AN INTERACTIVE RIVER BASIN WATER MANAGEMENT MODEL: SYNTHESIS AND APPLICATION

by

John M. Shafer

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AN INTERACTIVE RIVER BASIN WATER MANAGEMENT MODEL: SYNTHESIS AND APPLICATION

By

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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 multi-
purpose water management policy. The model is designed for the analysis
of water availabilities throughout a river basin over extended time peri-
ods. 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 institu-
tional dictates governing water allocation, such as water rights priori-
ties. Conveyance losses and return flows resulting from irrigation
practices can also be considered by MODSIM.

MODSIM is interfaced with an interactive conversational data manage-
ment 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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Summer, 1979
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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 snow-melt 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 sensitivities 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 especially 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,"

2. **HEC-3**: U.S. Army Corps of Engineers, "HEC-3 reservoir system
   analysis for conservation--user's manual," Hydrologic

3. **NW01**: R.W. Ribbens, "Program NW01 river network program--user's

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, Massachusetts
   Institute of Technology, August, 1977.

5. **MITSIM-E**: R.P. Schreiber, "A digital simulation model for con-
   junctive 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--


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

<table>
<thead>
<tr>
<th>Model Purpose:</th>
<th>Adjustment of various water flows throughout a river basin according to a set of weighted data to represent actual conditions in area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Type:</td>
<td>Hydrologic budget (allocation)</td>
</tr>
<tr>
<td>Type of Model:</td>
<td>Accounting</td>
</tr>
<tr>
<td>Problem Formulation</td>
<td>All inflows and outflows are determined for each canal system</td>
</tr>
<tr>
<td>Solution Approach:</td>
<td>Mass balance on each irrigation portion of basin</td>
</tr>
<tr>
<td>Application:</td>
<td>Specifically designed for Cache la Poudre River Basin, Colorado</td>
</tr>
<tr>
<td>Deterministic vs Stochastic:</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Time Period:</td>
<td>Monthly</td>
</tr>
<tr>
<td>Data Requirements:</td>
<td>Extensive land use inventory</td>
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<td></td>
<td>All inflows</td>
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<tr>
<td></td>
<td>Canal diversions</td>
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<tr>
<td></td>
<td>Consumptive loss coefficients</td>
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<td></td>
<td>Root zone flows</td>
</tr>
<tr>
<td>Output:</td>
<td>Detailed report of budget (including return flow, consumptive loss, etc.) for each canal system in basin</td>
</tr>
<tr>
<td>Major Assumptions:</td>
<td>Constant crop acreages under each canal</td>
</tr>
<tr>
<td></td>
<td>Uniform application and runoff of irrigation water</td>
</tr>
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<td></td>
<td>All errors accumulated in groundwater flows</td>
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<tr>
<td>Advantages:</td>
<td>Detailed consideration of irrigation sector</td>
</tr>
<tr>
<td></td>
<td>Considers mass balance for every irrigation canal in basin</td>
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<td></td>
<td>Return flows</td>
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<tr>
<td>Limitations:</td>
<td>Lacks flexibility of application to other river basins</td>
</tr>
<tr>
<td></td>
<td>Not designed for long-term planning studies</td>
</tr>
<tr>
<td></td>
<td>No detailed resolution of distributional aspects of river basin</td>
</tr>
<tr>
<td></td>
<td>All storage aggregated</td>
</tr>
</tbody>
</table>
Table II.2. MODEL: HEC-3

<p>| 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 |</p>
<table>
<thead>
<tr>
<th>Table II.3. MODEL: NWOL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model Purpose:</strong></td>
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<tr>
<td><strong>Problem Type:</strong></td>
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<tr>
<td><strong>Type of Model:</strong></td>
</tr>
<tr>
<td><strong>Problem Formulation:</strong></td>
</tr>
<tr>
<td><strong>Solution Approach:</strong></td>
</tr>
<tr>
<td><strong>Application:</strong></td>
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<tr>
<td><strong>Deterministic vs Stochastic:</strong></td>
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<tr>
<td><strong>Time Period:</strong></td>
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<tr>
<td><strong>Data Requirements:</strong></td>
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<tr>
<td><strong>Output:</strong></td>
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<tr>
<td><strong>Major Assumptions:</strong></td>
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<tr>
<td><strong>Advantages:</strong></td>
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<tr>
<td><strong>Limitations</strong></td>
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<tr>
<td><strong>Model Purpose:</strong></td>
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<tr>
<td><strong>Problem Type:</strong></td>
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<tr>
<td><strong>Type of Model:</strong></td>
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<tr>
<td><strong>Problem Formulation:</strong></td>
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<tr>
<td><strong>Solution Approach:</strong></td>
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<td><strong>Application:</strong></td>
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<tr>
<td><strong>Deterministic vs Stochastic:</strong></td>
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<td><strong>Time Period:</strong></td>
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<td><strong>Data Requirements:</strong></td>
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<td><strong>Output:</strong></td>
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<td><strong>Major Assumptions:</strong></td>
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<td><strong>Advantages:</strong></td>
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<td><strong>Limitations:</strong></td>
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</table>
| 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  
<p>|                               | • Cannot consider complex surface water system |</p>
<table>
<thead>
<tr>
<th>Table 11.6. MODEL: SIMYLD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model Purpose:</strong></td>
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<tr>
<td><strong>Problem Type:</strong></td>
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<tr>
<td><strong>Type of Model:</strong></td>
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<tr>
<td><strong>Problem Formulation:</strong></td>
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<tr>
<td><strong>Solution Approach:</strong></td>
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<td><strong>Application:</strong></td>
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<tr>
<td><strong>Deterministic vs Stochastic:</strong></td>
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<td><strong>Time Period:</strong></td>
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<td><strong>Data Requirements:</strong></td>
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<td><strong>Output:</strong></td>
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<td><strong>Major Assumptions:</strong></td>
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<td><strong>Limitations:</strong></td>
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</tbody>
</table>
Table II.7. MODEL: WADIST

<table>
<thead>
<tr>
<th>Feature</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Purpose:</td>
<td>Irrigation demand allocation</td>
</tr>
<tr>
<td>Problem Type:</td>
<td>Allocation</td>
</tr>
<tr>
<td>Type of Model:</td>
<td>Accounting</td>
</tr>
<tr>
<td>Problem Formulation:</td>
<td>Control point concept</td>
</tr>
<tr>
<td>Solution Approach:</td>
<td>Distribution of virgin flow according to prescribed entitlement</td>
</tr>
<tr>
<td>Application:</td>
<td>Designed for Colorado water law</td>
</tr>
<tr>
<td></td>
<td>Test case: Poudre River Basin</td>
</tr>
<tr>
<td>Deterministic vs Stochastic:</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Time Period:</td>
<td>Daily</td>
</tr>
<tr>
<td>Data Requirements:</td>
<td>Diversion data</td>
</tr>
<tr>
<td></td>
<td>Reservoir data</td>
</tr>
<tr>
<td></td>
<td>Daily flow data</td>
</tr>
<tr>
<td>Output:</td>
<td>Summary output of transfers to each canal system including debits and credits and sources of supply</td>
</tr>
<tr>
<td>Major Assumptions:</td>
<td>Constant water requirements</td>
</tr>
<tr>
<td></td>
<td>Constant loss factor</td>
</tr>
<tr>
<td></td>
<td>Surface return flow has one-day lag</td>
</tr>
<tr>
<td>Advantages:</td>
<td>Conveyance losses considered</td>
</tr>
<tr>
<td></td>
<td>Crop water requirements approximated</td>
</tr>
<tr>
<td></td>
<td>Return flows calculated</td>
</tr>
<tr>
<td>Limitations:</td>
<td>Distribution criteria must be predetermined</td>
</tr>
<tr>
<td></td>
<td>Cannot readily consider varying water rights structure</td>
</tr>
<tr>
<td></td>
<td>Daily time interval not suited for long-term planning studies</td>
</tr>
<tr>
<td></td>
<td>Specific to particular river basin</td>
</tr>
<tr>
<td></td>
<td>Constant demands for water</td>
</tr>
<tr>
<td>Model Purpose:</td>
<td>Watershed hydrology simulation</td>
</tr>
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<td>---------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Problem Type:</td>
<td>Allocation</td>
</tr>
<tr>
<td>Type of Model:</td>
<td>Watershed simulation with parameter optimization</td>
</tr>
<tr>
<td>Problem Formulation:</td>
<td>Decomposes river system into subbasins with all activity in subbasin aggregated</td>
</tr>
<tr>
<td>Solution Approach:</td>
<td>Mass balance from subbasin to subbasin</td>
</tr>
<tr>
<td>Application:</td>
<td>Upper Jordan River Drainage, Utah</td>
</tr>
<tr>
<td>Deterministic vs Stochastic:</td>
<td>Deterministic</td>
</tr>
<tr>
<td>Time Period:</td>
<td>Monthly</td>
</tr>
<tr>
<td>Data Requirements:</td>
<td>Temperature, precipitation, groundwater inflows, gaged flows, reservoir characteristics, irrigation diversions, imports, exports</td>
</tr>
<tr>
<td>Output:</td>
<td>Storage change, precipitation, snowmelt, and inflow &amp; outflow for each subbasin</td>
</tr>
<tr>
<td>Major Assumptions:</td>
<td>Subbasins are gaged at upstream and downstream boundaries</td>
</tr>
<tr>
<td>Advantages:</td>
<td>Considers basic hydrologic inputs to system</td>
</tr>
<tr>
<td></td>
<td>Capable of considering very large river basin systems</td>
</tr>
<tr>
<td></td>
<td>Groundwater consideration</td>
</tr>
<tr>
<td>Limitations:</td>
<td>Does not consider distributive complexities with any detail</td>
</tr>
<tr>
<td></td>
<td>No optimizing capability</td>
</tr>
<tr>
<td></td>
<td>No conveyance losses</td>
</tr>
<tr>
<td></td>
<td>Cannot consider complex channel morphology</td>
</tr>
</tbody>
</table>
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.

\[
\text{minimize} \quad \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij} q_{ij} \tag{III.1}
\]

subject to:

\[
\sum_{i=1}^{N} q_{ij} - \sum_{i=1}^{N} q_{ji} = 0 \quad ; \quad j=1,\ldots,N \tag{III.2}
\]

\[
\ell_{ij} \leq q_{ij} \leq u_{ij} \quad ; \quad \text{for } i,j=1,\ldots,N \tag{III.3}
\]

\[
\ell_{ij} > 0
\]

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 \( j \)
- \( \ell_{ij} \) = 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:

\[
R = \sum_{i=1}^{N} S_{it} + \sum_{i=1}^{N} I_{i,t+1}
\]  

(III.4)

\[
W = \sum_{i=1}^{N} S_{imax}
\]  

(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:

\[
LB = x_1 W \\
UB = x_2 W
\]  

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:** \( LB < R < UB \)
- **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-storage) 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:

\[
(w_{i,d})_t = - [1000 - (DEM_{i,t} \cdot 10)]
\]  

