are completely independent from all others. The confidence interval (for this case 95%) is the region of acceptance of this hypothesis, i.e., if correlation coefficient R(K) for lag K resides within the interval (-.133 to .133) then the hypothesis is accepted and R(K) is assumed not significantly different from zero. However, if R(K) resides beyond the confidence interval, then the hypothesis is rejected and a certain dependence according to lag K is assumed to exist among the values.

Once the appropriate number of monthly lags have been determined, a regression analysis can be performed. For this study, the multiple linear regression equation has the form:

$$\hat{R}(t) = a_1 + a_2D(t) + a_3D(t-1) + a_4D(t-2) + a_5\hat{R}(t-1) + a_6\hat{R}(t-2) \qquad \text{(VI.1)}$$

where:

$\hat{R}(t)$ = dependent variable: return flow for month t

$D(t)$ = independent variable: ditch diversion for month t

$D(t-1)$ = independent variable: ditch diversion for month t-1

$D(t-2)$ = independent variable: ditch diversion for month t-2

$\hat{R}(t-1)$ = independent variable: estimated return flow calculated for month t-1

$\hat{R}(t-2)$ = independent variable: estimated return flow calculated for month t-2

$a_1, a_2, a_3, \ldots, a_6$ = regression coefficients.

The same 18 year period used for the correlation coefficients determination is used to calculate the regression coefficients, a_i. The values of the a_i are listed in Table VI.12.

Table VI.12. Regression Coefficients for Return Flow Equation

Coefficient	Value
a_1	2427.0
a_2	0.072633
a_3	0.0039629
a_4	- 0.024521
a_5	0.65021
a_6	- 0.031957

These coefficients are used to predict return flows for the calibration period 1973-1975. The results are graphically displayed in Figure VI.8. Although the estimated values and the actual calculated values of return flows differ widely in 1975, based on the large values for ditch diversions and return flows for 1975, in comparison with mean monthly values for the 18 years, 1975 is considered an atypical year. However, the return flows calculated using the regression equation closely conform to the mean monthly values and the overall trends are consistent with both the mean and the three-year period return flows.

For extended planning studies, in which the groundwater basin morphology, water use distributions, and general river basin physiology (e.g. lining of unlined canals) are not subject to a significant level of change, such as the Rawhide Project, one would expect and perhaps

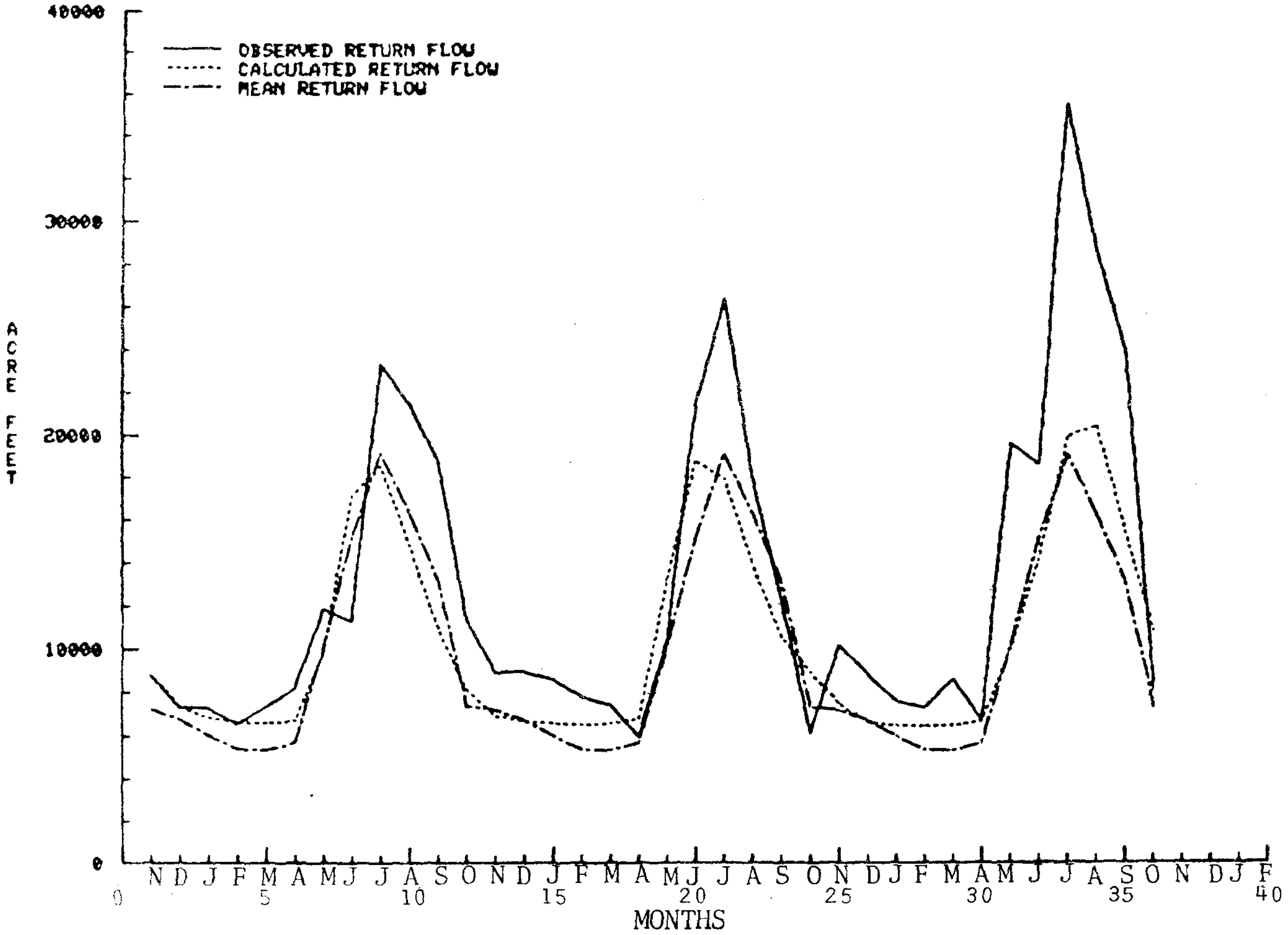

Figure VI.8. Comparison of calculated return flows with observed and mean return flows.

require that return flows fluctuate about the long term mean. This may not be true for short period, real time, operational studies, but for planning studies where one endeavors to determine most probable long range system behavior, based on operational guidelines, such is the case.

It must be noted that the above exercise is conducted off-line. The regression coefficients along with the appropriate monthly lag are input to MODSIM with information concerning the number of nodal demands contributing to return flow and the node to which the return flow accrues. MODSIM constructs the regression equation and iterates over the amount of demand satisfaction for each month, incorporating the return flows in the analysis as specified by the user.

CHAPTER VII

MANAGEMENT STUDIES

This chapter presents the method of analysis of the proposed water policy changes involved in each of the case studies outlined in Chapter V. The results produced by MODSIM are reported and then the implications of these results are discussed. Since both case studies represent *real world* problems confronting Colorado decision makers, the conclusions drawn from these studies and the associated impacts of these conclusions on the Cache la Poudre River system are important, and explained in detail.

A. Case Study #1

A.1 Method of analysis

The management strategy developed for this case study centers around the creation of a recreational reservoir out of Barnes Meadow and a recreational reservoir out of Twin Lake. As previously mentioned, these two reservoirs are considered to have the highest recreation potential of the five Greeley high mountain reservoirs. The management of these reservoirs with recreation included in a multipurpose framework is in marked contrast to the traditional operating policy demonstrated during the calibration phase.

The same simulation period used for model calibration is also used to perform the management study. Irrigation years 1973-75 are deemed acceptable for the analysis since they do represent a wet to dry cycle in the basin and complete information concerning the decomposed system is available. Also, during these years the high mountain reservoirs were emptied at the end of each year which is in conflict with stated management objectives.

The goal of this management study is to determine *what if*, for the three years in question, the high mountain reservoirs were operated in such a fashion that would provide for suitable water related recreation. The desired monthly storage levels for all five reservoirs are set at the maximum capacity of each reservoir. Desired storage levels for the remaining non-recreational reservoirs are set at zero for each month, thereby allowing these storage levels to freely fluctuate, based on the operation of the five high mountain reservoirs. The priorities assigned to each reservoir reflect the ordered preference of meeting the new management operating rules. Table VII.1 lists all the reservoirs and their corresponding priorities. Determination of these priority factors requires successive approximation. A set of initial priorities are selected. MODSIM computes storage levels based on these values. These storage levels are then compared to the desired levels for recreation enhancement, and the priority factors adjusted appropriately. It must also be remembered that throughout this analysis the priority established on demands is significantly higher than any reservoir storage priority to insure satisfaction of the demands for reservoir water.

It can be seen from these priorities that Barnes Meadow and Twin Lake reservoirs are given equally the highest consideration for storage maintenance, followed in order by Peterson, Commanche, and Big Beaver

Table VII.1. Storage Preferences for High Mountain Reservoir Management Analysis [$OPRP_{i,t}$]

Reservoir (i)	Priority Factors*		
	1972-1973	1973-1974	1974-1975
Peterson	50	50	50
Barnes Meadow	40	40	40
Big Beaver	80	80	80
Commanche	60	60	60
Twin Lake	40	40	40
Worster	75	75	75
Halligan	85	85	85
Park Creek	90	90	90
North Poudre #15	115	115	115
Milton Seaman	200	200	200
Aggregate	150	150	150

*A lower value is interpreted as a higher priority.

reservoirs. Priorities for the remaining non-recreational reservoirs reflect a desire to maintain water as high as possible in the system for added flexibility.

A.2 Results of analysis

Figures VII.1 thru VII.8 graphically display the results of this management analysis. Both the historical and the calculated monthly ending storage values are plotted over the 36 month simulation period. Keeping in mind that the same demand for reservoir water is met in each instance, and based on admittedly conservative evaporation rates, the alternative management strategy is clearly *hydrologically* viable. Upon initial filling, Barnes Meadow and Twin Lake reservoirs maintain near capacity storage levels throughout the simulation period, as expected. Also, Peterson Reservoir, which has the next greatest recreation potential (reflected by its priority in relation to Barnes Meadow and Twin Lake reservoirs) remains filled near capacity. Commanche and Big Beaver reservoirs are drawn empty in late 1975, which is acceptable. The remainder of the reservoirs fluctuate between zero storage and their maximum capacity as dictated by the demand pattern.

Carry-over storage at the end of the three-year period should be reasonably consistent with that calculated during calibration. A value of 6053 acre-feet of total carry-over storage was obtained from MODSIM calibration. This compares to a value of 4709 acre-feet of total carry-over storage for the new management scheme. A difference is expected due to changes in the distribution of the carry-over storage and variations in channel losses between calibration and management study results.

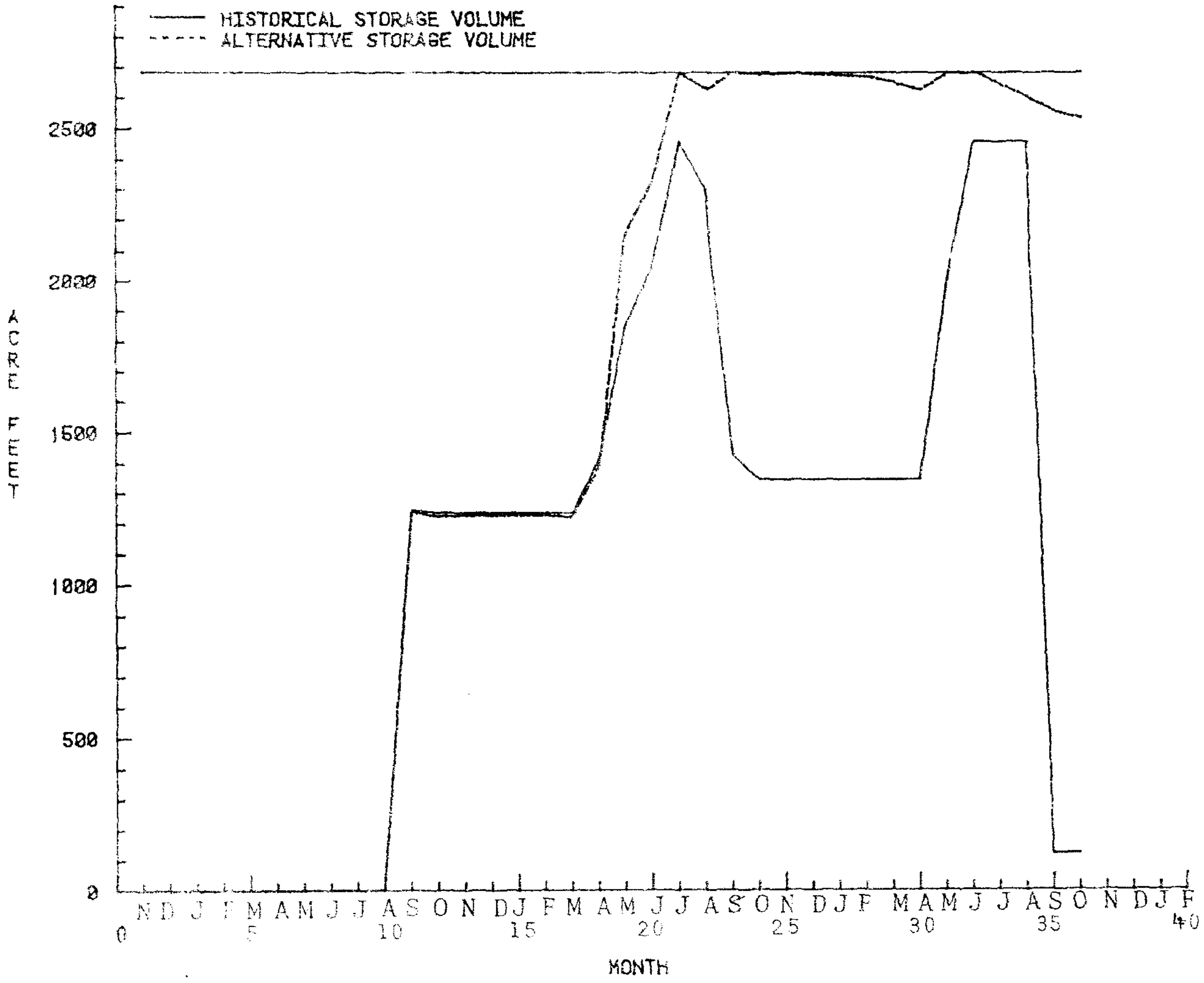

Figure VII.1. Barnes Meadow Reservoir.

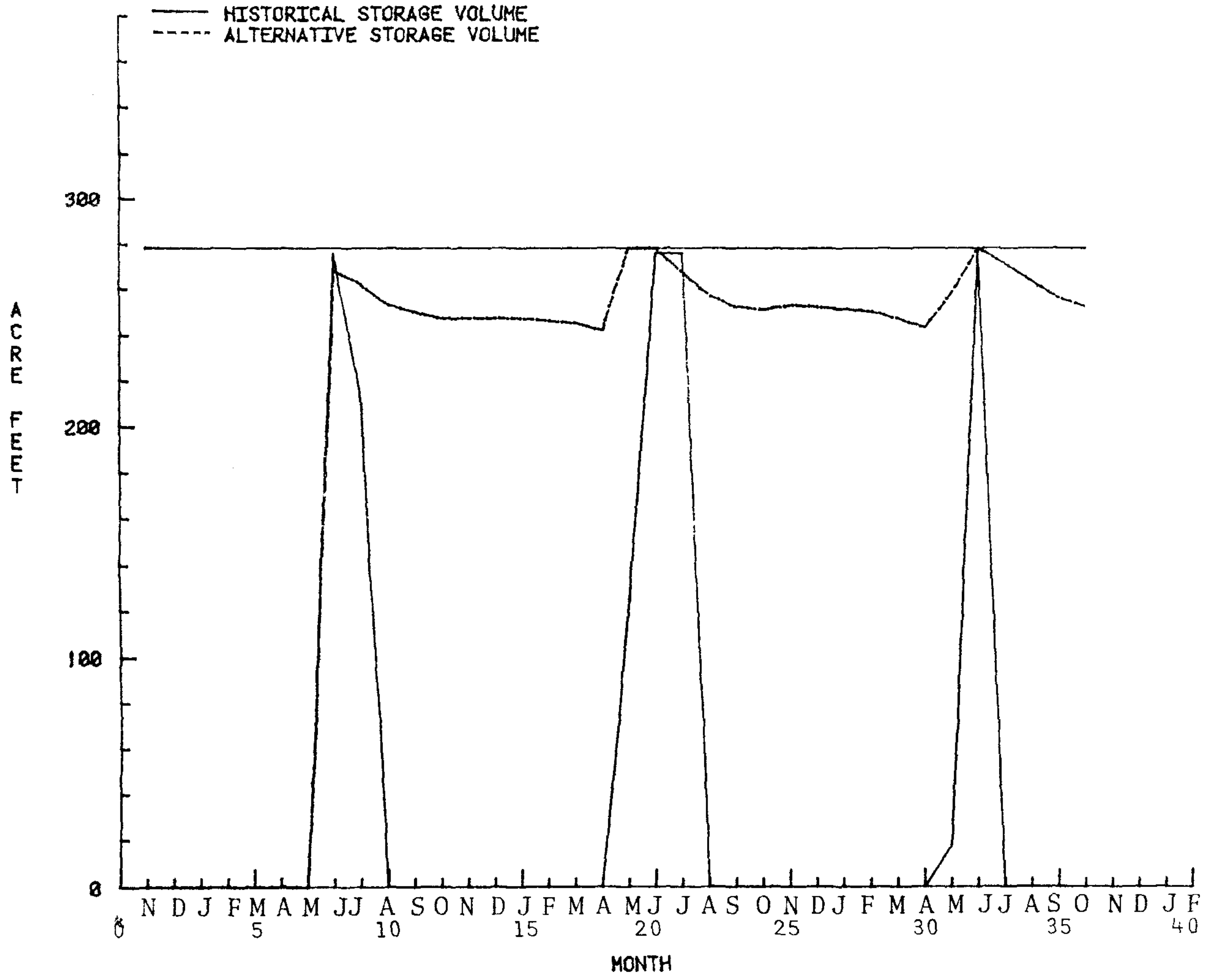

Figure VII.2. Twin Lake Reservoir.

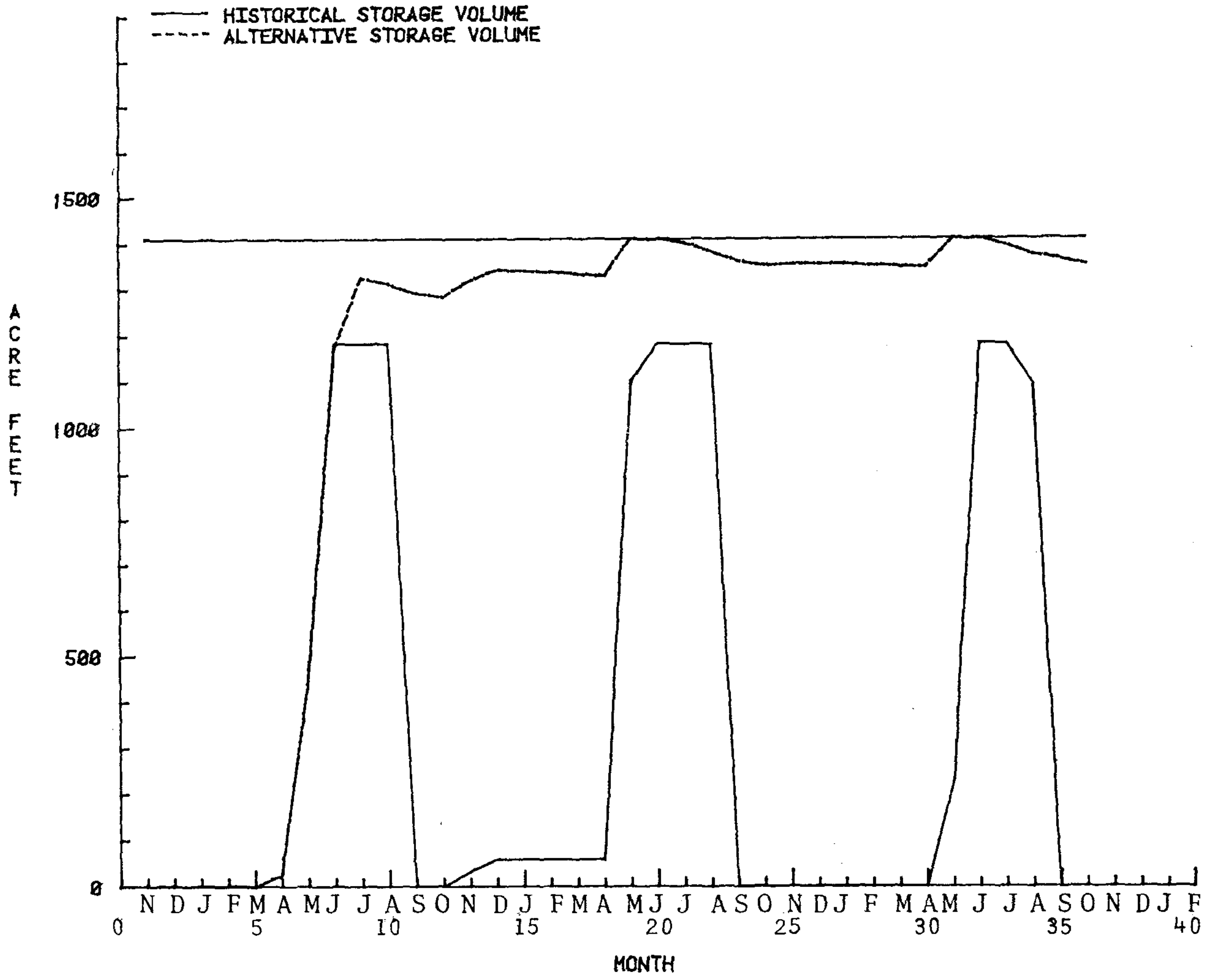

Figure VII.3. Peterson Lake Reservoir.

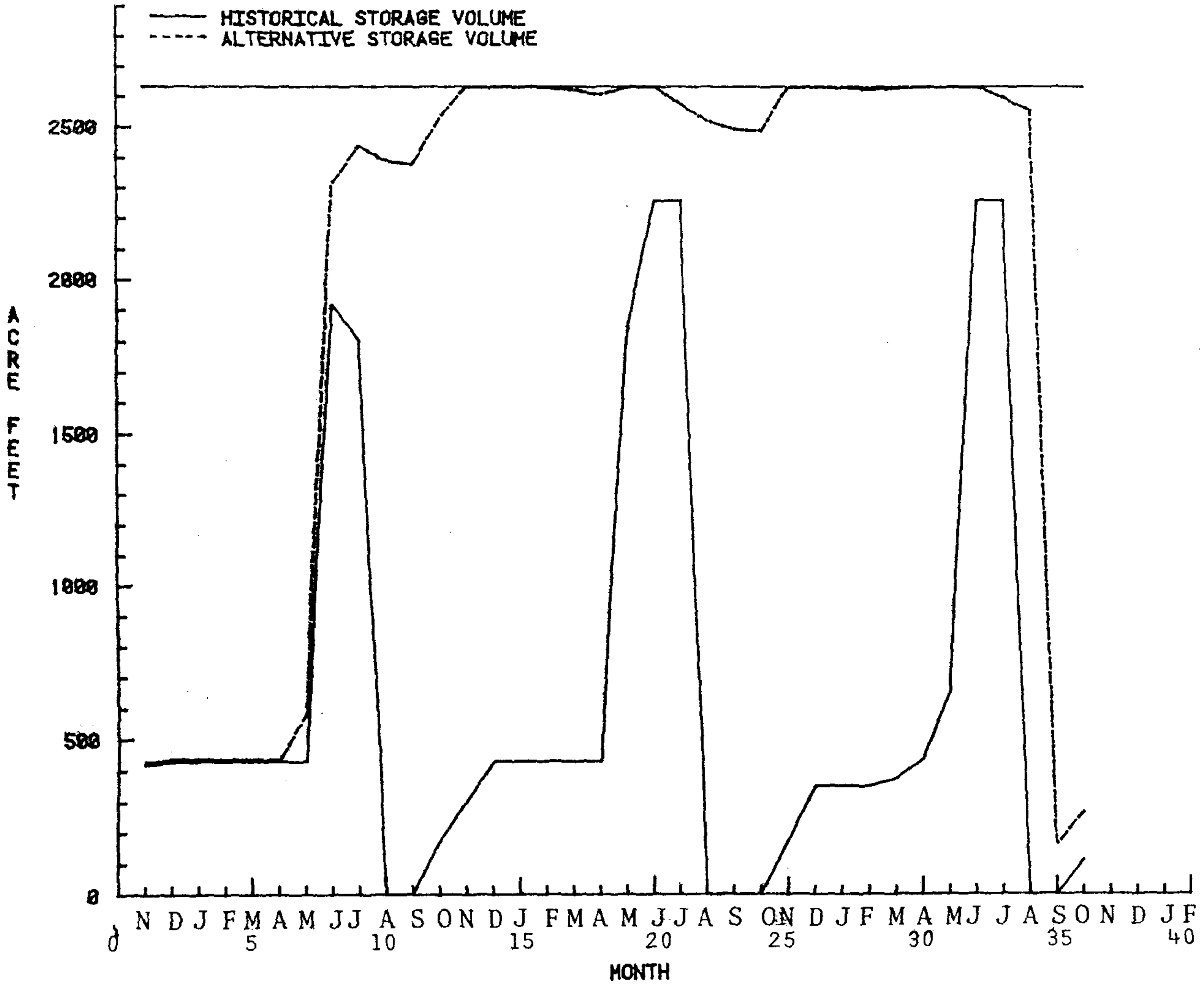

Figure VII.4. Commanche Reservoir.

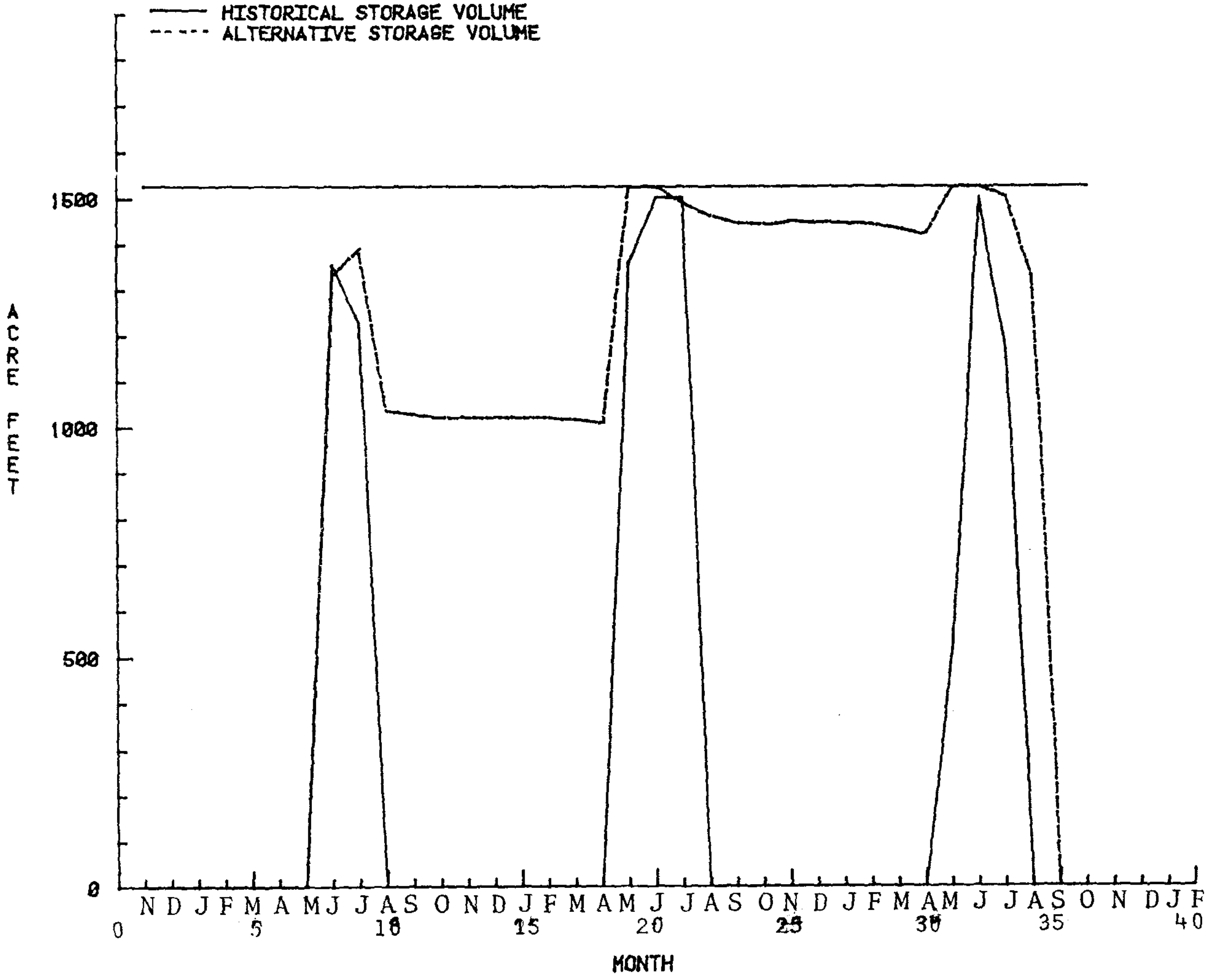

Figure VII.5. Big Beaver Reservoir.

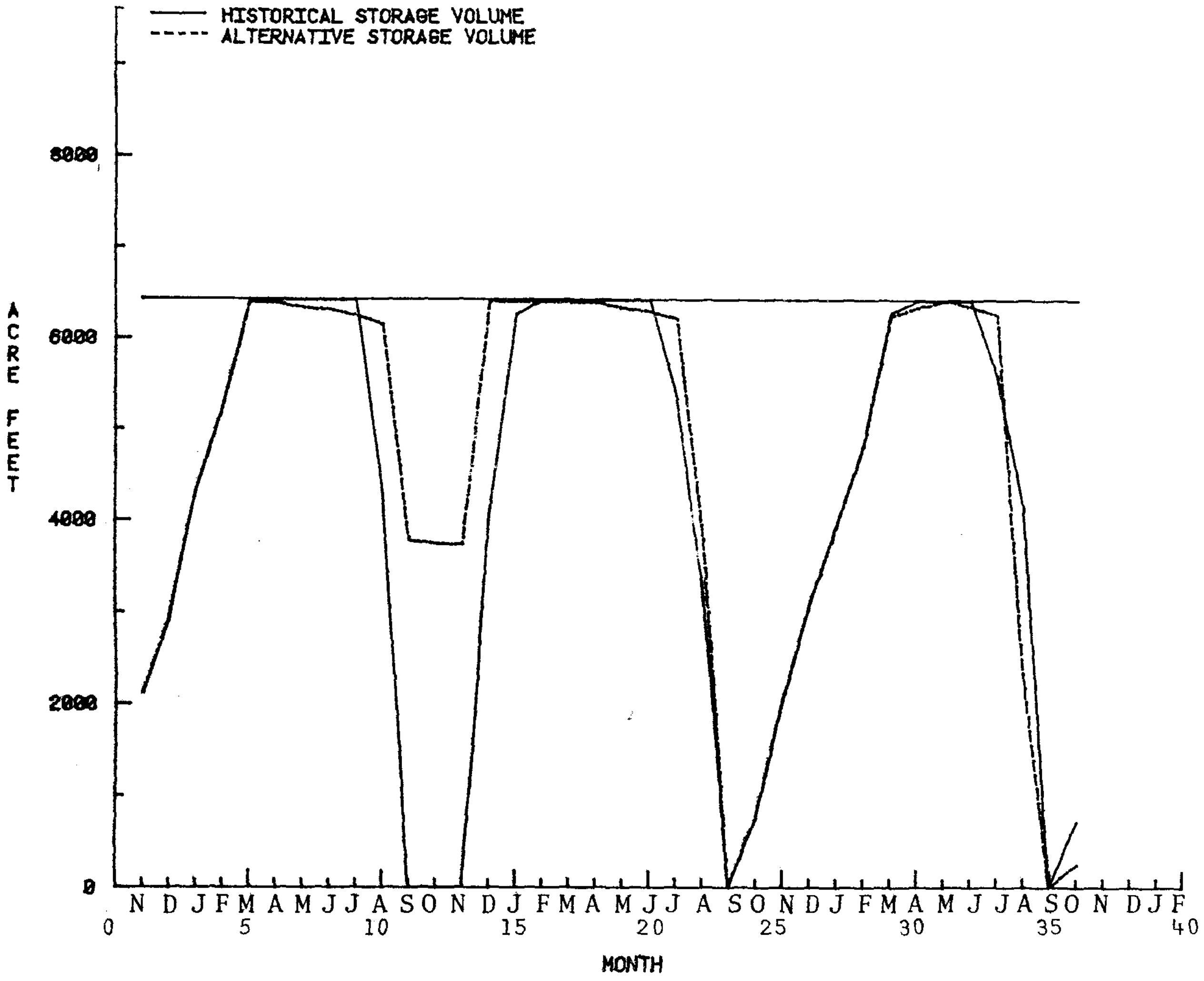

Figure VII.6. Halligan Reservoir.

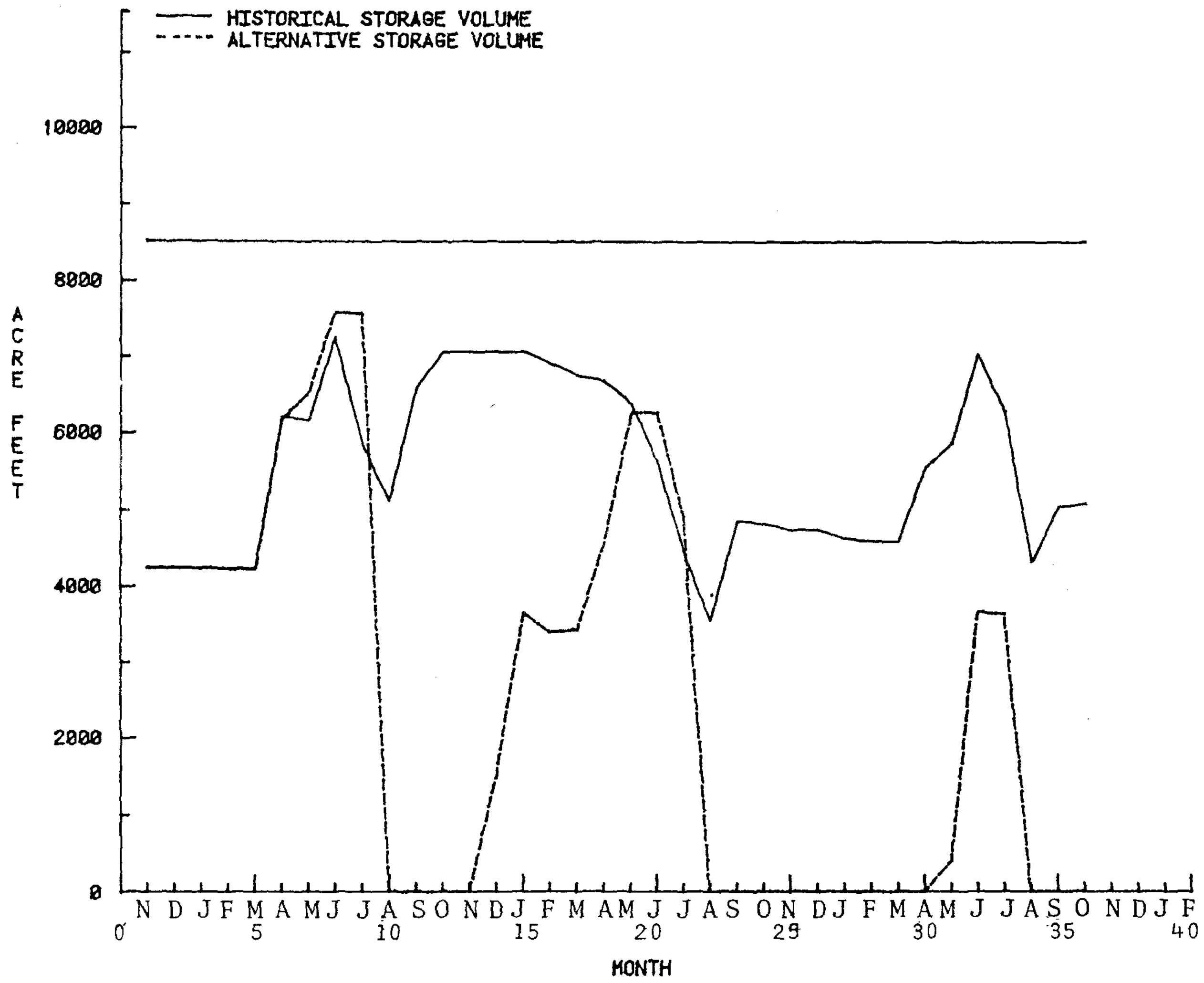

Figure VII.7. Park Creek Reservoir.

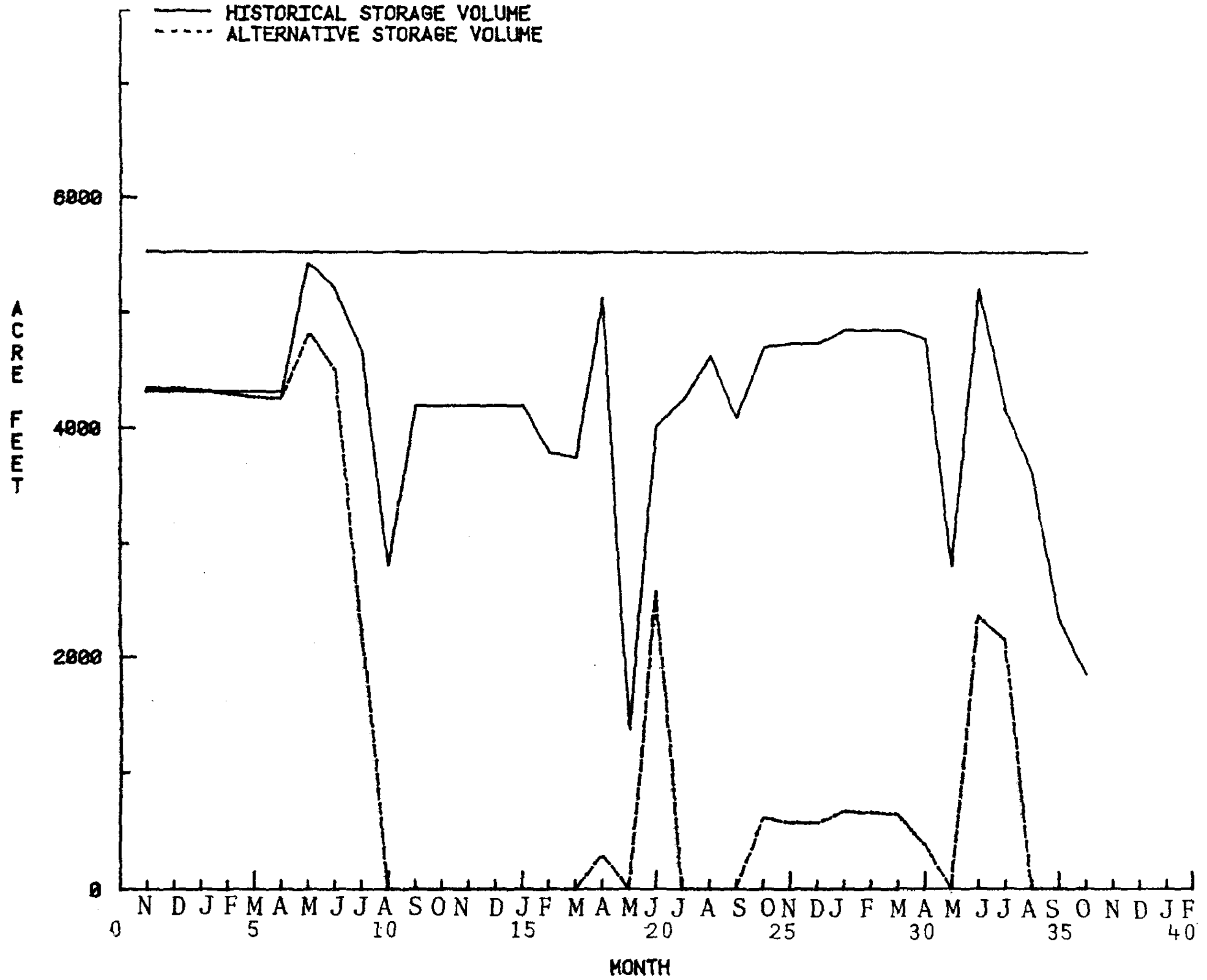

Figure VII.8. North Poudre Reservoir #15.

Consequently, a difference of 1344 acre-feet is not considered significant when the entire storage capacity of the subsystem is over 30,000 acre-feet.

A.3 Discussion of results

It is clear from Figures VII.1 thru VII.8 that the proposed management strategy simply specifies a shifting of stored water from reservoirs not conducive to recreation to those high country reservoirs with greater recreation potential. Large conservation pool levels are able to be maintained in three out of five high country reservoirs. Commanche Reservoir, however, must be emptied along with Big Beaver Reservoir which has no recreation potential whatsoever. For the three-year period considered in this study, it is evident that enough water is available in the subsystem to maintain storage levels in certain selected high country reservoirs, while still meeting the historical demand for water from all the reservoirs under investigation. This is partly due to the large difference in storage volume between the plains reservoirs and the high mountain reservoirs. The total combined storage volume for Twin Lake, Commanche, Peterson, and Barnes Meadow reservoirs is approximately 7000 acre-feet, while the combined storage of the non-recreational reservoirs is over 25,000 acre-feet, not including Milton Seaman Reservoir or the aggregated reservoirs.

The simulated operation of Halligan Reservoir is very near that which took place historically, except MODSIM produces slightly less drawdown at the end of 1973. For 1974 and 1975, the historical and simulated operation of the reservoir is identical. Significant operational changes in plains reservoirs occur in Park Creek Reservoir and North Poudre

Reservoir #15. From the figures, it is readily evident that a highly fluctuating, intraseasonal storage and release policy has been replaced by a more regular filling and emptying policy not unlike the operating policy historically observed for the high country reservoirs. Also, it should be noted that the ending storage in Worster Reservoir is the same for the new management scheme as the ending storage historically recorded, insuring that no additional water was obtained from this source. It is included in the analysis because Halligan Reservoir is on-line downstream from it, therefore, releases from Worster Reservoir contribute to the total inflow to Halligan Reservoir. To insure that no double accounting takes place, the initial storage in the aggregate reservoir is set equal to zero. Thereby, not allowing additional water from this source to be allocated toward the satisfaction of its own demand. The ending storage in the aggregate reservoir is also zero, which means that no water was taken from the other reservoirs unnecessarily.

There are many *legal* issues which also must be dealt with before attempting to actually implement this type of management practice. Such a strategy involves the storing of water out of legal priority. However, stored water is merely being transferred to other portions of the system, and overall demands should continue to be satisfactorily met. The exchange program is specificially designed for such an action.

The release or storage of water in the Greeley high mountain reservoirs would have no impact downstream of the turnout to the Munroe Canal. Fortunately, since the Munroe Canal is the highest (most upstream) diversion for irrigation water in the system, changing the operating policy of the high mountain reservoirs would have zero impact (positive or negative) on the remaining water use structure within the basin. It is true, however, that flow levels in the Cache la Poudre River above the Munroe Gravity Canal will be affected by changes in the operating policies of the high mountain reservoirs. Historically, releases from these reservoirs during late summer help to augment the natural flow in the river, which is low during this time. In recognition of this fact, the effect of the new management strategy on river flow levels is determined. Traditionally, the split between high mountain reservoir water delivered to the Munroe and North Poudre canal system and other reservoir water delivered to the system is approixmately 35% and 65%, respectively. The new management scheme results in a split in delivery of roughly 2% and 98% between high country and plains reservoirs. This change in percentage of the prospective sources of reservoir water is most critical in the first year when the mountain reservoirs are filling and release no water. Subsequent to filling, only that portion of the annual inflow necessary to maintain the storage pool is held while the remainder is released downstream. Calculated river flows vary from historical values only during the months of May through September (the typical operating period for high country reservoirs). Table VII.2 shows the percentage decrease in total river flow above the Munroe Canal and the resultant adjusted flow for 1973, the most critical year, for the new management system.

The minimum monthly flow occurs in February and is 1301 acre-feet. This flow is unaffected by the change in operating policy of the high mountain reservoirs. A decrease in flow volume begins in May and increases, as expected, to a maximum of approximately 87% of the

Table VII.2. Change in River Flow Above Munroe Canal - 1973

Month	% Decrease in Total River Flow Above Munroe Canal	Calculated Adjusted River Flow Above Munroe Canal - Acre-feet
NOV	0	2,497
DEC	0	1,590
JAN	0	1,460
FEB	0	1,301
MAR	0	2,000
APR	0	3,470
MAY	0.18	89,310
JUN	0.33	132,976
JUL	0.68	76,035
AUG	9.56	25,541
SEP	12.95	7,534
OCT	0	5,210

historical flow in September. However, the adjusted flow in September (7,534 acre-feet) is still above the minimum flow of six out of the twelve months. Based on this analysis, it is concluded that the new management strategy will not seriously alter volumetric flow levels in the river. However, a tradeoff analysis could easily be performed by running MODSIM for various increased minimum flow levels in the river.

In case of severe drought conditions, water could still be taken from the high country reservoirs to meet pressing downstream agricultural, industrial, and municipal water needs. Such emergency releases could be conducted in ways which would distribute the drawdown proportionally to the capacity of each reservoir in order to minimize the destruction of the fishery of any one particular reservoir. Since, by definition, the high mountain reservoirs are at higher elevations, there is much greater flexibility in meeting downstream water demands as a result of the new management approach. A small release from several of these reservoirs would serve the same purpose as a large release from a single reservoir. It should be noted that structural weaknesses in the dams of some of these reservoirs may prevent the maintenance of maximum pool year around. In these cases, appropriate upper bounds can easily be placed in MODSIM. Also, lower bounds on flow in some of the canals may need to be increased in order to maintain proper heads at turnouts and equalize the system hydraulically.

B. Case Study #2

B.1 Method of analysis

The goal of this case study is to determine if, using that portion of effluent from Fort Collins attributable to new foreign water, the

Rawhide Project cooling pond could be filled by 1985 and if, from the same source, a minimum of 4200 acre-feet can be supplied the power plant annually. To pursue this goal using MODSIM, the network for which the model was calibrated must be revised to better account for the proportions of new foreign water delivered to the City and new foreign water spilled downstream (Figure VII.9). Also, the interaction between the river and the Rawhide Pipeline is eliminated so that no direct flow may enter the pipeline. However, the network is adjusted in such a manner that still allows the City to divert effluent directly to the river as well as to the pipeline and Fossil Creek Reservoir. Long Draw Reservoir is decomposed into two reservoirs (dashed line) to reflect the fact that only 6000 acre-feet are available for storage of imported water. All imports to Long Draw Reservoir occur at node 10 with a storage capacity of 6000 acre-feet, while intrabasin inflows to Long Draw Reservoir are restricted to node 1 with a storage capacity of 4400 acre-feet. The combined capacity of the reservoir is the true 10,400 acre-feet. Linkages directly connecting Joe Wright Reservoir and Long Draw Reservoir with Fort Collins (links 2 and 4, respectively) were included in order to differentiate between these sources and the exercise of the direct flow rights of the City. These reservoirs also remain linked (directly or indirectly) to the river. Such a change allows the model to account for spills of water downstream that are not diverted to the City. Appropriate channel losses are considered in both branches for each reservoir.

Although the model was calibrated for the three-year historical period 1973 to 1975, the required management study planning horizon is

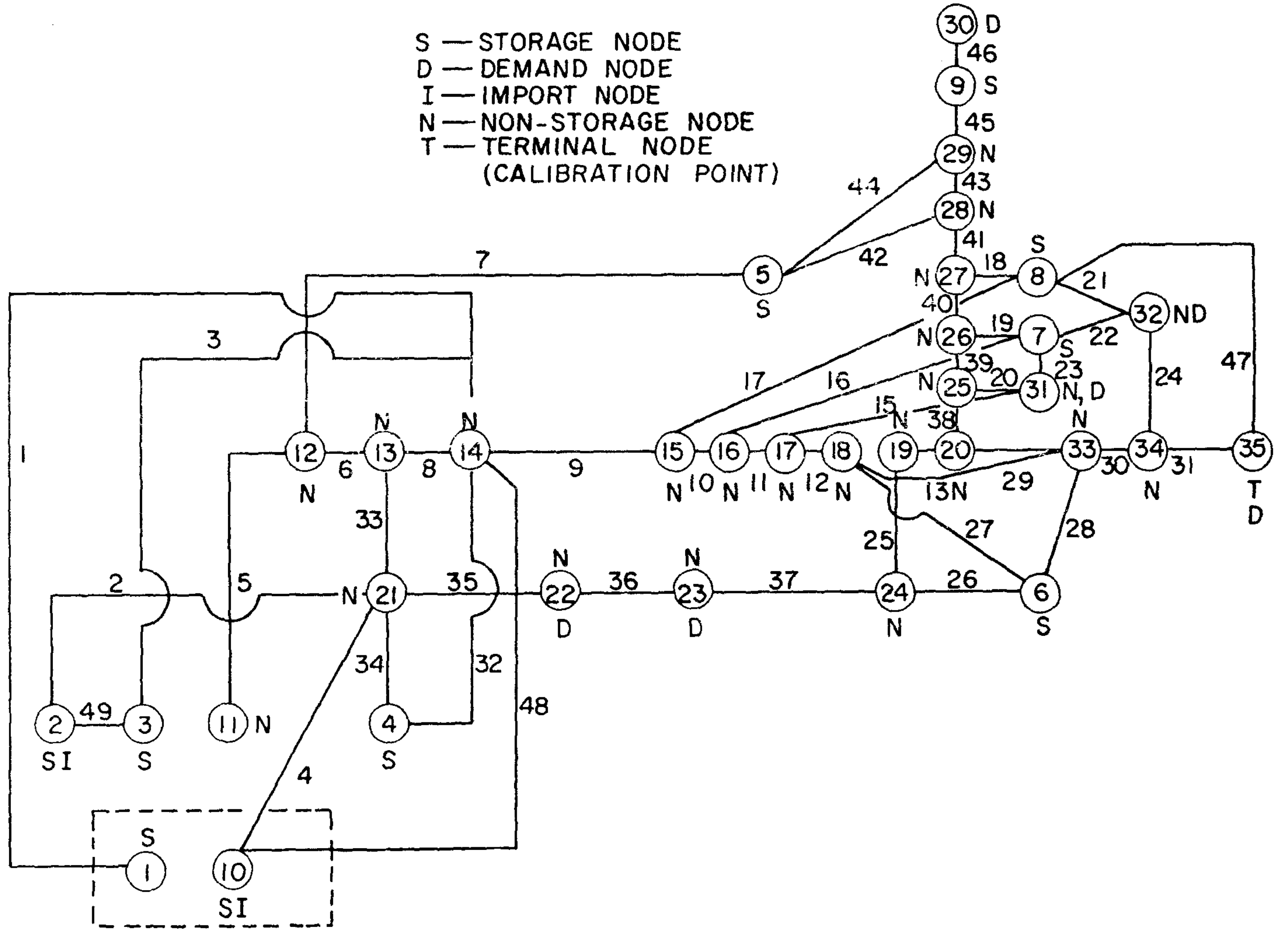

Figure VII.9. Revised network for Case Study #2.

19 years, from 1981 to 1999. This period is chosen in accordance with contract specifications which state that the filling of the cooling pond is to be initiated in 1981; the operation of the first generating unit is to begin in 1985; and the Windy Gap Project is to assume responsibility for meeting Rawhide Project demands in the year 2000. This extended 19 year period is consistent with the calibration phase since the river is over-appropriated which means that the water rights structure should not change appreciably. It is also assumed that the direct flow rights the City holds for Cache la Poudre River water will remain constant over this period. Table VII.3 lists the total monthly direct flow right exercised by Fort Collins. Each month throughout the analysis the appropriate direct flow must be totally diverted by the City before any reservoir water, including Horsetooth Reservoir water, can be delivered to the City. This constraint on the operation of the system is satisfied by setting the upper bound for the link connecting the City with the river at the City's direct flow right for each month and giving the link a very low cost as compared to all other links. In this manner, the most attractive transfer (from an optimization viewpoint) of water in the network is via this link (#33), and when feasible, flow should be at the upper bound.

The total annual demand for water by Fort Collins had to be estimated for the period 1981 to 1999. This was accomplished by fitting an exponential curve to the values forecast for years 1980, 1990, and 2000 by the Water Utilities Department, City of Fort Collins (1977). The projected annual Fort Collins demand over the period of analysis is presented in Figure VII.4. The same monthly distribution of the annual demand is employed for the management study as is for the calibration phase.

Table VII.3. Fort Collins Monthly Total Direct Flow Right

Month	Acre-Feet
NOV	864
DEC	893
JAN	893
FEB	807
MAR	893
APR	1054
MAY	1186
JUN	1148
JUL	1186
AUG	1186
SEP	1148
OCT	1035
TOTAL	12293

Table VII.4. Projected Annual Fort Collins Demand

Year	Acre-Feet
1981	19451
1982	20334
1983	21097
1984	21661
1985	22244
1986	22839
1987	23454
1988	24082
1989	24729
1990	25245
1991	26074
1992	26773
1993	27494
1994	28229
1995	28987
1996	29769
1997	30565
1998	31385
1999	32227

However, the monthly consumptive loss percentages of the City were modified slightly to better conform to normal conditions. These modified values are listed in Table VII.5. These values are used to determine what portion of the total monthly diversion of water by the City is available as effluent. It must be remembered, however, that under the contract, only the effluent attributable to new foreign water can be diverted to the pipe line. Again, the sequential preference of source of supply for Fort Collins is: (1) direct flow river water, (2) new foreign water (Joe Wright and Long Draw reservoirs), and (3) Horsetooth Reservoir water. Once, in any given month, the City has fully exercised its direct flow right, it can start to pull the transmountain water (if available) of which the resulting effluent can be diverted to the pipeline.

It was necessary to generate monthly data for both sources of foreign water (Michigan Ditch and Grand River Ditch) over the period of analysis. Resource Consultants, Inc. (1978) generated these data by determining the similarity of runoff potential of the watersheds which provide water for the Michigan Ditch and Grand River Ditch systems. Four years (1974 through 1977) of monthly data pertaining to the potential reusable water from the Michigan Ditch was correlated with the historical yield of the North Fork of the Michigan River to obtain 19 years of generated diversions via the Michigan Ditch. Table VII.6 contains these estimates of Michigan Ditch diversions. These data are input to MODSIM as annual values with appropriate monthly distributions. Estimates of Grand River Ditch diversions were generated in much the same manner and are reported in Table VII.7.

Table VII.5. Modified Consumptive Loss Percentages of the City of Fort Collins (Resource Consultants, Inc., 1978)

Month	Consumptive Loss (%)
NOV	1.5
DEC	1.5
JAN	1.5
FEB	1.5
MAR	1.5
APR	25.8
MAY	27.5
JUN	51.4
JUL	60.1
AUG	57.6
SEP	47.3
OCT	29.4

Figure VII.6. Generated Monthly Estimates of Michigan Ditch Diversions to Joe Wright Reservoir (acre-feet)

Year	May	June	July	Aug.	Sept.	Total
1981	152	1848	1123	334	30	3487
1982	237	2651	1262	315	39	4504
1983	199	2280	1061	266	33	3839
1984	151	1841	1120	333	30	3475
1985	211	2424	1125	281	35	4076
1986	204	2346	1089	272	34	3945
1987	241	2694	1288	322	40	4585
1988	144	744	341	52	0	1311
1989	147	1787	1092	325	29	3380
1990	209	2412	1118	279	35	4053
1991	190	1165	832	143	48	2378
1992	199	2287	1064	266	32	3848
1993	208	2386	1105	276	34	4009
1994	199	2281	1062	265	33	3840
1995	212	2434	1131	283	35	4095
1996	219	2497	1170	292	37	4215
1997	151	1847	1123	333	30	3484
1998	214	2430	1130	283	35	4092
1999	209	2407	1115	278	34	4043

Table VII.7. Generated Monthly Estimates of Grand Ditch Diversions to Long Draw Reservoir (acre-feet)

Year	May	June	July	Aug.	Sept.	Total
1981	308	1679	644	168	0	2799
1982	305	3763	4475	1322	305	10170
1983	555	3202	1786	493	123	6160
1984	219	1263	704	194	49	2429
1985	366	1993	764	199	0	3322
1986	406	2683	3740	1138	163	8130
1987	223	2753	3274	967	223	7440
1988	97	642	894	272	39	1944
1989	112	740	1032	314	45	2243
1990	916	4997	1916	500	0	8329
1991	85	557	777	236	34	1689
1992	779	4501	2510	693	173	8656
1993	282	1633	911	251	63	3140
1994	261	1504	840	232	58	2895
1995	1032	5632	2159	563	0	9386
1996	937	5109	1958	511	0	8515
1997	227	1312	732	202	50	2523
1998	599	3462	1931	533	133	6658
1999	158	1043	1454	443	63	3161

In Figure VII.10 the generated total imports of water from the Michigan Ditch and Grand River Ditch are plotted for each year. These values are then separated into three distinct groups; with the limitation that for any one year both imports must be in the same category. These groups are then interpreted as wet (1973), intermediate (1974), and dry (1975) according to the results of the calibration phase. Therefore, for each year a complete and representative hydrology is obtained for input to the model. For example, for 1985 the generated transmountain diversions are coupled with the 1985 projected Fort Collins demand. Historical adjusted inflows and demands along with the estimated return flows for 1974 are then combined with the 1985 projections to form a complete and consistent hydrological sequence for 1985. This approach is justifiable because the river is vastly over-appropriated. Most likely no additional water will be allocated to the various demand centers without significant changes in the character of the basin, which are not expected over the planning period. Also, dry years in relation to the volume of import should be associated with dry years in relation to unregulated inflows originating within the basin, and the amount of demand satisfaction realized in any year is directly proportional to the water available from snowmelt. This is the reason that, for this example, 1974 demands and return flows remain coupled with 1974 inflows. Likewise, it is doubtful that, for this limited area, great differences (relative to the size of the basin) in snowpacks would occur. Finally, it can be shown from the historical record that very rarely are there more than two dry years in succession, or for that matter two wet years. This observation influenced the placement of the imports into their respective

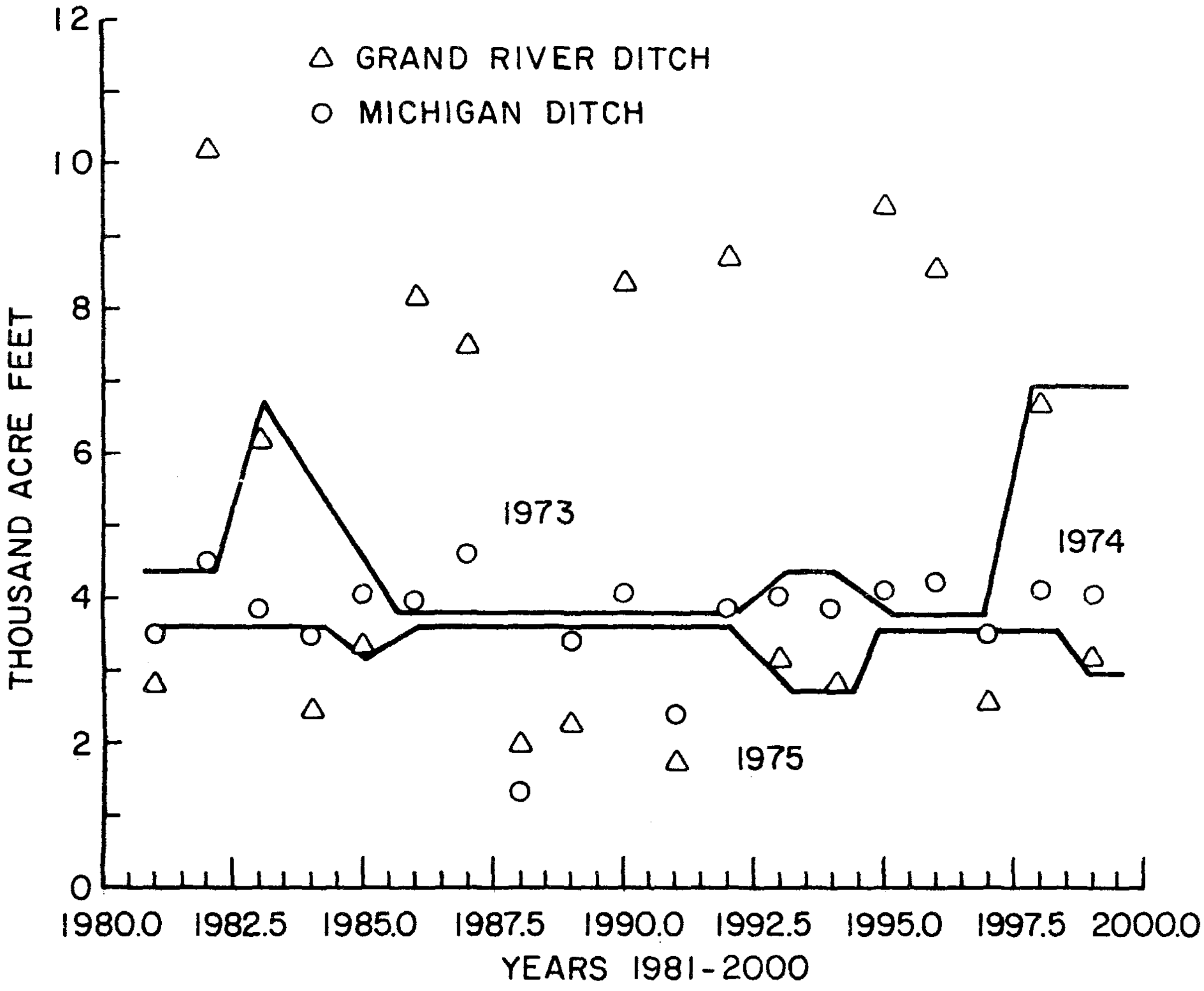

Figure VII.10. Estimated Grand River Ditch and Michigan Ditch imports.

categories. The hydrologic situation for each year of the analysis is constructed in the above fashion.

The 19 years of data were programmed and an initial set of priorities were chosen. MODSIM computed the transfers of water throughout the network based on these priorities. The results were analyzed by a supplemental computer program which takes the linkage flows calculated by MODSIM and tabulates the reusable effluent attributable to Joe Wright and Long Draw reservoir releases delivered to Fort Collins. The priorities (of storage versus release in the reservoirs) were then adjusted in such a manner as to converge on a value of 4200 acre-feet or more annual reusable water from these two reservoirs. A discussion of the method of adjustment of these priorities is included in the final section of this chapter. Fifteen successive adjustments of these priorities were necessary before a reasonable conclusion was obtained.

B.2 Results of analysis

First, the projected demand for water by Fort Collins is satisfied, without exception, in every year throughout the simulation period. Also, Fort Collins direct flow right is fully exercised in every month of the analysis, as required. Figure VII.11 shows the proportions of the supply (direct flow, Horsetooth Reservoir, Long Draw Reservoir, and Joe Wright Reservoir) contributing to each year's projected demand. It is interesting to note that the amount of Horsetooth Reservoir water required, according to the final scheme, steadily increases while the amount of Joe Wright and Long Draw reservoir water remains fairly constant.

In Figure VII.12 the amount of reusable effluent resulting from Joe Wright Resrvoir and Long Draw Reservoir releases to the City is displayed.

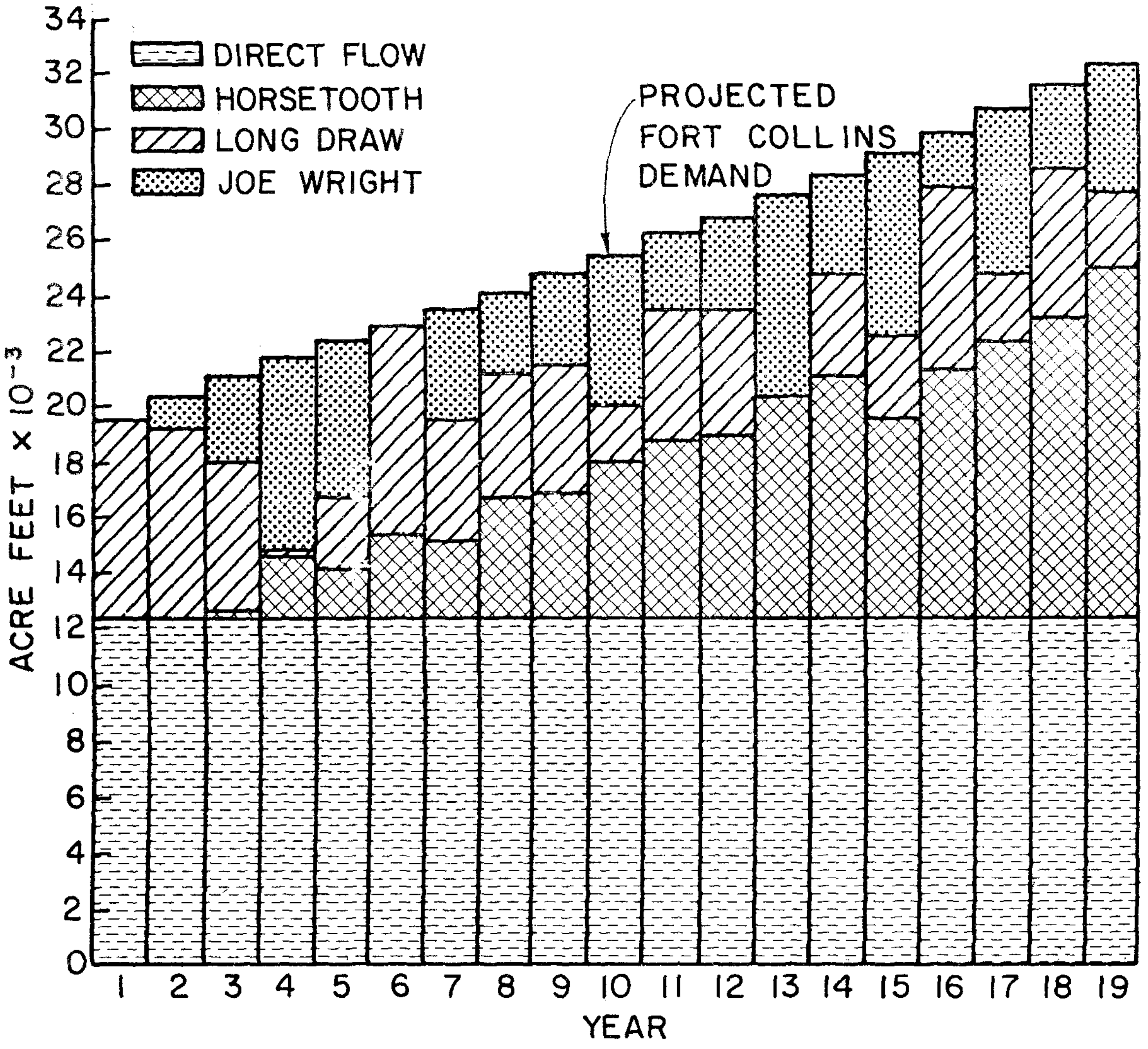

Figure VII.11. Proportion of Fort Collins demand met by various sources of supply.

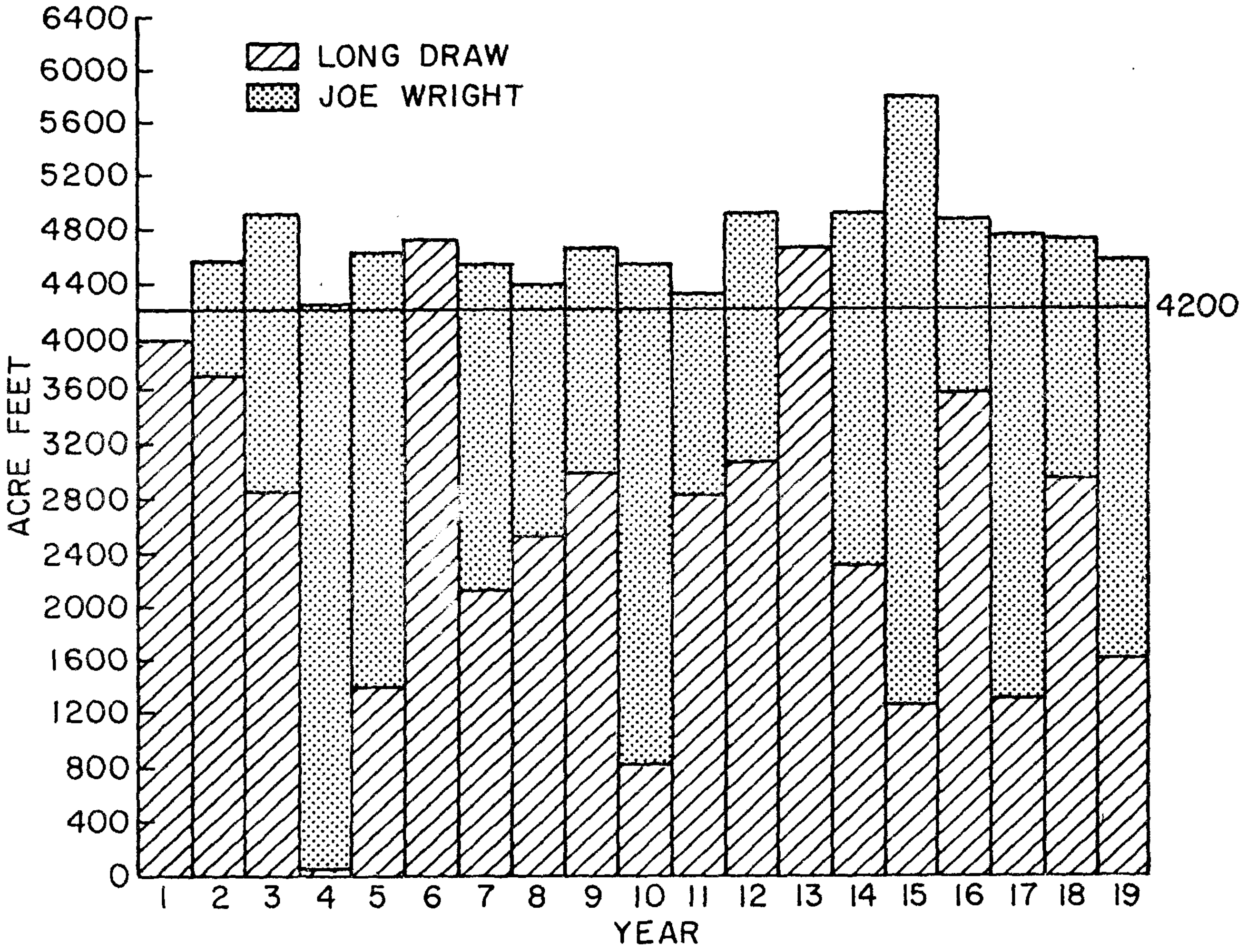

Figure VII.12. Reusable effluent deliverable to Rawhide pipeline.

Only in the first year (1981) is the return flow less than the 4200 acre-foot target. This is because the projected Fort Collins demand for 1981 is too small to allow enough water from the reservoirs to be used to obtain 4200 acre-feet of reusable effluent. However, in all the remaining years this target is exceeded. Excluding the first year, the mean annual deliverable effluent to Rawhide Pipeline is 4662 acre-feet, and for the entire 19 year period a surplus of 8776 acre-feet above the annual 4200 acre-feet required is calculated. Also, during several high flow years (importation of relatively large amounts of foreign water) spills from these two reservoirs occur. The total amount of spills calculated by the model equals 4075 acre-feet; 336 acre-feet from Joe Wright Reservoir and 3739 acre-feet from Long Draw Reservoir.

As noted earlier, the first four years of the analysis is designated as a filling period for the cooling pond. From the results obtained from MODSIM, there are 17,651 acre-feet of reusable water available for filling the pond during this period. A uniform rate of delivery is not essential to the filling, therefore, no borrowing or exchange program needs to be invoked. For the first four years, water is delivered to the pond as available. The capacity of the pond is estimated at 13,000 acre-feet, which means that about 4650 acre-feet of excess water is available for evaporative losses during filling. MODSIM calculates an evaporation loss during filling of 2239 acre-feet. This leaves an additional 2411 acre-feet for contingencies. The implications of these results are discussed in the next section.

B.3 Discussion of results

The amount of carry-over storage provided in both Joe Wright and Long Draw reservoirs from year to year is of critical importance to the ability of these reservoirs to meet the demand for reusable effluent. Figure VII.13 shows the combined and individual carry-over storage for these reservoirs throughout the period. However, to avoid spills as much as possible the reservoirs must be evacuated early in the year to allow storage space for the incoming transmountain diversions. This is particularly true during high flow years. The most realistic case is tested for this management study, in that the initial storage in Long Draw Reservoir is 6000 acre-feet while Joe Wright Reservoir begins empty. Ending storages are also 6000 acre-feet and zero, respectively.

From the manipulation of the storage priorities for Long Draw Reservoir and Joe Wright Reservoir certain insight into operational guidelines can be gained. The priorities selected for a particular simulation are based on the results obtained from the previous run. This means, that past the initial run, a certain degree of foreknowledge or forecasting is employed by the user in determining the adjustments of the priorities to better conform with his mental notion of how the system should function. This is not unrealistic, in that, the true operation of these reservoirs will not be performed in a vacuum. As experience is gained, a better understanding of system response will be acquired. Estimates of snowpack conditions will provide information concerning the hydrology for the upcoming season which in turn will allow for preliminary formulation of operational guidelines. There is also added realism since the model does the best it possibly can, given flexibility

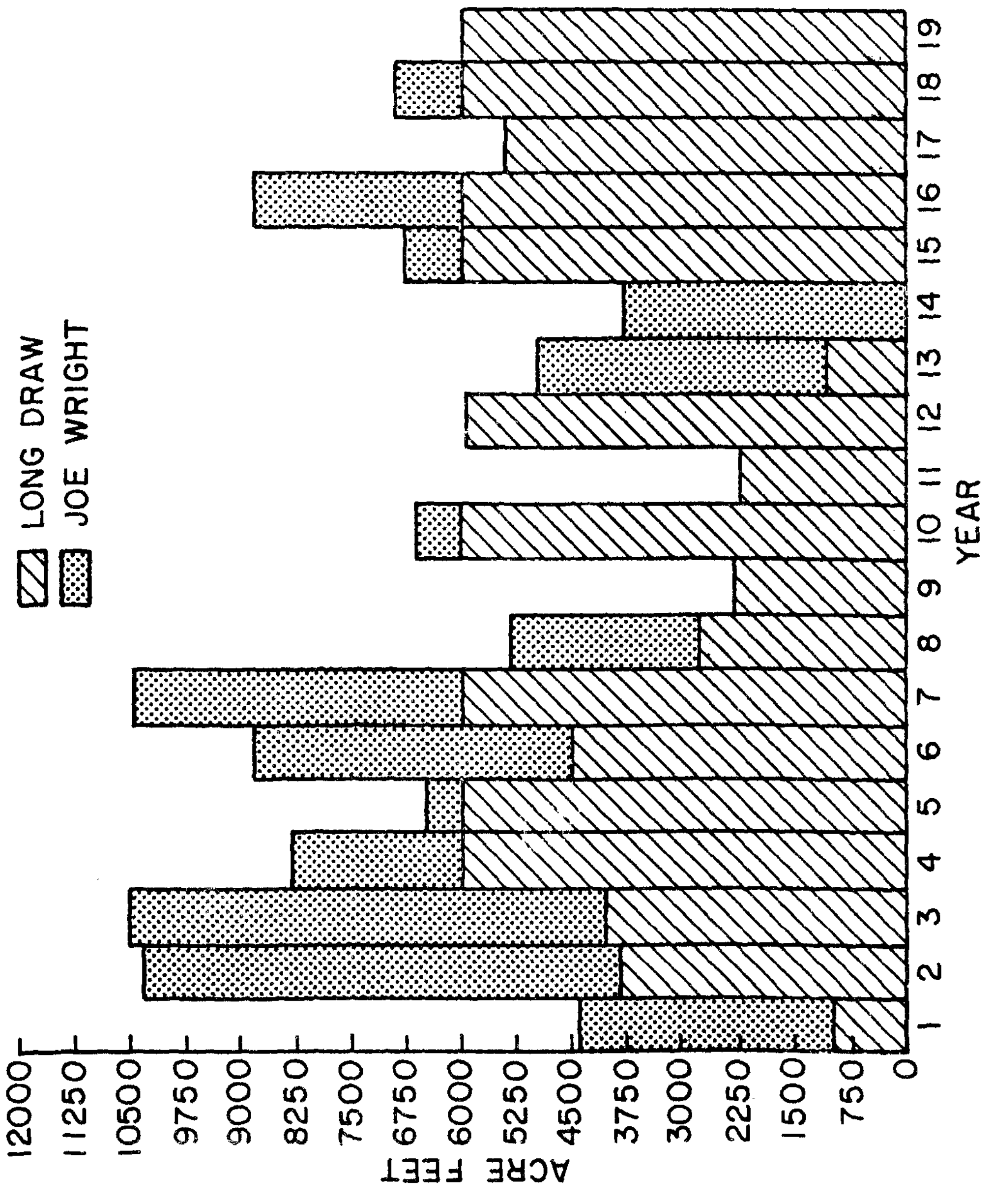

Figure VII.13. Individual and total carry-over storage for Joe Wright and Long Draw Reservoirs.

in the system, to apportion water to the various demand and storage centers on a month to month basis. It does not consider what happened last month or anticipate what will take place next month. However, it does select the optimum operating policy for the current month. The *user* must adjust the priorities placed on the transfer of water throughout the network to consider previous conditions and anticipate future developments.