(III.8)

where:

\[
(w_{i,d})_t = \text{cost of transporting one unit of water from real node } i \text{ to artificial demand node } d \text{ during month } t
\]
Figure III.1. Schematic diagram of linkage configuration for MODSIM.
DEM_{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 (DEM_{i,t}) increases, i.e. (DEM_{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 DEM_{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.

\[
(w_{i,ds})_t = - [1000 - (OPRP_{i,t} \cdot 10)] 
\]  

(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:

\[ \#\text{ARCS} = N_L + 4N_D + N_S + N_B \]

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 organiza-
tion 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.
    FIN,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.
**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 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? 5000
   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 .093 .093 .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 .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
  DIVERGIONS; FOLLOWED BY RETURN FLOWS
  EXAMPLE FOR 1 MONTH LAG
  A1+A2#D(T)+A3#D(T-1)+A4#RT-1)
  ? 789 .157 .0482 .6589

FOR INITIAL CALCULATIONS ENTER:
TOTAL DITCH DIVERSION AND TOTAL RETURN
FLOW OBSERVED FOR TIME PERIOD ZERO MINUS
11 ? 200 85

SAVE FILE AS PERMANENT FILE (YES OR NO)? YES
ENTER: UP TO 7 CHARACTER FILE NAME? CDATA
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 0 000.000.000.000.000.000.000.000.000.000.000.000.000.
RANK 3 25
DEMAND 4 0 0 0 000.000.000.000.000.000.000.000.000.000.000.000.000.
RANK 4 35
IMPORT 2
YEAR 1 2400.083.083.083.083.083.083.083.083.083.083.083.083.083.
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 2 400.000.000.000.000.000.000.000.000.000.000.000.000.000.
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.
****************** PROGRAM ADATA ******************

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 shortages
      unregulated inflows system loss
      upstream spills water pumped into a node
      demand water pumped from a node
      surface area end-of-month storage (actual)
      evaporation loss end-of-month storage (desired)
      downstream spills
   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 MODSIM

**Simulation Year 1**

**Calendar Year 1979**

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<tr>
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<th>INITIAL STORAGE</th>
<th>RESERVOIR NO. 1 RES 1</th>
<th>MAX. CAPACITY</th>
<th>SURFACE</th>
<th>EVAP</th>
<th>EVAP</th>
<th>DRAINAGE</th>
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**YEAR TOTALS:**

| RESERVOIR NO. 1 RES 1 | 11750 | 0 | 0 | 114 | 5537 | 0 | 0 |

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**YEAR TOTALS:**

| RESERVOIR NO. 2 RES 2 | 2300 | 0 | 0 | 3520 | 0 | 0 |

---

*Figure IV.5. Example output from Program MODSIM.*
### Volumetric Flow in Link 1

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**Total Flow Calculated**

**Return Flow Equation No. 1**

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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>
<thead>
<tr>
<th>SOURCE</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Inflows (Snowmelt, Precipitation)</td>
<td>44</td>
</tr>
<tr>
<td>Pumped Groundwater</td>
<td>33</td>
</tr>
<tr>
<td>CBT</td>
<td>17</td>
</tr>
<tr>
<td>Other Imported Waters (Transbasin Diversions)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

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. 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)

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean Annual Supply (acre-feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBT</td>
<td>7,203</td>
</tr>
<tr>
<td>Water Supply &amp; Storage Co.</td>
<td>833</td>
</tr>
<tr>
<td>North Poudre Irrigation Co.</td>
<td>4,190</td>
</tr>
<tr>
<td>Direct Flow</td>
<td>12,295*</td>
</tr>
<tr>
<td></td>
<td>24,519</td>
</tr>
</tbody>
</table>

*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)

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

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.*

*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 mouth 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>
<thead>
<tr>
<th>Reservoirs</th>
<th>Irrigation Ditches</th>
<th>Other Conveyances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Draw</td>
<td>Munroe Gravity Canal</td>
<td>Ft. Collins Pipeline</td>
</tr>
<tr>
<td>Joe Wright</td>
<td>Larimer &amp; Weld Canal</td>
<td>Charles Hansen Canal</td>
</tr>
<tr>
<td>Chambers Lake</td>
<td>Lake Canal</td>
<td>Timnath Reservoir Inlet</td>
</tr>
<tr>
<td>Horsetooth</td>
<td>New Cache la Poudre Canal</td>
<td>Rawhide Pipeline</td>
</tr>
<tr>
<td>North Poudre No. 6</td>
<td>Imports</td>
<td></td>
</tr>
<tr>
<td>Windsor</td>
<td>Imports</td>
<td>Michigan Ditch</td>
</tr>
<tr>
<td>Timnath</td>
<td></td>
<td>Grand River Ditch</td>
</tr>
<tr>
<td>Fossil Creek</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rawhide Cooling Pond</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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

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

<table>
<thead>
<tr>
<th>Link #</th>
<th>Maximum Flow (ac-ft/mo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15000</td>
</tr>
<tr>
<td>2</td>
<td>15000</td>
</tr>
<tr>
<td>3</td>
<td>15000</td>
</tr>
<tr>
<td>4</td>
<td>300000</td>
</tr>
<tr>
<td>5</td>
<td>300000</td>
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<td>6</td>
<td>300000</td>
</tr>
<tr>
<td>7</td>
<td>15000</td>
</tr>
<tr>
<td>8</td>
<td>300000</td>
</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>47</td>
<td>17689</td>
</tr>
</tbody>
</table>
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.
Table V.6. Typical Channel Capacities and Loss Coefficients

<table>
<thead>
<tr>
<th>Capacities</th>
<th>Capacity (acre-feet/month)</th>
<th>Loss (Percentage of Flow)</th>
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</thead>
<tbody>
<tr>
<td>Mainstream Cache 1a Poudre</td>
<td>300,000</td>
<td>5.0</td>
</tr>
<tr>
<td>Munroe Gravity Canal</td>
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<td>20.0-33.0</td>
</tr>
<tr>
<td>Hansen Supply Canal</td>
<td>91,000</td>
<td>---</td>
</tr>
<tr>
<td>Larimer and Weld Canal</td>
<td>60,667</td>
<td>20.0-33.0</td>
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<tr>
<td>Timnath Inlet</td>
<td>10,070</td>
<td>20.0-33.0</td>
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<tr>
<td>Lake Canal</td>
<td>9,100</td>
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<td>35,297</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Point</th>
<th>Timnath Reservoir</th>
<th>Fossil Creek Reservoir</th>
<th>Long Draw Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gage Ht (ft)</td>
<td>Area (ac)</td>
<td>Vol. (ac/ft)</td>
</tr>
<tr>
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<tr>
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<td>3.778</td>
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<td>13.22</td>
<td>196.00</td>
<td>1522.00</td>
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<tr>
<td>8</td>
<td>15.11</td>
<td>230.00</td>
<td>1988.00</td>
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<td>301.00</td>
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<td>569.00</td>
<td>8981.00</td>
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<tr>
<td>18</td>
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<td>609.00</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Gage Ht (ft)</th>
<th>Area (ac)</th>
<th>Vol. (ac/ft)</th>
<th>Gage Ht (ft)</th>
<th>Area (ac)</th>
<th>Vol. (ac/ft)</th>
<th>Gage Ht (ft)</th>
<th>Area (ac)</th>
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<td>62.22</td>
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<td>10519.00</td>
</tr>
</tbody>
</table>
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 \( (OPR_{i,t}) \) 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 evap-
oration 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 improve-
ment 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 lead-
ing 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 prior-
ities, 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 ($OPRP_{i,t}$)*

<table>
<thead>
<tr>
<th>Reservoir (i)</th>
<th>1973</th>
<th>1974</th>
<th>1975</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peterson</td>
<td>50</td>
<td>50</td>
<td>48</td>
</tr>
<tr>
<td>Barnes Meadow</td>
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<td>55</td>
<td>45</td>
</tr>
<tr>
<td>Big Beaver</td>
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<td>50</td>
<td>59</td>
</tr>
<tr>
<td>Commanche</td>
<td>55</td>
<td>50</td>
<td>59</td>
</tr>
<tr>
<td>Twin Lake</td>
<td>50</td>
<td>50</td>
<td>59</td>
</tr>
<tr>
<td>Worster</td>
<td>70</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td>Halligan</td>
<td>60</td>
<td>60</td>
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</tr>
<tr>
<td>Park Creek</td>
<td>70</td>
<td>70</td>
<td>48</td>
</tr>
<tr>
<td>N.P. #15</td>
<td>80</td>
<td>80</td>
<td>47</td>
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</tbody>
</table>

*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 $w_{i,t}$. 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 over-estimating 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 true 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)

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Water in Storage (Acre-Feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Draw</td>
<td>1174</td>
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<tr>
<td>Chambers Lake</td>
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</tr>
<tr>
<td>North Poudre No. 6</td>
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<tr>
<td>Fossil Creek</td>
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<td>Timnath</td>
<td>5455</td>
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<td>Windsor</td>
<td>9805</td>
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<tr>
<td>Horsetooth</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1973</td>
</tr>
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<td>-------</td>
<td>--------------</td>
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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.
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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)

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<td>River Diversion to Pipeline</td>
<td>776</td>
<td>796</td>
<td>816</td>
<td>750</td>
<td>748</td>
<td>834</td>
<td>1105</td>
<td>966</td>
<td>1196</td>
<td>1178</td>
<td>1034</td>
<td>1028</td>
<td>11,227</td>
</tr>
<tr>
<td>Transbasin</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td>587</td>
</tr>
<tr>
<td>TOTAL</td>
<td>826</td>
<td>796</td>
<td>822</td>
<td>754</td>
<td>764</td>
<td>858</td>
<td>1184</td>
<td>966</td>
<td>1261</td>
<td>1352</td>
<td>1472</td>
<td>1206</td>
<td>12,263</td>
</tr>
<tr>
<td>Horsetooth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>109</td>
</tr>
<tr>
<td>TOTAL</td>
<td>826</td>
<td>796</td>
<td>822</td>
<td>754</td>
<td>764</td>
<td>858</td>
<td>1184</td>
<td>966</td>
<td>1261</td>
<td>1352</td>
<td>1472</td>
<td>1206</td>
<td>12,263</td>
</tr>
<tr>
<td>(Demand at 21)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>340</td>
</tr>
<tr>
<td>2% to West Ft. Collins (Demand at 22)</td>
<td>17</td>
<td>16</td>
<td>16</td>
<td>15</td>
<td>17</td>
<td>17</td>
<td>30</td>
<td>30</td>
<td>47</td>
<td>42</td>
<td>39</td>
<td>28</td>
<td>314</td>
</tr>
<tr>
<td>Available at Ft. Collins</td>
<td>809</td>
<td>780</td>
<td>806</td>
<td>739</td>
<td>811</td>
<td>843</td>
<td>1486</td>
<td>1464</td>
<td>2291</td>
<td>2048</td>
<td>1916</td>
<td>1351</td>
<td>15,346</td>
</tr>
<tr>
<td>% Consumptive Loss</td>
<td>1.6</td>
<td>1.4</td>
<td>1.1</td>
<td>1.2</td>
<td>1.6</td>
<td>42.9</td>
<td>60.7</td>
<td>55.0</td>
<td>46.0</td>
<td>46.5</td>
<td>35.1</td>
<td>21.8</td>
<td></td>
</tr>
<tr>
<td>Consumptive Loss (Demand at 23)</td>
<td>13</td>
<td>11</td>
<td>9</td>
<td>9</td>
<td>13</td>
<td>362</td>
<td>902</td>
<td>805</td>
<td>1054</td>
<td>952</td>
<td>672</td>
<td>294</td>
<td>5,096</td>
</tr>
</tbody>
</table>
Table VI.8. Calculation of Adjusted Demand at Terminal Node - 1974 (Acre-Feet)