An example of the above discussion is shown in Figures VII.14 and VII.15 which display the sensitivity of storage priorities for Joe Wright and Long Draw reservoirs in determining carry-over storage. In both cases, for simulation #2, carry-over storage was minimal beyond 10 years; resulting in severe deficiencies in reaching the 4200 acre-foot target in many of these years. However, through successive adjustment of the priorities, adequate carry-over storage was achieved (simulation #15). *Adequate* refers to the fact that through the provision of carry-over storage, 4200 acre-feet, or more, of reusable effluent could be realized from these reservoirs even during dry years. The relationship between storage priority and carry-over storage is not linear, however. Physical feasibilities are also active in determining carry-over storage as well as the demand structure and variability of monthly consumptive loss rates. From Figures VII.14 and VII.15 it is evident that in the first five years or so of the analysis, the change in the priorities between the two simulation runs for both reservoirs has very little impact on carry-over storage. Therefore, there is no basic scheme in changing priorities other than gaining experience with the model. However, after a few model runs, the effect of changing the relative and absolute values of the priorities can be anticipated with greater and greater confidence.

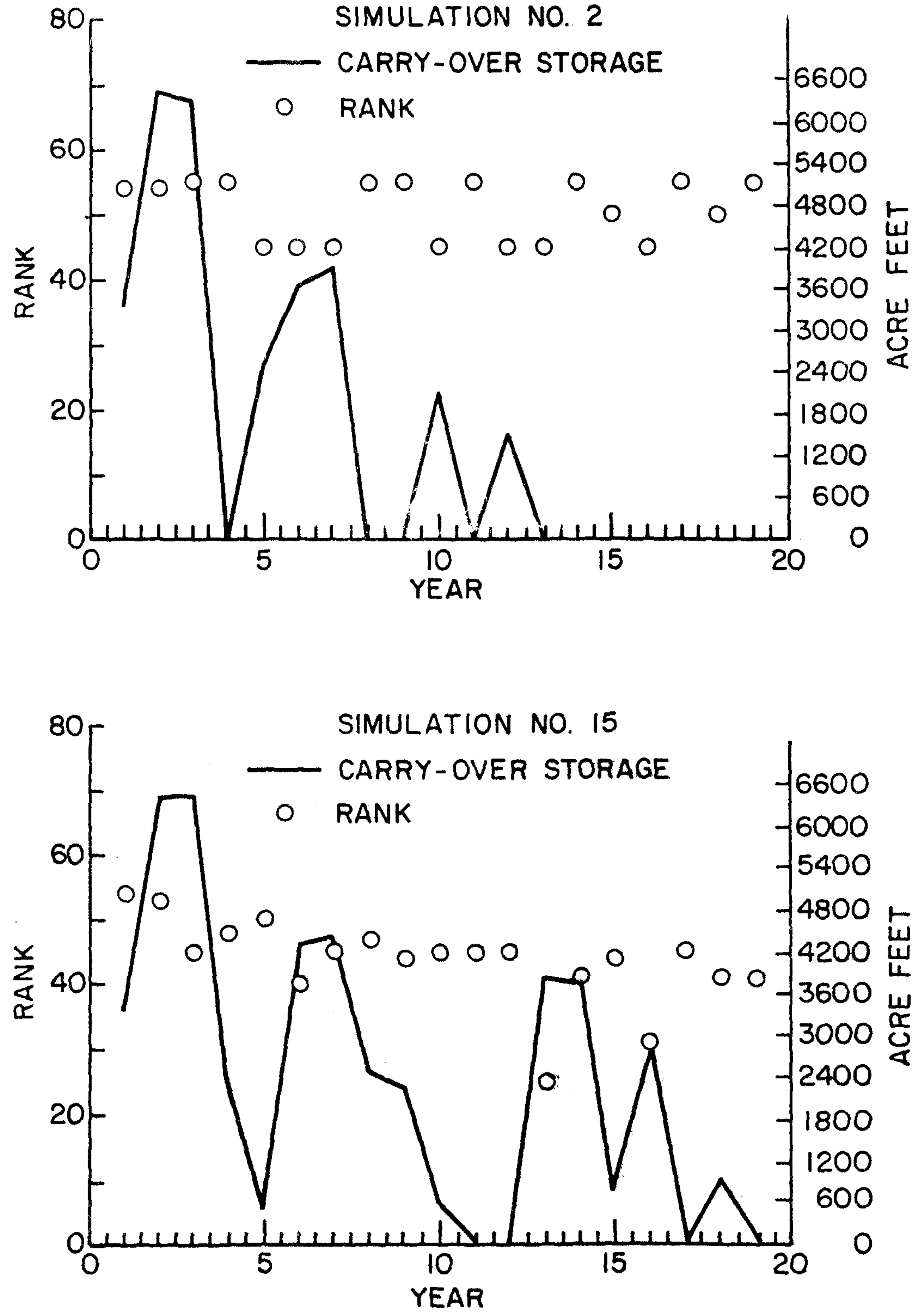

Figure VII.14. Sensitivity of storage priority vs carry-over storage for Joe Wright Reservoir.

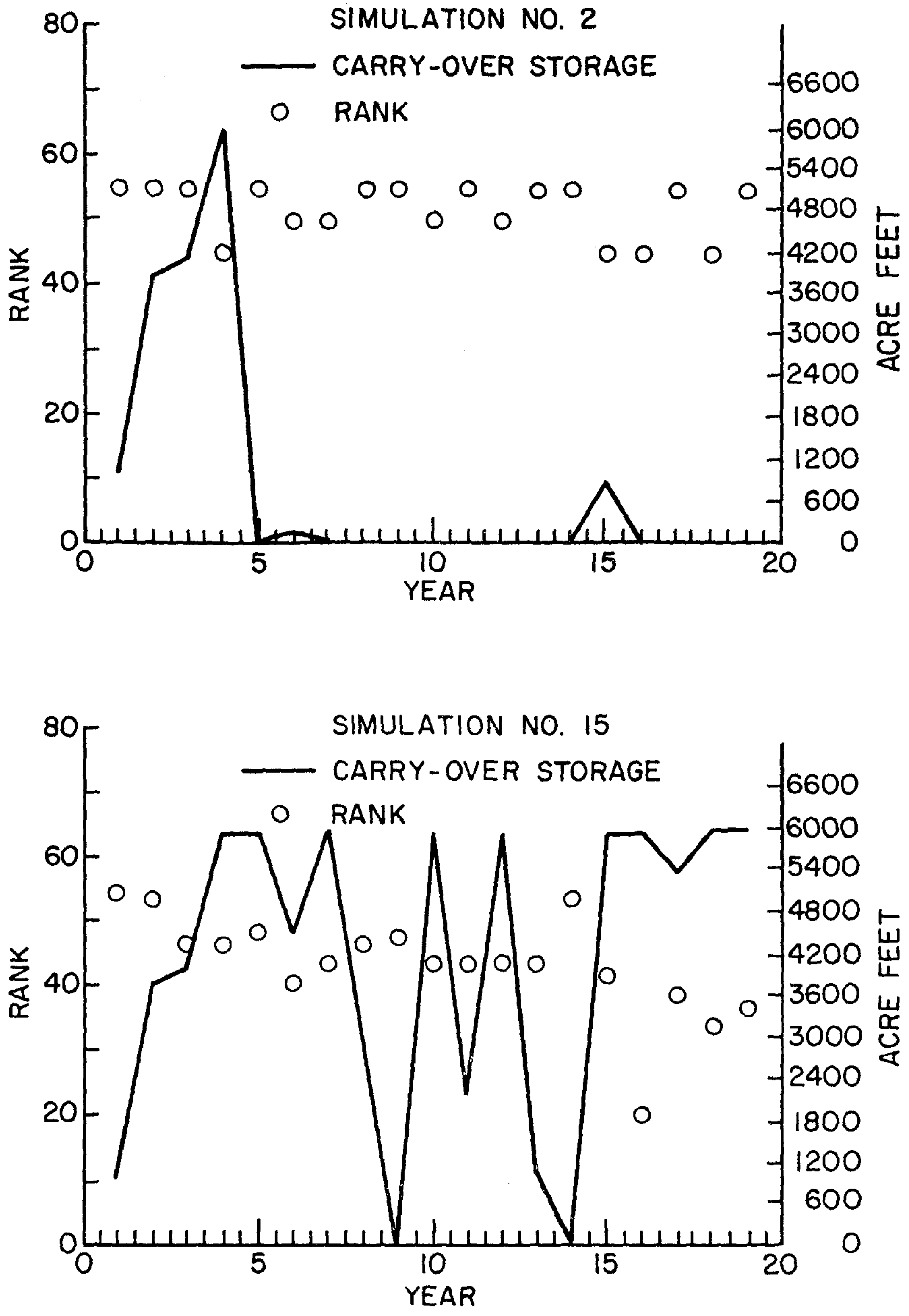

Figure VII.15. Sensitivity of storage priority vs carry-over storage for Long Draw Reservoir.

Along with the determination of the priorities to be placed on water transfers throughout the system, target storage levels must also be determined. Initially, the desired monthly ending storage levels for Long Draw and Joe Wright reservoirs were established at maximum capacity. Subsequently, it was discovered that such a policy leads to a greater amount of spills (water lost from first use opportunity by the City) than necessary. For this reason, in the first years of the analysis target storage levels were set below maximum capacities in order to evacuate part of the reservoirs to allow for the storage of anticipated large inflows later in the season. Figures VII.16 and VII.17 display the target monthly ending storage and the calculated monthly ending storage throughout the 19 year period for each reservoir. During the later part of the period, storage levels in Joe Wright Reservoir approach the maximum capacity but do not reach it, while Long Draw Reservoir storage levels remain at or near capacity during the final months. This scheme does not totally eliminate spills but it does reduce them considerably. Also, foreknowledge of the magnitude of transbasin diversions coupled with the variable consumptive loss rates characteristic of the return flow of the City, can be used to minimize spills. During high flow years, it is advantageous to transfer a large amount of foreign water to the City during the high consumptive loss months; while conversely, it is of benefit to transfer more foreign water to the City in low flow years during the low consumptive loss months.

Demand shortages throughout the remainder of the system are aggregated at the terminal node, and are reasonably consistent with the demand shortages occurring during the calibration phase of this study.

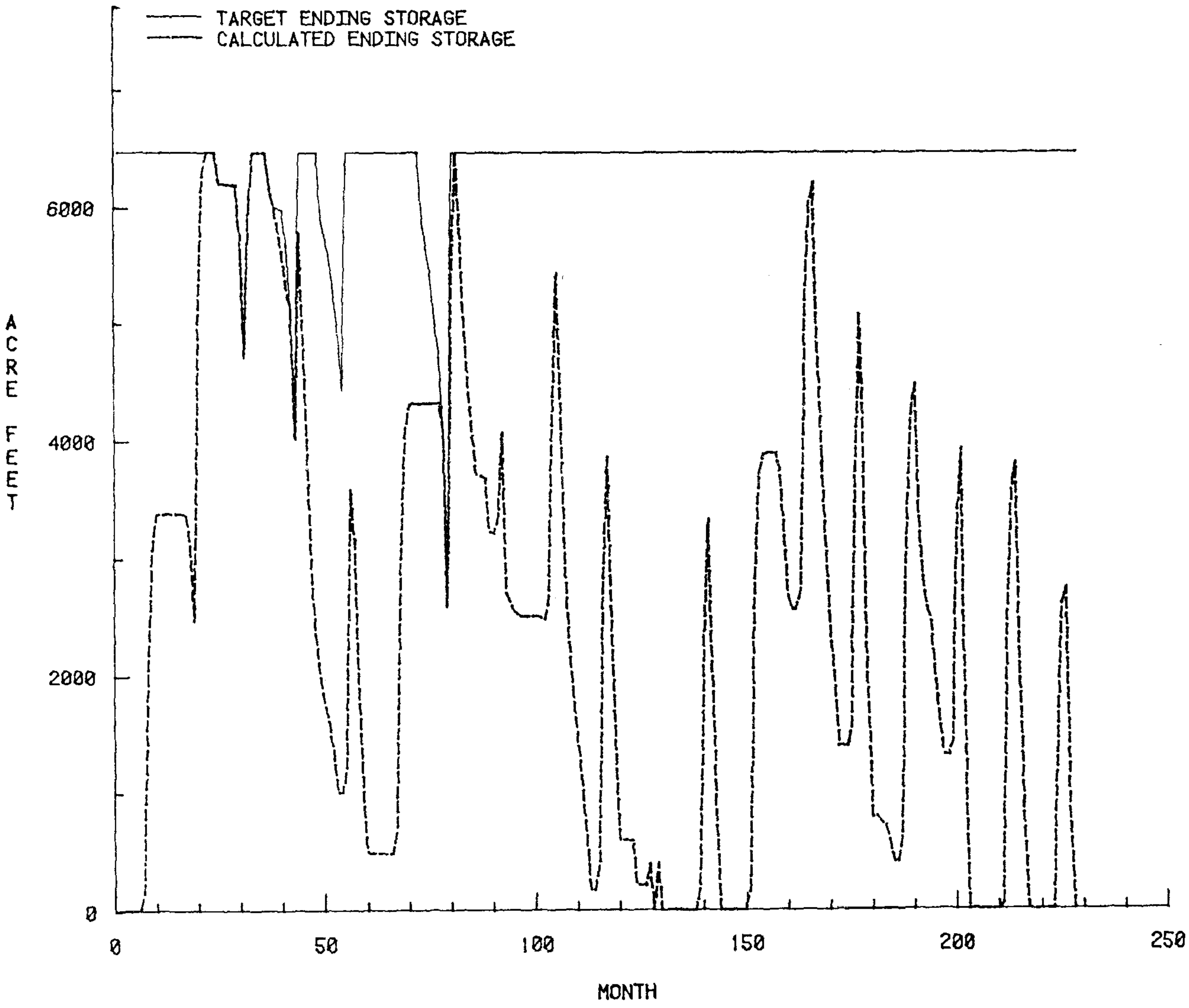

Figure VII.16. Target vs calculated end of month storage for Joe Wright Reservoir.

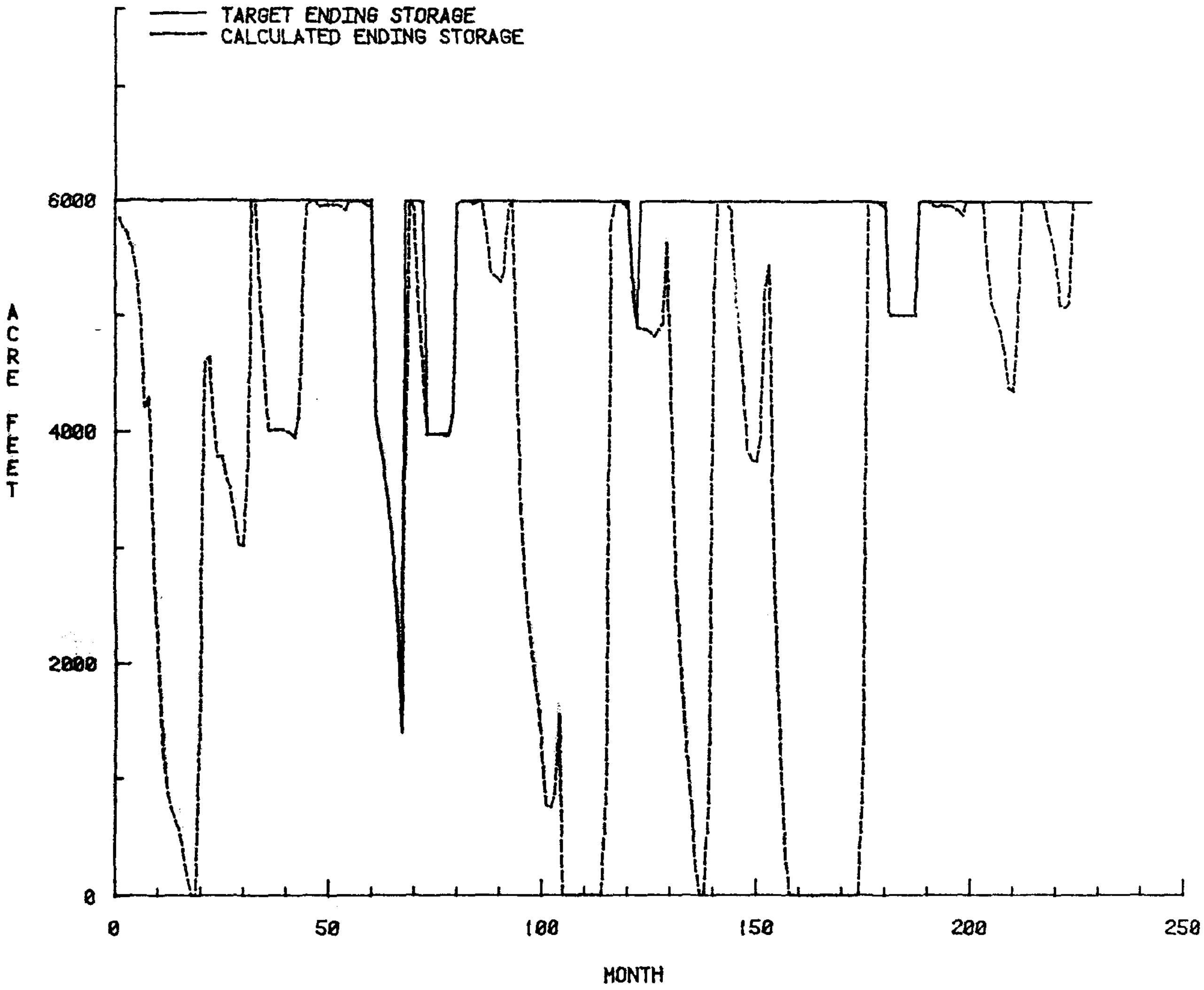

Figure VII.17. Target vs calculated end of month storage for Long Draw Reservoir.

An underestimate of the availability of Horsetooth Reservoir water to meet this demand is possibly part of the cause for the shortage. As Fort Collins draws increasing amounts of Horsetooth Reservoir water to meet projected demands, an increasing portion of this water becomes unavailable for downstream demand satisfaction. However, the shortages remain uniformly low (Figure VII.18), and most likely will be satisfied from additional Colorado-Big Thompson water imported to the basin. The simulated operating policy of the other reservoirs in the system is closely aligned with historical storage and release patterns in that they fill and empty on a seasonal basis during the period of analysis.

Finally, as mentioned in Chapter V, a *borrowing* agreement must be made between North Poudre Irrigation Company (owner of Fossil Creek Reservoir) and Fort Collins in order to provide a more desirable uniform rate of delivery of reusable effluent to the power plant. Such an arrangement would commence in 1985 and would consist of the borrowing by Rawhide Project, via the pipeline from Fossil Creek Reservoir, enough water to compensate for the difference between the reusable effluent and the desired pipeline diversion during months when the reusable effluent is less than the desired diversion. Otherwise, Rawhide Project will repay Fossil Creek Reservoir when the amount of reusable effluent exceeds the desired pipeline flow during any one month. Such an agreement is advantageous to both parties since the Rawhide Project will benefit from a uniform pumping rate and Fossil Creek Reservoir will receive additional water (reusable effluent exceeds 4200 acre-feet each year) to its storage decree and usually during low flow months. Also, the borrowing arrangement should have no impact on the direct flow rights structure along the river, since the pipeline would be borrowing

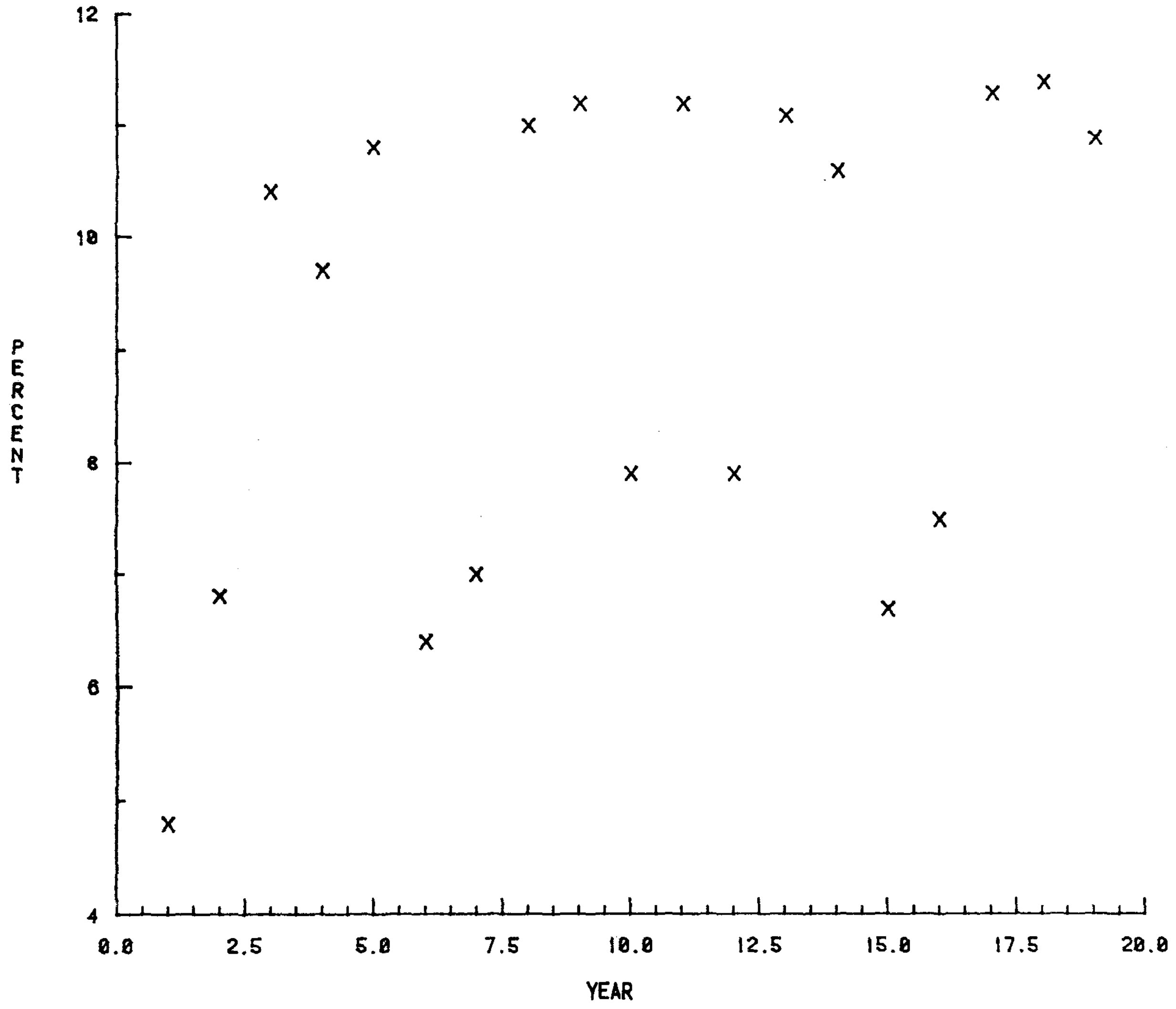

Figure VII.18. Annual percentage of shortage at terminal node.

only on the reservoir storage rights. Table VII.8 contains two examples of how this arrangement would function. The first year (1985) of power generation and 1991, the year the lowest level of reusable effluent is expected. Even for the worst year, the repayment is over 100 acre-feet greater than the amount borrowed.

Table VII.8. Example Borrowing Arrangement Between Pipeline and Fossil Creek Reservoir

Year	Month	Exchange with Fossil Creek Reservoir		Pipeline-Reservoir Exchange	
		Reusable Effluent	Desired Pipeline Diversion	Borrow From Fossil Creek	Repay Fossil Creek
1985	NOV	312	345	33	
	DEC	197	357	160	
	JAN	171	357	186	
	FEB	256	322	66	
	MAR	303	357	54	
	APR	0	345	345	
	MAY	145	356	211	
	JUN	882	345		537
	JUL	833	357		476
	AUG	639	356		283
	SEP	485	345		140
	OCT	339	357	18	
		4562	4200	1073	1436
1991	NOV	512	345		167
	DEC	337	357	20	
	JAN	0	357	357	
	FEB	362	322		40
	MAR	0	357	357	
	APR	0	345	345	
	MAY	0	356	356	
	JUN	913	345		568
	JUL	160	357	197	
	AUG	835	356		479
	SEP	674	345		329
	OCT	522	357		165
		4315	4200	1632	1748

CHAPTER VIII

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. Summary

A river basin water management planning model is synthesized from currently existing river basin models. MODSIM is specifically designed for the analysis of water availabilities throughout a complex river basin system according to preselected allocative priorities. The underlying principle of the operation of the model is that most physical river basin systems can be represented as capacitated flow networks. MODSIM employs the Out-of-Kilter Algorithm to minimize the total cost of flows in this graphical network of interconnected reservoirs, river reaches, pump canals, and gravity flow canals.

In addition to the consideration of the physical aspects of a river basin system, MODSIM is capable of simulating the storage and distributional preferences resulting from the institutional framework existing in a basin. This capability is achieved through a ranking procedure which is translated into pseudo-costs of water transfer. Using this ranking procedure, MODSIM apportions the available water for storage in various reservoirs and diversion of flow from the river according to preferences established by the user.

A methodology is also included which allows MODSIM to estimate return flows occurring from irrigated agriculture. Multiple linear regression is used to develop a predictive equation for return flows based on canal diversions and previously calculated return flows. This methodology is consistent with the general planning nature of MODSIM and produces results compatible with this modeling level.

The execution of the simulation package is accomplished in an interactive, conversational programming mode. This advantage adds great utility to the model since no appreciable knowledge of computer programming is necessary for the successful operation of MODSIM. Two conversational data organization programs are interfaced with MODSIM which query the user concerning the nature of the simulation and, based on his responses, construct a complete and executable data file.

Two case studies are undertaken to fully demonstrate the capability of MODSIM in aiding in the analysis of changes in water resources policy within a river basin. The first case study concerns the inclusion of recreation in a multipurpose management framework for certain high mountain reservoirs in the Cache la Poudre River Basin. Traditionally, these reservoirs have been operated exclusively for the provision of a late season irrigation water supply, often resulting in complete emptying of the reservoirs toward the end of the irrigation season. These reservoirs were previously evaluated according to their perceived recreation potential. Based on the conclusions concerning the recreation potential of these reservoirs, the case study addresses the question of the hydrologic and legal feasibility of maintaining stable pool elevations, at or near maximum, in two of these reservoirs.

The second case study analyzes the availability and opportunity of providing water for cooling purposes for the proposed Rawhide Project. By contract, the City of Fort Collins, Colorado is to provide the Rawhide Project with the opportunity to utilize sewer effluent attributable to newly developed or imported water first used by the City. Joe Wright Reservoir and Long Draw Reservoir are to be used as temporary storage facilities for the imported water which is subsequently to be released to Fort Collins. The project calls for the development, at the site, of a 13,000 acre-foot reservoir which must be filled prior to initial operation of the power plant, scheduled for 1985. Upon filling of the reservoir, the Rawhide Project will require no less than 4200 acre-feet of firm water annually.

MODSIM is calibrated for both case studies for the years 1973-1975 before the management alternative analyses are performed. Detailed calibration methodology is presented, followed by the results obtained from the calibration phase of the investigations. Acceptable duplication of historical records is achieved by successively adjusting model priorities placed on the transfer of water throughout the networks. An example of the use of the return flow calculation option is also included.

Upon successful MODSIM calibration, the model is used to analyze the feasibilities of both case studies management alternatives. The priorities placed on water transfers throughout the networks which are obtained from model calibration are adjusted to reflect the objectives of the alternate management policies. Complete data necessary for each analysis is presented along with the methodology for each case study. Finally, the results obtained from MODSIM are discussed along with their implications.

B. Conclusions and Recommendations

The conclusions drawn from this study pertain to three general areas: (1) conclusions concerning the model MODSIM and its utility, (2) conclusions concerning the two case studies, and (3) conclusions concerning the general nature of this study. From a consideration of conclusions, recommendations for improvements (both theoretical and practical) emerge, and are also discussed in this section.

B.1 The model

In relation to the desired river basin water management model set forth in Chapter II, synthesized MODSIM is more closely aligned than any of the models selected for review. Perhaps the most important aspect of the simulation package is the enhanced user capability provided by the interactive, conversational programming nature of the model. MODSIM is specifically designed as a *friendly* modeling package, in that, it is particularly oriented toward the analysis of complex river basin water management problems by those individuals who are most closely associated with these problems, the actual state and local planners and managers of our water resources. Even though MODSIM is a long-term water management model, it still could be used to evaluate the impact of several different planning options, although it will not select a plan.

MODSIM is capable of simulating the water storage, transport, and distribution morphology of a river basin system to a very high level of resolution, depending on the problem. However, it is not able to consider the inclusion of hydropower production in river basins. Since energy production is fast becoming one of the most important political and economic issues in the United States, and also since hydropower is relatively inexpensive and extremely clean in relation to other sources of energy, the inclusion of a hydropower production analysis option is recommended for future refinements of MODSIM.

The model is able to consider non-beneficial consumptive losses such as evaporation and conveyance losses. However, MODSIM, as it currently exists, can only consider beneficial consumptive losses as they relate to volumetric monthly demands. It is recommended that future efforts be devoted to the study of the possibility of expanding the irrigation sector of the model to include crop water requirements, perhaps based on evapotranspiration prediction. Nevertheless, it must be remembered that MODSIM is a long-term management model and care must be taken to insure that the model does not become unwieldy.

Another feature unique to MODSIM is its quasi-optimizing capability which enables it to include, very satisfactorily, the quantifiable aspects of institutional structures governing stream diversion, water storage, and exchange. This capability is a necessity if the model is to be used for planning purposes, whereby the existing institutional structure of a river basin may be modified slightly to reflect an alternate future allocative scheme.

Research is currently being conducted at Colorado State University on options for including the stochastic nature of inflows in the model. It is recommended that such an option be developed independently of MODSIM with the capability of being directly interfaced with the model. A modularized package has certain advantages in computer core storage savings and execution time minimization.

Since irrigation return flows are a significant aspect of the hydrology of an agriculturally productive river basin, such as the Cache la Poudre River Basin, the inclusion of a return flow consideration in the model is imperative. However, there is a wide range of methodology for this inclusion. An attempt is made to accurately model return flows (in a planning context) without making the model overly cumbersome. Nevertheless, it would be possible to include a stream-aquifer interaction model, similar to MITSIM-E, in a modularized packaged for studies where the current method of calculating return flows proves too unreliable.

B.2 The case studies

The two case studies are intended for the demonstration of the capability and utility of MODSIM. As such, the specific conclusions drawn from these studies offer initial guidelines for the management of the Cache la Poudre River Basin to achieve the stated goals of the case studies. However, further analysis may be required before actual implementation of results. For instance, dam safety investigations should be undertaken before any attempt is made to maintain storage levels near maximum in any of the high country reservoirs. Nevertheless, the results of the case study do show that, based on the hydrology considered, it would be possible to provide some level of recreational opportunity in these reservoirs without causing injury to other water users in the basin.

Similarly for the Rawhide Project, based on the hydrologic sequence considered, a firm annual water supply of 4200 acre-feet of reusable effluent from the City of Fort Collins could be provided. Although the synthetically generated transbasin diversions input to MODSIM do contain dry periods, many simulations of the system, varying both the sequence and severity of dry periods, would be necessary before any firm conclusions could be drawn.

Certain general conclusions from these studies, in relation to the model, also need to be addressed. The problem formulation, data gathering, and data organization phase of studies, such as in this report, is the single most important aspect of an investigation. Extreme care must be taken in developing a network that preserves those attributes of the real system which are being analyzed. The adage "what comes out is no better than what goes in" never had more relevance than to river basin modeling.

The calibration phase should be conducted with as much prior knowledge of system behavior as possible. There is no substitute for a thorough working knowledge of the river basin being modeled. With such information, insight into expected model outcome can be gained which helps to determine correct diversion priority adjustments necessary for acceptable calibration. These case studies, although requiring the preferential consideration of storage and demand, do not entirely illustrate the use of water rights priorities by MODSIM. Again, it is noted that there must be aggregation of priorities due to the volumetric transfer of water monthly by MODSIM. As such, only an approximation of these priorities is possible.

These two case studies represent actual *real world* problems which are analyzed by MODSIM. In this respect, they represent a true demonstration of the capability and application of MODSIM. Also, such being the case, they offer a guide to prospective model users concerning the types of information required, the design and consturction of the network, and the subsequent input of data and execution of MODSIM. Finally, considerable detail is afforded the interpretation of results obtained from MODSIM.

B.3 The report

This report is specifically written for a broad audience. It is intended to provide sufficient user documentation for the application of MODSIM to river basin water management problems by planner/managers. Also, it provides an in-depth presentation of the underlying methodology employed by the model, including a complete discussion and demonstration of the Out-of-Kilter Algorithm (Appendix A). Hopefully, this report also provides the reader with a feel for the types of problems which can be readily solved by MODSIM. Every model is created for a specific purpose and no model can realistically be applied to all problems.

It must be reiterated that river basin modeling is an evolutionary process. As new theory is tested and operational life is put on the model, continued improvements are made. Finally, a model, such as MODSIM, is nothing more than a tool. And, as any tool, its utility is closely related to the skill of the user.

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APPENDIX A

OUT-OF-KILTER ALGORITHM

APPENDIX A

OUT-OF-KILTER ALGORITHM

The Out-of-Kilter Algorithm determines minimum cost flows in branching type *circulating* networks. The general format for these problems is:

$$\text{minimize} \sum_{i=1}^{N} \sum_{j=1}^{N} c_{ij}\, x_{ij} \qquad \text{(A.1)}$$

subject to:

$$\sum_{j=1}^{N} x_{ij} - \sum_{j=1}^{N} x_{ji} = 0 \qquad \forall_i \qquad \text{(A.2)}$$

$$x_{ij} \leq u_{ij} \qquad \forall_{ij} \qquad \text{(A.3)}$$

$$x_{ij} \geq \ell_{ij} \qquad \forall_{ij} \qquad \text{(A.4)}$$

where:

c_{ij} = cost of moving one unit of commodity x along arc i,j from node i to node j

x_{ij} = amount of homogeneous commodity moving along arc i,j

u_{ij} = maximum capacity for arc i,j

ℓ_{ij} = minimum requirement for arc i,j.

The Out-of-Kilter Algorithm solves this problem via an efficient primal-dual simplex technique. Associating a dual variable, w_i, with each node conservation equation (A.2), dual variable h_{ij} with each upper bound constraint (A.3), and dual variable v_{ij} with each lower bound constraint (A.4), the dual problem is:

$$\text{maximize} \sum_{i=1}^{N} \sum_{j=1}^{N} \ell_{ij} v_{ij} - \sum_{i=1}^{N} \sum_{j=1}^{N} u_{ij} h_{ij} \qquad (A.5)$$

subject to:

$$w_i - w_j + v_{ij} - h_{ij} = c_{ij} \qquad \forall_{ij} \qquad (A.6)$$

$$h_{ij} \geq 0 \qquad \forall_{ij} \qquad (A.7)$$

$$v_{ij} \geq 0 \qquad \forall_{ij} \qquad (A.8)$$

$$-\infty \leq w_i \leq +\infty$$

Rearranging the terms of Equation A.6:

$$v_{ij} - h_{ij} = c_{ij} - w_i + w_j \qquad (A.10)$$

The w_i can be considered as a "commodity price" at node i. Therefore, $c_{ij}-w_i+w_j$ is the net arc cost, considering both shipment cost and the price of nodes terminating the arc. Thus, the net arc cost equals the shipment cost plus the difference in prices, w_i, at the terminating nodes.