<table>
<thead>
<tr>
<th>Calculated Flow at Terminal Node</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13350</td>
<td>10380</td>
<td>9420</td>
<td>9060</td>
<td>7360</td>
<td>7476</td>
<td>13528</td>
<td>41842</td>
<td>20718</td>
<td>16807</td>
<td>8667</td>
<td>8568</td>
<td>167,176</td>
</tr>
</tbody>
</table>

Ditches Not in Analysis

<table>
<thead>
<tr>
<th></th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boxelder</td>
<td>1744</td>
<td>1378</td>
<td>2265</td>
<td>1719</td>
<td>659</td>
<td>121</td>
<td>7,886</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chaffee</td>
<td>105</td>
<td>141</td>
<td>125</td>
<td>117</td>
<td></td>
<td></td>
<td>488</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Coy</td>
<td>14</td>
<td>283</td>
<td>303</td>
<td>376</td>
<td>297</td>
<td>248</td>
<td>46</td>
<td>1,567</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Arthur</td>
<td>1340</td>
<td>1169</td>
<td>1881</td>
<td>729</td>
<td>86</td>
<td></td>
<td>5,205</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larimer Co.#2</td>
<td>3429</td>
<td>3424</td>
<td>1307</td>
<td>1650</td>
<td>555</td>
<td></td>
<td>10,365</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Mercer</td>
<td>2482</td>
<td>1820</td>
<td>1627</td>
<td>1077</td>
<td>240</td>
<td></td>
<td>7,246</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Cache La Poudre</td>
<td>1071</td>
<td>921</td>
<td>832</td>
<td>1154</td>
<td>719</td>
<td>3619</td>
<td>3289</td>
<td>3859</td>
<td>1184</td>
<td>545</td>
<td>89</td>
<td>17,282</td>
<td></td>
</tr>
<tr>
<td>Jackson</td>
<td>2170</td>
<td>1934</td>
<td>1632</td>
<td>988</td>
<td>376</td>
<td></td>
<td>7,100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larimer Co. Canal</td>
<td>362</td>
<td></td>
<td>319</td>
<td>2109</td>
<td>20608</td>
<td>18970</td>
<td>23170</td>
<td>16490</td>
<td>4496</td>
<td>3838</td>
<td></td>
<td>90,362</td>
<td></td>
</tr>
<tr>
<td>Pleasant Valley and Lake</td>
<td>4536</td>
<td>4617</td>
<td>3357</td>
<td>3046</td>
<td>2481</td>
<td>818</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greeley Pipeline</td>
<td>760</td>
<td>719</td>
<td>709</td>
<td>630</td>
<td>739</td>
<td>744</td>
<td>251</td>
<td></td>
<td>1468</td>
<td>1702</td>
<td>1462</td>
<td>1303</td>
<td>10,487</td>
</tr>
</tbody>
</table>

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*

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

*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.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

<table>
<thead>
<tr>
<th>Lag (K)</th>
<th>Conf. Int. (1)</th>
<th>Correlation R(K)</th>
<th>Conf. Int. (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-.133</td>
<td>.688</td>
<td>.133</td>
</tr>
<tr>
<td>2</td>
<td>-.133</td>
<td>.383</td>
<td>.133</td>
</tr>
<tr>
<td>3</td>
<td>-.133</td>
<td>.028</td>
<td>.133</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Lag (K)</th>
<th>Conf. Int. (1)</th>
<th>Correlation R(K)</th>
<th>Conf. Int. (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-.133</td>
<td>.776</td>
<td>.133</td>
</tr>
<tr>
<td>1</td>
<td>-.133</td>
<td>.728</td>
<td>.133</td>
</tr>
<tr>
<td>2</td>
<td>-.133</td>
<td>.443</td>
<td>.133</td>
</tr>
<tr>
<td>3</td>
<td>-.133</td>
<td>.057</td>
<td>.133</td>
</tr>
</tbody>
</table>

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:

\[
\hat{R}(t) = a_1 + a_2D(t) + a_3D(t-1) + a_4D(t-2) + a_5\hat{R}(t-1) + a_6\hat{R}(t-2)
\]

(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

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a_1)</td>
<td>2427.0</td>
</tr>
<tr>
<td>(a_2)</td>
<td>0.072633</td>
</tr>
<tr>
<td>(a_3)</td>
<td>0.0039629</td>
</tr>
<tr>
<td>(a_4)</td>
<td>-0.024521</td>
</tr>
<tr>
<td>(a_5)</td>
<td>0.65021</td>
</tr>
<tr>
<td>(a_6)</td>
<td>-0.031957</td>
</tr>
</tbody>
</table>

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 Kawhide 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 reser-
voirs 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 is, 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 as-
signed 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 $[O{PRP}_i,t]$  

<table>
<thead>
<tr>
<th>Reservoir (i)</th>
<th>Priority Factors*</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peterson</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Barnes Meadow</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Big Beaver</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Commanche</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Twin Lake</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Worster</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Halligan</td>
<td>85</td>
<td>85</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Park Creek</td>
<td>90</td>
<td>90</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>North Poudre #15</td>
<td>115</td>
<td>115</td>
<td>115</td>
<td></td>
</tr>
<tr>
<td>Milton Seaman</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>150</td>
<td>150</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

*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.3. Peterson Lake 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 specifically 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 approximately 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

<table>
<thead>
<tr>
<th>Month</th>
<th>% Decrease in Total River Flow Above Munroe Canal</th>
<th>Calculated Adjusted River Flow Above Munroe Canal - Acre-feet</th>
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<td>1,301</td>
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<td>0</td>
<td>2,000</td>
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<tr>
<td>APR</td>
<td>0</td>
<td>3,470</td>
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<td>MAY</td>
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<tr>
<td>JUN</td>
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<td>132,976</td>
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<td>JUL</td>
<td>0.68</td>
<td>76,035</td>
</tr>
<tr>
<td>AUG</td>
<td>9.56</td>
<td>25,541</td>
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<tr>
<td>SEP</td>
<td>12.95</td>
<td>7,534</td>
</tr>
<tr>
<td>OCT</td>
<td>0</td>
<td>5,210</td>
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</tbody>
</table>
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

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<tr>
<th>Month</th>
<th>Acre-Feet</th>
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<tbody>
<tr>
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<tr>
<td>DEC</td>
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<td>FEB</td>
<td>807</td>
</tr>
<tr>
<td>MAR</td>
<td>893</td>
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<tr>
<td>APR</td>
<td>1054</td>
</tr>
<tr>
<td>MAY</td>
<td>1186</td>
</tr>
<tr>
<td>JUN</td>
<td>1148</td>
</tr>
<tr>
<td>JUL</td>
<td>1186</td>
</tr>
<tr>
<td>AUG</td>
<td>1186</td>
</tr>
<tr>
<td>SEP</td>
<td>1148</td>
</tr>
<tr>
<td>OCT</td>
<td>1035</td>
</tr>
<tr>
<td>TOTAL</td>
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Table VII.4. Projected Annual Fort Collins Demand

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<tr>
<td>1989</td>
<td>24729</td>
</tr>
<tr>
<td>1990</td>
<td>25245</td>
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<table>
<thead>
<tr>
<th>Year</th>
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<tr>
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<td>31385</td>
</tr>
<tr>
<td>1999</td>
<td>32227</td>
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</table>
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 pipeline. 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)

<table>
<thead>
<tr>
<th>Month</th>
<th>Consumptive Loss (%)</th>
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<tr>
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<td>SEP</td>
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Figure VII.6. Generated Monthly Estimates of Michigan Ditch Diversions to Joe Wright Reservoir (acre-feet)

<table>
<thead>
<tr>
<th>Year</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug.</th>
<th>Sept.</th>
<th>Total</th>
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<td>334</td>
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Table VII.7. Generated Monthly Estimates of Grand Ditch Diversions to Long Draw Reservoir (acre-feet)

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<th>Year</th>
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<th>July</th>
<th>Aug.</th>
<th>Sept.</th>
<th>Total</th>
</tr>
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<td>3462</td>
<td>1931</td>
<td>533</td>
<td>133</td>
<td>6658</td>
</tr>
<tr>
<td>1999</td>
<td>158</td>
<td>1043</td>
<td>1454</td>
<td>443</td>
<td>63</td>
<td>3161</td>
</tr>
</tbody>
</table>
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 Reservoir 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.

LONG DRAW

JOE WRIGHT

YEAR

ACRE FEET

12000
11500
9750
9000
8250
7500
6750
6000
5250
4500
3750
3000
2250
1500
750
0

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
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.10. Target vs calculated end of month storage for Joe Wright 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

<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Exchange with Fossil Creek Reservoir</th>
<th>Pipeline-Reservoir Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reusable Effluent</td>
<td>Desired Pipeline Diversion</td>
</tr>
<tr>
<td>1985</td>
<td>NOV</td>
<td>312</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td>DEC</td>
<td>197</td>
<td>357</td>
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<tr>
<td></td>
<td>JAN</td>
<td>171</td>
<td>357</td>
</tr>
<tr>
<td></td>
<td>FEB</td>
<td>256</td>
<td>322</td>
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<tr>
<td></td>
<td>MAR</td>
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<tr>
<td></td>
<td>APR</td>
<td>0</td>
<td>345</td>
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<td></td>
<td>MAY</td>
<td>145</td>
<td>356</td>
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<tr>
<td></td>
<td>JUN</td>
<td>882</td>
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<td></td>
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<td>833</td>
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<tr>
<td></td>
<td>AUG</td>
<td>639</td>
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</tr>
<tr>
<td></td>
<td>SEP</td>
<td>485</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td>OCT</td>
<td>339</td>
<td>357</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4562</td>
<td>4200</td>
</tr>
</tbody>
</table>

| 1991 | NOV   | 512            | 345                      | 167                       |
|      | DEC   | 357            | 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 construction 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:

\[
\text{minimize} \quad \sum_{i=1}^{N} \sum_{j=1}^{N} c_{ij} x_{ij} \quad (A.1)
\]

subject to:

\[
\sum_{j=1}^{N} x_{ij} - \sum_{j=1}^{N} x_{ji} = 0 \quad \forall i \quad (A.2)
\]

\[
x_{ij} \leq u_{ij} \quad \forall i,j \quad (A.3)
\]

\[
x_{ij} \geq l_{ij} \quad \forall i,j \quad (A.4)
\]