If v_{ij} and h_{ij} are *defined* as:

$$v_{ij} = \max \{0, c_{ij}-w_i+w_j\} \qquad (A.11)$$

$$h_{ij} = \max \{0, -(c_{ij}-w_i+w_j)\} \qquad (A.12)$$

given *any* w_i's, the dual problem always remains feasible. By further defining:

$$\overline{C}_{ij} = w_i - w_j - c_{ij} \qquad (A.13)$$

and applying the complementary slackness conditions, the optimality criteria can be determined as:

$$\text{If: } \overline{C}_{ij} < 0; \quad \text{then } x_{ij} = \ell_{ij} \qquad (A.14)$$

$$\overline{C}_{ij} > 0; \quad \text{then } x_{ij} = u_{ij} \qquad (A.15)$$

$$\overline{C}_{ij} = 0; \quad \text{then } \ell_{ij} \leq x_{ij} \leq u_{ij} \qquad (A.16)$$

Condition A.14 states that if a loss is incurred in shipping commodity from i to j, the flow should be as low as possible. Conversely, condition A.15 states that if it is profitable to send commodity from i to j then the flow should be as large as possible. Finally, if the net arc cost equals zero, indifference occurs as long as bounds are not violated. Any arc which satisfies one of the above conditions is termed *in-kilter*. Arcs which do not satisfy the above conditions are *out-of-kilter*. The Out-of-Kilter Algorithm systematically searches over conserving flows x_{ij} (primal) and values of w_i (dual) until each arc satisfies the optimality conditions. Possible *kilter states* for an arc are:

	$\overline{C}_{ij} < 0$	$\overline{C}_{ij} = 0$	$\overline{C}_{ij} > 0$
$x_{ij} > u_{ij}$	out	out	out
$x_{ij} = u_{ij}$	out	in	in
$\ell_{ij} < x_{ij} < u_{ij}$	out	in	out
$x_{ij} = \ell_{ij}$	in	in	out
$x_{ij} < \ell_{ij}$	out	out	out

Along with kilter states, *kilter numbers* are also defined. The kilter number of an arc is the minimal change in flow over that particular arc necessary to bring it to an in-kilter state. Arc kilter numbers are determined as:

	$\overline{C}_{ij} < 0$	$\overline{C}_{ij} = 0$	$\overline{C}_{ij} > 0$
$x_{ij} > u_{ij}$	$\|x_{ij}-\ell_{ij}\|$	$\|x_{ij}-u_{ij}\|$	$\|x_{ij}-u_{ij}\|$
$x_{ij} = u_{ij}$	$\|x_{ij}-\ell_{ij}\|$	0	0
$\ell_{ij} < x_{ij} < u_{ij}$	$\|x_{ij}-\ell_{ij}\|$	0	$\|x_{ij}-u_{ij}\|$
$x = \ell_{uj}$	0	0	$\|x_{ij}-u_{ij}\|$
$x < \ell_{ij}$	$\|x_{ij}-\ell_{ij}\|$	$\|x_{ij}-\ell_{ij}\|$	$\|x_{ij}-u_{ij}\|$

The following general steps list the strategy of the Out-of-Kilter Algorithm:

1. Begin with conserving flow (not necessarily feasible), $x_{ij}=0$, and a feasible solution to the dual, $w_i=0$. Determine kilter state of each arc and corresponding kilter number.
2. If network has an out-of-kilter arc, conduct the primal of the algorithm. Out-of-Kilter arc is selected and an attempt is made to construct a new conserving flow in such a way that the kilter number of no arc is worsened and that of the selected arc is improved.
3. When no improving flow can be constructed, the algorithm finds a new dual solution in such a way that no kilter number is worsened. Step #2 is repeated.
4. Iterating between steps #2 and #3, the algorithm either finds an optimal solution or determines that no feasible solution exists.

If an optimal solution exists, finite convergence is assured because there is a finite number of arcs and the kilter number of any arc is never allowed to increase. However, the kilter number of some arc is reduced at finite intervals (integer).

A labeling procedure has been developed for the solution of network problems via the Out-of-Kilter Algorithm. The following step-by-step process describes this node labeling solution technique.

1. Select a conserving flow; $x_{ij}=0$, and set dual variables $w_i=0$.
2. If all arcs are in-kilter, the optimal solution has been found, otherwise:
    a. select an out-of-kilter arc (p,q). If (p,q) is in a state where a flow increase, Δ_{pq} is required, then set $s=q$, $t=p$ and label for node equals $L(s)=(+t, \Delta_{pq})$
    b. If (p,q) is in a state where a flow decrease, Δ_{pq} is required, then set $s=p$, $t=q$ and $L(s)=(-t, \Delta_{pq})$.
3. If node i has a label, node j has no label, and flow may be increased by amount Δ_{ij}; assign node j label $L(j)=(+i, \Delta_j)$ where $\Delta_j=\text{minimum}\{\Delta_i, \Delta_{ij}\}$. If node i has a label, and node j has no label and flow may be decreased by Δ_{ji} along arc(j,i), then give node j label $L(j)=(-i, \Delta_j)$ where $\Delta_j=\text{minimum}\{\Delta_i, \Delta_{ji}\}$.

Repeat Step #3 until either node t is labeled (circulation), called *breakthrough* or no more nodes can be labeled, called *nonbreakthrough*. If breakthrough, go to Step #4; if nonbreakthrough, go to step #5.

4. Flow change: let $\Delta=\Delta_t$ and begin at node t. If $L(t)=(+k,y)$, then add Δ to x_{kt}; if $L(t)=(-k,y)$, then subtract Δ from x_{ky}. Backtrack through cycle until node t is reached again.

Go to Step #2.

5. Dual phase: Divide labeled nodes and unlabeled nodes into sets X and $\overline{X}$, respectively.

a. Define $S_1=\{(i\ j)\}$

where:

i is an element of X

j is an element of $\overline{X}$

$\overline{C}_{ij} < 0$

$x_{ij} \leq u_{ij}$

b. Define $S_2\{(i\ j)\}$

where:

i is an element of $\overline{X}$

j is an element of X

$\overline{C}_{ij} > 0$

$x_{ij} \geq \ell_{ij}$

If $S_1 \& S_2=\Phi$ (null set), stop; no feasible solution exists, otherwise: let $\theta=\text{minimum}\{|\overline{C}_{ij}|, \infty,\}$ considering all $(i\ j)$ in $S_1 \& S_2$.

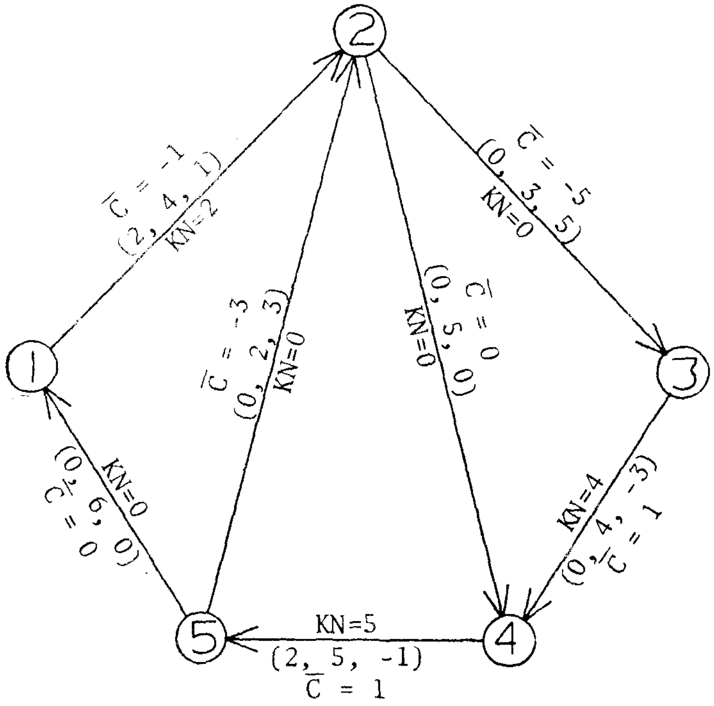
Change w_i according to:

$$w_i = \begin{cases} w_i+\theta & \text{if } i \in X \\ w_i & \text{if } i \in \overline{X} \end{cases}$$

Go to Step #2

Example hand calculation of solution to a network problem using the Out-of-Kilter Algorithm follows. The notation used for each arc; (ℓ, u, c), relates to the lower bound, upper bound, and arc cost. KN refers to kilter number.

EXAMPLE SOLUTION USING OUT-OF-KILTER ALGORITHM



STEP 1: $\overline{C}_{ij} = w_i - w_j - c_{ij}$

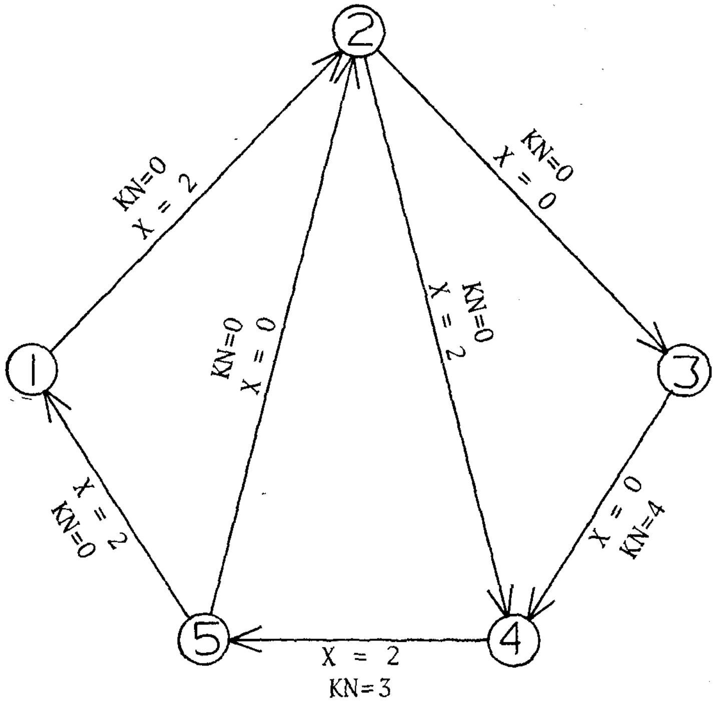
$x_{ij} = 0$
$w_i = 0$ Initial solution

STEP 2: • (p, q) = (1, 2); s=2, t=1; L(2) = (+1, 2)

STEP 3: • (i, j) = (2, 4); $\Delta_{ij} = 5$; $\text{Min}\{\Delta_i, \Delta_{ij}\} = \Delta_j = 2$; L(4)=(+2, 2)
• (i, j) = (4, 5); $\Delta_{ij} = 5$; $\text{Min}\{\Delta_i, \Delta_{ij}\} = \Delta_j = 2$; L(5)=(+4, 2)
• (i, j) = (5, 1); $\Delta_{ij} = 6$; $\text{Min}\{\Delta_i, \Delta_{ij}\} = \Delta_j = 2$; L(1)=(+5, 2)

BREAKTHROUGH

STEP 4: • $\Delta_t = 2 = \Delta$
• $X'_{51} = X_{51} + \Delta = 0 + 2 = 2$
• $X'_{45} = X_{34} + \Delta = 0 + 2 = 2$
• $X'_{24} = X_{24} + \Delta = 0 + 2 = 2$
• $X'_{12} = X_{12} + \Delta = 0 + 2 = 2$



STEP 2: $(p, q)=(3, 4)$; $s=4$, $t=3$; $L(4)=(+3, 4)$

STEP 3: $(i, j)=(4, 5)$; $L(5)=(+4, 3)$

$(i, j)=(5, 1)$; $L(1)=(+5, 3)$

$(i, j)=(4, 2)$; Added Reverse Flow; $L(2)=(-4, 2)$

NON-BREAKTHROUGH, COULD NOT GET TO NODE 3

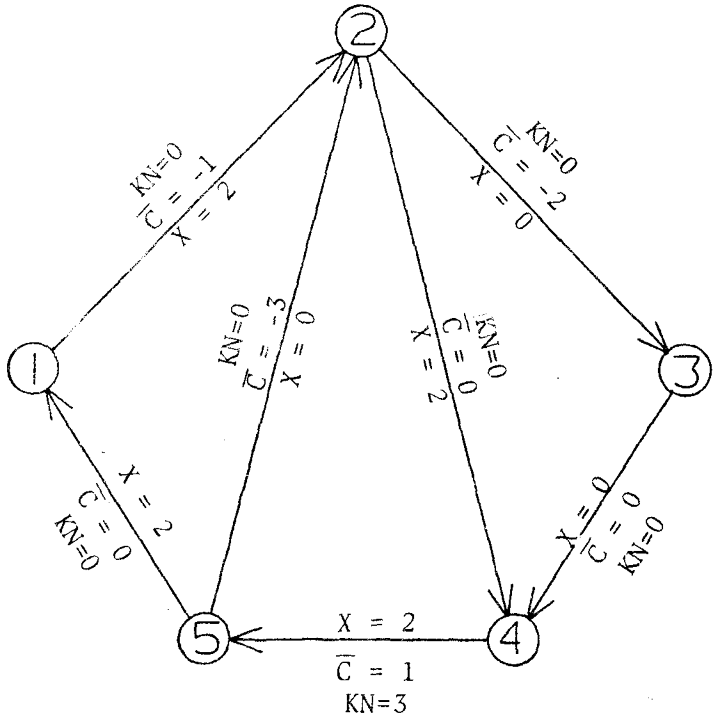
STEP 5: $X = \{1, 2, 4, 5\}$ $\bar{X} = \{3\}$

$S_1 = \{(2, 3)\}$, $S_2 = \{3, 4\}$

$\theta_1 = 5$, $\theta_2 = 3$

$\theta = 3$

$w_1=3$; $w_2=3$; $w_3=0$; $w_4=3$; $w_5=3$



Compute new $\bar{C}_{ij}$

STEP 2: • $(p, q)=(4, 5)$; $s=5$, $t=4$; $L(5)=(+4, 3)$

STEP 3: • $L(1)=(+5, 3)$

NON-BREAKTHROUGH

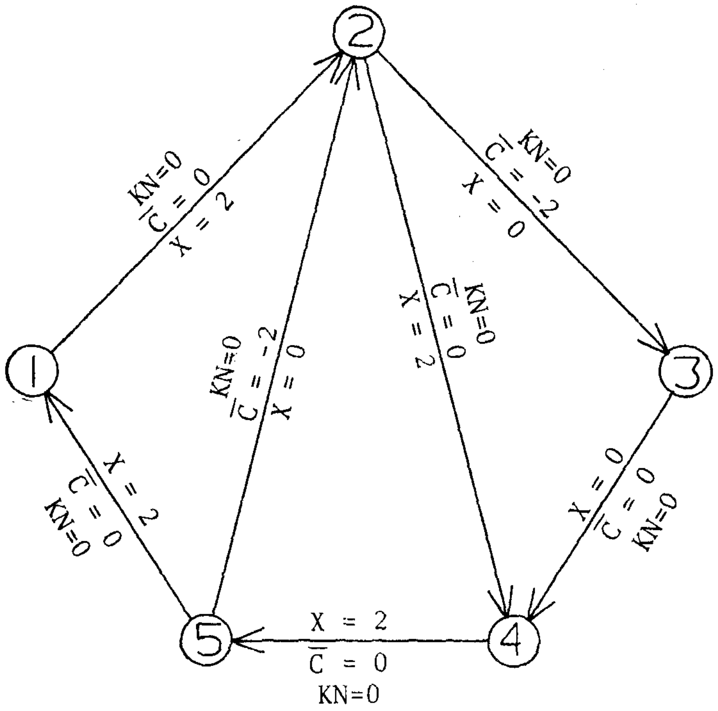
STEP 5: $X = \{5, 1\}$, $\bar{X} = \{2, 3, 4\}$

$S_1 = \{(5, 2), (1, 2)\}$, $\theta_1=1$

$\theta=1$

$S_2 = \{(4, 5)\}$, $\theta_2=1$

$w_1=4$; $w_2=3$; $w_3=0$; $w_4=3$; $w_5=4$



- Compute new $\overline{C}_{ij}$
- ALL ARCS ARE IN-KILTER, OPTIMAL SOLUTION HAS BEEN FOUND

APPENDIX B

SOURCE LISTING: PROGRAM ORGANZ

```
      PROGRAM ORGANIZ (INPUT,OUTPUT,TAPE8,A,TAPE1=A)
      DIMENSION TITLE(20),SP(30),RNAME(2),ACTAB(12,2),DEMR(12),
     *          DEMD(12),DIMP(12),JESVOL(30),OPRP(10),OPRR(12),
     *          CMAXV(12),A(15),IDIVL(15),IRTL(15),IRTFF(15)
      INTEGER RCAP,RMIN,FSTART,SP,ACTAB,DEM,DEMR,OPRP,CMAX,CMIN,COST,
     *        CMAXV
      PRINT 5
    5 FORMAT (/24(1H*),32H P R O G R A M   O R G A N I Z E ,24(1H*)//)
      PRINT 6
    6 FORMAT (12X,56HINTERACTIVE, CONVERSATIONAL DATA ORGANIZATION FOR M
     *ODSIM,//)
   11 PRINT 12
   12 FORMAT (1X,20H** BEGIN RECORD 1 **,/)
   15 FORMAT (A1)
C
C          B E G I N   R E C O R D   1
C
      REWIND 8
      PRINT*,'ARE CHANNEL LOSSES TO BE COMPUTED  (YES OR NO)',
      READ 15,ANS1
      IF (ANS1.EQ.1HY) GO TO 40
      LOPT=0
      GO TO 45
   40 LOPT=1
   45 PRINT*,'ECHO PRINT OF INPUT DATA  (YES OR NO)',
      READ 15, ANS2
      IF (ANS2.EQ.1HY) GO TO 50
      IOTT=0
      GO TO 55
   50 IOTT=1
   55 PRINT*,'SUMMARY OUTPUT  (YES OR NO)',
      READ 15, ANS3
      ISUM=0
      IF (ANS3.EQ.1HY) ISUM=1
      IALLY=0
      PRINT*,'AVG., WET, DRY STATES TO BE COMPUTED  (YES OR NO)',
      READ 15, ANS35
      IF (ANS35.EQ.1HN) IALLY=1
      IRTN=0
      PRINT*,'IS RETURN FLOW TO BE CALCULATED  (YES OR NO)',
      READ 15, ANS36
      IF (ANS36.EQ.1HY) IRTN=1
      WRITE(8,60) LOPT,IOTT,ISUM,IALLY,IRTN
   60 FORMAT('CONTROL OPTIONS',5I5)
      PRINT 61
   61 FORMAT (//1X,20H** BEGIN RECORD 2 **,/)
C
C          B E G I N   R E C O R D   2
C
      PRINT*,'ENTER: UP TO 80 CHARACTER TITLE'
      READ 62, (TITLE(I),I=1,20)
      WRITE(8,62) (TITLE(I),I=1,20)
   62 FORMAT (20A4)
   63 PRINT 64
   64 FORMAT (//1X,20H** BEGIN RECORD 3 **,/)
C
C          B E G I N   R E C O R D   3
```

```
C
      PRINT*,'ENTER: NO. OF NETWORK NODES',
      READ*,NJ
      PRINT*,'ENTER: TOTAL NO. OF NETWORK LINKS',
      READ*,NL
      PRINT*,'ENTER: NO. OF RESERVOIRS',
      READ*,NRES
      IF (NRES.LE.NJ) GO TO 66
   65 PRINT*,'**ERROR**'
      GO TO 63
   66 PRINT*,'ENTER: NO. OF RIVER REACHES',
      READ*,NR
      IF (NR.LE.NL) GO TO 67
      GO TO 65
   67 PRINT*,'ENTER: NO. OF DEMAND NODES',
      READ*,ND
      IF (ND.LE.NJ) GO TO 68
      GO TO 65
   68 PRINT*,'ENTER: NO. OF SPILL NODES',
      READ*,NS
      IF (NS.LE. NRES) GO TO 69
      GO TO 65
   69 PRINT*,'ENTER: NO. OF IMPORT NODES',
      READ*,IMN
      IF (IMN.LE.7) GO TO 71
      PRINT*,'**ERROR** MAXIMUM NO. OF IMPORT NODES = 7'
      GO TO 63
   71 PRINT*,'ENTER: NO. OF YEARS TO BE SIMULATED',
      READ*,NYEAR
      PRINT*,'ENTER: CALENDAR YEAR BEGINNING SIMULATION',
      READ*,IYEAR
      PRINT*,'ENTER: FROM-TO YEARS OF DETAILED OUTPUT DESIRED',
      READ*,IFRM,ITOY
      IF (ITOY.LE.NYEAR) GO TO 72
      PRINT*,'**ERROR** TOTAL NO. OF YEARS = ',NYEAR
      GO TO 63
   72 PRINT*,'IS FIRM YIELD TO BE CALCULATED  (YES OR NO)',
      READ 15,ANS4
      IYLD=0
      IF (ANS4.EQ.1HN) GO TO 70
      PRINT*,'WHICH NODE',
      READ*,IYLD
   70 KCT=1
      CPCT=0.0
      WRITE(8,75) NJ,NRES,NL,NR,NYEAR,ND,NS,IYEAR,IMN,IYLD,
     *            IFRM,ITOY,KCT,CPCT
   75 FORMAT('PARAMETERS',12I5,4X,I1,F5.3)
   77 PRINT 78
   78 FORMAT (//1X,20H** BEGIN RECORD 4 **,/)
C
C          B E G I N   R E C O R D   4
C
      DO 120 I=1,NJ
      IF (I.GT.NRES) GO TO 100
   84 PRINT*,'FOR RESERVOIR NO. ',I,':'
      PRINT*,'       ENTER: UP TO 8 CHARACTER NAME',
      READ 85, (RNAME(L),L=1,2)
```

```
  85 FORMAT (2A4)
     PRINT*,'      ENTER: NETWORK NODE NO.',
     READ*, J
      IF (J.LE.NJ) GO TO 86
     PRINT*,'**ERROR** MAXIMUM NO. OF NODES = ',NJ
     GO TO 84
  86 PRINT*,'      ENTER: MAXIMUM CAPACITY',
     READ*, RCAP
     PRINT*,'      ENTER: MINIMUM CAPACITY',
     READ*, RMIN
     PRINT*,'      ENTER: STARTING VOLUME',
     READ*, FSTART
     IF (FSTART.GE.RMIN.AND.FSTART.LE.RCAP) GO TO 94
     PRINT*,'**ERROR** STARTING VOLUME IS OUTSIDE OF BOUNDS'
     GO TO 86
  94 WRITE(8,95) (RNAME(L),L=1,2),J,RCAP,RMIN,FSTART
  95 FORMAT (2A4,2X,I5,3I10)
     GO TO 120
 100 PRINT*,'FOR JUNCTION NO. ',I,';'
     PRINT*,'      ENTER: UP TO 8 CHARACTER NAME',
     READ 85, (RNAME(L),L=1,2)
     PRINT*,'      ENTER: NETWORK NODE NO.',
     READ*,J
     IF (J.LE.NJ) GO TO 110
     PRINT*,'**ERROR** MAXIMUM NO. OF NODES = ',NJ
     GO TO 100
 110 RCAP=0
     RMIN=0
     FSTART=0
     WRITE(8,95) (RNAME(L),L=1,2),J,RCAP,RMIN,FSTART
 120 CONTINUE
 121 PRINT 122
 122 FORMAT (//1X,20H** BEGIN RECORD 5 **,/)
C
C          B E G I N   R E C O R D   5
C
     PRINT*,'ENTER: ',NS,' SPILL NODE(S) IN ORDER OF PREFERENCE',
     READ*,(SP(I),I=1,NS)
     WRITE(8,130) (SP(I),I=1,NS)
 130 FORMAT ('SPILLS',4X,12I5)
 131 PRINT 132
 132 FORMAT (//1X,20H** BEGIN RECORD 6 **,/)
C
C          B E G I N   R E C O R D   6
C
     PRINT*,'ENTER: NO. OF AREA-CAPACITY POINTS PER RES.',
     READ*,NPAIRS
     IF (NPAIRS.LE.18) GO TO 133
     PRINT*,'**ERROR** MAXIMUM NO. OF POINTS = 18'
     GO TO 131
 133 WRITE(8,134) NPAIRS
 134 FORMAT ('NO. PAIRS',1X,I5)
     DO 145 I=1,NRES
     PRINT*,'FOR RESERVOIR NO. ',I,';'
     DO 138 JJ=1,NPAIRS
     PRINT*,'      ENTER: POINT ',JJ,' [AREA-CAPACITY]',
     READ*, (ACTAB(JJ,L),L=1,2)
```

```
  138 CONTINUE
      WRITE(8,140) I,((ACTAB(K,L),L=1,2),K=1,NPAIRS)
  140 FORMAT('AREA-CAP',2X,I5,6I10/(15X,6I10))
  145 CONTINUE
  146 PRINT 147
  147 FORMAT (//1X,20H** BEGIN RECORD 7 **,/)
C
C           B E G I N   R E C O R D   7
C
      IF (IALLY.EQ.1) GO TO 190
      PRINT*,'AVG., WET, AND DRY HYDROLOGIC STATES WILL BE COMPUTED'
      DO 185 I=1,ND
  150 PRINT*,'FOR DEMAND NODE NO. ',I,';'
      PRINT*,'          ENTER: NETWORK NODE NO.',
      READ*,NODED
      PRINT*,'          IS THIS A FLOW THRU DEMAND  (YES OR NO)',
      READ 15, ANS45
      IDSTRM=0
      IF (ANS45.EQ.1HN) GO TO 151
      PRINT*,'          ENTER: NODE WHERE DEMAND ACCRUES',
      READ*, IDSTRM
  151 PRINT*,'          ENTER: PRIORITY FOR AVG. HYDROLOGIC STATE',
      READ*,DEMR(1)
      PRINT*,'          ENTER: PRIORITY FOR DRY  HYDROLOGIC STATE',
      READ*,DEMR(2)
      PRINT*,'          ENTER: PRIORITY FOR WET  HYDROLOGIC STATE',
      READ*,DEMR(3)
      PRINT*,'          IS MONTHLY DEMAND TO BE INPUT VIA DATA FILE  (YES OR
     * NO)',
      READ 15, ANS5
      IF (ANS5.EQ.1HY) GO TO 170
      PRINT*,'          ENTER: TOTAL ANNUAL DEMAND',
      READ*,DEM
      PRINT*,'          ENTER: MONTHLY DISTRIBUTION',
      READ*,(DEMD(J),J=1,12)
  170 DEM=0
      DO 171 J=1,12
      DEMD(J)=0.0
  171 CONTINUE
  178 WRITE(8,180) NODED,IDSTRM,DEM,(DEMR(K),K=1,3),(DEMD(J),J=1,12)
  180 FORMAT ('DEMAND',1X,2I3,I8,3I3,12F4.2)
  185 CONTINUE
      GO TO 230
  190 PRINT*,'PRIORITY FOR EACH YEAR OF SIMULATION WILL BE INPUT'
      DO 227 I=1,ND
  195 PRINT*,'FOR DEMAND NODE NO. ',I,';'
      PRINT*,'          ENTER: NETWORK NODE NO.',
      READ*,NODED
      PRINT*,'          IS THIS A FLOW THRU DEMAND  (YES OR NO)',
      READ 15, ANS46
      IDSTRM=0
      IF (ANS46.EQ.1HN) GO TO 193
      PRINT*,'          ENTER: NODE NO. WHERE DEMAND ACCRUES',
      READ*, IDSTRM
  193 DO 196 J=1,NYEAR
      PRINT*,'          ENTER: PRIORITY FOR SIMULATION YEAR ',J,
      READ*,DEMR(J)
```

```
  196 CONTINUE
      PRINT*,'       IS MONTHLY DEMAND TO BE INPUT VIA DATA FILE  (YES OR
     * NO)',
      READ 15, ANS5
      IF (ANS5.EQ.1HY) GO TO 210
      PRINT*,'       ENTER: TOTAL ANNUAL DEMAND',
      READ*,DEM
      PRINT*,'       ENTER: MONTHLY DISTRIBUTION',
      READ*,(DEMD(J),J=1,12)
  210 DEM=0
      DO 213 J=1,12
      DEMD(J)=0.0
  213 CONTINUE
  215 WRITE(8,217) NODED,IDSTRM,DEM,(DEMD(J),J=1,12)
  217 FORMAT ('DEMAND',1X,2I3,I8,9X,12F4.2)
      WRITE(8,219) NODED,(DEMR(J),J=1,NYEAR)
  219 FORMAT ('RANK',6X,11I5)
  227 CONTINUE
  230 IF (IMN.EQ.0) GO TO 246
  231 PRINT 232
  232 FORMAT (//1X,20H** BEGIN RECORD 8 **,/)
C
C         B E G I N   R E C O R D   8
C
      DO 245 I=1,IMN
      PRINT*,'FOR IMPORT NODE NO. ',I,';'
      PRINT*,'       ENTER: NETWORK NODE NO.',
      READ*, IMP
      WRITE(8,233) IMP
  233 FORMAT ('IMPORT',4X,I5)
      DO 2455 N=1,NYEAR
      PRINT*,'FOR SIMULATION YEAR NO. ',N
      PRINT*,'       ENTER: TOTAL ANNUAL IMPORT',
      READ*,IMPRT
      PRINT*,'       ENTER: MONTHLY DISTRIBUTION'
      READ*,(DIMP(J),J=1,12)
      WRITE(8,240) N,IMPRT,(DIMP(J),J=1,12)
  240 FORMAT ('YEAR',2X,I2,12X,I10,12F4.3)
 2455 CONTINUE
  245 CONTINUE
      GO TO 248
  246 WRITE(8,247)
  247 FORMAT ('IMPORT',8X,'0')
  248 IF (IALLY.EQ.1) GO TO 260
  249 PRINT 2495
 2495 FORMAT (//1X,20H** BEGIN RECORD 9 **,/)
C
C         B E G I N   R E C O R D   9
C
      PRINT*,'ENTER: NO. OF RESERVOIRS IN SUBSYSTEM',
      READ*,NSRS
      PRINT*,'ENTER: NETWORK NODE NO. OF RESERVOIRS IN SUBSYSTEM',
      READ*,(JESVOL(I),I=1,NSRS)
      PRINT*,'ENTER: FRACTION FOR AVERAGE LOW AND AVERAGE HIGH',
      READ*,AVGLO,AVGHI
      WRITE(8,250) NSRS,(JESVOL(J),J=1,NSRS)
  250 FORMAT ('SUBSYSTEM',1X,14I5)
```

```
      WRITE(8,255) AVGLO,AVGHI
  255 FORMAT ('AVERAGE ST',2(5X,F5.3))
  260 PRINT 262
  262 FORMAT (//1X,21H** BEGIN RECORD 10 **,/)
C
C          B E G I N   R E C O R D  10
C
      PRINT*,'ARE CONVERSION FACTORS NECESSARY  (YES OR NO)',
      READ 15,ANS7
      IF (ANS7.EQ.1HY) GO TO 265
      CONINF=0.0
      CONDEM=0.0
      CONFLO=0.0
      GO TO 270
  265 PRINT*,'ENTER: CONVERSION FOR LINK CAPACITIES TO STORAGE UNITS',
      READ*,CONFLO
      PRINT*,'ENTER: CONVERSION FOR INFLOWS TO STORAGE UNITS',
      READ*,CONINF
      PRINT*,'ENTER: CONVERSION FOR DEMANDS TO STORAGE UNITS',
      READ*,CONDEM
  270 WRITE(8,275) CONFLO,CONINF,CONDEM
  275 FORMAT ('FACTORS',3X,3(5X,F5.3))
  276 PRINT 277
  277 FORMAT (//1X,21H** BEGIN RECORD 11 **,/)
C
C          B E G I N   R E C O R D  11
C
      IF (IALLY.EQ.1) GO TO 315
      DO 310 I=1,NRES
      PRINT*,'FOR RESERVOIR NO. ',I,';'
      PRINT*,'       ENTER: PRIORITY FOR AVG. HYDROLOGIC STATE',
      READ*, OPRP(1)
      PRINT*,'       ENTER: DESIRED MONTHLY DISTRIBUTION'
      READ*, (OPRR(J),J=1,12)
      WRITE(8,285) I, OPRP(1),(OPRR(J),J=1,12)
  285 FORMAT(' RESERVOIR',I5,10X,I5,12F4.2)
      PRINT*,'       ENTER: PRIORITY FOR DRY HYDROLOGIC STATE',
      READ*, OPRP(2)
      PRINT*,'       ENTER: DESIRED MONTHLY DISTRIBUTION'
      READ*, (OPRR(J),J=1,12)
      WRITE(8,295) I,OPRP(2),(OPRR(J),J=1,12)
  295 FORMAT(' OPERATING',I5,10X,I5,12F4.2)
      PRINT*,'       ENTER: PRIORITY FOR WET HYDROLOGIC STATE',
      READ*, OPRP(3)
      PRINT*,'       ENTER: DESIRED MONTHLY DISTRIBUTION'
      READ*, (OPRR(J),J=1,12)
      WRITE(8,305) I,OPRP(3),(OPRR(J),J=1,12)
  305 FORMAT('  RULES    ',I5,10X,I5,12F4.2)
  310 CONTINUE
      GO TO 336
  315 DO 335 I=1,NRES
      PRINT*,'FOR RESERVOIR NO. ',I,';'
      DO 330 J=1,NYEAR
      PRINT*,'       ENTER: PRIORITY FOR SIMULATION YEAR ',J,
      READ*,OPRP(J)
      PRINT*,'       ENTER: MONTHLY DESIRED DISTRIBUTION'
      READ*,(OPRR(L),L=1,12)
```

```
      WRITE(8,325) I,OPRP(J),(OPRR(L),L=1,12)
  325 FORMAT('ANNUAL OPR',I5,10X,I5,12F4.2)
  330 CONTINUE
  335 CONTINUE
  336 PRINT 337
  337 FORMAT (//1X,21H** BEGIN RECORD 12 **,/)
C
C          B E G I N   R E C O R D  12
C
      PRINT*,'ENTER: NO. OF LINKS WITH VARIABLE CAPACITY',
      READ*, NVARL
      WRITE(8,338) NVARL
  338 FORMAT('NVARLKS',3X,I5)
      IF (NVARL) 339,347,339
  339 DO 346 I=1,NVARL
      PRINT*,'FOR VARIABLE CAPACITY LINK NO. ',I,';'
      PRINT*,'       ENTER: NETWORK LINK NO.',
      READ*,LINK
      PRINT*,'       ENTER: MINIMUM CAPACITY',
      READ*,CMIN
      PRINT*,'       ENTER: ORIGIN NODE NO.',
      READ*,LF
      PRINT*,'       ENTER: TERMINATION NODE NO.',
      READ*,LT
      XLCF=0.0
      IF (LOPT) 341,342,341
  341 PRINT*,'       ENTER: LOSS COEFFICIENT',
      READ*,XLCF
  342 PRINT*,'       ENTER: UNIT COST',
      READ*,COST
      PRINT*,'       ENTER: MAXIMUM CAPACITY FOR EACH MONTH'
      READ*,(CMAXU(J),J=1,12)
      WRITE(8,344) LINK,NF,NT,CMIN,XLCF,COST
  344 FORMAT ('LINK',6X,3I5,10X,F10.8,I5)
      WRITE(8,345) (CMAXU(J),J=1,12)
  345 FORMAT ('CMAXU',3X,12I6)
  346 CONTINUE
  347 NLLL=NL-NVARL
      IF (NLLL.EQ.0) GO TO 361
      PRINT*,'ENTER REMAINING LINKAGE CONFIGURATION'
      DO 360 I=1,NLLL
      PRINT*,'ENTER: NETWORK LINK NO.',
      READ*,LINK
      PRINT*,'       ENTER: MAXIMUM CAPACITY',
      READ*,CMAX
      PRINT*,'       ENTER: MINIMUM CAPACITY',
      READ*,CMIN
      PRINT*,'       ENTER: ORIGIN NODE NO.',
      READ*,LF
      PRINT*,'       ENTER: TERMINATION NODE NO.',
      READ*,LT
      IF (LOPT.EQ.1) GO TO 349
      XLCF=0.0
      GO TO 350
  349 PRINT*,'       ENTER: LOSS COEFFICIENT',
      READ*,XLCF
  350 PRINT*,'       ENTER: UNIT COST',
```

```
      READ*,COST
      WRITE(8,355) LINK,LF,LT,CMAX,CMIN,XLCF,COST
  355 FORMAT('LINK',6X,3I5,2I10,F10.8,I5)
  360 CONTINUE
  361 IF (IRTN.EQ.0) GO TO 397
C
C          B E G I N   R E C O R D  13
C
      PRINT 362
  362 FORMAT (//1X,21H** BEGIN RECORD 13 **,/)
      PRINT*,'ENTER: NO. OF RETURN FLOW EQUATIONS',
      READ*,NEQU
      PRINT*,'ENTER: NO. OF TIME PERIODS TO BE LAGGED',
      READ*,NLAGS
      WRITE(8,363) NEQU,NLAGS
  363 FORMAT ('NEQU,NLAGS',2I5)
      LAGS=2*NLAGS+2
      DO 385 I=1,NEQU
      PRINT*,'FOR RETURN FLOW EQU. NO. ',I,':'
      PRINT*,'       ENTER: NO. OF NODES CONTRIBUTING TO RTFLOW',
      READ*,NDNEQU
      PRINT*,'       ENTER: NODE NO. WHERE FLOW RETURNS',
      READ*,JRTFT
      PRINT*,'       ENTER: NODES WHICH CONTRIBUTE TO RTFLOW',
      READ*,(IRTFF(J),J=1,NDNEQU)
      PRINT*,'       ENTER: REGRESSION COEF. BEGINNING WITH',
     *'              THE CONSTANT TERM, FOLLOWED BY DITCH '
      PRINT*,'              DIVERSIONS, FOLLOWED BY RETURN FLOWS'
      PRINT*,'              EXAMPLE FOR 1 MONTH LAG',
     *'       A1+A2*D(T)+A3*D(T-1)+A4*R(T-1)'
      READ*,(A(J),J=1,LAGS)
      WRITE(8,365) (A(J),J=1,LAGS)
  365 FORMAT (8G10.4)
      WRITE(8,366) NDNEQU,JRTFT
  366 FORMAT ('EQU',2X,2I5)
      WRITE(8,367) (IRTFF(J),J=1,NDNEQU)
  367 FORMAT ('EQU',2X,15I5)
      PRINT 369
  369 FORMAT (/)
      PRINT*,'       FOR INITIAL CALCULATIONS ENTER:'
      DO 370 K=1,NLAGS
      PRINT*,'       TOTAL DITCH DIVERSION AND TOTAL RETURN'
      PRINT*,'       FLOW OBSERVED FOR TIME PERIOD ZERO MINUS '
      PRINT*,'       ',K,':',
      READ*, IDIVL(K),IRTL(K)
  370 CONTINUE
      WRITE(8,371) ((IDIVL(K),IRTL(K)),K=1,NLAGS)
  371 FORMAT ('LAGS',1X,12I6)
  385 CONTINUE
C
C          F I L E   N A M E
C
  397 REWIND 8
      PRINT 398
  398 FORMAT (//)
  399 REWIND 1
      PRINT*,'SAVE FILE AS PERMANENT FILE  (YES OR NO)',
```

```
      READ 15, ANS8
      IF (ANS8.EQ.1HN) GO TO 999
      PRINT*,'ENTER: UP TO 7 CHARACTER FILE NAME',
      READ 400, FILN
  400 FORMAT (A7)
      WRITE(1,410) FILN
  410 FORMAT ('COPY,TAPE8,',A7,'.')
      WRITE(1,420) FILN
  420 FORMAT ('REWIND,',A7,'.')
      WRITE(1,430) FILN
  430 FORMAT ('REPLACE,',A7,'.')
      PRINT*,'IS A LISTING REQUIRED  (YES OR NO)',
      READ 15, ANS9
      IF (ANS9.EQ.1HN) GO TO 999
      WRITE(1,440) FILN
  440 FORMAT ('COPY,',A7,',OUTPUT.')
  999 STOP
      END
```

APPENDIX C

SOURCE LISTING: PROGRAM ADATA

```
   PROGRAM ADATA (INPUT=65,OUTPUT,TAPE10,TAPE11,B,TAPE2=B)
   DIMENSION IDEM(40),IFLO(40),IEVAP(40)
   DIMENSION FLOW(20,40,12),DEMD(20,40,12),EVAP(20,20,12)
   DATA FLOW/9600*0.0/,DEMD/9600*0.0/,EVAP/4800*0.0/
   REWIND 10
   REWIND 11
   PRINT 1
 1 FORMAT (/,27(1H*),26H P R O G R A M  A D A T A ,27(1H*),//)
   PRINT 2
 2 FORMAT (10X,57HBINARY INFLOW, DEMAND, AND EVAP. FILE CREATION FOR
  *MODSIM,//)
   PRINT*,'ENTER: TOTAL NO. OF NODES',
   READ*,NJ
   PRINT*,'ENTER: TOTAL NO. OF RESERVOIRS',
   READ*,NRES
   PRINT*,'ENTER: NO. OF YEARS TO BE SIMULATED',
   READ*,NYEAR
   PRINT*,' '
   PRINT*,'ENTER: NO. OF DEMAND NODES',
   READ*,NDEM
   PRINT*,'ENTER: NODE NO. OF EACH DEMAND NODE'
   READ*,(IDEM(J),J=1,NDEM)
   PRINT*,' '
   PRINT*,'ENTER: NO. OF NODES WHERE UNREGULATED INFLOW OCCURS',
   READ*,NUREG
   PRINT*,'ENTER: NODE NO. OF EACH UNREG. INFLOW NODE'
   READ*,(IFLO(J),J=1,NUREG)
   PRINT*,' '
   PRINT*,'ENTER: NO. OF RESERVOIRS WITH EVAP. > 0',
   READ*,NEVAP
   IF (NEVAP.EQ.0) GO TO 10
   PRINT*,'ENTER: NODE NO. OF RESERVOIRS WITH EVAP. > 0'
   READ*,(IEVAP(J),J=1,NEVAP)
10 DO 100 IY=1,NYEAR
   DO 90 JU=1,NJ
   IF (NUREG.EQ.0) GO TO 20
   DO 15 KK=1,NUREG
   IF (JU.NE.IFLO(KK)) GO TO 15
   PRINT*,'ENTER: MONTHLY INFLOWS FOR NODE ',JU,' YEAR ',IY
   READ*,(FLOW(IY,JU,K),K=1,12)
   PRINT*,' '
15 CONTINUE
20 IF (NDEM.EQ.0) GO TO 30
   DO 25 KK=1,NDEM
   IF (JU.NE.IDEM(KK)) GO TO 25
   PRINT*,'ENTER: MONTHLY DEMANDS FOR NODE ',JU,' YEAR ',IY
   READ*,(DEMD(IY,JU,K),K=1,12)
   PRINT*,' '
25 CONTINUE
30 IF (NEVAP.EQ.0) GO TO 90
   DO 35 KK=1,NEVAP
   IF (JU.NE.IEVAP(KK)) GO TO 35
   PRINT*,'ENTER: MONTHLY EVAP. RATES FOR RES. NO. ',JU,' YEAR ',IY
   READ*,(EVAP(IY,JU,K),K=1,12)
   PRINT*,' '
35 CONTINUE
90 CONTINUE
```

```
      WRITE(10) ((FLOW(IY,J,K),K=1,12),J=1,NJ),
     *          ((DEMD(IY,J,K),K=1,12),J=1,NJ),
     *          ((EVAP(IY,J,K),K=1,12),J=1,NRES)
      WRITE(11,115) ((FLOW(IY,J,K),K=1,12),J=1,NJ),
     *              ((DEMD(IY,J,K),K=1,12),J=1,NJ)
  115 FORMAT (6F12.0)
      WRITE(11,116) ((EVAP(IY,J,K),K=1,12),J=1,NRES)
  116 FORMAT (6F12.4)
  100 CONTINUE
      REWIND 10
      REWIND 11
      PRINT*,'ENTER: UP TO 7 CHARACTER PFN FOR BINARY FILE',
      READ 101, INAM
  101 FORMAT (A7)
      WRITE(2,102) INAM
  102 FORMAT ('REPLACE,TAPE10=',A7,'.')
      PRINT*,'SAVE COPY OF CODED DATA FILE ALSO  (YES OR NO)',
      READ 130, ANS0
      IF (ANS0.EQ.1HN) GO TO 119
      PRINT*,'ENTER: UP TO 7 CHARACTER PFN FOR CODED FILE',
      READ 107, INAM
  107 FORMAT (A7)
      WRITE(2,108) INAM
  108 FORMAT ('REPLACE,TAPE11=',A7,'.')
  119 REWIND 2
      PRINT 120
  120 FORMAT (//1X,27HJOB SUCCESSFULLY COMPLETED.)
      PRINT*,'PRINT-OUT OF DATA FILE  (YES OR NO)',
      READ 130, ANS
  130 FORMAT (A1)
      IF (ANS.EQ.1HN) GO TO 999
      PRINT 140
  140 FORMAT (/1X,4HFLOW,/)
      PRINT 145, ((J,(FLOW(I,J,K),K=1,12),J=1,NJ),I=1,NYEAR)
  145 FORMAT (2X,I3,5X,12F7.0)
      PRINT 150
  150 FORMAT (/1X,6HDEMAND,/)
      PRINT 145, ((J,(DEMD(I,J,K),K=1,12),J=1,NJ),I=1,NYEAR)
      PRINT 160
  160 FORMAT (/1X,11HEVAPORATION,/)
      PRINT 165, ((J,(EVAP(I,J,K),K=1,12),J=1,NRES),I=1,NYEAR)
  165 FORMAT (2X,I3,5X,12F7.3)
  999 STOP
      END
```

APPENDIX D

SOURCE LISTING: PROGRAM MODSIM

```
      PROGRAM MODSIM                                                    MOD 0010
     1(INPUT=65,OUTPUT=65,TAPE5=INPUT,TAPE6=OUTPUT,TAPE10,TAPE15)       MOD 0020
C                                                                       MOD 0030
C                                                                       MOD 0040
C     ******************************************************************MOD 0050
C                                                                       MOD 0060
C     PROGRAM MODSIM - RIVER BASIN SIMULATION PACKAGE                   MOD 0070
C     ORIGINAL DEVELOPMENT - CARLOS PUENTES                             MOD 0080
C     SYSTEMS ENGINEERING DIVISION, TEXAS WATER DEVELOPMENT BOARD       MOD 0090
C     MARCH 1972                                                        MOD 0100
C     MODIFICATIONS - JOHN M. SHAFER                                    MOD 0110
C     COLORADO STATE UNIVERSITY                                         MOD 0120
C     1978-1979                                                         MOD 0130
C                                                                       MOD 0140
C     ******************************************************************MOD 0150
C                                                                       MOD 0160
      COMMON /CONTRL/        KIN          , KOUT         , KAPE1       , MOD 0170
     1         KAPE4                                                    MOD 0180
      COMMON /IPRNT/         IPRNT        , IYLD         , ITOY        , MOD 0190
     1         IFROM                                                    MOD 0200
      COMMON /LDATA/         XLCF(50)     , XCLL(50,12) , LOPT        , MOD 0210
     1         TOL         , IALLY        , IRTN                        MOD 0220
C                                                                       MOD 0230
      DATA KIN,KOUT,KAPE1,KAPE4/5,6,10,15/                              MOD 0240
C                                                                       MOD 0250
C                                                                       MOD 0260
      REWIND KAPE4                                                      MOD 0270
C                                                                       MOD 0280
C       CONTROL OPTIONS:                                                MOD 0290
C                         IF: LOPT=1, CHANNEL LOSSES WILL BE CONSIDERED MOD 0300
C                             IOTT=1, ECHO PRINT OF INPUT DATA          MOD 0310
C                             ISUM=1, SUMMARY OUTPUT                    MOD 0320
C                             IALLY=1, INPUT PRIORITY FOR EACH YEAR     MOD 0330
C                             IRTN=1, RETURN FLOW WILL BE CALCULATED    MOD 0340
C                                                                       MOD 0350
      READ (KIN,100) LOPT,IOTT,ISUM,IALLY,IRTN                          MOD 0360
  100 FORMAT (15X,5I5)                                                  MOD 0370
C                                                                       MOD 0380
C                               STEP 02                                 MOD 0390
C                               CALL INPUT AND OUTPUT SUBROUTINES       MOD 0400
C                               TO READ AND PRINT INPUT VARIABLES       MOD 0410
C                                                                       MOD 0420
      CALL CARDS                                                        MOD 0430
      IF (IOTT.EQ.1) CALL OUT1                                          MOD 0440
C                                                                       MOD 0450
C                                                                       MOD 0460
C                               STEP 03                                 MOD 0470
C                               BUILD NETWORK AND OPERATE SYSTEM        MOD 0480
C                                                                       MOD 0490
      CALL SETNET                                                       MOD 0500
      CALL OPRATE                                                       MOD 0510
C                                                                       MOD 0520
C                               STEP 04                                 MOD 0530
C                               CALL SUMMARIES PRINT ROUTINES           MOD 0540
```

```
        C                                                                    MOD 0550
              IF (ISUM.EQ.1) CALL OUT3                                       MOD 0560
        C                                                                    MOD 0570
              REWIND KAPE4                                                   MOD 0580
              END                                                            MOD 0590
SUBROUTINE ADJUST     73/73    OPT=2 TRACE                  FTN 4.6+452        79/05/10. 13.11.59

              SUBROUTINE ADJUST (IY,IQUIT,ICNT)                              ADJ 0010
              INTEGER             TOTLS                                      ADJ 0020
              INTEGER             RCAP        , RMIN       , FSTART     ,    ADJ 0030
             1        CMAXU     , ACTAB       , DEM        , DEMR       ,    ADJ 0040
             2        OPRP      , SP                                         ADJ 0050
              COMMON /CONTRL/     KIN         , KOUT       , KAPE1      ,    ADJ 0060
             1        KAPE4                                                  ADJ 0070
              COMMON /IPRNT/      IPRNT       , IYLD       , ITOY       ,    ADJ 0080
             1        IFROM                                                  ADJ 0090
              COMMON /PARM/       NJ          , NRES       , NJUNC      ,    ADJ 0100
             1        NL        , NC          , NYEAR      , ND         ,    ADJ 0110
             2        NS        , IYEAR       , IMN        , TITLE(20)  ,    ADJ 0120
             3        NR        , NPAIRS                                     ADJ 0130
              COMMON /PRNT/       ICAP(40,12,13)           , TOTLS(40,20,12) ADJ 0140
              COMMON /RESU/       RNAME(40,2) , RCAP(40)   , RMIN(40)   ,    ADJ 0150
             1        FSTART(40)  , ACTAB(10,18,2)         , OPRR(20,10,12), ADJ 0160
             2        OPRP(20,10) , SP(10)    , DEM(40)    , DEMD(40,12) ,   ADJ 0170
             3        EVAP(10,12) , U(40,12)  , IMP(2)     , DIMP(2,12,20),  ADJ 0180
             4        DEMR(40,20) , IMPRT(2,20)                              ADJ 0190
              COMMON /CONFAC/     AVRGLO      , AVRGHI     , CONFLO     ,    ADJ 0200
             1        CONDEM    , CONINF      , CPCT       , NSRS       ,    ADJ 0210
             2        LRULE     , JESVOL(10)                                 ADJ 0220
              IF (ICNT.EQ.0) WRITE (KOUT,100) TITLE,IYLD,(RNAME(IYLD,I),I = 1,2)ADJ 0230
          100 FORMAT (1H1//20X,20A4//10X,34HDETERMINE FIRM YIELD OF RESERVOIR ,IADJ 0240
             12,2X,2A4//10X,9HITERATION,2X,4HYEAR,2X,10HOLD DEMAND,2X,10H  SHORTADJ 0250
             2AGE,2X,10HNEW DEMAND,2X,20HSHORT./DEMAND RATIO )               ADJ 0260
              ISHTA = 0                                                      ADJ 0270
              JN = IYLD                                                      ADJ 0280
              IYD = 1                                                        ADJ 0290
        C                                                                    ADJ 0300
        C                           STEP 01                                  ADJ 0310
        C                           DETERMINE GREATEST YEARLY SHORTAGE       ADJ 0320
        C                           AND YEAR INCURRED                        ADJ 0330
        C                                                                    ADJ 0340
              PCT = 0.0                                                      ADJ 0350
              DO 110 IKY = 1,NYEAR                                           ADJ 0360
                 ITSHRT = 0                                                  ADJ 0370
                 ITSHRT = TOTLS(JN,IKY,8)                                    ADJ 0380
                 IF (ISHTA.GT.ITSHRT) GO TO 110                              ADJ 0390
                 IYD = IKY                                                   ADJ 0400
                 ISHTA = ITSHRT                                              ADJ 0410
        C                                                                    ADJ 0420
        C                           STEP 02                                  ADJ 0430
        C                           IF SHORTAGE IS ZERO INCREMENT DEMAND     ADJ 0440
        C                           BY 10 PERCENT                            ADJ 0450
        C                                                                    ADJ 0460
          110 CONTINUE                                                       ADJ 0470
              IF (ISHTA.EQ.0) NUDMD = FLOAT(DEM(JN)) * 1.1                   ADJ 0480
        C                                                                    ADJ 0490
```

```
C                                  STEP 03                                 ADJ 0500
C                                  IF SHORTAGE GREATER THAN 0, DECREASE    ADJ 0510
C                                  ANNUAL DEMAND BY THE RATIO SHORTAGES/YEARSADJ 0520
C                                                                          ADJ 0530
      IF (ISHTA.EQ.0) GO TO 120                                            ADJ 0540
      PCT = FLOAT(ISHTA)/FLOAT(DEM(JN))                                    ADJ 0550
      IF (PCT.LE.CPCT) IQUIT = 0                                           ADJ 0560
      IF (PCT.LE.0.01) IQUIT = 0                                           ADJ 0570
      NUDMD = DEM(JN) - (ISHTA * PCT * 100.0)/IYD                          ADJ 0580
      NUDMD = DEM(JN) - ISHTA/IYD                                          ADJ 0590
C                                                                          ADJ 0600


C                                  STEP 04                                 ADJ 0610
C                                  IF ITCRATIONS GREATER THAN 20 OR SHORTAGE/ADJ 0620
C                                  LESS THAN CPCT- QUIT-                   ADJ 0630
C                                                                          ADJ 0640
  120 CONTINUE                                                             ADJ 0650
      ICNT = ICNT + 1                                                      ADJ 0660
      IF (ICNT.GT.20) IQUIT = 0                                            ADJ 0670
      WRITE (KOUT,130) ICNT,IYD,DEM(JN),ISHTA,NUDMD,PCT                    ADJ 0680
  130 FORMAT (14X,I2,6X,I3,3I12,F12.3)                                     ADJ 0690
      DEM(JN) = NUDMD                                                      ADJ 0700
      RETURN                                                               ADJ 0710
C                                                                          ADJ 0720
      END                                                                  ADJ 0730
SUBROUTINE AREA      73/73   OPT=2 TRACE                  FTN 4.6+452       79/05/10. 13.11.59

      SUBROUTINE AREA (X,Y,J)                                              ARE 0010
      INTEGER              RCAP        , RMIN         , FSTART       ,     ARE 0020
     1        CMAXU       , ACTAB       , DEM          , DEMR         ,     ARE 0030
     2        OPRP        , SP                                             ARE 0040
      INTEGER              START       , STEND        , USE          ,     ARE 0050
     1        UREG        , ISHTM       , ISPIL        , AREAX        ,     ARE 0060
     2        EVPT        , AMAX        , AMIN                             ARE 0070
      INTEGER              X           , Y                                 ARE 0080
      COMMON /CONTRL/      KIN         , KOUT         , KAPE1        ,     ARE 0090
     1        KAPE4                                                        ARE 0100
      COMMON /IPRNT/       IPRNT       , IYLD         , ITOY         ,     ARE 0110
     1        IFROM                                                        ARE 0120
      COMMON /PARM/        NJ          , NRES         , NJUNC        ,     ARE 0130
     1        NL          , NC          , NYEAR        , ND           ,     ARE 0140
     2        NS          , IYEAR       , IMN          , TITLE(20)    ,     ARE 0150
     3        NR          , NPAIRS                                         ARE 0160
      COMMON /RESV/        RNAME(40,2) , RCAP(40)     , RMIN(40)     ,     ARE 0170
     1        FSTART(40)  , ACTAB(10,18,2)             , OPRR(20,10,12),   ARE 0180
     2        OPRP(20,10) , SP(10)      , DEM(40)      , DEMD(40,12)  ,    ARE 0190
     3        EVAP(10,12) , U(40,12)    , IMP(2)       , DIMP(2,12,20),    ARE 0200
     4        DEMR(40,20) , IMPRT(2,20)                                    ARE 0210
      COMMON /WRKD/        START(40)   , STEND(40)    , USE(40)      ,     ARE 0220
     1        UREG(40)    , ISHTM(40,13), ISPIL(40,13), AREAX(40)    ,     ARE 0230
     2        EVPT(40)    , AMAX(40)    , AMIN(40)     , IAREA(40)         ARE 0240
      ROFF = .499                                                          ARE 0250
C                                                                          ARE 0260
C                                  STEP 01                                 ARE 0270
C                                  BASED ON RES VOL DETERMINE AREA         ARE 0280
```

```
      C                                                                     ARE 0290
            DO 100 I = 1,NPAIRS                                             ARE 0300
               IF (X - ACTAB(J,I,2)) 120,110,100                            ARE 0310
        100 CONTINUE                                                        ARE 0320
      C                                                                     ARE 0330
        110 Y = ACTAB(J,I,1)                                                ARE 0340
            GO TO 130                                                       ARE 0350
      C                                                                     ARE 0360
      C                         STEP 02                                     ARE 0370
      C                         IF VOL BETWEEN POINTS INTERPOLATE           ARE 0380
      C                         FOR AREA                                    ARE 0390
      C                                                                     ARE 0400
        120 X1 = ACTAB(J,I,2) - ACTAB(J,I - 1,2)                            ARE 0410
            Y1 = ACTAB(J,I,1) - ACTAB(J,I - 1,1)                            ARE 0420
            X2 = X - ACTAB(J,I - 1,2)                                       ARE 0430
            X3 = (X2/X1) * Y1                                               ARE 0440
            Y = ACTAB(J,I - 1,1) + IFIX(X3 + ROFF)                          ARE 0450
        130 CONTINUE                                                        ARE 0460
            RETURN                                                          ARE 0470
      C                                                                     ARE 0480
            END                                                             ARE 0490
SUBROUTINE CHANLS     73/73   OPT=2 TRACE                    FTN 4.6+452       79/05/10. 13.11.59

            SUBROUTINE CHANLS (MON,ITER,IDONE,L7,LB,MAXD,IV)                CHN 0010
            INTEGER               HI          , FLOW          , USE          CHN 0020
            COMMON /CONTRL/       KIN         , KOUT          , KAPE1    ,   CHN 0030
           1        KAPE4                                                   CHN 0040
            COMMON /PARM/         NJ          , NRES          , NJUNC    ,   CHN 0050
           1        NL          , NC          , NYEAR         , ND       ,   CHN 0060
           2        NS          , IYEAR       , IMN           , TITLE(20) ,  CHN 0070
           3        NR          , NPAIRS                                    CHN 0080
            COMMON /WRKD/         START(40)   , STEND(40)     , USE(40)  ,   CHN 0090
           1        UREG(40)    , ISHTM(40,13), ISPIL(40,13), AREAX(40) ,   CHN 0100
           2        EVPT(40)    , AMAX(40)    , AMIN(40)      , IAREA(40)    CHN 0110
            COMMON /LINK/         LNODE(50,2) , CMAX(50)      , CMIN(50)     CHN 0120
            COMMON /LNKFLW/       LNKFLO(50,13)               , LNKAFL(50,13), CHN 0130
           1        LNKMX(50,13)                                            CHN 0140
            COMMON /ADATA/        NARC        , NMAX          , FESIBL   ,   CHN 0150
           1        NTIME       , NT(500)     , NF(500)       , HI(500)  ,   CHN 0160
           2        LO(500)     , FLOW(500)   , COST(500)                   CHN 0170
            COMMON /LDATA/        XLCF(50)    , XCLL(50,12) , LOPT       ,   CHN 0180
           1        TOL         , IALLY                                     CHN 0190
            COMMON /CONFAC/       AVRGLO      , AVRGHI        , CONFLO   ,   CHN 0200
           1        CONDEM      , CONIMF      , CPCT          , MSRS     ,   CHN 0210
           2        LRULE       , JESVOL(10)                                CHN 0220
            DIMENSION             IUSE(40)                                  CHN 0230
            DATA TOL,ITERMX/1.0,10/                                         CHN 0240
            IDONE = 0                                                       CHN 0250
            TDIFF = 0.0                                                     CHN 0260
            ITER = ITER + 1                                                 CHN 0270
            TLOSS1 = 0.0                                                    CHN 0280
            IF (ITER.EQ.1) TLOSS2 = 0.0                                     CHN 0290
            DO 100 J = 1,NJ                                                 CHN 0300
               IUSE(J) = 0                                                  CHN 0310
        100 CONTINUE                                                        CHN 0320
            DO 110 L = 1,NL                                                 CHN 0330
```

```
                 LNKFLO(L,MON) = FLOW(L)/CONFLO                           CHN 0340
                 XCLL(L,MON) = FLOAT(LNKFLO(L,MON)) * XLCF(L)             CHN 0350
                 NN = LNODE(L,2)                                          CHN 0360
                 IUSE(NN) = IUSE(NN) + IFIX(XCLL(L,MON))                  CHN 0370
                 TLOSS1 = TLOSS1 + XCLL(L,MON)                            CHN 0380
         110 CONTINUE                                                     CHN 0390
             DO 120 J = 1,NJ                                              CHN 0400
                 IUSE(J) = IUSE(J) + USE(J)                               CHN 0410
         120 CONTINUE                                                     CHN 0420
             TDIFF = ABS(TLOSS1 - TLOSS2)                                 CHN 0430
             IF (TDIFF.LE.TOL) GO TO 160                                  CHN 0440
             IF (ITER.GE.ITERMX) GO TO 140                                CHN 0450
             TLOSS2 = TLOSS1                                              CHN 0460
             MAXD = 0                                                     CHN 0470
             DO 130 L = L7,L8                                             CHN 0480
                 JN = NF(L)                                               CHN 0490
                 HI(L) = IUSE(JN)                                         CHN 0500
                 MAXD = MAXD + HI(L)                                      CHN 0510
         130 CONTINUE                                                     CHN 0520
             GO TO 170                                                    CHN 0530
         140 WRITE (KOUT,150) MON,IY                                      CHN 0540
         150 FORMAT (1H0,70H****** CHANNEL LOSS FUNCTION WOULD NOT CONVERGE TO CHN 0550
            1SPECIFIED TOLERANCE,2X,7HMONTH =,I2,2X,6HYEAR =,I3)          CHN 0560
         160 IDONE = 1                                                    CHN 0570
         170 DO 180 L = 1,NL                                              CHN 0580
                 LNKFLO(L,MON) = 0                                        CHN 0590
         180 CONTINUE                                                     CHN 0600


             RETURN                                                       CHN 0610
             END                                                          CHN 0620
 SUBROUTINE CARDS       73/73   OPT=2 TRACE               FTN 4.6+452       79/05/10. 13.11.59

             SUBROUTINE CARDS                                             CRD 0010
             INTEGER               RCAP         , RMIN         , FSTART     ,  CRD 0020
            1          CMAXU     , ACTAB        , DEM          , DEMR       ,  CRD 0030
            2          OPRP      , SP           , CMAX         , CMIN       ,  CRD 0040
            3          COST                                                   CRD 0050
             COMMON /CONTRL/       KIN          , KOUT         , KAPE1      ,  CRD 0060
            1          KAPE4                                                  CRD 0070
             COMMON /IPRNT/        IPRNT        , IYLD         , ITOY       ,  CRD 0080
            1          IFROM                                                  CRD 0090
             COMMON /PARM/         NJ           , NRES         , NJUNC      ,  CRD 0100
            1          NL        , NC           , NYEAR        , ND         ,  CRD 0110
            2          NS        , IYEAR        , INN          , TITLE(20)  ,  CRD 0120
            3          NR        , NPAIRS                                     CRD 0130
             COMMON /RESU/         RNAME(40,2) , RCAP(40)     , RMIN(40)   ,  CRD 0140
            1          FSTART(40) , ACTAB(10,18,2)             , OPRR(20,10,12), CRD 0150
            2          OPRP(20,10) , SP(10)       , DEM(40)      , DEMD(40,12) , CRD 0160
            3          EVAP(10,12) , U(40,12)     , IMP(2)       , DIMP(2,12,20), CRD 0170
            4          DEMR(40,20) , IMPRT(2,20)                              CRD 0180
             COMMON /LINK/         LNODE(50,2) , CMAX(50)     , CMIN(50)      CRD 0190
             COMMON /CONFAC/       AVRGLO       , AVRGHI       , CONFLO     ,  CRD 0200
            1          CONDEM    , CONINF       , CPCT         , NSRS       ,  CRD 0210
            2          LRULE     , JESVOL(10)                                 CRD 0220
             COMMON /LDATA/        XLCF(50)     , XCLL(50,12) , LOPT       ,  CRD 0230
```

```
     1          TOL          , IALLY        , IRTN                             CRD 0240
      COMMON /R1/              NEQU         , NLAGS       , A(10,15)     ,     CRD 0250
     1          NDNEQU(10)   , IRTFF(10,15), JRTFT(10)    , IRTF(10,240),     CRD 0260
     2          IDIVL(10,15), IRTL(10,15)                                      CRD 0270
      COMMON /D/               NDMD(40)     , IDSTRM(40)  , ITHRU(40)    ,     CRD 0280
     1          NVARL        , LVAR(50)     , CMAXU(50,12)                     CRD 0290
      COMMON /ADATA/           NARC         , NMAX        , FESIBL       ,     CRD 0300
     1          NTIME        , NT(500)      , NF(500)     , HI(500)      ,     CRD 0310
     2          LO(500)      , FLOW(500)    , COST(500)                        CRD 0320
      DO 110 J = 1,NJ                                                          CRD 0330
         DO 100 K = 1,20                                                       CRD 0340
            DEMR(J,K) = 99                                                     CRD 0350
            OPRP(K,J) = 99                                                     CRD 0360
  100    CONTINUE                                                              CRD 0370
         IDSTRM(J) = 0                                                         CRD 0380
  110 CONTINUE                                                                 CRD 0390
C                                                                              CRD 0400
C                               STEP 01                                        CRD 0410
C                               READ FILE A CARDS                              CRD 0420
C                                                                              CRD 0430
      READ (KIN,120) (TITLE(I),I = 1,20)                                       CRD 0440
      IF (EOF(KIN)) 520,130,520                                                CRD 0450
  120 FORMAT (20A4)                                                            CRD 0460
C                                                                              CRD 0470
  130 READ (KIN,140) NJ,NRES,NL,NR,NYEAR,ND,NS,IYEAR,IMN,IYLD,IFRM,ITOY,CRD 0480
     1KCT,CPCT                                                                 CRD 0490
  140 FORMAT (10X,12I5,4X,I1,F5.0)                                             CRD 0500
      IF (CPCT.LE.0.0) CPCT = 0.10                                             CRD 0510
C                                                                              CRD 0520
      IFROM = IFRM                                                             CRD 0530
      NC = NL - NR                                                             CRD 0540
C                                                                              CRD 0550
C                               STEP 02                                        CRD 0560
C                               READ FILE B CARDS                              CRD 0570
C                                                                              CRD 0580
      DO 150 I = 1,NJ                                                          CRD 0590
  150 READ (KIN,160) J,(RNAME(J,K),K = 1,2),RCAP(J),RMIN(J),FSTART(J)   CRD 0600
 SUBROUTINE CARDS       73/73   OPT=2 TRACE                    FTN 4.6+452       79/05/10. 13.11.59

  160 FORMAT (T11,I5,T1,2A4,T16,3I10)                                          CRD 0610
C                                                                              CRD 0620
C                               STEP 03                                        CRD 0630
C                               READ FILE C CARDS                              CRD 0640
C                                                                              CRD 0650
      READ (KIN,170) (SP(I),I = 1,NS)                                          CRD 0660
  170 FORMAT (10X,12I5)                                                        CRD 0670
C                                                                              CRD 0680
C                               STEP 04                                        CRD 0690
C                               READ FILE D CARDS                              CRD 0700
C                                                                              CRD 0710
      READ (KIN,180) NPAIRS                                                    CRD 0720
  180 FORMAT (10X,I5)                                                          CRD 0730
      DO 190 I = 1,NRES                                                        CRD 0740
  190 READ (KIN,200) J,((ACTAB(J,K,L),L = 1,2),K = 1,NPAIRS)                  CRD 0750
  200 FORMAT (10X,I5,6I10/(15X,6I10))                                          CRD 0760
C                                                                              CRD 0770
```

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C                                   STEP 05                              CRD 0780
C                                   READ FILE E CARDS                    CRD 0790
C                                                                        CRD 0800
      DO 230 I = 1,ND                                                    CRD 0810
         READ (KIN,210) J,IDSTRM(J),DEM(J),(DEMR(J,K),K = 1,3),(DEMD(J,KCRD 0820
     1   ),K = 1,12)                                                     CRD 0830
  210 FORMAT (7X,2I3,I8,3I3,12F4.0)                                      CRD 0840
         IF (IALLY.GT.0) READ (KIN,220) J,(DEMR(J,K),K = 1,NYEAR)        CRD 0850
  220 FORMAT (10X,11I5)                                                  CRD 0860
         NDMD(I) = J                                                     CRD 0870
  230 CONTINUE                                                           CRD 0880
C                                                                        CRD 0890
C                                   STEP 06                              CRD 0900
C                                   READ FILE F CARD                     CRD 0910
C                                                                        CRD 0920
      DO 270 I = 1,IMN                                                   CRD 0930
         READ (KIN,240) IMP(I)                                           CRD 0940
  240 FORMAT (10X,I5)                                                    CRD 0950
         DO 260 K = 1,NYEAR                                              CRD 0960
            READ (KIN,250) IMPRT(I,K),(DIMP(I,J,K),J = 1,12)             CRD 0970
  250 FORMAT (20X,I10,12F4.0)                                            CRD 0980
  260    CONTINUE                                                        CRD 0990
  270 CONTINUE                                                           CRD 1000
C                                                                        CRD 1010
C                                   STEP 06                              CRD 1020
C                                   READ FILE G CARDS                    CRD 1030
C                                                                        CRD 1040
      IF (IALLY.GT.0) GO TO 300                                          CRD 1050
C                                                                        CRD 1060
      READ (KIN,280) NSRS,(JESVOL(I),I = 1,NSRS)                         CRD 1070
  280 FORMAT (10X,14I5)                                                  CRD 1080
      READ (KIN,290) AVRGLO,AVRGHI                                       CRD 1090
  290 FORMAT (10X,2F10.0)                                                CRD 1100
C                                                                        CRD 1110
C                                   STEP 07                              CRD 1120
C                                   READ FILE H CARD                     CRD 1130
C                                                                        CRD 1140
  300 READ (KIN,310) CONFLO,CONINF,CONDEM                                CRD 1150
  310 FORMAT (10X,3F10.0)                                                CRD 1160
      IF (CONINF.LE.0.0) CONINF = 1.0                                    CRD 1170
      IF (CONDEM.LE.0.0) CONDEM = 1.0                                    CRD 1180
      IF (CONFLO.LE.0.0) CONFLO = 1.0                                    CRD 1190
C                                                                        CRD 1200
 SUBROUTINE CARDS       73/73   OPT=2 TRACE                  FTN 4.6+452        79/05/10. 13.11.59

C                                   STEP 08                              CRD 1210
C                                   READ FILE I CARDS                    CRD 1220
C                                                                        CRD 1230
      IF (IALLY) 320,320,350                                             CRD 1240
C                                                                        CRD 1250
  320 DO 330 K = 1,NRES                                                  CRD 1260
  330 READ (KIN,340) (J,OPRP(L,J),(OPRR(L,J,I),I = 1,12),L = 1,3)        CRD 1270
  340 FORMAT (10X,I5,10X,I5,12F4.0)                                      CRD 1280
C                                                                        CRD 1290
      GO TO 370                                                          CRD 1300
  350 DO 360 K = 1,NRES                                                  CRD 1310
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            DO 360 I = 1,NYEAR
               READ (KIN,340) J,OPRP(I,J),(OPRR(I,J,L),L = 1,12)                CRD 1320
        360 CONTINUE                                                            CRD 1330
                                                                                CRD 1340
      C                                                                         CRD 1350
      C                             STEP 09                                     CRD 1360
      C                             READ FILE J CARDS                           CRD 1370
      C                                                                         CRD 1380
        370 READ (KIN,380) NUARL                                                CRD 1390
        380 FORMAT (10X,I5)                                                     CRD 1400
            IF (NUARL.EQ.0) GO TO 420                                           CRD 1410
            DO 410 LL = 1,NUARL                                                 CRD 1420
               READ (KIN,390) L,(LNODE(L,I),I = 1,2),CMIN(L),XLCF(L),COST(L)    CRD 1430
        390 FORMAT (10X,3I5,10X,I10,F10.0,I5)                                   CRD 1440
               LVAR(LL) = L                                                     CRD 1450
               READ (KIN,400) (CMAXU(L,I),I = 1,12)                             CRD 1460
        400 FORMAT (8X,12I6)                                                    CRD 1470
        410 CONTINUE                                                            CRD 1480
        420 LRM = NL - NUARL                                                    CRD 1490
            IF (LRM.EQ.0) GO TO 450                                             CRD 1500
            DO 440 LL = 1,LRM                                                   CRD 1510
               READ (KIN,430) L,(LNODE(L,I),I = 1,2),CMAX(L),CMIN(L),XLCF(L),CCRD 1520
           1   OST(L)                                                           CRD 1530
        430 FORMAT (10X,3I5,2I10,F10.0,I5)                                      CRD 1540
        440 CONTINUE                                                            CRD 1550
        450 IF (IRTN.EQ.0) RETURN                                               CRD 1560
            READ (KIN,460) MEQU,NLAGS                                           CRD 1570
        460 FORMAT (10X,2I5)                                                    CRD 1580
            LAGS = 2 * NLAGS + 2                                                CRD 1590
            DO 510 I = 1,MEQU                                                   CRD 1600
               READ (KIN,470) (A(I,J),J = 1,LAGS)                               CRD 1610
        470 FORMAT (8F10.0)                                                     CRD 1620
               READ (KIN,480) NDNEQU(I),JRTFT(I)                                CRD 1630
        480 FORMAT (5X,2I5)                                                     CRD 1640
               IDUMB = NDNEQU(I)                                                CRD 1650
               READ (KIN,490) (IRTFF(I,J),J = 1,IDUMB)                          CRD 1660
        490 FORMAT (5X,15I5)                                                    CRD 1670
               READ (KIN,500) ((IDIVL(I,J),IRTL(I,J)),J = 1,NLAGS)              CRD 1680
        500 FORMAT (5X,12I6)                                                    CRD 1690
        510 CONTINUE                                                            CRD 1700
            RETURN                                                              CRD 1710
        520 CALL EXIT                                                           CRD 1720
            STOP                                                                CRD 1730
      C                                                                         CRD 1740
            END                                                                 CRD 1750
  SUBROUTINE DATA1      73/73    OPT=2 TRACE                   FTN 4.6+452       79/05/10. 13.11.59

            SUBROUTINE DATA1                                                    DAT 0010
            INTEGER            RCAP         , RMIN        , FSTART       ,      DAT 0020
           1        CMAXU    , ACTAB        , DEM         , DEMR         ,      DAT 0030
           2        OPRP     , SP           , CMAX        , CMIN                DAT 0040
            INTEGER            START        , UREG                              DAT 0050
            COMMON /CONTRL/    KIN          , KOUT        , KAPE1        ,      DAT 0060
           1        KAPE4                                                       DAT 0070
            COMMON /IPRNT/     IPRNT        , IYLD        , ITOY         ,      DAT 0080
           1        IFROM                                                       DAT 0090
            COMMON /PARM/      NJ           , NRES        , NJUNC        ,      DAT 0100
```

```
     1        ML          , NC          , MYEAR       , ND          ,   DAT 0110
     2        MS          , IYEAR       , IMN         , TITLE(20)   ,   DAT 0120
     3        MR          , NPAIRS                                      DAT 0130
      COMMON /WRKD/         START(40)   , STEND(40)   , USE(40)     ,   DAT 0140
     1        UREG(40)    , ISHTM(40,13), ISPIL(40,13), AREAX(40)   ,   DAT 0150
     2        EVPT(40)    , AMAX(40)    , AMIN(40)    , IAREA(40)       DAT 0160
      COMMON /PRNT/         ICAP(40,12,13)            , TOTLS(40,20,12) DAT 0170
      COMMON /RESV/         RNAME(40,2) , RCAP(40)    , RMIN(40)    ,   DAT 0180
     1        FSTART(40)  , ACTAB(10,18,2)            , OPRR(20,10,12), DAT 0190
     2        OPRP(20,10) , SP(10)      , DEM(40)     , DEMD(40,12) ,   DAT 0200
     3        EVAP(10,12) , U(40,12)    , IMP(2)      , DIMP(2,12,20),  DAT 0210
     4        DEMR(40,20) , IMPRT(2,20)                                 DAT 0220
      COMMON /LINK/         LNODE(50,2) , CMAX(50)    , CMIN(50)        DAT 0230
      COMMON /CONFAC/       AVRGLO      , AVRGHI      , CONFLO      ,   DAT 0240
     1        CONDEM      , CONINF      , CPCT        , NSRS        ,   DAT 0250
     2        LRULE       , JESVOL(10)                                  DAT 0260
      COMMON /DEMON/        DEMON(40,13)                                DAT 0270
C                                                                       DAT 0280
C                             STEP 03                                   DAT 0290
C                             READ ONE YEAR OF DATA (INFLOW,DEMAND,EVAP)DAT 0300
C                             FOR NODES IN SYSTEM                       DAT 0310
C                                                                       DAT 0320
      ENTRY DATA2                                                       DAT 0330
      READ (KAPE1) ((U(J,K),K = 1,12),J = 1,NJ),((DEMON(J,K),K = 1,12),JDAT 0340
     1 = 1,NJ),((EVAP(J,K),K = 1,12),J = 1,NRES)                        DAT 0350
      DO 100 J = 1,NJ                                                   DAT 0360
      DO 100 K = 1,12                                                   DAT 0370
C                                                                       DAT 0380
C                             STEP 04                                   DAT 0390
C                             MODIFY INFLOWS AND DEMANDS BY MULTIPLIER  DAT 0400
C                             IF REQUIRED                               DAT 0410
C                                                                       DAT 0420
         U(J,K) = U(J,K) * COMINF                                       DAT 0430
         DEMON(J,K) = DEMON(J,K) * CONDEM                               DAT 0440
  100 CONTINUE                                                          DAT 0450
      RETURN                                                            DAT 0460
C                                                                       DAT 0470
C                                                                       DAT 0480
      ENTRY RULE                                                        DAT 0490
      TSUBMX = 0.0                                                      DAT 0500
      UTRSYS = 0.0                                                      DAT 0510
C                                                                       DAT 0520
C                             STEP 05                                   DAT 0530
C                             DETERMINE MAX AMOUNT OF STORAGE AND AVAILADAT 0540
C                             IN SUBSYSTEM                              DAT 0550
C                                                                       DAT 0560
      DO 110 KN = 1,NSRS                                                DAT 0570
         JN = JESVOL(KN)                                                DAT 0580
         TSUBMX = TSUBMX + RCAP(JN)                                     DAT 0590
         UTRSYS = UTRSYS + START(JN) + UREG(JN)                         DAT 0600
SUBROUTINE DATA1      73/73   OPT=2 TRACE                   FTN 4.6+452       79/05/10. 13.11.59