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:
\[
\text{maximize } \sum_{i=1}^{N} \sum_{j=1}^{N} \ell_{ij} v_{ij} - \sum_{i=1}^{N} \sum_{j=1}^{N} u_{ij} h_{ij} \tag{A.5}
\]

subject to:

\[
w_i - w_j + v_{ij} - h_{ij} = c_{ij} \quad v_{ij} \tag{A.6}
\]

\[
h_{ij} \geq 0 \quad v_{ij} \tag{A.7}
\]

\[
v_{ij} \geq 0 \quad v_{ij} \tag{A.8}
\]

\[-\infty \leq w_i \leq +\infty \]

Rearranging the terms of Equation A.6:

\[
v_{ij} - h_{ij} = c_{ij} - w_i + w_j \tag{A.10}
\]

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:

\[
v_{ij} = \max \{0, c_{ij} - w_i + w_j\} \tag{A.11}
\]

\[
h_{ij} = \max \{0, -(c_{ij} - w_i + w_j)\} \tag{A.12}
\]

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

\[
\overline{c}_{ij} = w_i - w_j - c_{ij} \tag{A.13}
\]

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

If: \( \overline{c}_{ij} < 0 \); then \( x_{ij} = \ell_{ij} \) \( \tag{A.14} \)

If: \( \overline{c}_{ij} > 0 \); then \( x_{ij} = u_{ij} \) \( \tag{A.15} \)

If: \( \overline{c}_{ij} = 0 \); then \( \ell_{ij} \leq x_{ij} \leq u_{ij} \) \( \tag{A.16} \)
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:

<table>
<thead>
<tr>
<th>( \bar{c}_{ij} &lt; 0 )</th>
<th>( \bar{c}_{ij} = 0 )</th>
<th>( \bar{c}_{ij} &gt; 0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( x_{ij} &gt; u_{ij} )</td>
<td>out</td>
<td>out</td>
</tr>
<tr>
<td>( x_{ij} = u_{ij} )</td>
<td>out</td>
<td>in</td>
</tr>
<tr>
<td>( \ell_{ij} &lt; x_{ij} &lt; u_{ij} )</td>
<td>out</td>
<td>in</td>
</tr>
<tr>
<td>( x_{ij} = \ell_{ij} )</td>
<td>in</td>
<td>in</td>
</tr>
<tr>
<td>( x_{ij} &lt; \ell_{ij} )</td>
<td>out</td>
<td>out</td>
</tr>
</tbody>
</table>

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:
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, \( \Delta_{pq} \) 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, \( \Delta_{pq} \) 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 \( \Delta_{ij} \); assign node \( j \) label \( L(j) = (+i, \Delta_j) \) where \( \Delta_j = \min(\Delta_i, \Delta_{ij}) \). If node \( i \) has a label, and node \( j \) has no label and flow may be decreased by \( \Delta_{ji} \) along arc \((j, i)\), then give node \( j \) label \( L(j) = (-i, \Delta_j) \) where \( \Delta_j = \min(\Delta_i, \Delta_{ji}) \).

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 \( \Delta \) to \( x_{kt} \); if \( L(t) = (-k, y) \), then subtract \( \Delta \) 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:
\[
\begin{align*}
  i & \text{ is an element of } X \\
  j & \text{ is an element of } \overline{X} \\
  \overline{c}_{ij} & < 0 \\
  x_{ij} & \leq u_{ij}
\end{align*}
\]

b. Define \( S_2 = \{(i, j)\} \)
where:
\[
\begin{align*}
  i & \text{ is an element of } \overline{X} \\
  j & \text{ is an element of } X \\
  \overline{c}_{ij} & > 0 \\
  x_{ij} & \geq l_{ij}
\end{align*}
\]

If \( S_1 \cap S_2 = \emptyset \) (null set), stop; no feasible solution exists, otherwise: let \( \theta = \min \{ |\overline{c}_{ij}|, \infty \} \) considering all \((i, j)\) in \( S_1 \cap S_2 \).

Change \( w_i \) according to:
\[
\begin{align*}
  w_i + \theta & \quad \text{if } i \in X \\
  w_i & \quad \text{if } i \in \overline{X}
\end{align*}
\]

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: 
\((i, j) = (4, 5)\); \(L(5) = (+4, 3)\)
\((i, j) = (5, 1); \ L(1) = (+5, 3)\)
\((i, j) = (4, 2); \ \text{Added Reverse Flow}; \ L(2) = (-4, 2)\)

**NON-BREAKTHROUGH, COULD NOT GET TO NODE 3**

STEP 5: 
\(X = \{1, 2, 4, 5\} \quad \bar{X} = \{3\}\)

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

\(\theta_1 = 5, \quad \theta_2 = 3\)

\(\theta = 3\)

\(w_1 = 3; \ w_2 = 3; \ w_3 = 0; \ w_4 = 3; \ w_5 = 3\)
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:** \(X = \{5, 1\}, \ \bar{X} = \{2, 3, 4\}\)

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

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

\(w_1 = 4; \ w_2 = 3; \ w_3 = 0; \ w_4 = 5; \ w_5 = 4\)
- Compute new $\bar{c}_{ij}$

- ALL ARCS ARE IN-KILTER, OPTIMAL SOLUTION HAS BEEN FOUND
APPENDIX B

SOURCE LISTING: PROGRAM ORGANZ
PROGRAM ORGANIZ (INPUT, OUTPUT, TAPEB, A, TAPE1-A)
DIMENSION TITLE(I), PSI(I), AMSC(I), ACTAB(I2, I), DIERR(I2),
DSM(I2), DMPH(I2), RESOL(I2), PPPR(I10), DPOR(I12),
CRA(12), A(15), IDIV(15), IRTH(15), IRTHF(15)
INTEGER RCAP, RAIN, PSTART, SP, ACTAB, DEM, DERR, OPAP, CMAX, CHIN, COST,
CRAK, PRIM, PINT, LOPT, PRNG, POEM, KERR, KPRE, KFT, KFTP, KBR, KBRP
PRINT 5
FORMAT (/24(1X), 32H PROGRAM ORGANIZE, 24(1X)//)
PRINT 6
FORMAT (12X, 52H INTERACTIVE, CONVERSATIONAL DATA ORGANIZATION FOR M
RDSIN.//)
11 PRINT 12
12 FORMAT (1X, 20H BEGIN RECORD 1 //)
13 FORMAT (1X)

BEGIN RECORD 1

REWIND 2
PRINT, 'ARE CHANNEL LOSSES TO BE COMPUTED (YES OR NO)?',
READ 15, ANS1
IF (AN51.EQ.1) 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 (AN52.EQ.1) GO TO 50
IOTT=0
GO TO 55
50 IOTT=1
55 PRINT', 'SUMMARY OUTPUT (YES OR NO)?',
READ 15, ANS3
ISUM=0
IF (AN53.EQ.1) ISUM=1
IALLY=0
PRINT, 'HUG: WET, DRY STATES TO BE COMPUTED (YES OR NO)?',
READ 15, AN54
ISUM=0
IF (AN54.EQ.1) ISUM=1
IALLY=0
PRINT, 'IS RETURN FLOW TO BE CALCULATED (YES OR NO)?',
READ 15, ANS5
ISUM=0
IF (AN55.EQ.1) ISUM=1
WRITE(8, 60) LOPT, IOTT, ISUM, IALLY, IRTN
60 FORMAT ('CONTROL OPTIONS, SIS')
PRINT 6
61 FORMAT (/1X, 20H BEGIN RECORD 2 //)

BEGIN RECORD 2

PRINT, 'ENTER: UP TO 20 CHARACTER TITLE',
READ 62, (TITLE(I), I=1, 20)
WRITE(8, 60) (TITLE(I), I=1, 20)
62 FORMAT (20A4)
63 PRINT 64
64 FORMAT (/1X, 20H BEGIN RECORD 3 //)

BEGIN RECORD 3
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, IMM
IF (IMM.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.IYEAR) GO TO 72
PRINT *, 'ERROR! TOTAL NO. OF YEARS = ', IYEAR
GO TO 63
72 PRINT *, 'IS FIRM YIELD TO BE CALCULATED (YES OR NO)'.
READ IS, ANS4
IVLD=0
IF (ANSM.EQ.1) GO TO 70
PRINT *, 'WHICH NODE'.
READ, IVLD
70 KCT=1
CPCT=0.0
WRITE (8,75) NJ, NRES, NL, NR, NYEAR, ND, NS, IYEAR, IRY, IVLD,
& IFRM, ITOY,ECT,CPCT
75 FORMAT ('PARAMETERS',12I5,4X,11F5.3)
77 PRINT 78
78 FORMAT ('1X,2D9.3 BEGIN RECORD 4 II')
BEGIN RECORD 4

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(I),I=1,2)
85 FORMAT (2A4)
PRINT, "ENTER NETWORK MODE NO.",
READS, J
IF (J.LT.2) GO TO 86
PRINT, "ERROR: MAXIMUM NO. OF NODES = ",J
GO TO 84
86 PRINT, "ENTER MAXIMUM CAPACITY",
READS, RCAP
PRINT, "ENTER MINIMUM CAPACITY",
READS, RM
PRINT, "ENTER STARTING VOLUME",
READS, 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,1S,1I10)
GO TO 129
100 PRINT, "FOR JUNCTION NO. ",J,
PRINT, "ENTER: UP TO 8 CHARACTER NAME",
READS, (RNAME(L),L=1,2)
PRINT, "ENTER NETWORK MODE NO.",
READS, J
IF (J.LE.MJ) GO TO 110
PRINT, "ERROR: MAXIMUM NO. OF NODES = ",MJ
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,2AH 2 BEGIN RECORD 5 #)
C
C BEGIN RECORD 5
C
PRINT, "ENTER: "#HS, "SPILL MODE(S) IN ORDER OF PREFERENCE",
READS, (SP(I),I=1,MJ)
WRITE(8,130) (SP(I),I=1,MJ)
130 FORMAT ('SPILLS',4X,1D15)
131 PRINT 132
132 FORMAT (/1X,2AH 2 BEGIN RECORD 6 #)
C
C BEGIN RECORD 6
C
PRINT, "ENTER NO. OF AREA-CAPACITY POINTS PER RES.",
READS, NPAIRS
IF (NPAIRS.LE.18) GO TO 133
PRINT, "ERROR: MAXIMUM NO. OF POINTS = 18"
GO TO 121
133 WRITE(8,134) NPAIRS
134 FORMAT ('NO. PAIRS',1X,15)
DO 135 I=1,NPAIRS
PRINT, "FOR RESERVOIR NO. ",I,""
DO 136 JJ=1,NPAIRS
PRINT, "ENTER POINT ",JJ," AREA-CAPACITY"
READS, (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',EX,15.81/x,81/)
145 CONTINUE
146 PRINT 147
147 FORMAT (/1X,20H** BEGIN RECORD #2 **/)