  110 CONTINUE                                                          DAT 0610
C                                                                       DAT 0620
C                             STEP 06                                   DAT 0630
C                             DETERMINE RULE ACCORDING TO SUB-SYSTEM STADAT 0640
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      C                           AVRG=1,DRY=2,WET=3                 DAT 0650
      C                                                              DAT 0660
            LRULE = 1                                                DAT 0670
            XMAX = TSUBMX * AVRGHI                                   DAT 0680
            XMIN = TSUBMX * AVRGLO                                   DAT 0690
            IF (WTRSYS.LT.XMIN) LRULE = 2                            DAT 0700
            IF (WTRSYS.GT.XMAX) LRULE = 3                            DAT 0710
            IF (AVRGLO.LE.0.0) LRULE = 1                             DAT 0720
            IF (AVRGHI.LE.0.0) LRULE = 1                             DAT 0730
            RETURN                                                   DAT 0740
      C                                                              DAT 0750
            END                                                      DAT 0760
 SUBROUTINE OPRATE     73/73   OPT=2 TRACE           FTN 4.6+452     79/05/10. 13.11.59

            SUBROUTINE OPRATE                                        OPR 0010
            LOGICAL FESIBL                                           OPR 0020
            INTEGER              TOTLS      , STVG       , STEMP     OPR 0030
            INTEGER              HI         , COST       , FLOW      OPR 0040
            INTEGER              START      , STEND      , USE      , OPR 0050
           1        UREG       , ISHTM      , ISPIL      , AREAX    , OPR 0060
           2        EVPT       , AMAX       , AMIN                  , OPR 0070
            INTEGER              RCAP       , RMIN       , FSTART   , OPR 0080
           1        CMAXU      , ACTAB      , DEM        , DEMR     , OPR 0090
           2        OPRP       , SP         , CMAX       , CMIN     , OPR 0100
            COMMON /CONTRL/      KIN        , KOUT       , KAPE1    , OPR 0110
           1        KAPE4                                            OPR 0120
            COMMON /IPRNT/       IPRNT      , IYLD       , ITOY     , OPR 0130
           1        IFROM                                            OPR 0140
            COMMON /PARM/        NJ         , NRES       , NJUNC    , OPR 0150
           1        NL         , NC         , NYEAR      , ND       , OPR 0160
           2        NS         , IYEAR      , IMN        , TITLE(20) , OPR 0170
           3        NR         , NPAIRS                              OPR 0180
            COMMON /PRNT/        ICAP(40,12,13)          , TOTLS(40,20,12) OPR 0190
            COMMON /WRKD/        START(40)  , STEND(40)  , USE(40)  , OPR 0200
           1        UREG(40)   , ISHTM(40,13), ISPIL(40,13), AREAX(40) , OPR 0210
           2        EVPT(40)   , AMAX(40)   , AMIN(40)   , IAREA(40) OPR 0220
            COMMON /RESV/        RNAME(40,2) , RCAP(40)  , RMIN(40) , OPR 0230
           1        FSTART(40) , ACTAB(10,18,2)          , OPRR(20,10,12), OPR 0240
           2        OPRP(20,10) , SP(10)    , DEM(40)    , DEMD(40,12) , OPR 0250
           3        EVAP(10,12) , U(40,12)  , IMP(2)     , DIMP(2,12,20), OPR 0260
           4        DEMR(40,20) , IMPRT(2,20)                        OPR 0270
            COMMON /LINK/        LNODE(50,2) , CMAX(50)  , CMIN(50)  OPR 0280
            COMMON /LNKFLW/      LNKFLO(50,13)           , LNKAFL(50,13), OPR 0290
           1        LNKMX(50,13)                                     OPR 0300
            COMMON /ADATA/       NARC       , NMAX       , FESIBL   , OPR 0310
           1        NTIME      , NT(500)    , NF(500)    , HI(500)  , OPR 0320
           2        LO(500)    , FLOW(500)  , COST(500)              OPR 0330
            COMMON /CONFAC/      AVRGLO     , AVRGHI     , CONFLO   , OPR 0340
           1        CONDEM     , CONINF     , CPCT       , NSRS     , OPR 0350
           2        LRULE      , JESVOL(10)                          OPR 0360
            COMMON /DEMON/       DEMON(40,13)                        OPR 0370
            COMMON /LDATA/       XLCF(50)   , XCLL(50,12) , LOPT    , OPR 0380
           1        TOL        , IALLY      , IRTN                   OPR 0390
            COMMON /R1/          NEQU       , NLAGS      , A(10,15) , OPR 0400
           1        NONEQU(10) , IRTFF(10,15), JRTFT(10)  , IRTF(10,240), OPR 0410
           2        IDIVL(10,15), IRTL(10,15)                        OPR 0420
```

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C                                                                      OPR 0430
C                                                                      OPR 0440
      COMMON /D/          NDMD(40)    , IDSTRM(40)  , ITHRU(40)   ,    OPR 0450
     1         NVARL      , LVAR(50)    , CMAXV(50,12)                 OPR 0460
C                                                                      OPR 0470
C                                                                      OPR 0480
      DIMENSION           IA(70)      , IB(70)      , IC(70)           OPR 0490
C                                                                      OPR 0500
C                                                                      OPR 0510
C                          STEP 01                                     OPR 0520
C                          ZERO OUT ARRAYS AND INITIALIZE              OPR 0530
C                          VARIABLES                                   OPR 0540
C                                                                      OPR 0550
  100 NR = NL - NC                                                     OPR 0560
      ROFF = 0.499                                                     OPR 0570
      ITOT = 0                                                         OPR 0580
      IQUIT = 0                                                        OPR 0590
      DO 110 L = 1,NL                                                  OPR 0600
SUBROUTINE OPRATE     73/73   OPT=2 TRACE               FTN 4.6+452       79/05/10. 13.11.59

      DO 110 I = 1,13                                                  OPR 0610
         LNKFLO(L,I) = 0                                               OPR 0620
         LNKAFL(L,I) = 0                                               OPR 0630
         LNKMX(L,I) = 0                                                OPR 0640
  110 CONTINUE                                                         OPR 0650
      DO 120 J = 1,NJ                                                  OPR 0660
         STEND(J) = 0                                                  OPR 0670
         ITOT = ITOT + RCAP(J)                                         OPR 0680
      DO 120 N = 1,12                                                  OPR 0690
         ISHTR(J,N) = 0                                                OPR 0700
         ISPIL(J,N) = 0                                                OPR 0710
  120 CONTINUE                                                         OPR 0720
C                                                                      OPR 0730
C                          STEP 02                                     OPR 0740
C                          SETS BOUND ON ARCS ; AND UPPER AND          OPR 0750
C                          LOWER CONSTRAINTS ON PHYSICAL LINKS         OPR 0760
C     SET LIMITS ON ARCS                                               OPR 0770
C                                                                      OPR 0780
      L1 = NL + 1                                                      OPR 0790
      L2 = NL + NJ                                                     OPR 0800
      L3 = L2 + 1                                                      OPR 0810
      L4 = L2 + NJ                                                     OPR 0820
      L5 = L4 + 1                                                      OPR 0830
      L6 = L4 + NJ                                                     OPR 0840
      L7 = L6 + 1                                                      OPR 0850
      L8 = L6 + NJ                                                     OPR 0860
      L9 = L8 + 1                                                      OPR 0870
      LA = L8 + NRES                                                   OPR 0880
      LB = NR + 1                                                      OPR 0890
C                                                                      OPR 0900
      DO 130 L = 1,NARC                                                OPR 0910
         HI(L) = 0                                                     OPR 0920
         LO(L) = 0                                                     OPR 0930
         FLOW(L) = 0                                                   OPR 0940
  130 CONTINUE                                                         OPR 0950
C                                                                      OPR 0960
```

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      C     SET HI + LO ON LINKS                                             OPR 0970
      C                                                                      OPR 0980
            DO 140 L = 1,NL                                                  OPR 0990
               LO(L) = CMIN(L) * CONFLO                                      OPR 1000
               IF (NUARL.EQ.0) HI(L) = CMAX(L) * CONFLO                      OPR 1010
        140 CONTINUE                                                         OPR 1020
      C                                                                      OPR 1030
      C                                                                      OPR 1040
      C                               STEP 03                                OPR 1050
      C                               PRICE RIVER REACHES TO 1 AND CANALS TO 2 OPR 1060
      C                                                                      OPR 1070
            DO 150 L = 1,NL                                                  OPR 1080
               IF (COST(L).NE.0) GO TO 150                                   OPR 1090
               COST(L) = 1                                                   OPR 1100
               IF (L.GT.NR) COST(L) = 2                                      OPR 1110
        150 CONTINUE                                                         OPR 1120
      C                                                                      OPR 1130
      C                                                                      OPR 1140
      C                               STEP 04                                OPR 1150
      C                               IF FIRM YIELD RUN - SET SWITCH         OPR 1160
      C                                                                      OPR 1170
      C     SET SWITCHES AND CONTROL FOR YIELD RUN                           OPR 1180
      C                                                                      OPR 1190
            IF (IYLD.EQ.0) GO TO 160                                         OPR 1200
   SUBROUTINE OPRATE     73/73   OPT=2 TRACE                  FTN 4.6+452       79/05/10. 13.11.59

            IQUIT = 1                                                        OPR 1210
        160 REWIND KAPE1                                                     OPR 1220
      C                                                                      OPR 1230
            ISTRT = 1                                                        OPR 1240
            NYR = NYEAR                                                      OPR 1250
      C                                                                      OPR 1260
      C                                                                      OPR 1270
      C                               STEP 06                                OPR 1280
      C                               NTIME=1 FOR FIRST SOLUTION             OPR 1290
      C                               BEGIN YEARLY LOOP                      OPR 1300
      C                                                                      OPR 1310
      C                                                                      OPR 1320
      C     START YEARLY LOOP                                                OPR 1330
      C                                                                      OPR 1340
      C                                                                      OPR 1350
            IY = ISTRT                                                       OPR 1360
        170 IF (LOPT) 200,200,180                                            OPR 1370
        180 DO 190 L = 1,NL                                                  OPR 1380
            DO 190 M = 1,12                                                  OPR 1390
               XCLL(L,M) = 0.0                                               OPR 1400
        190 CONTINUE                                                         OPR 1410
        200 CONTINUE                                                         OPR 1420
            DO 210 J = 1,NJ                                                  OPR 1430
            DO 210 I = 1,12                                                  OPR 1440
               TOTLS(J,IY,I) = 0                                             OPR 1450
        210 CONTINUE                                                         OPR 1460
      C                                                                      OPR 1470
      C                               STEP 07                                OPR 1480
      C                               READ MONTHLY DATA FOR ONE YEAR         OPR 1490
      C                                                                      OPR 1500
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      CALL DATA2                                                        OPR 1510
C                                                                       OPR 1520
      JFLAG = 0                                                         OPR 1530
      DO 220 J = 1,NJ                                                   OPR 1540
         IF (IDSTRM(J).EQ.0) GO TO 220                                  OPR 1550
         JFLAG = 1                                                      OPR 1560
  220 CONTINUE                                                          OPR 1570
C                                                                       OPR 1580
C                                                                       OPR 1590
C                                   STEP 08                             OPR 1600
C                                   SET BEGIN STORAGES TO STARTING      OPR 1610
C                                                                       OPR 1620
      IF (IY.GT.1) GO TO 240                                            OPR 1630
      DO 230 J = 1,NRES                                                 OPR 1640
         STEND(J) = FSTART(J)                                           OPR 1650
  230 CONTINUE                                                          OPR 1660
C                                                                       OPR 1670
C                                   STEP 09                             OPR 1680
C                                   BEGIN MONTHLY LOOP                  OPR 1690
C     ENTER SEASONAL LOOP                                               OPR 1700
C                                                                       OPR 1710
  240 DO 750 MON = 1,12                                                 OPR 1720
         JMONY = ((IY - 1) * 12) + MON                                  OPR 1730
         IF (NVARL.EQ.0) GO TO 280                                      OPR 1740
         DO 270 L = 1,NL                                                OPR 1750
            DO 260 LL = 1,NVARL                                         OPR 1760
               IF (LVAR(LL).EQ.L) GO TO 250                             OPR 1770
               GO TO 260                                                OPR 1780
  250          HI(L) = CMAXV(L,MON) * CONFLO                            OPR 1790
               GO TO 270                                                OPR 1800
  SUBROUTINE OPRATE     73/73   OPT=2 TRACE               FTN 4.6+452       79/05/10. 13.11.59

  260       CONTINUE                                                    OPR 1810
            HI(L) = CMAX(L) * CONFLO                                    OPR 1820
  270    CONTINUE                                                       OPR 1830
  280    IDONE = 1                                                      OPR 1840
         ITER1 = 0                                                      OPR 1850
         NTIME = 1                                                      OPR 1860
         ICONV = 0                                                      OPR 1870
         JFLAG2 = 1                                                     OPR 1880
  290    ITER = 0                                                       OPR 1890
         DO 300 J = 1,NJ                                                OPR 1900
            USE(J) = 0                                                  OPR 1910
            EVPT(J) = 0                                                 OPR 1920
            UREG(J) = 0                                                 OPR 1930
            START(J) = 0                                                OPR 1940
         DO 300 I = 1,13                                                OPR 1950
            ICAP(J,MON,I) = 0                                           OPR 1960
  300    CONTINUE                                                       OPR 1970
         DO 310 L = 1,NARC                                              OPR 1980
            FLOW(L) = 0                                                 OPR 1990
  310    CONTINUE                                                       OPR 2000
C                                                                       OPR 2010
C                                   STEP 10                             OPR 2020
C                                   SET INFLOWS AND DEMANDS - IF A TOTAL      OPR 2030
C                                   YEARLY DEMAND IS GIVEN USE IT X DISTRIB.  OPR 2040
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      C                                                             OPR 2050
                DO 340 J = 1,NJ                                     OPR 2060
                   USE(J) = IFIX(DEMON(J,MON) + ROFF)               OPR 2070
                   IF (DEM(J).GT.0) USE(J) = DEM(J) * DEMD(J,MON) + ROFF        OPR 2080
                   UREG(J) = IFIX(U(J,MON) + ROFF)                  OPR 2090
                   START(J) = STEND(J)                              OPR 2100
                   IF ((JFLAG.EQ.0).OR.(ITER1.EQ.0)) GO TO 320      OPR 2110
                   UREG(J) = UREG(J) + ITHRU(J)                     OPR 2120
          320      IF ((IRTN.EQ.0).OR.(ICONV.EQ.0)) GO TO 340       OPR 2130
                   DO 330 I = 1,NEQU                                OPR 2140
                      IF (JRTFT(I).EQ.J) UREG(J) = UREG(J) + IRTF(I,JMONY)      OPR 2150
          330      CONTINUE                                         OPR 2160
          340   CONTINUE                                            OPR 2170
                IF (IMN) 370,370,350                                OPR 2180
      C                                                             OPR 2190
      C                              STEP 11                        OPR 2200
      C                              IF IMPORT - ADD AMOUNT TO INFLOW AT NODE  OPR 2210
      C                                                             OPR 2220
          350   DO 360 I = 1,IMN                                    OPR 2230
                   MOIMP = IMPRT(I,IY) * DIMP(I,MON,IY) + ROFF      OPR 2240
                   UREG(IMP(I)) = UREG(IMP(I)) + MOIMP              OPR 2250
          360   CONTINUE                                            OPR 2260
      C                                                             OPR 2270
      C                              STEP 12                        OPR 2280
      C                              DETERMINE RESERVOIR OPERATING RULE        OPR 2290
      C                                                             OPR 2300
          370   CONTINUE                                            OPR 2310
                IF (IALLY) 380,380,390                              OPR 2320
          380   CALL RULE                                           OPR 2330
                GO TO 400                                           OPR 2340
          390   LRULE = IY                                          OPR 2350
      C                                                             OPR 2360
          400   CONTINUE                                            OPR 2370
      C                                                             OPR 2380
      C                              STEP 13                        OPR 2390
      C                              SET BOUNDS ON INITIAL STORAGE ARCS        OPR 2400
   SUBROUTINE OPRATE      73/73   OPT=2 TRACE              FTN 4.6+452       79/05/10. 13.11.59

      C      SET BOUNDS + FLOWS ON STORAGE ARCS                     OPR 2410
      C                                                             OPR 2420
      C                                                             OPR 2430
                IAT = 0                                             OPR 2440
                ISUM = 0                                            OPR 2450
                LO(NARC - 3) = 0                                    OPR 2460
                DO 420 L = L1,L2                                    OPR 2470
                   JN = NT(L)                                       OPR 2480
                   LO(L) = START(JN) + UREG(JN)                     OPR 2490
                   HI(L) = LO(L)                                    OPR 2500
                   FLOW(L) = LO(L)                                  OPR 2510
                   ISUM = ISUM + FLOW(L)                            OPR 2520
      C                                                             OPR 2530
                   NP = L + NJ                                      OPR 2540
                   NN = L + 2 * NJ                                  OPR 2550
                   IA(JN) = 0                                       OPR 2560
                   IB(JN) = 0                                       OPR 2570
                   IC(JN) = 0                                       OPR 2580
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              IF (RCAP(JN).EQ.0) GO TO 410                                   OPR 2590
      C                                                                      OPR 2600
      C                              STEP 14                                 OPR 2610
      C                              ESTIMATE EVAP FOR MONTH                 OPR 2620
      C                                                                      OPR 2630
              STUG = 0.5 * (START(JN) + RCAP(JN))                            OPR 2640
              CALL AREA (STUG,ISURA,JN)                                      OPR 2650
              IA(JN) = ISURA * EVAP(JN,MON) + ROFF                           OPR 2660
              STUG = 0.5 * (START(JN) + RMIN(JN))                            OPR 2670
              CALL AREA (STUG,ISURA,JN)                                      OPR 2680
              IB(JN) = ISURA * EVAP(JN,MON) + ROFF                           OPR 2690
              STUG = 0.5 * (START(JN) + OPRR(LRULE,JN,MON) * RCAP(JN))       OPR 2700
              CALL AREA (STUG,ISURA,JN)                                      OPR 2710
              IC(JN) = ISURA * EVAP(JN,MON) + ROFF                           OPR 2720
      C                                                                      OPR 2730
      C                              STEP 15                                 OPR 2740
      C                              SET UP BOUNDS FOR DESIRED STORAGE ARCS  OPR 2750
      C                              BASED ON RULES - PRICE ARCS FROM RANK   OPR 2760
      C                              INPUT - CALCULATE BOUNDS FOR FINAL STORAGEOPR 2770
      C                              ARCS                                    OPR 2780
      C                                                                      OPR 2790
              IAT = IAT + IA(JN)                                             OPR 2800
              MINPOL = RMIN(JN)                                              OPR 2810
              LO(NP) = IB(JN) + MINPOL                                       OPR 2820
              IF (LO(L).LT.LO(NP)) LO(NP) = LO(L)                            OPR 2830
              IF (LO(NP).LT.0) LO(NP) = 0                                    OPR 2840
              LO(NN) = 0                                                     OPR 2850
              HI(NP) = OPRR(LRULE,JN,MON) * RCAP(JN) + IC(JN)                OPR 2860
              COST(NP) =  - (1000 - OPRP(LRULE,JN) * 10)                     OPR 2870
              HI(NN) = (1.0 - OPRR(LRULE,JN,MON)) * RCAP(JN) + IA(JN) - ICOPR 2880
           1  (JN)                                                           OPR 2890
              IF (HI(NN).LT.0) HI(NN) = 0                                    OPR 2900
              IF (HI(NP).GT.LO(NP)) GO TO 410                                OPR 2910
              HI(NP) = LO(NP)                                                OPR 2920
              HI(NN) = RCAP(JN) - HI(NP)                                     OPR 2930
              IF (HI(NN).LT.0) HI(NN) = 0                                    OPR 2940
        410   CONTINUE                                                       OPR 2950
              FLOW(NN) = FLOW(L)                                             OPR 2960
              LO(NARC - 3) = LO(NARC - 3) + LO(NP)                           OPR 2970
        420 CONTINUE                                                         OPR 2980
      C                                                                      OPR 2990
      C                              STEP 16                                 OPR 3000
SUBROUTINE OPRATE      73/73   OPT=2 TRACE                  FTN 4.6+452        79/05/10. 13.11.59

      C                              SET UP BOUNDS IN MASS BALANCE ARCS      OPR 3010
      C                                                                      OPR 3020
            FLOW(NARC - 3) = ISUM                                            OPR 3030
            HI(NARC - 3) = ITOT + IAT                                        OPR 3040
            FLOW(NARC) = ISUM                                                OPR 3050
            HI(NARC) = FLOW(NARC)                                            OPR 3060
            LO(NARC) = FLOW(NARC)                                            OPR 3070
      C                                                                      OPR 3080
      C                              STEP 17                                 OPR 3090
      C                              SET UP DEMAND ARCS AND PRICE            OPR 3100
      C                              ACCORDING TO RANK                       OPR 3110
      C     SET LIMITS ON DEMAND ARCS                                        OPR 3120
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C                                                                       OPR 3130
      MAXD = 0                                                          OPR 3140
      DO 430 L = L7,L8                                                  OPR 3150
         JN = NF(L)                                                     OPR 3160
         HI(L) = USE(JN)                                                OPR 3170
         COST(L) =  - (1000 - DEMR(JN,LRULE) * 10)                      OPR 3180
         MAXD = MAXD + HI(L)                                            OPR 3190
  430 CONTINUE                                                          OPR 3200
  440 CONTINUE                                                          OPR 3210
      HI(NARC - 1) = MAXD                                               OPR 3220
      IF (LOPT.EQ.1.AND.ITER.GE.1) GO TO 480                            OPR 3230
C                                                                       OPR 3240
C                            STEP 18                                    OPR 3250
C                            SET UP SPILL ARCS AND PRICE                OPR 3260
C                            ACCORDING TO ORDER                         OPR 3270
C    SET LIMITS ON SPILL ARCS                                           OPR 3280
C                                                                       OPR 3290
      MAXS = 0                                                          OPR 3300
      DO 470 L = L9,LA                                                  OPR 3310
         JN = NF(L)                                                     OPR 3320
         NTX = 0                                                        OPR 3330
C                                                                       OPR 3340
         DO 450 K = 1,NS                                                OPR 3350
            IF (JN.EQ.SP(K).AND.NS.NE.0) NTX = 1                        OPR 3360
            IF (NTX.EQ.1) GO TO 460                                     OPR 3370
  450    CONTINUE                                                       OPR 3380
         K = 0                                                          OPR 3390
  460    KS = K                                                         OPR 3400
         HI(L) = ITOT * 10 * NTX                                        OPR 3410
         COST(L) = NTX * 10000 * (1 + KS)                               OPR 3420
         MAXS = MAXS + HI(L)                                            OPR 3430
  470 CONTINUE                                                          OPR 3440
      HI(NARC - 2) = MAXS                                               OPR 3450
C                                                                       OPR 3460
C                                                                       OPR 3470
  480 CONTINUE                                                          OPR 3480
C                                                                       OPR 3490
C                            STEP 19                                    OPR 3500
C                            CALL NETWORK FLOW ALGORITHM                OPR 3510
C                                                                       OPR 3520
      CALL SUPERK                                                       OPR 3530
      IF (.NOT.FESIBL) GO TO 770                                        OPR 3540
      NTIME = 2                                                         OPR 3550
C                                                                       OPR 3560
      IF (LOPT.EQ.1) CALL CHANLS (MON,ITER,IDONE,L7,L8,MAXD,IY)         OPR 3570
      IF (IDONE.EQ.0) GO TO 440                                         OPR 3580
C                                                                       OPR 3590
      DO 490 L = 1,NL                                                   OPR 3600
SUBROUTINE OPRATE    73/73   OPT=2 TRACE                 FTN 4.6+452       79/06/10. 13.11.59

         FLOW(L) = FLOW(L) - INT(XCLL(L,MON))                           OPR 3610
  490 CONTINUE                                                          OPR 3620
      IF (JFLAG.EQ.0) GO TO 530                                         OPR 3630
      DO 500 J = 1,NJ                                                   OPR 3640
         ITHRU(J) = 0                                                   OPR 3650
  500 CONTINUE                                                          OPR 3660
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               DO 520 L = 1,NL                                                OPR 3670
                  DO 510 J = 1,NJ                                             OPR 3680
                     IF (IDSTRM(J).EQ.0) GO TO 510                            OPR 3690
                     IF (LNODE(L,2).EQ.J) ITHRU(IDSTRM(J)) = ITHRU(IDSTRM(J)) OPR 3700
          1          + FLOW(L)                                                OPR 3710
   510            CONTINUE                                                    OPR 3720
   520         CONTINUE                                                       OPR 3730
               IF ((JFLAG.EQ.1).AND.(IRTN.EQ.0)) GO TO 540                    OPR 3740
               ITER1 = 1                                                      OPR 3750
   530         IF (IRTN.EQ.0) GO TO 550                                       OPR 3760
               CALL RTFLOW (MON,IY,JFLAG2,ICONV,JMONY,L7,L8)                  OPR 3770
               IF (JFLAG2.EQ.0) GO TO 290                                     OPR 3780
               GO TO 550                                                      OPR 3790
   540         IF (ITER1.NE.0) GO TO 550                                      OPR 3800
               ITER1 = 1                                                      OPR 3810
               GO TO 290                                                      OPR 3820
C                                                                             OPR 3830
C                                    STEP 20                                  OPR 3840
C                                    BUILD SHORTAGE ARRAY                     OPR 3850
C                                                                             OPR 3860
   550         DO 560 L = L7,L8                                               OPR 3870
                  JN = NF(L)                                                  OPR 3880
                  ISHTM(JN,MON) = HI(L) - FLOW(L)                             OPR 3890
   560         CONTINUE                                                       OPR 3900
C                                                                             OPR 3910
C                                                                             OPR 3920
C                                    STEP 21                                  OPR 3930
C                                    BUILD SPILL ARRAY                        OPR 3940
C                                                                             OPR 3950
               DO 570 L = L9,LA                                               OPR 3960
                  JN = NF(L)                                                  OPR 3970
                  ISPIL(JN,MON) = FLOW(L)                                     OPR 3980
   570         CONTINUE                                                       OPR 3990
C                                                                             OPR 4000
C                                                                             OPR 4010
C                                    STEP 22                                  OPR 4020
C                                    CALCULATE FINAL RES STORAGE              OPR 4030
C                                   AND SET MONTHLY EVAP ESTIMATE             OPR 4040
C                                                                             OPR 4050
               DO 580 L = L3,L4                                               OPR 4060
                  JN = NF(L)                                                  OPR 4070
                  LN = L + NJ                                                 OPR 4080
                  STEND(JN) = FLOW(L) + FLOW(LN)                              OPR 4090
                  EVPT(JN) = IA(JN)                                           OPR 4100
                  IF (FLOW(L).EQ.0) EVPT(JN) = IB(JN)                         OPR 4110
                  IF (FLOW(LN).EQ.0) EVPT(JN) = IC(JN)                        OPR 4120
                  IF (STEND(JN).LT.0) STEND(JN) = 0                           OPR 4130
   580         CONTINUE                                                       OPR 4140
C                                                                             OPR 4150
C                                    STEP 23                                  OPR 4160
C                                    CALCULATE MONTHLY EVAP. AND DETERMINE    OPR 4170
C                                    RES. ENDING STORAGE                      OPR 4180
C                                                                             OPR 4190
               DO 650 L = L3,L4                                               OPR 4200
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          ICHK = 0                                                       OPR 4210
          JN = NF(L)                                                     OPR 4220
          IF (RCAP(JN).LE.0) GO TO 650                                   OPR 4230
          EUP = EUPT(JN)                                                 OPR 4240
          STEMP = STEND(JN)                                              OPR 4250
  590     IF (STEMP.GT.RCAP(JN)) STEMP = RCAP(JN)                        OPR 4260
          STUG = (STEMP + START(JN)) * 0.5                               OPR 4270
          CALL AREA (STUG,ISURA,JN)                                      OPR 4280
          ETEMP = 0.0                                                    OPR 4290
          IAREA(JN) = ISURA                                              OPR 4300
          IF (EVAP(JN,MON)) 600,640,600                                  OPR 4310
  600     ETEMP = ISURA * EVAP(JN,MON) + ROFF                            OPR 4320
          IF (ABS(ETEMP - EUP).LT.5.0) GO TO 640                         OPR 4330
          ICHK = ICHK + 1                                                OPR 4340
          IF (ICHK.LE.100) GO TO 630                                     OPR 4350
          WRITE (KOUT,610) JN,ETEMP,EUP,ISURA,START(JN),STEND(JN)        OPR 4360
  610 FORMAT (5X,3HJN=,I3,5X,6HETEMP=,F12.4,5X,4HEUP=,F10.4,5X,6HISURA=,OPR 4370
     1I10,7HSTART =,I10,8HSTEND = ,I10)                                  OPR 4380
          WRITE (KOUT,620) IY,MON,STEMP                                  OPR 4390
  620 FORMAT (//3I10)                                                    OPR 4400
          CALL EXIT                                                      OPR 4410
  630     CONTINUE                                                       OPR 4420
          EUP = ETEMP                                                    OPR 4430
          STEMP = STEND(JN) - EUP                                        OPR 4440
          IF (STEMP.LT.0) STEMP = 0                                      OPR 4450
          GO TO 590                                                      OPR 4460
  640     STEMP = ETEMP                                                  OPR 4470
          STEND(JN) = STEND(JN) - STEMP                                  OPR 4480
          IF (STEND(JN).LT.0) STEND(JN) = 0                              OPR 4490
          IF (STEND(JN).GT.RCAP(JN)) STEND(JN) = RCAP(JN)                OPR 4500
          EUPT(JN) = STEMP                                               OPR 4510
  650   CONTINUE                                                         OPR 4520
C                                                                        OPR 4530
C                                                                        OPR 4540
C                            STEP 25                                     OPR 4550
C                            BUILD PRINT-ARRAY WITH MONTHY DATA          OPR 4560
C                                                                        OPR 4570
        DO 700 J = 1,NRES                                                OPR 4580
          ICAP(J,MON,1) = START(J)                                       OPR 4590
          ICAP(J,MON,2) = WREG(J)                                        OPR 4600
          ICAP(J,MON,4) = USE(J)                                         OPR 4610
          ICAP(J,MON,5) = IAREA(J) + ROFF                                OPR 4620
          ICAP(J,MON,6) = EUPT(J)                                        OPR 4630
          ICAP(J,MON,8) = ISHTR(J,MON)                                   OPR 4640
          ICAP(J,MON,11) = ISPIL(J,MON)                                  OPR 4650
          ICAP(J,MON,12) = STEND(J)                                      OPR 4660
          ICAP(J,MON,13) = OPRR(LRULE,J,MON) * RCAP(J) + ROFF            OPR 4670
          IDN = 0                                                        OPR 4680
          IUP = 0                                                        OPR 4690
          IPI = 0                                                        OPR 4700
          IPO = 0                                                        OPR 4710
C                                                                        OPR 4720
C                            STEP 26                                     OPR 4730
C                            SET UP UPSTREAM AND DOWNSTREAM FLOWS        OPR 4740
C                                                                        OPR 4750
          IF (NR.EQ.0) GO TO 670                                         OPR 4760
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            DO 660 L = 1,NR                                                 OPR 4770
               LNKFLO(L,MON) = FLOW(L)/CONFLO                               OPR 4780
               IF (LNODE(L,1).EQ.J) IDN = IDN + FLOW(L)                     OPR 4790
               IF (LNODE(L,2).EQ.J) IUP = IUP + FLOW(L)                     OPR 4800
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  660       CONTINUE                                                        OPR 4810
C                                                                           OPR 4820
            ICAP(J,MON,3) = IUP                                             OPR 4830
            ICAP(J,MON,7) = IDN                                             OPR 4840
C                                                                           OPR 4850
  670       IF (NC.EQ.0) GO TO 690                                          OPR 4860
            DO 680 L = LB,NL                                                OPR 4870
               LNKFLO(L,MON) = FLOW(L)/CONFLO                               OPR 4880
               IF (LNODE(L,1).EQ.J) IPO = IPO + FLOW(L)                     OPR 4890
               IF (LNODE(L,2).EQ.J) IPI = IPI + FLOW(L)                     OPR 4900
  680       CONTINUE                                                        OPR 4910
  690       CONTINUE                                                        OPR 4920
            ICAP(J,MON,9) = IPI                                             OPR 4930
            ICAP(J,MON,10) = IPO                                            OPR 4940
C                                                                           OPR 4950
C                                STEP 27                                    OPR 4960
C                                CALCULATE AVER. AND MAX FLOWS              OPR 4970
C                                                                           OPR 4980
  700   CONTINUE                                                            OPR 4990
        DO 710 L = 1,NL                                                     OPR 5000
            LNKAFL(L,MON) = LNKAFL(L,MON) + LNKFLO(L,MON)/NYEAR             OPR 5010
            IF (LNKFLO(L,MON).GT.LNKMX(L,MON)) LNKMX(L,MON) = LNKFLO(L,MOPR 5020
     1      ON)                                                             OPR 5030
  710   CONTINUE                                                            OPR 5040
C                                                                           OPR 5050
        NDS = NJ - NRES                                                     OPR 5060
        IF (NDS.EQ.0) GO TO 730                                             OPR 5070
C                                                                           OPR 5080
        DO 720 J = 1,NDS                                                    OPR 5090
           JN = J + NRES                                                    OPR 5100
           ICAP(JN,MON,2) = UREG(JN)                                        OPR 5110
           ICAP(JN,MON,4) = USE(JN)                                         OPR 5120
           ICAP(JN,MON,8) = ISHTM(JN,MON)                                   OPR 5130
  720   CONTINUE                                                            OPR 5140
  730   CONTINUE                                                            OPR 5150
C                                                                           OPR 5160
C                                                                           OPR 5170
C                                STEP 28                                    OPR 5180
C                                ADD MONTHLY AMOUNTS FOR YEAR TOTALS        OPR 5190
C                                                                           OPR 5200
        DO 740 JN = 1,NJ                                                    OPR 5210
           IF (MON.EQ.1) TOTLS(JN,IY,1) = START(JN)                         OPR 5220
           IF (MON.EQ.12) TOTLS(JN,IY,12) = STEND(JN)                       OPR 5230
        DO 740 I = 2,11                                                     OPR 5240
           TOTLS(JN,IY,I) = TOTLS(JN,IY,I) + ICAP(JN,MON,I)                 OPR 5250
  740   CONTINUE                                                            OPR 5260
C                                                                           OPR 5270
  750 CONTINUE                                                              OPR 5280
C                                                                           OPR 5290
C                                STEP 29                                    OPR 5300
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          C                             IF ONE PASS OR CONVERGENCE AND PRINT       OPR 5310
          C                             YEAR-CALL YEARLY PRINT ROUTINE             OPR 5320
          C                                                                        OPR 5330
                KEY = 1                                                            OPR 5340
                CALL OUT2 (IY)                                                     OPR 5350
          C                                                                        OPR 5360
                IY = IY + 1                                                        OPR 5370
                IF (IY.LE.NYEAR) GO TO 170                                         OPR 5380
          C                                                                        OPR 5390
          C                                                                        OPR 5400
SUBROUTINE OPRATE     73/73   OPT=2 TRACE                      FTN 4.6+452        79/05/10. 13.11.59

          C                             STEP 30                                    OPR 5410
          C                             CALL ROUTINE TO ADJUST ANNUAL DEMAND       OPR 5420
          C                             AT YIELD NODE IF NECESSARY                 OPR 5430
          C                                                                        OPR 5440
                IF (IQUIT.EQ.0) GO TO 760                                          OPR 5450
                CALL ADJUST (IY,IQUIT,ICNT)                                        OPR 5460
                GO TO 160                                                          OPR 5470
          C                                                                        OPR 5480
            760 CONTINUE                                                           OPR 5490
          C                                                                        OPR 5500
          C                             STEP 31                                    OPR 5510
          C                             PRINT ARC DUMP IF SOLUTION INFEASIBLE      OPR 5520
          C                                                                        OPR 5530
                RETURN                                                             OPR 5540
            770 WRITE (KOUT,780) IY,MON,(L,NF(L),NT(L),LO(L),HI(L),FLOW(L),COST(L)OPR 5550
               1,L = 1,NARC)                                                       OPR 5560
            780 FORMAT (1H1/20X,20HSOLUTION INFEASIBLE ,5H YEAR,I3,7H  MONTH,I3//6OPR 5570
               10H     LINK  FROM   TO     LO       HI         FLOW     COST  //(3OPR 5580
               2I5,4I10))                                                          OPR 5590
                RETURN                                                             OPR 5600
          C                                                                        OPR 5610
                END                                                                OPR 5620
SUBROUTINE OUT1       73/73   OPT=2 TRACE                      FTN 4.6+452        79/05/10. 13.11.59

                SUBROUTINE OUT1                                                    OT1 0010
                INTEGER               RCAP         , RMIN         , FSTART      ,   OT1 0020
               1        CMAXU        , ACTAB       , DEM          , DEMR        ,   OT1 0030
               2        OPRP         , SP          , CMAX         , CMIN            OT1 0040
                COMMON /CONTRL/       KIN          , KOUT         , KAPE1       ,   OT1 0050
               1        KAPE4                                                      OT1 0060
                COMMON /IPRNT/        IPRNT        , IYLD         , ITOY        ,   OT1 0070
               1        IFROM                                                      OT1 0080
                COMMON /PARM/         NJ           , NRES         , NJUNC       ,   OT1 0090
               1        NL           , NC          , NYEAR        , ND          ,   OT1 0100
               2        NS           , IYEAR       , IMN          , TITLE(20)   ,   OT1 0110
               3        NR           , NPAIRS                                      OT1 0120
                COMMON /RESU/         RNAME(40,2)  , RCAP(40)     , RMIN(40)    ,   OT1 0130
               1        FSTART(40)   , ACTAB(10,18,2)             , OPRR(20,10,12), OT1 0140
               2        OPRP(20,10)  , SP(10)      , DEM(40)      , DEMD(40,12) ,   OT1 0150
               3        EVAP(10,12)  , U(40,12)    , IMP(2)       , DIMP(2,12,20),  OT1 0160
               4        DEMR(40,20)  , IMPRT(2,20)                                 OT1 0170
                COMMON /LINK/         LNODE(50,2)  , CMAX(50)     , CMIN(50)        OT1 0180
                COMMON /CONFAC/       AURGLO       , AURGHI       , CONFLO      ,   OT1 0190
               1        CONDEM       , CONINF      , CPCT         , NSRS        ,   OT1 0200
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      2         LRULE       , JESVOL(10)                                OT1 0210
       COMMON /ADATA/         NARC         , NMAX        , FESIBL     , OT1 0220
      1         NTIME       , NT(500)      , NF(500)     , HI(500)    , OT1 0230
      2         LO(500)     , FLOW(500)    , COST(500)                  OT1 0240
       COMMON /D/             NDMD(40)     , IDSTRM(40)  , ITHRU(40)  , OT1 0250
      1         NVARL       , LVAR(50)     , CMAXV(50,12)               OT1 0260
       COMMON /LDATA/         XLCF(50)     , XCLL(50,12) , LOPT       , OT1 0270
      1         TOL         , IALLY        , IRTN                       OT1 0280
       COMMON /R1/            NEQU         , NLAGS       , A(10,15)   , OT1 0290
      1         NDNEQU(10)  , IRTFF(10,15), JRTFT(10)    , IRTF(10,240),OT1 0300
      2         IDIVL(10,15), IRTL(10,15)                               OT1 0310
       DIMENSION              COND(3)      , LOUT(2)                    OT1 0320
       DATA COND/4HAVRG,4HDRY ,4HWET /                                  OT1 0330
       DATA LOUT/8H  WILL  ,8HWILL NOT/                                 OT1 0340
C                                                                       OT1 0350
C                              STEP 01                                  OT1 0360
C                              PRINT OUT ALL INPUT INFORMATION          OT1 0370
C                                                                       OT1 0380
       IIII = 2                                                         OT1 0390
       WRITE (KOUT,100) TITLE                                           OT1 0400
   100 FORMAT (1H1//10X,35HRIVER BASIN SIMULATION PACKAGE:     ,10X,42HPROOT1 0410
      1GRAM MODSIM - COLORADO STATE UNIVERSITY,//20X,20A4)              OT1 0420
       WRITE (KOUT,110) NJ,NRES,NL,NR,IYEAR,NYEAR,ND,NS,IYLD,IMN        OT1 0430
   110 FORMAT (//10X,15X,17HNUMBER OF NODES =,I5,7X,7X,22HNUMBER OF RESEROT1 0440
      1VOIRS =,I3//10X,15X,17HNUMBER OF LINKS =,I5,7X,4X,25HNUMBER OF RIVOT1 0450
      2ER REACHES =,I3//10X,32HCALENDAR YEAR OPERATION STARTS =,I5,7X,29HOT1 0460
      3NUMBER OF YEARS TO SIMULATE =,I3//10X,8X,24HNUMBER OF DEMAND NODESOT1 0470
      4 =,I5,7X,6X,23HNUMBER OF SPILL NODES =,I3//30X,12HYIELD NODE =,I5,OT1 0480
      57X,5X,24HNUMBER OF IMPORT NODES =,I3)                            OT1 0490
       IF (LOPT.EQ.1) IIII = 1                                          OT1 0500
       WRITE (KOUT,120) LOUT(IIII)                                      OT1 0510
   120 FORMAT (//10X,15HCHANNEL LOSSES ,A8,14H BE CONSIDERED)           OT1 0520
       IF (LOPT.EQ.1) WRITE (KOUT,130) TOL                              OT1 0530
   130 FORMAT (1H ,18X,11HTOLERANCE =,F8.3,/)                           OT1 0540
       IIII = 2                                                         OT1 0550
       IF (IRTN.EQ.1) IIII = 1                                          OT1 0560
       WRITE (KOUT,140) LOUT(IIII)                                      OT1 0570
   140 FORMAT (/10X,13HRETURN FLOWS ,A8,14H BE CALCULATED)              OT1 0580
       WRITE (KOUT,150)                                                 OT1 0590
   150 FORMAT (//10X,8HNODE NO.,3X,9HNODE NAME,4X,9(1H-),12H CAPACITIES ,OT1 0600
 SUBROUTINE OUT1       73/73   OPT=2 TRACE                     FTN 4.6+452        79/05/10. 13.11.59

      19(1H-),5X,6HYEARLY/10X,26X,28HMAXIMUM   MINIMUM   STARTING,5X,6HDEOT1 0610
      2MAND)                                                            OT1 0620
       DO 160 J = 1,NJ                                                  OT1 0630
          IF (MOD(J,20).NE.0) GO TO 160                                 OT1 0640
          WRITE (KOUT,100) TITLE                                        OT1 0650
          WRITE (KOUT,150)                                              OT1 0660
   160 WRITE (KOUT,170) J,(RNAME(J,I),I = 1,2),RCAP(J),RMIN(J),FSTART(J),OT1 0670
      1DEM(J)                                                           OT1 0680
   170 FORMAT (/10X,I3,8X,2A4,4X,2I10,1X,I10,3X,I8)                     OT1 0690
       WRITE (KOUT,100) TITLE                                           OT1 0700
       WRITE (KOUT,180)                                                 OT1 0710
   180 FORMAT (//10X,20HSYSTEM CONFIGURATION//10X,8HLINK NO.,4X,9HFROM NOOT1 0720
      1DE,5X,7HTO NODE,5X,13HMAX. CAPACITY,4X,13HMIN. CAPACITY,5X,16HLOSSOT1 0730
      2 COEFFICIENT,11X,4HCOST)                                         OT1 0740
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      DO 250 L = 1,NL                                                   OT1 0750
         IF (MOD(L,20).NE.0) GO TO 190                                  OT1 0760
         WRITE (KOUT,100) TITLE                                         OT1 0770
         WRITE (KOUT,180)                                               OT1 0780
190      IF (NVARL.EQ.0) GO TO 230                                      OT1 0790
         DO 220 LL = 1,NVARL                                            OT1 0800
            IF (LVAR(LL).EQ.L) GO TO 200                                OT1 0810
            GO TO 220                                                   OT1 0820
200         WRITE (KOUT,210) L,(LNODE(L,I),I = 1,2),CMIN(L),XLCF(L),COSTOT1 0830
   1        (L)                                                         OT1 0840
210 FORMAT (/10X,2X,I2,12X,I2,12X,I2,5X,14HVARIES MONTHLY,7X,I10,16X,FOT1 0850
     15.3,10X,I5)                                                       OT1 0860
            GO TO 250                                                   OT1 0870
220      CONTINUE                                                       OT1 0880
230      WRITE (KOUT,240) L,(LNODE(L,I),I = 1,2),CMAX(L),CMIN(L),XLCF(L)OT1 0890
   1     ,COST(L)                                                       OT1 0900
240 FORMAT (/10X,2X,I2,12X,I2,12X,I2,9X,I10,7X,I10,16X,F5.3,10X,I5)   OT1 0910
250 CONTINUE                                                            OT1 0920
      WRITE (KOUT,260) (SP(I),I = 1,NS)                                 OT1 0930
260 FORMAT (///10X,27HLIST OF SPILL RESERVOIRS - ,14I5//)               OT1 0940
      IF (IMN.EQ.0) GO TO 300                                           OT1 0950
      WRITE (KOUT,100) TITLE                                            OT1 0960
      DO 290 I = 1,IMN                                                  OT1 0970
         DO 280 K = 1,NYEAR                                             OT1 0980
            WRITE (KOUT,270) IMP(I),IMPRT(I,K),(DIMP(I,J,K),J = 1,12)   OT1 0990
270 FORMAT (/10X,9HNODE NO. ,I2,5X,16HYEARLY IMPORT = ,I8/26X,29HMONTHOT1 1000
     1LY IMPORT DISTRIBUTION: ,12F5.2)                                  OT1 1010
280      CONTINUE                                                       OT1 1020
290 CONTINUE                                                            OT1 1030
300 IF (IALLY.GT.0) GO TO 330                                           OT1 1040
      WRITE (KOUT,310) (JESVOL(I),I = 1,NSRS)                           OT1 1050
310 FORMAT (//10X,25HSUB-SYSTEM OF RESERVOIRS ,14I5)                    OT1 1060
      AVLO = AVRGLO * 100.                                              OT1 1070
      AVHI = AVRGHI * 100.                                              OT1 1080
      WRITE (KOUT,320) AVLO,AVHI                                        OT1 1090
320 FORMAT (//10X,28H'AVERAGE' DEFINED AS BETWEEN,F6.1,5H, AND,F6.1,26OT1 1100
     1H PERCENT FULL OF SUBSYSTEM)                                      OT1 1110
      GO TO 360                                                         OT1 1120
330 WRITE (KOUT,340)                                                    OT1 1130
340 FORMAT (//10X,57H** AVERAGE, WET, AND DRY STATES WILL NOT BE CALCUOT1 1140
     1LATED **)                                                         OT1 1150
      WRITE (KOUT,350)                                                  OT1 1160
350 FORMAT (/10X,56H   DESIRED OPERATING LEVELS WILL BE INPUT FOR EACHOT1 1170
     1 YEAR)                                                            OT1 1180
360 WRITE (KOUT,370) CONFLO,CONINF,CONDEM                               OT1 1190
370 FORMAT (///10X,7HFACTORS//15X,28HMULTIPLY LINK CAPACITIES BY ,F8.3OT1 1200
SUBROUTINE OUT1        73/73   OPT=2 TRACE                    FTN 4.6+452        79/06/10. 13.11.50

     1//15X,28HMULTIPLY INFLOWS BY ....... ,F8.2//15X,28HMULTIPLY DEMANDOT1 1210
     2S BY ....... ,F8.2)                                               OT1 1220
      WRITE (KOUT,100) TITLE                                            OT1 1230
      IF (IALLY.GT.0) GO TO 430                                         OT1 1240
      WRITE (KOUT,380)                                                  OT1 1250
380 FORMAT (//10X,30X,27HMONTHLY DEMAND DISTRIBUTION/10X,8HNODE NO.6X,OT1 1260
     14X,4H  1 ,3X,4H  2 ,3X,4H  3 ,3X,4H  4 ,3X,4H  5 ,3X,4H  6 ,3X,4H OT1 1270
     2 7 ,3X,4H  8 ,3X,4H  9 ,3X,4H 10 ,3X,4H 11 ,3X,4H 12 ,3X,8H  RANK OT1 1280
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      3X)                                                               OT1 1290
      WRITE (KOUT,390)                                                  OT1 1300
  390 FORMAT (112X,11HAUG DRY WET)                                      OT1 1310
      DO 420 J = 1,NJ                                                   OT1 1320
      DO 420 INJ = 1,ND                                                 OT1 1330
         IF (J - NDMD(INJ)) 420,400,420                                 OT1 1340
  400    WRITE (KOUT,410) J,(DEMD(J,K),K = 1,12),(DEMR(J,I),I = 1,3)    OT1 1350
  410 FORMAT (/10X,2X,I2,10X,12F7.4,3X,3I4)                             OT1 1360
  420 CONTINUE                                                          OT1 1370
      GO TO 500                                                         OT1 1380
  430 WRITE (KOUT,440)                                                  OT1 1390
  440 FORMAT (//10X,31HANNUAL RANKING FOR DEMAND NODES)                 OT1 1400
      DO 490 J = 1,NJ                                                   OT1 1410
      DO 490 INJ = 1,ND                                                 OT1 1420
         IF (J - NDMD(INJ)) 490,450,490                                 OT1 1430
  450    WRITE (KOUT,460)                                               OT1 1440
  460 FORMAT (/)                                                        OT1 1450
         DO 470 I = 1,NYEAR                                             OT1 1460
  470    WRITE (KOUT,480) J,I,DEMR(J,I)                                 OT1 1470
  480 FORMAT (15X,9HNODE NO. ,I2,3X,4HYEAR,I3,3X,7HRANK = ,I3)          OT1 1480
  490 CONTINUE                                                          OT1 1490
  500 WRITE (KOUT,100) TITLE                                            OT1 1500
      WRITE (KOUT,510)                                                  OT1 1510
  510 FORMAT (//10X,30X,45HDESIRED MONTHLY STORAGE LEVEL (PERCENT FULL) OT1 1520
     130X,4HRANK/10X,13HRESERVOIR NO.)                                  OT1 1530
      IF (IALLY.GT.0) GO TO 540                                         OT1 1540
      DO 520 J = 1,NRES                                                 OT1 1550
         IF (MOD(J,8).EQ.0) WRITE (KOUT,100) TITLE                      OT1 1560
  520 WRITE (KOUT,530) J,(COMD(L),(OPRR(L,J,I),I = 1,12),OPRP(L,J),L = 1OT1 1570
     1,3)                                                               OT1 1580
  530 FORMAT (/10X,2X,I2,3X,A4,3X,12F7.4,5X,I4/(17X,A4,3X,12F7.4,5X,I4))OT1 1590
      GO TO 590                                                         OT1 1600
  540 DO 580 J = 1,NRES                                                 OT1 1610
         WRITE (KOUT,550)                                               OT1 1620
  550 FORMAT (/)                                                        OT1 1630
         IF (MOD(J,5).EQ.0) WRITE (KOUT,100) TITLE                      OT1 1640
         DO 560 L = 1,NYEAR                                             OT1 1650
  560    WRITE (KOUT,570) J,L,(OPRR(L,J,I),I = 1,12),OPRP(L,J)          OT1 1660
  570 FORMAT (11X,I2,3X,4HYEAR,I2,2X,12F7.4,5X,I4)                      OT1 1670
  580 CONTINUE                                                          OT1 1680
  590 WRITE (KOUT,100) TITLE                                            OT1 1690
      WRITE (KOUT,600)                                                  OT1 1700
  600 FORMAT (//40X,33HRESERVOIRS AREA - CAPACITY TABLES//)             OT1 1710
      K = 0                                                             OT1 1720
      N2 = 0                                                            OT1 1730
  610 K = K + 1                                                         OT1 1740
      N1 = N2 + 1                                                       OT1 1750
      N2 = K * 6                                                        OT1 1760
      IF (N1.GT.NRES) N1 = 0                                            OT1 1770
      IF (N2.GT.NRES) N2 = NRES                                         OT1 1780
      IF (N1.EQ.0) GO TO 650                                            OT1 1790
      IF (K.GT.1) WRITE (KOUT,100) TITLE                                OT1 1800
SUBROUTINE OUT1        73/73    OPT=2 TRACE                  FTN 4.6+452       79/05/10. 13.11.58

      WRITE (KOUT,620) (KRS,KRS = N1,N2)                                OT1 1810
  620 FORMAT (10X,6(4X,13HRESERVOIR NO.,I3)/3X,5HPOINT,2X,6(5X,4HAREA,1XOT1 1820
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     1,2X,8HCAPACITY))                                                 OT1 1830
      DO 630 NPT = 1,NPAIRS                                            OT1 1840
  630 WRITE (KOUT,640) NPT,((ACTAB(JN,NPT,KKK),KKK = 1,2),JN = N1,N2)  OT1 1850
  640 FORMAT (3X,I2,5X,6(I9,1X,I10))                                   OT1 1860
      GO TO 610                                                        OT1 1870
  650 CONTINUE                                                         OT1 1880
      IF (IRTN.EQ.0) RETURN                                            OT1 1890
      WRITE (KOUT,100) TITLE                                           OT1 1900
      LAGS = 2 * NLAGS + 2                                             OT1 1910
      DO 700 I = 1,NEQU                                                OT1 1920
         IDUMB = NDNEQU(I)                                             OT1 1930
         WRITE (KOUT,660) I,NLAGS,JRTFT(I)                             OT1 1940
  660 FORMAT (//10X,25HFOR RETURN FLOW EQUATION:,I3,14H NO. OF LAGS =,I30T1 1950
     1,22H FLOW RETURNS TO NODE:,I3)                                   OT1 1960
         WRITE (KOUT,670) (IRTFF(I,J),J = 1,IDUMB)                     OT1 1970
  670 FORMAT (/10X,41HNODE DEMANDS CONTRIBUTING TO RETURN FLOW:,15I3)  OT1 1980
         DO 690 J = 1,LAGS                                             OT1 1990
            WRITE (KOUT,680) I,J,A(I,J)                                OT1 2000
  680 FORMAT (/10X,2HA(,I2,1H,,I2,2H)=,1X,G12.5)                       OT1 2010
  690    CONTINUE                                                      OT1 2020
  700 CONTINUE                                                         OT1 2030
      RETURN                                                           OT1 2040
C                                                                      OT1 2050
      END                                                              OT1 2060
 SUBROUTINE OUT2        73/73    OPT=2 TRACE               FTN 4.6+452        79/05/10. 13.11.59

      SUBROUTINE OUT2 (IY)                                             OT2 0010
      INTEGER              TOTLS        , P                            OT2 0020
      INTEGER              RCAP         , RMIN        , FSTART     ,   OT2 0030
     1       CMAXU       , ACTAB        , DEM         , DEMR       ,   OT2 0040
     2       OPRP        , SP                                          OT2 0050
      COMMON /CONTRL/      KIN          , KOUT        , KAPE1      ,   OT2 0060
     1       KAPE4                                                     OT2 0070
      COMMON /IPRNT/       IPRNT        , IYLD        , ITOY       ,   OT2 0080
     1       IFROM                                                     OT2 0090
      COMMON /PARM/        NJ           , NRES        , NJUNC      ,   OT2 0100
     1       NL          , NC           , NYEAR       , ND         ,   OT2 0110
     2       NS          , IYEAR        , INN         , TITLE(20)  ,   OT2 0120
     3       NR          , NPAIRS                                      OT2 0130
      COMMON /PRNT/        ICAP(40,12,13)             , TOTLS(40,20,12) OT2 0140
      COMMON /RESU/        RNAME(40,2) , RCAP(40)     , RMIN(40)   ,   OT2 0150
     1       FSTART(40)  , ACTAB(10,18,2)             , OPRR(20,10,12), OT2 0160
     2       OPRP(20,10) , SP(10)       , DEM(40)     , DEMD(40,12) ,  OT2 0170
     3       EVAP(10,12) , U(40,12)     , IMP(2)      , DIMP(2,12,20), OT2 0180
     4       DEMR(40,20) , IMPRT(2,20)                                 OT2 0190
      COMMON /LNKFLW/      LNKFLO(50,13)              , LNKAFL(50,13), OT2 0200
     1       LNKMX(50,13)                                              OT2 0210
      COMMON /D/           NDMD(40)     , IDSTRM(40)  , ITHRU(40)  ,   OT2 0220
     1       NVARL       , LVAR(50)     , CMAXU(50,12)                 OT2 0230
      COMMON /LDATA/       XLCF(50)     , XCLL(50,12) , LOPT       ,   OT2 0240
     1       TOL         , IALLY        , IRTN                         OT2 0250
      COMMON /R1/          NEQU         , NLAGS       , A(10,15)   ,   OT2 0260
     1       NDNEQU(10)  , IRTFF(10,15), JRTFT(10)    , IRTF(10,240),  OT2 0270
     2       IDIVL(10,15), IRTL(10,15)                                 OT2 0280
C                                                                      OT2 0290
C                          STEP 01                                     OT2 0300
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C                                 PRINT OUT MONTHLY DATA FOR YEAR       OT2 0310
C                                                                       OT2 0320
      P = 1                                                             OT2 0330
      ICALYR = IYEAR - 1 + IY                                           OT2 0340
      KTD = 0                                                           OT2 0350
      DO 160 J = 1,NRES                                                 OT2 0360
         IF (MOD(P,3).EQ.1.OR.J.EQ.1) WRITE (KOUT,100) TITLE,IY,ICALYR  OT2 0370
  100 FORMAT (1H1/20X,20A4//3X,15HSIMULATION YEAR,I3,5X,13HCALENDAR YEAROT2 0380
     1,I5)                                                              OT2 0390
C                                                                       OT2 0400
         WRITE (KOUT,110) J,(RNAME(J,I),I = 1,2),RCAP(J),RMIN(J)        OT2 0410
  110 FORMAT (/21X,12HRESERVOIR NO,I3,2X,2A4,4X,13HMAX. CAPACITY,I8,2X,1OT2 0420
     19HMIN. OPERATING POOL,I8)                                         OT2 0430
C                                                                       OT2 0440
         WRITE (KOUT,120)                                               OT2 0450
  120 FORMAT (1H0,9X,7HINITIAL,5X,4HUREG,3X,6HUPSTRM,12X,7HSURFACE,2X,4HOT2 0460
     1EVAP,4X,4HEVAP,2X,7HDWNSTRM,12X,6HPUMPED,4X,6HPUMPED,3X,6HSYSTEM,1OT2 0470
     2X,7HEND MO.,4X,5HOPER./1X,129H  MONTH  STORAGE  INFLOWS   SPILLS  OT2 0480
     3 DEMAND      AREA    RATE     LOSS    SPILLS SHORTAGE     INTO    OUTOT2 0490
     4     LOSS  CONTENT     RULE)                                      OT2 0500
C                                                                       OT2 0510
         DO 130 MON = 1,12                                              OT2 0520
  130    WRITE (KOUT,140) MON,(ICAP(J,MON,I),I = 1,5),EVAP(J,MON),(ICAP(OT2 0530
     1   J,MON,I),I = 6,13)                                             OT2 0540
  140 FORMAT (4X,I2,2X,5I9,2X,F5.2,2X,I6,2I9,I8,4I9)                    OT2 0550
C                                                                       OT2 0560
         WRITE (KOUT,150) (TOTLS(J,IY,I),I = 2,4),(TOTLS(J,IY,I),I = 6,1OT2 0570
     1   1)                                                             OT2 0580
  150 FORMAT (/1X,4X,12HYEAR TOTALS,3I9,15X,3I9,I8,4I9)                 OT2 0590
         P = P + 1                                                      OT2 0600
SUBROUTINE OUT2       73/73   OPT=2 TRACE               FTN 4.6+452       79/05/10. 13.11.59

C                                                                       OT2 0610
  160 CONTINUE                                                          OT2 0620
C                                                                       OT2 0630
      II = NRES + 1                                                     OT2 0640
      DO 220 J = II,NJ                                                  OT2 0650
      DO 220 INJ = 1,ND                                                 OT2 0660
         IF (J - NDMD(INJ)) 220,170,220                                 OT2 0670
  170    IF (MOD(P,3).EQ.1) WRITE (KOUT,100) TITLE,IY,ICALYR            OT2 0680
         WRITE (KOUT,180) J,(RNAME(J,I),I = 1,2)                        OT2 0690
  180 FORMAT (/21X,11HDEMAND NODE,I3,2X,2A4//21X,5HMONTH,9X,6HDEMAND,5X,OT2 0700
     110H  SHORTAGE)                                                    OT2 0710
         DO 190 MON = 1,12                                              OT2 0720
  190    WRITE (KOUT,200) MON,ICAP(J,MON,4),ICAP(J,MON,8)               OT2 0730
  200 FORMAT (21X,I3,7X,I10,5X,I10)                                     OT2 0740
         WRITE (KOUT,210) TOTLS(J,IY,4),TOTLS(J,IY,8)                   OT2 0750
  210 FORMAT (20X,11HYEAR TOTALS,2(I10,5X))                             OT2 0760
         P = P + 1                                                      OT2 0770
  220 CONTINUE                                                          OT2 0780
      DO 320 L = 1,NL                                                   OT2 0790
         IF (L.NE.1) GO TO 260                                          OT2 0800
         IF (MOD(P,2).EQ.1) GO TO 230                                   OT2 0810
         WRITE (KOUT,100) TITLE,IY,ICALYR                               OT2 0820
  230    WRITE (KOUT,240)                                               OT2 0830
  240 FORMAT (/1X,48X,27H* VOLUMETRIC FLOW IN LINK *)                   OT2 0840
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          WRITE (KOUT,250) (I,I = 1,12)                                     OT2 0850
  250 FORMAT (1X,6HSEASON,8X,12(I2,7X),5HAVERG/1X,8HLINK NO.)               OT2 0860
  260     LNKFLO(L,13) = 0                                                  OT2 0870
          X = 0.0                                                           OT2 0880
          DO 270 I = 1,12                                                   OT2 0890
             X = X + FLOAT(LNKFLO(L,I))/12.                                 OT2 0900
  270     CONTINUE                                                          OT2 0910
          X = X + 0.499999                                                  OT2 0920
          LNKFLO(L,13) = IFIX(X)                                            OT2 0930
          WRITE (KOUT,290) L,(LNKFLO(L,I),I = 1,13)                         OT2 0940
          WRITE (KAPE4,280) IY,L,(LNKFLO(L,I),I = 1,13)                     OT2 0950
  280 FORMAT (2I5,13I8)                                                     OT2 0960
  290 FORMAT (1X,4X,I3,13I9)                                                OT2 0970
          IF (LOPT) 320,320,300                                             OT2 0980
  300     WRITE (KOUT,310) (XCLL(L,I),I = 1,12)                             OT2 0990
  310 FORMAT (1X,4X,4HLOSS,12F9.0,/)                                        OT2 1000
  320 CONTINUE                                                              OT2 1010
      IF (IRTN.EQ.0) RETURN                                                 OT2 1020
      WRITE (KOUT,330)                                                      OT2 1030
  330 FORMAT (///1X,23HRETURN FLOWS CALCULATED,/)                           OT2 1040
      IBEG = ((IY - 1) * 12) + 1                                            OT2 1050
      IEND = IBEG + 11                                                      OT2 1060
      DO 370 I = 1,NEQU                                                     OT2 1070
          WRITE (KOUT,340) I,JRTFT(I)                                       OT2 1080
  340 FORMAT (/1X,25HRETURN FLOW EQUATION NO.:,I3,5X,20HRETURNS TO NODE     OT2 1090
     1NO.:,I3,/)                                                            OT2 1100
          WRITE (KOUT,350) (J,J = 1,12)                                     OT2 1110
  350 FORMAT (1X,6HSEASON,8X,12(I2,7X),/)                                   OT2 1120
          WRITE (KOUT,360) (IRTF(I,J),J = IBEG,IEND)                        OT2 1130
  360 FORMAT (1X,7X,12I9)                                                   OT2 1140
  370 CONTINUE                                                              OT2 1150
      RETURN                                                                OT2 1160
      END                                                                   OT2 1170
SUBROUTINE OUT3        73/73   OPT=2 TRACE                  FTN 4.6+452        79/05/10. 13.11.59

      SUBROUTINE OUT3                                                       OT3 0010
      INTEGER             TOTLS                                             OT3 0020
      COMMON /CONTRL/     KIN          , KOUT        , KAPE1       ,        OT3 0030
     1         KAPE4                                                        OT3 0040
      COMMON /IPRNT/      IPRNT        , IYLD        , ITOY        ,        OT3 0050
     1         IFROM                                                        OT3 0060
      COMMON /PARM/       NJ           , NRES        , NJUNC       ,        OT3 0070
     1         NL       , NC           , NYEAR       , ND          ,        OT3 0080
     2         NS       , IYEAR        , IMN         , TITLE(20)   ,        OT3 0090
     3         NR       , NPAIRS                                            OT3 0100
      COMMON /PRNT/       ICAP(40,12,13)             , TOTLS(40,20,12)      OT3 0110
      COMMON /LNKFLW/     LNKFLO(50,13)              , LNKAFL(50,13),       OT3 0120
     1         LNKMX(50,13)                                                 OT3 0130
      DIMENSION           AVE(2)       , XMA(2)                             OT3 0140
      DIMENSION           DNA(2)                                            OT3 0150
      DATA AVE/4HAVER,4HAGE /,XMA/4HMAXI,4HMUM /                            OT3 0160
      DATA DNA/4HNODE,4HYEAR/                                               OT3 0170
C                                                                           OT3 0180
      IPTOD = 0                                                             OT3 0190
      IPTOU = 0                                                             OT3 0200
      IPTOI = 0                                                             OT3 0210
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      IPTOD = 0                                                         OT3 0220
      IPTOS = 0                                                         OT3 0230
      IPTOL = 0                                                         OT3 0240
      IPTOG = 0                                                         OT3 0250
C                                                                       OT3 0260
C                              STEP 01                                  OT3 0270
C                              PRINT OUT YEARLY DATA FOR ALL NODES      OT3 0280
C                                                                       OT3 0290
      DO 100 KY = 1,NYEAR                                               OT3 0300
         WRITE (KOUT,130) TITLE,DNA(2),KY,DNA(1)                        OT3 0310
      DO 100 J = 1,NJ                                                   OT3 0320
  100 WRITE (KOUT,160) J,(TOTLS(J,KY,N),N = 1,2),TOTLS(J,KY,4),TOTLS(J,KOT3 0330
     1Y,8),TOTLS(J,KY,6),(TOTLS(J,KY,N),N = 11,12)                      OT3 0340
C                                                                       OT3 0350
C                                                                       OT3 0360
C                              STEP 02                                  OT3 0370
C                              PRINT OUT NODE DATA FOR ALL YEARS        OT3 0380
C                                                                       OT3 0390
      DO 120 J = 1,NJ                                                   OT3 0400
         WRITE (KOUT,130) TITLE,DNA(1),J,DNA(2)                         OT3 0410
         DO 110 KY = 1,NYEAR                                            OT3 0420
            WRITE (KOUT,160) KY,(TOTLS(J,KY,N),N = 1,2),TOTLS(J,KY,4),TOOT3 0430
     1      TLS(J,KY,8),TOTLS(J,KY,6),(TOTLS(J,KY,N),N = 11,12)         OT3 0440
C                                                                       OT3 0450
            IPTOB = IPTOB + TOTLS(J,KY,1)                               OT3 0460
            IPTOU = IPTOU + TOTLS(J,KY,2)                               OT3 0470
            IPTOD = IPTOD + TOTLS(J,KY,4)                               OT3 0480
            IPTOS = IPTOS + TOTLS(J,KY,8)                               OT3 0490
            IPTOE = IPTOE + TOTLS(J,KY,6)                               OT3 0500
            IPTOL = IPTOL + TOTLS(J,KY,11)                              OT3 0510
            IPTOG = IPTOG + TOTLS(J,KY,12)                              OT3 0520
C                                                                       OT3 0530
  110    CONTINUE                                                       OT3 0540
         WRITE (KOUT,180) IPTOU,IPTOD,IPTOS,IPTOE,IPTOL                 OT3 0550
C                                                                       OT3 0560
C                              STEP 03                                  OT3 0570
C                              FIND YEARLY AVERAGES                     OT3 0580
C                                                                       OT3 0590
         IPTOU = IPTOU/NYEAR                                            OT3 0600
 SUBROUTINE OUT3       73/73  OPT=2 TRACE                 FTN 4.6+452        79/05/10. 13.11.59

         IPTOD = IPTOD/NYEAR                                            OT3 0610
         IPTOS = IPTOS/NYEAR                                            OT3 0620
         IPTOE = IPTOE/NYEAR                                            OT3 0630
         IPTOL = IPTOL/NYEAR                                            OT3 0640
C                                                                       OT3 0650
         WRITE (KOUT,190) IPTOU,IPTOD,IPTOS,IPTOE,IPTOL                 OT3 0660
C                                                                       OT3 0670
         IPTOB = 0                                                      OT3 0680
         IPTOU = 0                                                      OT3 0690
         IPTOD = 0                                                      OT3 0700
         IPTOS = 0                                                      OT3 0710
         IPTOE = 0                                                      OT3 0720
         IPTOL = 0                                                      OT3 0730
         IPTOG = 0                                                      OT3 0740
  120 CONTINUE                                                          OT3 0750
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      KY = 100000                                                       OT3 0760
      WRITE (KOUT,130) TITLE,DNA(2),KY,DNA(2)                           OT3 0770
  130 FORMAT (1H1/20X,20A4//20X,35HSIMULATION PERIOD TOTAL SUMMARY BY ,AOT3 0780
     14,I3//5X,A4,13H START. STRG.,13H  UNREG. FLOW,13H      DEMANDS,13HOT3 0790
     2    SHORTAGES,13H  EVAPORATION,13H  SYSTEM LOSS,13H ENDING STRG.) OT3 0800
C                                                                       OT3 0810
      DO 170 KY = 1,NYEAR                                               OT3 0820
         DO 150 J = 2,NJ                                                OT3 0830
            DO 140 N = 1,12                                             OT3 0840
               TOTLS(1,KY,N) = TOTLS(1,KY,N) + TOTLS(J,KY,N)            OT3 0850
  140       CONTINUE                                                    OT3 0860
  150    CONTINUE                                                       OT3 0870
C                                                                       OT3 0880
C                               STEP 04                                 OT3 0890
C                               PRINT OVERALL SYSTEM BY YEAR            OT3 0900
C                                                                       OT3 0910
         WRITE (KOUT,160) KY,(TOTLS(1,KY,N),N = 1,2),TOTLS(1,KY,4),TOTLSOT3 0920
     1   (1,KY,8),TOTLS(1,KY,6),(TOTLS(1,KY,N),N = 11,12)               OT3 0930
  160 FORMAT (5X,I4,7I13)                                               OT3 0940
         IPTOB = IPTOB + TOTLS(1,KY,1)                                  OT3 0950
         IPTOU = IPTOU + TOTLS(1,KY,2)                                  OT3 0960
         IPTOD = IPTOD + TOTLS(1,KY,4)                                  OT3 0970
         IPTOS = IPTOS + TOTLS(1,KY,8)                                  OT3 0980
         IPTOE = IPTOE + TOTLS(1,KY,6)                                  OT3 0990
         IPTOL = IPTOL + TOTLS(1,KY,11)                                 OT3 1000
         IPTOG = IPTOG + TOTLS(1,KY,12)                                 OT3 1010
  170 CONTINUE                                                          OT3 1020
C                                                                       OT3 1030
      WRITE (KOUT,180) IPTOU,IPTOD,IPTOS,IPTOE,IPTOL                    OT3 1040
  180 FORMAT (//6X,13HPERIOD TOTALS,3X,5I13)                            OT3 1050
C                                                                       OT3 1060
      IPTOU = IPTOU/NYEAR                                               OT3 1070
      IPTOD = IPTOD/NYEAR                                               OT3 1080
      IPTOS = IPTOS/NYEAR                                               OT3 1090
      IPTOE = IPTOE/NYEAR                                               OT3 1100
      IPTOL = IPTOL/NYEAR                                               OT3 1110
C                                                                       OT3 1120
C                               STEP 05                                 OT3 1130
C                               PRINT OUT AVERAGE TOTALS                OT3 1140
C                                                                       OT3 1150
      WRITE (KOUT,190) IPTOU,IPTOD,IPTOS,IPTOE,IPTOL                    OT3 1160
  190 FORMAT (//4X,15HPERIOD AVERAGES,3X,5I13)                          OT3 1170
      DO 210 L = 1,NL                                                   OT3 1180
         IF (L.EQ.1) WRITE (KOUT,200) TITLE,AVE,(I,I = 1,12)            OT3 1190
  200 FORMAT (1H1/20X,20A4/20X,17HSIMULATION PERIOD,1X,2A4,1X,13HMONTHLYOT3 1200
SUBROUTINE OUT3        73/73    OPT=2 TRACE                   FTN 4.6+462       79/05/10. 13.11.59

     1 FLOWS//1X,4X,6HSEASON,4X,12(I2,7X)/1X,8HLINK NO.)                OT3 1210
  210 WRITE (KOUT,220) L,(LNKAFL(L,I),I = 1,12)                         OT3 1220
  220 FORMAT (1X,5X,I2,3X,12I9)                                         OT3 1230
C                                                                       OT3 1240
      DO 230 L = 1,NL                                                   OT3 1250
         IF (L.EQ.1) WRITE (KOUT,200) TITLE,XMA,(I,I = 1,12)            OT3 1260
C                                                                       OT3 1270
  230 WRITE (KOUT,220) L,(LNKMX(L,I),I = 1,12)                          OT3 1280
      RETURN                                                            OT3 1290
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              C                                                                  OT3 1300
                    END                                                          OT3 1310
  SUBROUTINE RIGHT       73/73    OPT=2 TRACE                   FTN 4.6+452     79/05/10. 13.11.59