BEGIN RECORD #2

IF (IALLY.EQ.1) GO TO 190
PRINT*,"AVG., WET, AND DRY HYDROLOGIC STATES WILL BE COMPUTED"
DO 185 I=1,NB
PRINT*,"ENTER NETWORK NODE NO.", I,
READ,NODED
PRINT*,"IS THIS A FLOW THRU DEMAND (YES OR NO)?",
READ YES, ANS45
IDSTRM=0
IF (ANS45.EQ.1) 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 YES, ANS55
IF (ANS55.EQ.1) 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
DEM(J)=0.9
171 CONTINUE
178 WRITE(8,180) NODED,IDSTRM,DEM,(DEMR(K),K=1,3),(DEMD(J),J=1,12)
180 FORMAT ('DEMAND',EX,213,8,313,12F4.2)
185 CONTINUE
GO TO 230
190 PRINT*,"PRIORITY FOR EACH YEAR OF SIMULATION WILL BE INPUT"
DO 225 I=1,NB
PRINT*,"ENTER NETWORK NODE NO.", I,
READ,NODED
PRINT*,"IS THIS A FLOW THRU DEMAND (YES OR NO)?",
READ YES, ANS46
IDSTRM=0
IF (ANS46.EQ.1) 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
8 NO)"
READ IS, ANS5
IF (ANSS.EQ.1.NY) GO TO 210
PRINT, *, "ENTER: TOTAL ANNUAL DEMAND",
READS, DEM
PRINT, *, "ENTER: MONTHLY DISTRIBUTION",
READS, (DEM(J), J=1,12)
210 DEM=0
DO 213 J=1,12
213 DEM(J)=0
215 WRITE(8,217) NODE1, IDSTRM, DEM, (DEM(J), J=1,12)
217 FORMAT ("DEMAND",1X,2I3,18,5X,12F4.2)
WRITE(8,219) NODE1, DEM(N), J=1,NYEAR
219 FORMAT ("RANK",6X,11I5)
227 CONTINUE
230 IF (IMP.EQ.0) GO TO 246
231 PRINT 232
232 FORMAT (/1X,20H11 BEGIN RECORD 8 II,/)  
233 CONTINUE
234 PRINT, *, "BEGIN RECORD 8"
235 DO 245 J=1,IMP
236 PRINT, *, "ENTER: NETWORK NODE NO. ".J,",
PRINT, *, "ENTER: NETWORK NODE NO.",
READS, IMP
WRITE(8,233) IMP
237 FORMAT ("IMPORT",4X,I5)
238 DO 245 N=1,NYEAR
239 PRINT, *, "ENTER: TOTAL ANNUAL IMPORT",
PRINT, *, "ENTER: MONTHLY DISTRIBUTION",
READS, IMP(N), IMP, (IMP(J), J=1,12)
240 FORMAT ("YEAR",6X,15,12X,116,18F4.3)
245 CONTINUE
246 CONTINUE
247 WRITE(8,247)
248 CONTINUE
249 FORMAT ("IMPORT",8X,*)
248 IF (J(N, JALY/J=1,2) GO TO 250
249 PRINT 2495
2495 FORMAT (/1X,20H11 BEGIN RECORD 9 II,/)  
249 CONTINUE
250 CONTINUE
250 PRINT, *, "BEGIN RECORD 9"
251 PRINT, *, "ENTER: NO. OF RESERVOIRS IN SUBSYSTEM",
READS, NSRS
PRINT, *, "ENTER: NETWORK NODE NO. OF RESERVOIRS IN SUBSYSTEM",
READS, JESUOIL,I=1,NSRS
PRINT, *, "ENTER: FRACTION FOR AVERAGE LOW AND AVERAGE HIGH",
READS, ALOH, AUGH
WRITE(8,250) NSRS, (JESUOIL(J), J=1,NSRS)
250 FORMAT ("SUBSYSTEM",1X,14I5)
WRITE(9,255) AUCLO, AUCMH
255 FORMAT ("AVERAGE ST",2(E15,F3.3))
262 PRINT 262
262 FORMAT ("//1X,21H18 BEGIN RECORD 10 //")

BEGIN RECORD 10

PRINT *, "ARE CONVERSION FACTORS NECESSARY (YES OR NO)?", READ IBM5
IF (IBM5.EQ.0.0) GO TO 265
CONINF=0.0
CONDEM=0.0
CONLO=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(9,275) CONFLO, CONINF, CONDEM
275 FORMAT ("FACTORS",3X,3(5X,F3.3))
277 PRINT 277
277 FORMAT ("//1X,21H18 BEGIN RECORD 11 //")

BEGIN RECORD 11

IF (ITALIY.EQ.1) GO TO 315
DO 310 I=1,NRES
PRINT *, "ENTER NO. FOR RESERVOIR NO. ",I,".";
PRINT *, "ENTER: PRIORITY FOR AVG. HYDROLOGIC STATE", READ, OPPR(1)
PRINT *, "ENTER: DESIRED MONTHLY DISTRIBUTION", READ, (OPPR(J),J=1,12)
WRITE(8,285) I, OPPR(1), (OPPR(J),J=1,12)
285 FORMAT ("RESERVOIR",15X,10X,12F4.2)
PRINT *, "ENTER: PRIORITY FOR DRY HYDROLOGIC STATE", READ, OPPR(2)
PRINT *, "ENTER: DESIRED MONTHLY DISTRIBUTION", READ, (OPPR(J),J=1,12)
WRITE(8,295) I, OPPR(2), (OPPR(J),J=1,12)
295 FORMAT ("OPERATING",15X,10X,12F4.2)
PRINT *, "ENTER: PRIORITY FOR WET HYDROLOGIC STATE", READ, OPPR(3)
PRINT *, "ENTER: DESIRED MONTHLY DISTRIBUTION", READ, (OPPR(J),J=1,12)
WRITE(8,305) I, OPPR(3), (OPPR(J),J=1,12)
305 FORMAT ("RULES ",15X,10X,12F4.2)
310 CONTINUE
GO TO 336

315 DO 335 I=1,NRES
PRINT *, "ENTER NO. FOR RESERVOIR NO. ",I,".";
DO 330 J=1,NYEAR
PRINT *, "ENTER: PRIORITY FOR SIMULATION YEAR ",J,
READ, OPPR(J)
PRINT *, "ENTER: MONTHLY DESIRED DISTRIBUTION", READ, (OPPR(L),L=1,12)
330 CONTINUE

335 CONTINUE
GO TO 336
WRITE(8,325) I,OPRRJ,(OPRR(L),L=1,12)
325 FORMAT(*ANNUAL OPR* ,15,18X,15,12F4.2)
326 CONTINUE
327 FORMAT(/1X,21X,BEGIN RECORD 12 28,/
            B,C,C)
328 PRINT 337
329 FORMAT(/1X,21X-BEGIN RECORD 12
        PRINTS,'ENTER: NO. OF LINKS WITH VARIABLE CAPACITY',
        READS, NUMRL
        WRITE(8,338) NUMRL
330 FORMAT(*NUMRLS* ,3X,15)
        IF (NUMRL) 339,337,339
331 DO 346 I=1,NUMRL
        PRINTS,'FOR VARIABLE CAPACITY LINK NO. "' ,I,'",'
        READS, LINK
        PRINTS,'ENTER: NETWORK LINK NO.',
        READS, LIN
        PRINTS,'ENTER: MINIMUM CAPACITY',
        READS, CMIN
        PRINTS,'ENTER: ORIGIN NODE NO.',
        READS, LF
        PRINTS,'ENTER: TERMINATION NODE NO.',
        READS, LT
        XLCF=0.0
            IF (LOPT) 341,342,341
341 PRINTS,'ENTER: LOSS COEFFICIENT',
        READS, XLCF
342 PRINTS,'ENTER: UNIT COST',
        READS, COST
        PRINTS,'ENTER: MAXIMUM CAPACITY FOR EACH MONTH',
        READS, (CMAX(I),I=1,12)
        WRITE(8,344) LINK,CMIN,CMAX,XLCF,COST
344 FORMAT(*LINK* ,6X,315,18X,10.8,15)
        WRITE(8,345) (CMAX(I),I=1,12)
345 FORMAT(*CMAX* ,3X,12I8)
346 CONTINUE
347 NULL-ML-MUARL
                              IF (NULL.EQ.0) GO TO 361
            PRINTS,'ENTER REMAINING LINKAGE CONFIGURATION'
                              DO 360 I=1,NULL
            PRINTS,'ENTER: NETWORK LINK NO.',
                              READS, LINK
            PRINTS,'ENTER: MAXIMUM CAPACITY',
                              READS, CMAX
            PRINTS,'ENTER: MINIMUM CAPACITY',
                              READS, CMIN
            PRINTS,'ENTER: ORIGIN NODE NO.',
                              READS, LF
            PRINTS,'ENTER: TERMINATION NODE NO.',
                              READS, LT
            XLCF=0.8
                              IF (LOPT.EQ.1) GO TO 349
349 PRINTS,'ENTER: LOSS COEFFICIENT',
                              READS, XLCF
350 PRINTS,'ENTER: UNIT COST',
350
READ COST
WRITE(8,365) LINK,LF,LT,CPMA,CMIN,XLCF,COST
355 FORMAT("LINK",6X,315,2110,F10.8,15)
360 CONTINUE
361 IF (IRTNL.EQ.0) GO TO 397

BEGIN RECORD 13

PRINT 362
FORMAT (/1X,21HE BEGNN RECORD 13 %",
READ,MEQU
PRINTS,"ENTER: NO. OF RETURN FLOW EQUATIONS",
READ,MLAGS
WRITE(8,363) MEQU,MLAGS

363 FORMAT (*MEQU,MLAGS*,215)
LAGS=2*MLAGS+2
DO 365 I=1,MEQU
PRINTS,"FOR RETURN FLOW EQU. NO. ",I,
PRINTS," ENTER: NO. OF NODES CONTRIBUTING TO RTFLOW",
READ,NDMEQU
PRINTS," ENTER: NODE NO. WHERE FLOW RETURNS",
READ,RTFT
PRINTS," ENTER: NODES WHICH CONTRIBUTE TO RTFLOW",
READ,(IRTFF(J),J=1,NDMEQU)
PRINTS,"
PRINTS," ENTER: REGRESSION COEF. BEGINNING WITH",
PRINTS," THE CONSTANT TERM, FOLLOWED BY DITCH",
PRINTS," DIVERSIONS, FOLLOWED BY RETURN FLOWS",
PRINTS," EXAMPLE FOR 1 MONTH LAG",
PRINTS," \begin{array} A1+R2D(T)+R3D(T-1)+R4D(T-1) \end{array}"
READ, (A(J),J=1,LAGS)
WRITE(8,365) (A(J),J=1,LAGS)