                    SUBROUTINE RIGHT (I,INDEX)                                   RHT 0010
                    COMMON /CONTRL/       KIN           , KOUT         , KAPE1        ,   RHT 0020
                   1          KAPE4                                              RHT 0030
                    COMMON /ADATA/        NR            , NN           , FESIBL       ,   RHT 0040
                   1          NTIME     , NA(500)       , NF(500)      , JSAVE(500)   ,   RHT 0050
                   2          ILO(500)  , NC(500)       , ISAVE(500)                 RHT 0060
                    COMMON    IUV(84)   , LABL(84)      , NODE(84)     , MIDL(84)     ,   RHT 0070
                   1          KOS(1000) , MIR(1000)                                  RHT 0080
                    COMMON    JUV(1000)                                              RHT 0090
                    MID = MIDL(I)                                                    RHT 0100
                    IA = NODE(I)                                                     RHT 0110
                    DO 100 II = IA,MID                                               RHT 0120
                       IF (MIR(II) - INDEX) 100,130,100                              RHT 0130
                100 CONTINUE                                                         RHT 0140
                    KWAY = 1                                                         RHT 0150
                110 WRITE (KOUT,160) I,INDEX,KWAY                                    RHT 0160
                    IFROM = NODE(I)                                                  RHT 0170
                    ITO = NODE(I + 1) - 1                                            RHT 0180
                    WRITE (KOUT,120) IFROM,MIDL(I),ITO,(K,MIR(K),K = IFROM,ITO)      RHT 0190
                120 FORMAT (3I6/(20I6))                                              RHT 0200
                    RETURN                                                           RHT 0210
                130 ITEMP = MIR(MID)                                                 RHT 0220
                    MIR(MID) = INDEX                                                 RHT 0230
                    MIR(II) = ITEMP                                                  RHT 0240
                    MIDL(I) = MID - 1                                                RHT 0250
                    RETURN                                                           RHT 0260
                    ENTRY LEFT                                                       RHT 0270
                    MID = MIDL(I) + 1                                                RHT 0280
                    IB = NODE(I + 1) - 1                                             RHT 0290
                    DO 140 II = MID,IB                                               RHT 0300
                       IF (MIR(II) - INDEX) 140,150,140                              RHT 0310
                140 CONTINUE                                                         RHT 0320
                    KWAY = 2                                                         RHT 0330
                    GO TO 110                                                        RHT 0340
                150 ITEMP = MIR(MID)                                                 RHT 0350
                    MIR(MID) = INDEX                                                 RHT 0360
                    MIR(II) = ITEMP                                                  RHT 0370
                    MIDL(I) = MID                                                    RHT 0380
                    RETURN                                                           RHT 0390
                160 FORMAT (5H NODE,I5,5H  ARC,I5,16H  LOST ON SHIFT ,I4,4H LOC,I4)  RHT 0400
                    ENTRY DUMPO                                                      RHT 0410
                    ID = INDEX                                                       RHT 0420
                    NLINES = I                                                       RHT 0430
                    WRITE (KOUT,210) ID                                              RHT 0440
                    DO 190 M = 1,NLINES                                              RHT 0450
                       N = M + NR                                                    RHT 0460
                       I = NA(N)                                                     RHT 0470
                       J = NA(M)                                                     RHT 0480
                       L = ILO(M)                                                    RHT 0490
                       K = JSAVE(M)                                                  RHT 0500
                       KOST = ISAVE(M)                                               RHT 0510
                       KBAR = KOS(M)                                                 RHT 0520
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             IFLOW = K - MC(M)                                                  RHT 0530
             IF (IFLOW.LT.L.OR.IFLOW.GT.K) WRITE (KOUT,220)                    RHT 0540
             IF (KBAR) 170,190,180                                              RHT 0550
      170    IF (IFLOW.LT.K) WRITE (KOUT,230)                                   RHT 0560
             GO TO 190                                                          RHT 0570
      180    IF (IFLOW.GT.L) WRITE (KOUT,230)                                   RHT 0580
      190 WRITE (KOUT,200) M,I,J,L,K,IFLOW,KOST,KBAR                            RHT 0590
      200 FORMAT (3I5,3I10,5X,2I10)                                             RHT 0600
SUBROUTINE RIGHT      73/73   OPT=2 TRACE                  FTN 4.6+452       79/05/10. 13.11.59

      210 FORMAT (71H1 ARC     I     J          L          K        IFLOW       RHT 0610
        1  KOST       KBAR,I15/)                                                RHT 0620
      220 FORMAT (39H THE FOLLOWING ARC IS PRIMAL INFEASIBLE)                   RHT 0630
      230 FORMAT (37H THE FOLLOWING ARC IS DUAL INFEASIBLE)                     RHT 0640
          RETURN                                                                RHT 0650
    C                                                                           RHT 0660
          END                                                                   RHT 0670
SUBROUTINE RTFLOW     73/73   OPT=2 TRACE                  FTN 4.6+452       79/05/10. 13.11.59

          SUBROUTINE RTFLOW (MON,IY,JFLAG2,ICONV,JMONY,L7,L8)                   RTF 0010
          COMMON /CONTRL/        KIN           , KOUT         , KAPE1       ,   RTF 0020
        1         KAPE4                                                         RTF 0030
          INTEGER                FLOW          , COST                           RTF 0040
          COMMON /ADATA/         NARC          , NMAX         , FESIBL      ,   RTF 0050
        1         NTIME        , NT(500)       , NF(500)      , HI(500)     ,   RTF 0060
        2         LO(500)      , FLOW(500)     , COST(500)                      RTF 0070
          COMMON /R1/            NEQU          , NLAGS        , A(10,15)    ,   RTF 0080
        1         NDNEQU(10)   , IRTFF(10,15), JRTFT(10)      , IRTF(10,240),   RTF 0090
        2         IDIVL(10,15), IRTL(10,15)                                     RTF 0100
          DIMENSION              IADD(10,15) , IR1(10)        , IPASTD(40,240), RTF 0110
        1         IDIF(10)                                                      RTF 0120
          DATA IPASTD/9600*0/                                                   RTF 0130
          DO 110 I = 1,10                                                       RTF 0140
             DO 100 II = 1,15                                                   RTF 0150
                IADD(I,II) = 0                                                  RTF 0160
      100    CONTINUE                                                           RTF 0170
      110 CONTINUE                                                              RTF 0180
          DO 120 L = L7,L8                                                      RTF 0190
             JN = NF(L)                                                         RTF 0200
             IPASTD(JN,JMONY) = FLOW(L)                                         RTF 0210
      120 CONTINUE                                                              RTF 0220
    C                                                                           RTF 0230
          IF (ICONV.EQ.1) GO TO 140                                             RTF 0240
          DO 130 I = 1,NEQU                                                     RTF 0250
             IR1(I) = 0                                                         RTF 0260
      130 CONTINUE                                                              RTF 0270
          ICOUNT = 0                                                            RTF 0280
      140 ICOUNT = ICOUNT + 1                                                   RTF 0290
          IF (JMONY.LE.NLAGS) GO TO 260                                         RTF 0300
          DO 170 I = 1,NEQU                                                     RTF 0310
             IDUMB = NDNEQU(I)                                                  RTF 0320
             DO 160 J = 1,IDUMB                                                 RTF 0330
                IXX = IRTFF(I,J)                                                RTF 0340
                IADD(I,1) = IADD(I,1) + IPASTD(IXX,JMONY)                       RTF 0350
                DO 150 N = 1,NLAGS                                              RTF 0360
                   IADD(I,N + 1) = IADD(I,N + 1) + IPASTD(IXX,JMONY - N)        RTF 0370
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  150         CONTINUE                                                   RTF 0380
  160      CONTINUE                                                      RTF 0390
  170 CONTINUE                                                           RTF 0400
      DO 190 I = 1,NEQU                                                  RTF 0410
         IRTF(I,JMONY) = INT(A(I,1) + A(I,2) * FLOAT(IADD(I,1)))         RTF 0420
         DO 180 N = 1,NLAGS                                              RTF 0430
            IRTF(I,JMONY) = IRTF(I,JMONY) + INT(A(I,N + 2) * FLOAT(IADD(RTF 0440
     1      I,N + 1))) + INT(A(I,NLAGS + N + 2) * FLOAT(IRTF(I,JMONY - IRTF 0450
     2      )))                                                          RTF 0460
  180    CONTINUE                                                        RTF 0470
  190 CONTINUE                                                           RTF 0480
  200 IF (ICONV.EQ.1) GO TO 220                                          RTF 0490
      DO 210 I = 1,NEQU                                                  RTF 0500
         IR1(I) = IRTF(I,JMONY)                                          RTF 0510
  210 CONTINUE                                                           RTF 0520
      JFLAG2 = 0                                                         RTF 0530
      ICONV = 1                                                          RTF 0540
      RETURN                                                             RTF 0550
  220 JFLAG2 = 1                                                         RTF 0560
      DO 230 I = 1,NEQU                                                  RTF 0570
         IDIF(I) = IABS(IR1(I) - IRTF(I,JMONY))                          RTF 0580
         IF (IDIF(I).LE.1) GO TO 230                                     RTF 0590
         JFLAG2 = 0                                                      RTF 0600
SUBROUTINE RTFLOW     73/73   OPT=2 TRACE                 FTN 4.6+452       79/05/10. 13.11.59

         IR1(I) = IRTF(I,JMONY)                                          RTF 0610
  230 CONTINUE                                                           RTF 0620
      IF (ICOUNT.GT.10) GO TO 240                                        RTF 0630
      RETURN                                                             RTF 0640
  240 WRITE (KOUT,250) MON,IY                                            RTF 0650
  250 FORMAT (1H-,50H*** WARNING  RETURN FLOW WILL NOT CONVERGE MONTH ,RTF 0660
     1I2,6H YEAR ,I2,/)                                                  RTF 0670
      JFLAG2 = 1                                                         RTF 0680
      RETURN                                                             RTF 0690
  260 NBACK = NLAGS - JMONY + 1                                          RTF 0700
      NPAST = NLAGS - NBACK                                              RTF 0710
      DO 320 I = 1,NEQU                                                  RTF 0720
         IDUMB = NONEQU(I)                                               RTF 0730
         DO 300 J = 1,IDUMB                                              RTF 0740
            IXX = IRTFF(I,J)                                             RTF 0750
            IADD(I,1) = IADD(I,1) + IPASTD(IXX,JMONY)                    RTF 0760
            IF (NPAST.EQ.0) GO TO 280                                    RTF 0770
            DO 270 N = 1,NPAST                                           RTF 0780
               IADD(I,N + 1) = IADD(I,N + 1) + IPASTD(IXX,JMONY - N)     RTF 0790
               IADD(I,NLAGS + N + 1) = IRTF(I,JMONY - N)                 RTF 0800
  270       CONTINUE                                                     RTF 0810
  280       DO 290 N = 1,NBACK                                           RTF 0820
               IADD(I,NPAST + N + 1) = IDIVL(I,N)                        RTF 0830
               IADD(I,NLAGS + NPAST + N + 1) = IRTL(I,N)                 RTF 0840
  290       CONTINUE                                                     RTF 0850
  300    CONTINUE                                                        RTF 0860
         IRTF(I,JMONY) = INT(A(I,1) + A(I,2) * FLOAT(IADD(I,1)))         RTF 0870
         DO 310 N = 1,NLAGS                                              RTF 0880
            IRTF(I,JMONY) = IRTF(I,JMONY) + INT(A(I,N + 2) * FLOAT(IADD(RTF 0890
     1      I,N + 1))) + INT(A(I,NLAGS + N + 2) * FLOAT(IADD(I,NLAGS + NRTF 0900
     2       + 1)))                                                      RTF 0910
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  310  CONTINUE                                         RTF 0920
  320 CONTINUE                                          RTF 0930
      GO TO 200                                         RTF 0940
      END                                               RTF 0950
SUBROUTINE SETNET    73/73   OPT=2 TRACE                FTN 4.6+452     79/05/10. 13.11.59

      SUBROUTINE SETNET                                        SET 0010
      COMMON /CONTRL/     KIN      , KOUT     , KAPE1     ,    SET 0020
     1     KAPE4                                               SET 0030
      COMMON /PARM/       NJ       , NRES     , NJUNC     ,    SET 0040
     1     NL           , NC       , NYEAR    , ND        ,    SET 0050
     2     NS           , IYEAR    , INN      , TITLE(20) ,    SET 0060
     3     NR           , NPAIRS                               SET 0070
      COMMON /LINK/       LNODE(50,2) , CMAX(50) , CMIN(50)    SET 0080
      COMMON /ADATA/      NARC     , NMAX     , FESIBL    ,    SET 0090
     1     NTIME        , NT(500)  , NF(500)  , HI(500)   ,    SET 0100
     2     LO(500)      , FLOW(500), COST(500)                 SET 0110
C                                                              SET 0120
C                          STEP 01                             SET 0130
C                          SET UP ALL FROM AND TO NODES BY LINK NO.  SET 0140
C                                                              SET 0150
      DO 100 L = 1,NL                                          SET 0160
        NF(L) = LNODE(L,1)                                     SET 0170
        NT(L) = LNODE(L,2)                                     SET 0180
  100 CONTINUE                                                 SET 0190
C                                                              SET 0200
C                          STEP 02                             SET 0210
C                          SET UP ALL INITIAL ARCS             SET 0220
C                                                              SET 0230
      NARC = NL                                                SET 0240
      N = NJ + 1                                               SET 0250
      DO 110 K = 1,NJ                                          SET 0260
        NARC = NARC + 1                                        SET 0270
        NF(NARC) = N                                           SET 0280
        NT(NARC) = K                                           SET 0290
  110 CONTINUE                                                 SET 0300
C                                                              SET 0310
C                          STEP 03                             SET 0320
C                          SET UP ALL DESIRED STORAGE ARCS     SET 0330
C                                                              SET 0340
      N = NJ + 2                                               SET 0350
      DO 120 K = 1,NJ                                          SET 0360
        NARC = NARC + 1                                        SET 0370
        NF(NARC) = K                                           SET 0380
        NT(NARC) = N                                           SET 0390
  120 CONTINUE                                                 SET 0400
C                                                              SET 0410
C                          STEP 04                             SET 0420
C                          SET UP ALL FINAL STORAGE ARCS       SET 0430
C                                                              SET 0440
      DO 130 K = 1,NJ                                          SET 0450
        NARC = NARC + 1                                        SET 0460
        NF(NARC) = K                                           SET 0470
        NT(NARC) = N                                           SET 0480
  130 CONTINUE                                                 SET 0490
C                                                              SET 0500
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      C                               STEP 05                                  SET 0510
      C                               SET UP ALL DEMAND ARCS                   SET 0520
      C                                                                        SET 0530
            N = NJ + 3                                                         SET 0540
            DO 140 K = 1,NJ                                                    SET 0550
               NARC = NARC + 1                                                 SET 0560
               NT(NARC) = N                                                    SET 0570
               NF(NARC) = K                                                    SET 0580
        140 CONTINUE                                                           SET 0590
      C                                                                        SET 0600
 SUBROUTINE SETNET     73/73   OPT=2 TRACE                 FTN 4.6+452       79/05/10. 13.11.59
      C                               STEP 06                                  SET 0610
      C                               SET UP ALL SPILL ARCS                    SET 0620
      C                                                                        SET 0630
            N = NJ + 4                                                         SET 0640
            DO 150 K = 1,NRES                                                  SET 0650
               NARC = NARC + 1                                                 SET 0660
               NT(NARC) = N                                                    SET 0670
               NF(NARC) = K                                                    SET 0680
        150 CONTINUE                                                           SET 0690
      C                                                                        SET 0700
      C                               STEP 07                                  SET 0710
      C                               SET UP MASS BALANCE ARCS                 SET 0720
      C                                                                        SET 0730
            NMAX = NJ + 5                                                      SET 0740
            NF(NARC + 1) = NJ + 2                                              SET 0750
            NT(NARC + 1) = NMAX                                                SET 0760
            NF(NARC + 2) = NJ + 4                                              SET 0770
            NT(NARC + 2) = NMAX                                                SET 0780
            NF(NARC + 3) = NJ + 3                                              SET 0790
            NT(NARC + 3) = NMAX                                                SET 0800
            NF(NARC + 4) = NMAX                                                SET 0810
            NT(NARC + 4) = NJ + 1                                              SET 0820
      C                                                                        SET 0830
            NARC = NARC + 4                                                    SET 0840
            RETURN                                                             SET 0850
      C                                                                        SET 0860
            END                                                                SET 0870
 SUBROUTINE SUPERK     73/73   OPT=2 TRACE                 FTN 4.6+452       79/06/10. 13.11.59

            SUBROUTINE SUPERK                                                  SPK 0010
            COMMON /CONTRL/       KIN         , KOUT        , KAPE1      ,     SPK 0020
           1        KAPE4                                                      SPK 0030
            COMMON /ADATA/        NR          , NN          , FESIBL     ,     SPK 0040
           1        NTIME       , NA(500)     , NF(500)     , JSAVE(500) ,     SPK 0050
           2        ILO(500)    , NC(500)     , ISAVE(500)                     SPK 0060
            COMMON  IWV(84)     , LABL(84)    , NODE(84)    , MIDL(84)   ,     SPK 0070
           1        KOS(1000)   , MIR(1000)                                    SPK 0080
            COMMON  JWV(1000)   , NSAVE(84)                                    SPK 0090
            LOGICAL FESIBL                                                     SPK 0100
            MAXA = 500                                                         SPK 0110
            FESIBL = .TRUE.                                                    SPK 0120
            INFIN = 100000000                                                  SPK 0130
            IFLOW = 0                                                          SPK 0140
            KLAB = 0                                                           SPK 0150
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      KPOT = 0                                                          SPK 0160
      KBRK = 0                                                          SPK 0170
      IP = 0                                                            SPK 0180
      NUMS = 0                                                          SPK 0190
      IPL = 0                                                           SPK 0200
      NR2 = NR * 2                                                      SPK 0210
      NN1 = NN + 1                                                      SPK 0220
      IF (NTIME.GT.1) GO TO 130                                         SPK 0230
      DO 100 I = 1,NN1                                                  SPK 0240
         NODE(I) = 0                                                    SPK 0250
  100 LABL(I) = 0                                                       SPK 0260
      DO 110 M = 1,NR                                                   SPK 0270
         N = M + NR                                                     SPK 0280
         I = NF(M)                                                      SPK 0290
         J = NA(M)                                                      SPK 0300
         IFLOW = NC(M)                                                  SPK 0310
         KOST = ISAVE(M)                                                SPK 0320
         NODE(I) = NODE(I) + 1                                          SPK 0330
         NODE(J) = NODE(J) + 1                                          SPK 0340
         NA(N) = I                                                      SPK 0350
         KOS(M) = KOST                                                  SPK 0360
         KOS(N) =  - KOST                                               SPK 0370
         NC(M) = JSAVE(M) - IFLOW                                       SPK 0380
         NC(N) = IFLOW - ILO(M)                                         SPK 0390
  110 CONTINUE                                                          SPK 0400
      DO 120 I = 1,NN1                                                  SPK 0410
  120 NSAVE(I) = NODE(I)                                                SPK 0420
      GO TO 160                                                         SPK 0430
  130 DO 140 I = 1,NN1                                                  SPK 0440
         NODE(I) = NSAVE(I)                                             SPK 0450
  140 LABL(I) = 0                                                       SPK 0460
      DO 150 M = 1,NR                                                   SPK 0470
         N = M + NR                                                     SPK 0480
         IFLOW = NC(M)                                                  SPK 0490
         KOST = ISAVE(M) + KOS(M)                                       SPK 0500
         KOS(M) = KOST                                                  SPK 0510
         KOS(N) =  - KOST                                               SPK 0520
         NC(M) = JSAVE(M) - IFLOW                                       SPK 0530
         NC(N) = IFLOW - ILO(M)                                         SPK 0540
  150 CONTINUE                                                          SPK 0550
  160 CONTINUE                                                          SPK 0560
C                                                                       SPK 0570
C     ******************************************************************SPK 0580
C                                                                       SPK 0590
C     SETUP SECTION                                                     SPK 0600
SUBROUTINE SUPERK     73/73   OPT=2 TRACE                     FTN 4.6+452        79/05/10. 13.11.59

C                                                                       SPK 0610
C     ******************************************************************SPK 0620
C                                                                       SPK 0630
      KL = 1                                                            SPK 0640
      DO 170 K = 1,NN1                                                  SPK 0650
         JK = NODE(K)                                                   SPK 0660
         NODE(K) = KL                                                   SPK 0670
         JUV(K) = KL                                                    SPK 0680
         KL = JK + KL                                                   SPK 0690
```

```
  170 MIDL(K) = KL - 1                                                  SPK 0700
      DO 290 L = 1,NR                                                   SPK 0710
         LL = L + NR                                                    SPK 0720
         J = NA(L)                                                      SPK 0730
         I = NA(LL)                                                     SPK 0740
         KOST = KOS(L)                                                  SPK 0750
         K = NC(L)                                                      SPK 0760
         LO =  - NC(LL)                                                 SPK 0770
C                                                                       SPK 0780
C     RIGHT=2   LEFT=1                                                  SPK 0790
C                                                                       SPK 0800
         MAIN = 2                                                       SPK 0810
         MIRROR = 2                                                     SPK 0820
         IF (KOST) 180,180,190                                          SPK 0830
  180    IF (K) 210,210,200                                             SPK 0840
  190    IF (LO) 240,250,200                                            SPK 0850
  200    MAIN = 1                                                       SPK 0860
  210    IF (KOST) 220,230,230                                          SPK 0870
  220    IF (K) 240,250,250                                             SPK 0880
  230    IF (LO) 240,250,250                                            SPK 0890
  240    MIRROR = 1                                                     SPK 0900
  250    IF (MAIN.EQ.2) GO TO 260                                       SPK 0910
         II = JUV(I)                                                    SPK 0920
         MIR(II) = L                                                    SPK 0930
         JUV(I) = II + 1                                                SPK 0940
         GO TO 270                                                      SPK 0950
  260    II = MIDL(I)                                                   SPK 0960
         MIR(II) = L                                                    SPK 0970
         MIDL(I) = II - 1                                               SPK 0980
  270    IF (MIRROR.EQ.2) GO TO 280                                     SPK 0990
         II = JUV(J)                                                    SPK 1000
         MIR(II) = LL                                                   SPK 1010
         JUV(J) = II + 1                                                SPK 1020
         GO TO 290                                                      SPK 1030
  280    II = MIDL(J)                                                   SPK 1040
         MIR(II) = LL                                                   SPK 1050
         MIDL(J) = II - 1                                               SPK 1060
  290 CONTINUE                                                          SPK 1070
C                                                                       SPK 1080
C     ******************************************************************SPK 1090
C                                                                       SPK 1100
C     GO - SUPERKILTER                                                  SPK 1110
C                                                                       SPK 1120
C     ******************************************************************SPK 1130
C                                                                       SPK 1140
      ND = INFIN                                                        SPK 1150
C                                                                       SPK 1160
C     MAIN LOOP (1000)                                                  SPK 1170
C                                                                       SPK 1180
      NR2 = NR * 2                                                      SPK 1190
      DO 1130 MAIN = 1,NR                                               SPK 1200
SUBROUTINE SUPERK     73/73   OPT=2 TRACE                  FTN 4.6+452       79/05/10. 13.11.59

         MAINR = MAIN + NR                                              SPK 1210
      DO 1130 MODE = 1,2                                                SPK 1220
         IF (MODE.EQ.2) GO TO 300                                       SPK 1230
```

```
      II = MAIN                                                   SPK 1240
      JZ = MAINM                                                  SPK 1250
      GO TO 310                                                   SPK 1260
  300 II = MAINM                                                  SPK 1270
      JZ = MAIN                                                   SPK 1280
  310 IF (NC(II)) 350,320,330                                     SPK 1290
  320 IF (NC(JZ)) 340,1120,1120                                   SPK 1300
  330 IF (KOS(II)) 340,320,320                                    SPK 1310
C                                                                 SPK 1320
C       IS,IT = START,END NODE NOS, JS,JT = ARC,MIRROR ARC NOS    SPK 1330
C             FOR ARC NEEDING FLOW INCREASE                       SPK 1340
C       WANT TO INCREASE FLOW, START LABLEING AT JJ               SPK 1350
C                                                                 SPK 1360
  340 IS = NA(JZ)                                                 SPK 1370
      JS = II                                                     SPK 1380
      IT = NA(II)                                                 SPK 1390
      JT = JZ                                                     SPK 1400
      GO TO 360                                                   SPK 1410
C                                                                 SPK 1420
C       WANT TO DECREASE FLOW, START LABELING AT II               SPK 1430
C                                                                 SPK 1440
  350 IT = NA(JZ)                                                 SPK 1450
      IS = NA(II)                                                 SPK 1460
      JS = JZ                                                     SPK 1470
      JT = II                                                     SPK 1480
C                                                                 SPK 1490
C     LABELING PROCEDURE                                          SPK 1500
C                                                                 SPK 1510
  360 IPL = 1                                                     SPK 1520
      IPLL = 1                                                    SPK 1530
      IPS = 0                                                     SPK 1540
      NUMS = 0                                                    SPK 1550
      LABL(IT) = JS                                               SPK 1560
      IWV(IPL) = IT                                               SPK 1570
  370 KLAB = KLAB + 1                                             SPK 1580
      GO TO 390                                                   SPK 1590
  380 IF (IPS - IPL) 390,640,390                                  SPK 1600
  390 IPS = IPS + 1                                               SPK 1610
      IA = IUV(IPS)                                               SPK 1620
      IB = NODE(IA)                                               SPK 1630
      IE = MIDL(IA)                                               SPK 1640
      IF (IB - IE) 400,400,380                                    SPK 1650
  400 DO 420 JJ = IB,IE                                           SPK 1660
         J = MIR(JJ)                                              SPK 1670
         NUNODE = NA(J)                                           SPK 1680
         IF (LABL(NUNODE)) 420,410,420                            SPK 1690
  410    LABL(NUNODE) = J                                         SPK 1700
         IPL = IPL + 1                                            SPK 1710
         IWV(IPL) = NUNODE                                        SPK 1720
         IF (NUNODE - IS) 420,430,420                             SPK 1730
  420 CONTINUE                                                    SPK 1740
      GO TO 380                                                   SPK 1750
C                                                                 SPK 1760
C     BREAKTHROUGH     BREAKTHROUGH     BREAKTHROUGH              SPK 1770
C                                                                 SPK 1780
  430 KBRK = KBRK + 1                                             SPK 1790
```

```
            IALPHA = INFIN                                            SPK 1800
C                                                                     SPK 1810
C     FIRST RETRACE                                                   SPK 1820
C                                                                     SPK 1830
C          IJ = PREDECESSOR ARC INDEX                                 SPK 1840
C          JI = MIRROR ARC INDEX                                      SPK 1850
C          K = JUU POINTER                                            SPK 1860
C          NEXT = PREDECESSOR NODE                                    SPK 1870
C                                                                     SPK 1880
         K = 0                                                        SPK 1890
         NOW = IS                                                     SPK 1900
  440    IJ = LABL(NOW)                                               SPK 1910
         JI = IJ - NR                                                 SPK 1920
         IF (JI) 450,450,460                                          SPK 1930
  450    JI = JI + NR2                                                SPK 1940
  460    NEXT = NA(JI)                                                SPK 1950
         K = K + 1                                                    SPK 1960
         IF (KOS(IJ)) 480,480,470                                     SPK 1970
  470    NET =  - NC(JI)                                              SPK 1980
         JUU(K) = NET                                                 SPK 1990
         GO TO 490                                                    SPK 2000
  480    NET = NC(IJ)                                                 SPK 2010
         JUU(K) = NET                                                 SPK 2020
  490    IALPHA = MIN0(IALPHA,NET)                                    SPK 2030
         IF (NEXT - IS) 500,510,500                                   SPK 2040
  500    NOW = NEXT                                                   SPK 2050
         GO TO 440                                                    SPK 2060
C                                                                     SPK 2070
C     SECOND RETRACE                                                  SPK 2080
C                                                                     SPK 2090
  510    K = 0                                                        SPK 2100
         NOW = IS                                                     SPK 2110
  520    IJ = LABL(NOW)                                               SPK 2120
         JI = IJ - NR                                                 SPK 2130
         IF (JI) 530,530,540                                          SPK 2140
  530    JI = JI + NR2                                                SPK 2150
  540    NEXT = NA(JI)                                                SPK 2160
         K = K + 1                                                    SPK 2170
         NC(IJ) = NC(IJ) - IALPHA                                     SPK 2180
         NET = NC(JI)                                                 SPK 2190
         NETNU = NET + IALPHA                                         SPK 2200
         NC(JI) = NETNU                                               SPK 2210
         IF (KOS(JI)) 580,550,580                                     SPK 2220
  550    IF (NET) 560,560,580                                         SPK 2230
  560    IF (NETNU) 580,580,570                                       SPK 2240
  570    CALL LEFT (NOW,JI)                                           SPK 2250
  580    IF (JUU(K) - IALPHA) 600,590,600                             SPK 2260
  590    CALL RIGHT (NEXT,IJ)                                         SPK 2270
  600    IF (NEXT - IS) 610,620,610                                   SPK 2280
  610    NOW = NEXT                                                   SPK 2290
         GO TO 520                                                    SPK 2300
C                                                                     SPK 2310
C     ERASE LABELS AND GO FOR O-K CHECK                               SPK 2320
C                                                                     SPK 2330
```

```
        620    DO 630 I = 1,IPL                                            SPK 2340
                  J = IWV(I)                                               SPK 2350
        630    LABL(J) = 0                                                 SPK 2360
               GO TO 310                                                   SPK 2370
      C                                                                    SPK 2380
      C     POTENTIAL CHANGE                                               SPK 2390
      C                                                                    SPK 2400
 SUBROUTINE SUPERK     73/73    OPT=2 TRACE               FTN 4.6+452        79/05/10. 13.11.59

        640    KPOT = KPOT + 1                                             SPK 2410
               KSET = NUMS                                                 SPK 2420
               NEWLAB = 0                                                  SPK 2430
               NUMS = 0                                                    SPK 2440
               IMTHRU = 0                                                  SPK 2450
               MIN = INFIN                                                 SPK 2460
               NEW = NONS                                                  SPK 2470
               NONS = MAXA + 1                                             SPK 2480
               IF (KSET) 740,740,650                                       SPK 2490
        650    IF (NEW - MAXA) 660,660,690                                 SPK 2500
      C                                                                    SPK 2510
      C       NON-S (L,L-) SET RECYCLING FILTER                            SPK 2520
      C                                                                    SPK 2530
        660    MAXNEW = MAXA + NEW                                         SPK 2540
               DO 680 L = NEW,MAXA                                         SPK 2550
                  K = MAXNEW - L                                           SPK 2560
                  KK = JWV(K)                                              SPK 2570
                  KKK = NA(KK)                                             SPK 2580
                  IF (LABL(KKK)) 680,670,680                               SPK 2590
        670       NONS = NONS - 1                                          SPK 2600
                  JWV(NONS) = KK                                           SPK 2610
        680    CONTINUE                                                    SPK 2620
      C                                                                    SPK 2630
      C       S-SET RECYCLING FILTER                                       SPK 2640
      C                                                                    SPK 2650
        690    DO 730 K = 1,KSET                                           SPK 2660
                  KK = JWV(K)                                              SPK 2670
                  KKK = NA(KK)                                             SPK 2680
                  IF (LABL(KKK)) 730,700,730                               SPK 2690
        700       IF (KOS(KK)) 720,720,710                                 SPK 2700
        710       NUMS = NUMS + 1                                          SPK 2710
                  JWV(NUMS) = KK                                           SPK 2720
                  MIN = MIN0(MIN,KOS(KK))                                  SPK 2730
                  GO TO 730                                                SPK 2740
        720       NONS = NONS - 1                                          SPK 2750
                  JWV(NONS) = KK                                           SPK 2760
        730    CONTINUE                                                    SPK 2770
        740    CONTINUE                                                    SPK 2780
               IF (IPLL - IPL) 750,750,830                                 SPK 2790
      C                                                                    SPK 2800
      C       FIND MIN(C-BAR) OVER SET S                                   SPK 2810
      C                                                                    SPK 2820
        750    DO 820 LL = IPLL,IPL                                        SPK 2830
                  L = IWV(LL)                                              SPK 2840
                  JMID = MIDL(L) + 1                                       SPK 2850
                  JRT = NODE(L + 1) - 1                                    SPK 2860
                  IF (JMID - JRT) 780,780,820                              SPK 2870
```

```
        760        DO 810 KK = JMID,JRT                                   SPK 2880
                      K = MIR(KK)                                         SPK 2890
                      I = NA(K)                                           SPK 2900
                      IF (LABL(I)) 810,770,810                            SPK 2910
        770           IF (NC(K)) 800,780,780                              SPK 2920
        780           IF (KOS(K)) 800,800,790                             SPK 2930
        790           NUMS = NUMS + 1                                     SPK 2940
                      JUU(NUMS) = K                                       SPK 2950
                      MIN = MIN0(MIN,KOS(K))                              SPK 2960
                      GO TO 810                                           SPK 2970
        800           NONS = NONS - 1                                     SPK 2980
                      JUU(NONS) = K                                       SPK 2990
        810        CONTINUE                                               SPK 3000
  SUBROUTINE SUPERK        73/73    OPT=2 TRACE            FTN 4.6+452      79/05/10. 13.11.59

        820     CONTINUE                                                  SPK 3010
        830     IPLL = IPL + 1                                            SPK 3020
                IF (NUMS) 840,840,890                                     SPK 3030
        840     FESIBL = .FALSE.                                          SPK 3040
                CALL DUMPO (NR,II)                                        SPK 3050
                WRITE (KOUT,880) IS,IT,II                                 SPK 3060
                WRITE (KOUT,850) (I,LABL(I),I = 1,NN)                     SPK 3070
                WRITE (KOUT,860) (I,IUU(I),I = 1,IPL)                     SPK 3080
                WRITE (KOUT,870) (JUU(I),I = NEW,MAXA)                    SPK 3090
        850 FORMAT (16H LABELS, BY NODE,/(5(I9,1H=,I10)))                 SPK 3100
        860 FORMAT (20H LABELED NODES (IUU),/(10I10))                     SPK 3110
        870 FORMAT (22H THE SET (L,L-), NON-S,/(10I10))                   SPK 3120
        880 FORMAT (4H0IS=,I5,6H   IT=,I5,10X,16HINFEASIBLE ARC =,I5)     SPK 3130
                RETURN                                                    SPK 3140
      C                                                                   SPK 3150
      C     UPDATE RELATIVE COSTS                                         SPK 3160
      C                                                                   SPK 3170
      C       UPDATE COST FOR SET S                                       SPK 3180
      C                                                                   SPK 3190
        890     DO 960 I = 1,NUMS                                         SPK 3200
                   IJ = JUU(I)                                            SPK 3210
                   JI = IJ - NR                                           SPK 3220
                   IF (JI) 900,900,910                                    SPK 3230
        900        JI = IJ + NR                                           SPK 3240
        910        KOST = KOS(IJ) - MIN                                   SPK 3250
                   KOS(IJ) = KOST                                         SPK 3260
                   KOS(JI) =  - KOST                                      SPK 3270
                   IF (KOST) 960,920,960                                  SPK 3280
        920        IF (NC(IJ)) 960,960,930                                SPK 3290
        930        NODEB = NA(IJ)                                         SPK 3300
                   CALL LEFT (NA(JI),IJ)                                  SPK 3310
                   IF (LABL(NODEB)) 960,940,960                           SPK 3320
        940        LABL(NODEB) = IJ                                       SPK 3330
                   IPL = IPL + 1                                          SPK 3340
                   IUU(IPL) = NODEB                                       SPK 3350
                   IF (NODEB - IS) 960,950,960                            SPK 3360
        950        INTHRU = 1                                             SPK 3370
        960     CONTINUE                                                  SPK 3380
      C                                                                   SPK 3390
      C       UPDATE COST FOR NON-S                                       SPK 3400
      C                                                                   SPK 3410
```

```
             IF (NONS - MAXA) 970,970,1050                               SPK 3420
       970   DO 1040 I = NONS,MAXA                                       SPK 3430
                IJ = JUU(I)                                              SPK 3440
                JI = IJ - NR                                             SPK 3450
                IF (JI) 980,980,990                                      SPK 3460
       980      JI = IJ + NR                                             SPK 3470
       990      KOSTA = KOS(IJ)                                          SPK 3480
                KOSTB = KOSTA - MIN                                      SPK 3490
                KOS(IJ) = KOSTB                                          SPK 3500
                KOS(JI) =  - KOSTB                                       SPK 3510
      C                                                                  SPK 3520
      C     CHECK FOR MIRROR LEAVING MU STATE                            SPK 3530
      C     CHECK LATER FOR COMBINING IF-CHECKS HERE                     SPK 3540
      C                                                                  SPK 3550
                IF (KOSTA) 1040,1000,1000                                SPK 3560
      1000      IF (KOSTB) 1010,1040,1040                                SPK 3570
      1010      IF (NC(IJ)) 1040,1020,1020                               SPK 3580
      1020      IF (NC(JI)) 1040,1040,1030                               SPK 3590
      1030      CALL RIGHT (NA(IJ),JI)                                   SPK 3600
SUBROUTINE SUPERK       73/73   OPT=2 TRACE          FTN 4.6+452      79/05/10. 13.11.59

      1040   CONTINUE                                                    SPK 3610
      C                                                                  SPK 3620
      C     OUT-OF-KILTER CHECK                                          SPK 3630
      C                                                                  SPK 3640
      1050   IF (NC(II)) 1080,1060,1070                                  SPK 3650
      1060   IF (NC(JZ)) 1080,1100,1100                                  SPK 3660
      1070   IF (KOS(II)) 1080,1060,1060                                 SPK 3670
      C                                                                  SPK 3680
      C     BREAKTHROUGH CHECK                                           SPK 3690
      C                                                                  SPK 3700
      1080   IF (IMTHRU) 1090,1090,430                                   SPK 3710
      1090   IF (IPS - IPL) 370,640,370                                  SPK 3720
      1100   DO 1110 I = 1,IPL                                           SPK 3730
                J = IUU(I)                                               SPK 3740
      1110   LABL(J) = 0                                                 SPK 3750
      1120   CONTINUE                                                    SPK 3760
      1130 CONTINUE                                                      SPK 3770
           TOTAL = 0.                                                    SPK 3780
           DO 1140 I = 1,NR                                              SPK 3790
             KOS(I) = KOS(I) - ISAVE(I)                                  SPK 3800
             NC(I) = JSAVE(I) - NC(I)                                    SPK 3810
             TOTAL = TOTAL + NC(I) * ISAVE(I)                            SPK 3820
      1140 CONTINUE                                                      SPK 3830
           RETURN                                                        SPK 3840
      C                                                                  SPK 3850
           END                                                           SPK 3860
```

APPENDIX E

ACKNOWLEDGMENT OF RESEARCH BY WATER COMMISIONER, DISTRICT NO. 3

1876

DIVISION OF WATER RESOURCES

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On behalf of the Division of Water Resources I wish to compliment John Shafer and others on his thesis for the improved management of the waters in the high mountain reservoirs for the benefit of fishing and recreation interests without causing injury to irrigators.

Much of the data was obtained from the records of the Division of Water Resources compiled by myself and previous water commissioners. It is encouraging to have interested parties affirm the management of the water in the Poudre River for multipurpose use.

John W Neutze
John W. Neutze
Water Commissioner, District No. 3

Colorado Water Resources
Research Institute
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