365 FORMAT (BG10.4)
WRITE(8,366) NDMEQU,RTFT
366 FORMAT (*EQU*,2X,215)
WRITE(8,367) (IRTFF(J),J=1,NDMEQU)
367 FORMAT (*EQU*,2X,1515)
PRINT 369
369 FORMAT (/)
PRINTS," FOR INITIAL CALCULATIONS ENTER:
DO 370 K=1,MLAGS
PRINTS," TOTAL DITCH DIVERSION AND TOTAL RETURN",
PRINTS," FLOW OBSERVED FOR TIME PERIOD ZERO MINUS",
PRINTS," *.K.*"
READ, IDIVL(K),IRTL(K)
370 CONTINUE
WRITE(8,371) ((IDIVL(K),IRTL(K)),K=1,MLAGS)
371 FORMAT (*LAGS*,1X,1216)
385 CONTINUE

FILE NAME
397 REWIND 8
PRINT 398
398 FORMAT (//)
399 REWIND 1
PRINTS,"SAVE FILE AS PERMANENT FILE (YES OR NO),

READ 15, ANS
IF (ANSS.EQ.100) GO TO 999
PRINTS,'ENTER UP TO 7 CHARACTER FILE NAME'.
READ 499, FILM
499 FORMAT (A7)
WRITE(1,410) FILM
410 FORMAT ('COPY,TAPES,,A7,,'')
WRITE(1,420) FILM
420 FORMAT ('REWIND,,A7,'')
WRITE(1,430) FILM
430 FORMAT ('REPLACE,,,A7,,'')
PRINTS,'IS A LISTING REQUIRED (YES OR NO)'.
READ 15, ANS9
IF (ANSS.EQ.100) GO TO 999
WRITE(1,440) FILM
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 IDEN(40),IFLO(40),IEUAP(40)
DIMENSION FLOW(20,40,12),DER(20,40,12),EUVAP(20,20,12)
DATA FLOW/50000.0,DER/200000.0,EUVAP/400000.0/,
REUNO 10
REUNO 11
PRINT 1
1 FORMAT (/27(1X),25H PROGRAM A DATA, 27(1X),/)
PRINT 2
2 FORMAT (189,51H BINARY INFLOW, DEMAND, AND EUVAP. FILE CREATION FOR
MODSIM,/) PRINT 
" ENTER: TOTAL NO. OF NODES", READ,AN
PRINT " ENTER: TOTAL NO. OF RESERVOIRS", READ,ARN
PRINT " ENTER: NO. OF YEARS TO BE SIMULATED", READ,A YEAR
PRINT 
" ENTER: NO. OF DEMAND NODES", READ,AND
PRINT " ENTER: NO. OF DEMAND NODES WHERE UNREGULATED INFLOW OCCURS", READ,AN REG
PRINT " ENTER: NO. OF EACH DEMAND NODE" READ, (IDEN(J),J=1,NDEN)
PRINT " ENTER: NO. OF NODES WHERE UNREGULATED INFLOW OCCURS", READ,AN REG
PRINT " ENTER: NO. OF EACH UNREG. INFLOW NODE" READ, (IFLO(J),J=1,AN REG)
PRINT " ENTER: NO. OF RESERVOIRS WITH EUVAP. > 0", READ,AN EUAP IF (AN EUAP.EQ.0) GO TO 10
PRINT " ENTER: NO. OF RESERVOIRS WITH EUVAP. > 0" READ, (IEUAP(J),J=1,AN EUAP)
10 DO 10 IY=1,NYEAR
10 DO 10 JU=1,AN
IF (AN REG.EQ.0) GO TO 20
DO 15 KK=1,AN REG
IF (JU.AN.1,AN REG) GO TO 15
PRINT " ENTER: MONTHLY INFLOWS FOR NODE ",JU," YEAR ",IY
READ, (FLOW(JU,K),K=1,12)
PRINT */
15 CONTINUE
20 IF (AN REG.EQ.0) GO TO 30
DO 25 KK=1,AN REG
IF (JU,.AN 1,AN REG) GO TO 25
PRINT " ENTER: MONTHLY DEMANDS FOR NODE ",JU," YEAR ",IY
READ, (DER(JU,K),K=1,12)
PRINT */
25 CONTINUE
30 IF (AN EUAP.EQ.0) GO TO 90
DO 35 KK=1,AN EUAP
IF (JU,.AN 1,AN EUAP) GO TO 35
PRINT " ENTER: MONTHLY EUVAP. RATES FOR RES. NO. ",JU," YEAR ",IY
READ, (EUVAP(JU,K),K=1,12)
PRINT */
35 CONTINUE
90 CONTINUE
WRITE(10) ((FLOW(I,J,K),K=1,12),J=1,NJ),
1 1 (EXAM(I,J,K),K=1,12),J=1,NJ),
2 (EXAM(I,J,K),K=1,12),J=1,NJ),
WRITE(11,115) ((FLOW(I,J,K),K=1,12),J=1,NJ),
2 (EXAM(I,J,K),K=1,12),J=1,NJ)
115 FORMAT (6F12.4)
WRITE(11,116) ((EXAM(I,J,K),K=1,12),J=1,NRES)
116 FORMAT (6F12.4)
100 CONTINUE
REWIN D 10
PRINT 11
PRINT 1, ENTER! UP TO 7 CHARACTER PFN FOR BINARY FILE*.
READ 105, INAM
101 FORMAT (A7)
WRITE(2,102) INAM
102 FORMAT ('REPLACE,TAPE10**',A7,'**')
PRINT 1, 'SAVE COPY OF CODED DATA FILE ALSO (YES OR NO)?'
READ 138, AN04
IF (AN04.EQ.1) GO TO 119
PRINT 1, '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 REWIN D 2
PRINT 120
120 FORMAT ('**I.X,27HJOB SUCCESSFULLY COMPLETED**')
PRINT 1, 'PRINT-OUT OF DATA FILE (YES OR NO)?'
READ 139, AN05
130 FORMAT (A1)
IF (AN05.EQ.1) GO TO 999
PRINT 140
140 FORMAT ('**I.X,4HFLOW,**')
PRINT 145, ((FLOW(I,J,K),K=1,12),J=1,NJ),I=1,NYEAR)
145 FORMAT (2X,13,5X,12F7.0)
PRINT 150
150 FORMAT ('**I.X,5HDemand,**')
PRINT 145, ((EXAM(I,J,K),K=1,12),J=1,NJ),I=1,NYEAR)
PRINT 160
160 FORMAT ('**I.X,1HEXPARATION,**')
PRINT 165, ((EXAM(I,J,K),K=1,12),J=1,NRES),I=1,NYEAR)
165 FORMAT (2X,13,5X,12F7.3)
999 STOP
END
APPENDIX D

SOURCE LISTING: PROGRAM MODSIM
PROGRAM MODSIM

COMMON /CTRL/ KIN, KOUT, KAPE1
COMMON /KAPE4/ KAPE4
COMMON /IMPR1/ IMPR1, IVLD, ITOV
COMMON /IFROM/ IFROM
COMMON /DATA/ XLDF(50), XLLF(50,12), LOPT, TOL, IALLY, IRTH

DATA KIN,KOUT,KAPE1,KAPE4/5,6,10,15/

REWIND KAPE4

CONTROL OPTIONS:

IF: LOPT=1, CHANNEL LOSSES WILL BE CONSIDERED
IOTT=1, ECHO PRINT OF INPUT DATA
ISUM=1, SUMMARY OUTPUT
IALY=1, INPUT PRIORITY FOR EACH YEAR
IRTH=1, RETURN FLOW WILL BE CALCULATED

READ (KIN,100) LOPT, IOTT, ISUM, IALLY, IRTH

FORMAT (15X,515)

STEP 62
CALL INPUT AND OUTPUT SUBROUTINES TO READ AND PRINT INPUT VARIABLES

CALL CARDS
IF (IOTT.EQ.1) CALL OUT1

STEP 03
BUILD NETWORK AND OPERATE SYSTEM

CALL SETNET
CALL OPERATE

STEP 04
CALL SUMMARIES PRINT ROUTINES
50  IF (ISHTA.EQ.0) GO TO 120
55  PCT = FLOAT(ISHTA)/FLOAT(DEM(JN))
60  IF (PCT.LT.0.01) QUIT = 0
65  IF (PCT.LE.0.01) QUIT = 0
70  MUDD = DEM(JN) - (ISHTA * PCT * 100.0)/IVD
75  MUDD = DEM(JN) - ISHTA/IVD
80  CONTINUE
85  WRITE (KOUT,130) ICNT,IVD,DEM(JN),ISHTA,MUDD,PCT
90  FORMAT (1E12.6,13,3I12,13.3)
95  RETURN
100  SUBROUTINE AREA END
105  73/73 OPT-2 TRACE
109  79/95-10. 13.11.59
1  SUBROUTINE AREA (X,Y,J)
10  INTEGER RCAP, RMES, FSTART, ARE 0010
15  1 CRAPV, ACTAB, DEM, ARE 0020
20  2 GPRP, SP, ARE 0030
25  INTEGER NRES, NAREA, NB 0100
30  1 ML, MC, NYEAR, ARE 0110
35  2 MG, IMEAN, ARE 0120
40  3 MR, MNPAIRS 0130
45  COMMON /CRTRL/ RNAME(40,2), RCAP(40), RMES(40), ARE 0170
50  1 FSTART(40), ACTAB(10,10,2), OPRR(20,10,12), ARE 0190
55  2 OPRR(20,10,12), SP(10), DEM(40), ARE 0200
60  3 DEM(40), IDM(2,12,20), ARE 0210
65  4 UREG(40), ISHTA(40,13), ISPIR(40,13), ARE 0220
70  1 IMP(40,20), ARE 0230
75  2 IMP(40,20), ARE 0240
80  COMMON /PRM/ RNAME(40,2), RNAME(40,2), ARE 0250
85  1 ROFF , ARE 0260
90  24/20
95  C   BASED ON RES VOL DETERMINE AREA
100  C   STEP 01
105
C

DO 100 I = 1, NPAIRS
  IF (X - ACTAB(J, I, 2)) 120, 110, 100
100 CONTINUE
C

110 Y = ACTAB(J, I, 1)
GO TO 130
C
  STEP 02
  IF VOL BETWEEN POINTS INTERPOLATE FOR AREA
C
  AREA
C
  120 X1 = ACTAB(J, I, 2) - ACTAB(J, I, 1, 2)
  Y1 = ACTAB(J, I, 1) - ACTAB(J, I, 1, 1)
  X2 = X - ACTAB(J, I, 1, 2)
  X3 = (X2/X1) * Y1
  Y = ACTAB(J, I, 1, 1) + IFIX(X3 + ROFF)
130 CONTINUE
END

SUBROUTINE CHAMS 73/73 OPT+2 TRACE FTR 4.6+452 79/05/10. 13.11.59

1
SUBROUTINE CHAMS (MOM, ITER, IDONE, L7, LB, MAXB, IVY)
INTEGER
COMMON /CTRL/ N, H, FLOW, USE
COMMON /KAP/ KIM, KOUT, KAPE
1 C
COMMON /PAR/ NJ, NRES, NJUNC
2 N, NC, NV, NVAR
3 N, NRES, NPAIRS
COMMON /X/I/ START(40), STEND(40), USE(40)
10 C
COMMON /U/ URES(40), USHTY(40, 13), USPL(40, 13), USRAX(40)
2 COMMON /V/I/ VMAP(40), VARI(40), VAREA(40)
11 COMMON /LINK/ LMODE(50, 2), CNAX(50), CNV(50)
12 COMMON /LINKFL/ LMODEFL(50, 13), LMVF(50, 13)
13 COMMON /A/I/ MAXC, MVARC, NMAX, NMAX, FESIBL
15 COMMON /DATA/ NTIME, NT(500), NF(500), HI(500)
2 COMMON /DATA/ RO(500), FLOW(500), COST(500)
20 COMMON /DATA/ XLCF(50), XCLL(50, 12), LOPT
1 COMMON /T/ TOL, TALLY
2 COMMON /CONFAC/ NARGLO, NARGHI, CONFLO
20 COMMON /CONF/ COND, CONCF, CPT, MERS
21 COMMON /J/ L, J ~ 1, JU
22 DIMENSION
DATA TOL, ITERMX/1.0, 10/
IDONE = 0
TDIFF = 0.0
ITER = ITER + 1
TLOSS1 = 0.0
IF (ITER.EQ.1) TLOSS2 = 0.0
30 DO 100 J = 1, MJ
  IUSE(J) = 0
100 CONTINUE
DO 110 L = 1, NL
110
35. LUNFLO(L,ROM) = FLOW(L)/CONFLO
40. XCLL(L,ROM) = FLOWL(L)*CONFLO(L)/XCLF(L)
50. NM = LMODE(L),B
55. IU(E)(NM) = IU(E)(NM) + IFIX(XCLL(L,ROM))
60. TLOSS1 = TLOSS1 + XCLL(L,ROM)
65. 110 CONTINUE
70. DO 120 J = 1, NJ
75. IU(E)(J) = IU(E)(J) + USE(J)
80. 120 CONTINUE
85. TDIFF = ABS(TLOSS1 - TLOSS2)
90. IF (TDIFF > TOL) GO TO 140
95. IF (ITER.GE.ITERN) GO TO 140
100. TLOSS2 = TLOSS1
105. MAXD = 0
110. DO 120 L = L7, LB
115. JM = NF(L)
120. HI(L) = IU(E)(JM)
125. MAX = MAX + HI(L)
130. CONTINUE
135. GO TO 170
140. WRITE (KOUT,150) ROM, IV
145. 150 FORMAT (1H4,9H33 CHANNEL LOSS FUNCTION WOULD NOT CONVERGE TO
150. 13H SPECIFIED TOLERANCE, D6, MONTH =, D7, D8, YEAR =, D9)
155. ISPEC = 1
160. 160 DO 180 L = 1, ML
165. LUNFLO(L,ROM) = 0
170. 170 CONTINUE
175. 180 CONTINUE

RETURN
END

SUBROUTINE CARDS 73/73 O/P=2 TRACE

RETURN 73/73 O/P=2 TRACE
10 TOL, IALLY, IRTH
20 COMMON /L/ MARC, NMAX, LNW, LT, NMAX
30 COMMON /D/ NTIME, NT(500), N(500), H(500), COST(500)
40 DO 10 J = 1, M
50 DEMJ(J,K) = 0.0
60 ⋯
100 CONTINUE
110 CONTINUE

STEP B1
READ FILE A CARDS

READ (KIM,120) (TITLE(I),I = 1,20)
IF (EOF(KIM)) 500, 130, 500
120 FORMAT (246)

130 READ (KIM) MD, NVES, NL, NR, NVEAR, MD, MS, NVEAR, IN, LVLD, IFRM, IT70Y, IC440
140 FORMAT (1X,1215,M1,11, F5.0)
IF (CPRCT.LE.8.0) CPRCT = 0.10

IFROM = IFRM
NC = NL - NR
READ FILE B CARDS

DO 150 I = 1, M
150 READ (KIM,150) J, (NMAX(J,K),K = 1,2), RCAP(J), BM(J), FSTART(J)

SUBROUTINE CARDS 73/73 OPT=2 TRACE FTM 4.61-452 79/05/10 13.11.59

160 FORMAT (T11,15,T1,244,T16,3115)

READ FILE C CARDS

READ (KIM,170) (SP(I),I = 1, MS)
170 FORMAT (1X,1215)

READ FILE D CARDS

READ (KIM,100) NPAIRS
180 FORMAT (1X,15)
DO 190 I = 1, NPRE
190 READ (KIM,200) J, (ACTAB(J,K,L),L = 1,2), K = 1,NPAIRS
200 FORMAT (1X,15,6I10/(15X,6I10))
DO 320 I = 1, NSA
   READ (KIN, 210) J, IDSTRM(J), DEM(J), (DEM(J, K), K = 1, 13), (DEM(J, K, CRD), K = 1, 13)
   210 FORMAT (7X, I13, 13I3, 13F4.0)
   IF (IALLY.GT.0) READ (KIN, 220) J, (DEM(J, K), K = 1, MYEAR)
   220 FORMAT (16X, 11I5)
   NDMD(I) = J
   CONTINUE

DO 270 I = 1, 13
   READ (KIN, 240) IMP(I)
   240 FORMAT (10X, 15)
   DO 260 K = 1, MYEAR
      READ (KIN, 250) IMPRT(I, K), (DIMP(I, J, K), J = 1, 12)
   250 FORMAT (28X, 110, 13F4.0)
   CONTINUE

IF (IALLY.GT.0) GO TO 300

READ (KIN, 280) MRS, (JESR(J), I = 1, MRS)
280 FORMAT (16X, 14I5)
READ (KIN, 290) AURGLO, AURGH
290 FORMAT (16X, 2F10.0)

READ FILE H CARD

READ FILE I CARDS

DO 300 K = 1, MRES
   READ (KIN, 340) (J, OMPR(L, J), (OMPR(L, J, I), I = 1, 12), L = 1, 3)
300 FORMAT (16X, 15, 16X, 15, 13F4.0)
320 CONTINUE
DO TO 370
   350 DO 360 K = 1, MRES
360 CONTINUE

SUBROUTINE CARDS 73/73 OPT-2 TRACEN FTH 4.6+452 73/05/10. 13.11.59
DO 360 I = 1, IMAX
  READ (KIN, 340) J, OPRP(I, J), (OPRP(I, J, L), L = 1, 12)
  CONTINUE
  STEP 99
  READ FILE J CARDS
370 READ (KIN, 380) NUMRL
  FORMAT (10X, 15)
  IF (NUMRL.EQ.0) GO TO 420
  DO 410 LL = 1, NUMRL
  READ (KIN, 380) L, (LMODE(L, I), I = 1, 2), CRNM(L), XLCL(L), COST(L)
390 FORMAT (10X, 315, 10X, 110, F10.0, 15)
  LMAX(L) = L
  READ (KIN, 400) (CMAXU(L, I), I = 1, 12)
  CMAXU = LMAX
  480 FORMAT (8X, 1216)
  CONTINUE
  490 CONTINUE
  410 CONTINUE
  420 LRM = ML - NUMRL
  IF (LRM.EQ.0) GO TO 450
  DO 440 LL = 1, LRM
  READ (KIN, 430) L, (LMODE(L, I), I = 1, 2), CRNM(L), XLCL(L), COD(L)
  450 IF (LMAX(L).LT.1) GO TO 470
  READ (KIN, 470) (A(I, J), J = 1, LMAX(L))
  RETURN
470 FORMAT (8F10.6)
  480 CONTINUE
  490 CONTINUE
  500 CONTINUE
  CONTINUE
175 END

SUBROUTINE DATA  73/73  OPT 2  TRACE  FTM 4.6+452
79/06/10. 13:11:59

1
SUBROUTINE DATA
  INTEGER CMAXU, RCMAP, RAIN, FSTART, DAT 0010
  CMAXU, RCMAP, RAIN, FSTART, DAT 0010
  2
OPRP, SP, CRMX, CRIN, DATE 0010
OPRP, SP, CRMX, CRIN, DATE 0010
  5
INTEGER START, UREG, KAPEI, DATE 0054
COMMON /CONTROL/ KIN, KOUT, KAPEI, DATE 0070
  1
COMMON /PRINT/ KIN, IYLD, ITAG, DATE 0089
COMMON /PRINT/ KIN, IYLD, ITAG, DATE 0089
  10
COMMON /PARAM/ HJ, MRES, HJYHC, DATE 0140
1  NL ; NC ; NYEAR ; ND ; DAT 0110
2  NS ; IYEAR ; INN ; TITLE(20) ; DAT 0120
3  NR ; NPAIRS ; DAT 0130
4  COMM ; NUNRC/ ; START(40) ; STEND(40) ; USE(40) ; DAT 0140
5  1 ; UREG(40) ; ISHTL(40,13) ; ISPIL(40,13) ; AREA(40) ; DAT 0150
2  EVAP(40) ; AMAX(40) ; ANIN(40) ; IAREA(40) ; DAT 0160
3  COMMON /PREP/ ; IP(40,12,13) ; I1(10) ; I2(10) ; DAT 0170
4  COMMON /RES/ ; I1A(40,12,12) ; IDIM(40,12) ; DAT 0180
5  COMMON /FSTART(40) ; ACTAB(10,10,2) ; DAT 0190
6  COMMON /OPRP(20,10) ; SP(10) ; DAT 0200
7  COMMON /DEMR(40,12) ; IM(2) ; DIM(2,12,20) ; DAT 0210
8  COMMON /LINK/ ; LMODE(50,2) ; CMAX(50) ; CMIN(50) ; DAT 0220
9  COMMON /CONFIG/ ; AURGLO ; AURCHI ; CONFLO ; DAT 0230
10 1 ; CONDEN ; CONINF ; CPCT ; MSRS ; DAT 0240
11 2 ; LAUL ; JESVOL(10) ; DAT 0250
12 COMMON /DEMON/ ; DEMON(40,13) ; DAT 0260

30 1 ; ENTRY DATA2 ; READ ONE YEAR OF DATA (INFLO,DEMAND,EVAP) ; DAT 0300
2 ; FOR NODES IN SYSTEM ; DAT 0310
3 ; ENTRY DATA2 ; READ (KAP)(1) :(U,J,K) : (1,1,1), J = 1, N. ; DAT 0320
4 ; ((DEMON(J,K),K = 1,12),J = 1, NRES) ; DAT 0330
5 ; DO 100 J = 1, NJ ; DAT 0340
6 ; DO 100 K = 1, 12 ; DAT 0350
7 ; ENTRY RULE ; RETURN ; DAT 0360
8 ; ENTRY RULE ; TSUBMX = 0.0 ; DAT 0400
9 ; UTRSYS = 0.0 ; DAT 0410
10 ; ENTRY RULE ; TSUBMX = 0.0 ; DAT 0420
11 ; TSUBMX = TSUBNX + RCAP(JN) ; DAT 0430
12 ;TSUBNX = TSUBNX + RCAP(JN) ; DAT 0440
13 ; UTRSYS = UTRSYS + START(JN) + UREG(JN) ; DAT 0450
14 ; SUBROUTINE DATA1 ; ; DAT 0460
15 ; 73/73 ; DAT 0470
16 ; 70/10/10. 13.11.59 ; DAT 0480
17 110 ; CONTINUE ; DAT 0510
18 110 ; CONTINUE ; DAT 0520
19 110 ; CONTINUE ; DAT 0530
20 110 ; CONTINUE ; DAT 0540
21 110 ; CONTINUE ; DAT 0550
22 110 ; CONTINUE ; DAT 0560
23 110 ; CONTINUE ; DAT 0570
24 110 ; CONTINUE ; DAT 0580
25 110 ; CONTINUE ; DAT 0590
26 110 ; CONTINUE ; DAT 0600
27 110 ; CONTINUE ; DAT 0610
28 110 ; CONTINUE ; DAT 0620
29 110 ; CONTINUE ; DAT 0630
30 110 ; CONTINUE ; DAT 0640
65         CANVRG*1,DRY*2,NUT*3       DAT 9650
C         LRULE = 1
C         XMAX = TAU0MX*AURGHI
C         XMIN = TAU0MN*AURGLO
C         IF (UTSURS.LT.XMIN) LRULE = 2
C         IF (UTSURS.GT.XMAX) LRULE = 3
C         IF (AURGLO.LE.0.8) LRULE = 1
C         RETURN
75     END
SUBROUTINE OPRATE 74/73 OPT=2 TRACE FTM 4.6+452 79/05/10. 13.11.59
1     SUBROUTINE OPRATE       OPR 0010
      LOGICAL FESIBL       OPR 0029
      INTEGER             OPR 0030
1     INTEGER             OPR 0040
1     Islamabad             OPR 0050
1     Islamabad             OPR 0060
1     Islamabad             OPR 0070
1     Islamabad             OPR 0080
1     Islamabad             OPR 0090
1     Islamabad             OPR 0100
1     Islamabad             OPR 0110
1     Islamabad             OPR 0120
1     Islamabad             OPR 0130
1     Islamabad             OPR 0140
1     Islamabad             OPR 0150
1     Islamabad             OPR 0160
1     Islamabad             OPR 0170
1     Islamabad             OPR 0180
1     Islamabad             OPR 0190
1     Islamabad             OPR 0200
1     Islamabad             OPR 0210
1     Islamabad             OPR 0220
1     Islamabad             OPR 0230
1     Islamabad             OPR 0240
1     Islamabad             OPR 0250
1     Islamabad             OPR 0260
1     Islamabad             OPR 0270
1     Islamabad             OPR 0280
1     Islamabad             OPR 0290
1     Islamabad             OPR 0300
1     Islamabad             OPR 0310
1     Islamabad             OPR 0320
1     Islamabad             OPR 0330
1     Islamabad             OPR 0340
1     Islamabad             OPR 0350
1     Islamabad             OPR 0360
1     Islamabad             OPR 0370
1     Islamabad             OPR 0380
1     Islamabad             OPR 0390
1     Islamabad             OPR 0400
1     Islamabad             OPR 0410
1     Islamabad             OPR 0420
COMMON /H/ MDAD(40), IDSTRM(40), ITHRU(40),
        HXA(50), LUAB(50), CR Hus(50, 12)
DIMENSION IA(70), IB(70), IC(70)

STEP 01
ZERO OUT ARRAYS AND INITIALIZE
VARIABLES

100 NR = ML - MC
ROFF = 0.499
ITOT = 0
IGUIT = 0

60 DO 110 I = 1, ML
SUBROUTINE OPRATE 73/73 OPT-1 TRACE
            FTN 4.6+452 70/05/10. 13.11.59

    DO 110 I = 1, 12
        LMCFLO(L,I) = 0
        LMCFLX(L,I) = 0
        LMCFLS(L,I) = 0

110 CONTINUE

    DO 120 J = 1, MJ
        STMB(J) = 0
        ITOT = ITOT + RCP(J)

    DO 120 K = 1, 12
        ISMRA(J,K) = 0
        ISMRL(J,K) = 0

120 CONTINUE

STEP 02
SETS BOUND ON ARCS, AND UPPER AND LOWER CONSTRAINTS ON PHYSICAL LINKS

75 SET LIMITS ON ARCS

L1 = ML + 1
L2 = ML + MJ
L3 = L2 + 1
L4 = L2 + MJ
L5 = L4 + 1
L6 = L4 + MJ
L7 = L6 + 1
L8 = L6 + MJ
L9 = L8 + 1
LA = L8 + MRES
LB = NR + 1

DO 130 L = 1, NARC
    HL(L) = 0
    LO(L) = 0
    FLOWL(L) = 0

130 CONTINUE
SET HI + LO ON LINKS

DO 140 L = 1,ML
    DO (L,J) = 1,ML
        IF (NUARL.EQ.0) HI(L) = CMAX(L) * CONFL
    140 CONTINUE

105

STEP 03
PRICE RIVER REACHES TO 1 AND CANALS TO 2

DO 150 L = 1,ML
    IF (COST(L).NE.0) GO TO 150
    COST(L) = 1
    IF (L.GT.NR) COST(L) = 2
150 CONTINUE

110

STEP 04
IF FIRM YIELD RUN - SET SWITCH

SET SWITCHES AND CONTROL FOR YIELD RUN

120

SUBROUTINE OPRATE 73/73 OPT=2 TRACE
FTN 4.6+452 79/05/10. 13.11.59

IQUIT = 1

160 REWIND IAEPE

ISTR + 1

125

MVR = MYEAR

STEP 06
WHOLE FOR FIRST SOLUTION
BEGIN YEARLY LOOP

START YEARLY LOOP

IV = ISTR
170 IF (LOPT) 200,290,140
180 DO 190 L = 1,ML
190 CONTINUE

140

DO 200 M = 1,ML
200 CONTINUE

145

TOTLS(J,IV,I) = 0

210 CONTINUE

STEP 07
READ MONTHLY DATA FOR ONE YEAR

150

C

C
CALL DATA

JFLAG = 0
DO 220 J = 1, N
IF (IINSTRA(J), EQ, 0) GO TO 220
JFLAG = 1

220 CONTINUE

C C C C C C

160 C C C C C C

STEP 08
SET BEGIN STORAGES TO STARTING

C C C C C C

C C

165 C C C C C C

IF (IV, GT, 1) GO TO 240
DO 230 J = 1, NMES

165 C C C C C C

STEND(J) = FSTART(J)

230 CONTINUE

C C C C C C

170 C C C C C C

ENTER SEASONAL LOOP

C C C C C C

240 DO 750 NM = 1, 12
JMONY = ((IV - 1) * 12) + NM
IF (NM, GT, 0) GO TO 280

175 C C C C C C

DO 250 L = 1, NL
IF (LMAR(LL), EQ, L) GO TO 250

175 C C C C C C

GO TO 250

250 C C C C C C

H[L] = CMAX(L, NM) * CONFO

GO TO 270

180 C C C C C C

SUBROUTINE OPRATE

73/73 OPT-2 TRACE

FTN 4.6.452

78/05/12 13.11.59

C C C C C C

260 C C C C C C

CONTINUE

C C C C C C

H[L] = CMAX(L, NM) * CONFO

270 C C C C C C

CONTINUE

280 C C C C C C

IDONE = 1

185 C C C C C C

ITER = 0

NTIME = 1

ICONV = 0

JFLAG2 = 1

200 C C C C C C

ITER = 0

DO 300 J = 1, NJ
USE(J) = 0
EVPT(J) = 0
UMREG(J) = 0
START(J) = 0

190 C C C C C C

DO 300 L = 1, NI
ICAP(J, L) = 0

195 C C C C C C

DO 300 I = 1, 13
ICAP(J, L) = 0

300 C C C C C C

CONTINUE

DO 310 L = 1, NMRC
FLOW(L) = 0

200 C C C C C C

310 C C C C C C

CONTINUE

C C C C C C

STEP 10
SET INFLOWS AND DEMANDS - IF A TOTAL

C C C C C C

YEARLY DEMAND IS GIVEN USE IT X DISTRIBUTION.
DO 340 J = 1, MJ
   USE(J) = IFIX(DEMAND(J, MON) + ROFF)
   IF (DEP(J, GT, 0)) USE(J) = DEP(J) * DEM(J, MON) + ROFF
   UREG(J) = IFIX(U(J, MON) + ROFF)
   START(J) = STREN(J)
   IF ((JFLAG(EQU), OR (IITER1.EQ, 0)) GO TO 320
   UREG(J) = UREG(J) + ITRUC(J)
   IF ((ITRM.EQ, 0), OR (ICOMN.EQ, 0)) GO TO 340
   DO 330 I = 1, MON
   IF (ITRTFI(EQU, I) EQU(J) + UREG(J) + IRTI(J, J))
   CONTINUE
   CONTINUE
   IF (INH(J) = 370, 370, 370)
   320
   330
   STEP 11
   IF IMPORT - ADD AMOUNT TO INFLOW AT NODE
   350
   DO 360 I = 1, INH
   DIMP(I) = DIMP(I, MON, IV) + ROFF
   UREG(I, IMP(I)) = UREG(I, IMP(I)) + DIMP(I)
   CONTINUE
   CONTINUE
   360
   370
   STEP 12
   DETERMINE RESERVOIR OPERATING RULE
   380
   IF (ITALY) = 380, 380, 390
   390
   CALL RULE
   GO TO 400
   URULE - IV
   400
   CONTINUE
   CONTINUE
   410
   420
   STEP 13
   SET BOUNDS ON INITIAL STORAGE ARCS

SUBROUTINE OPERATE 73/73 OPT 2 TRACE FTN 4.6, 452 73/05/10, 13.11.55

SET BOUNDS + FLOWS ON STORAGE ARCS

IAT = 0
ISUM = 0
LO(MARC - 3) = 0
DO 420 L = 1, L2
   JN = MT(L)
   LO(L) = START(JN) + UREG(JN)
   M1(L) = LD(L)
   FLOW(L) = LD(L)
   ISUM = ISUM + FLOW(L)
   MP = L + MJ
   MM = L + 2 MJ
   IA(JN) = 0
   IB(JN) = 0
   IC(JN) = 0
   420
   430
   440
   450
   460
   470
   480
   490
   500
   510
   520
   530
   540
   550
   560
   570
   580
   590
   600
IF (RCAP(JM).EQ.0) GO TO 410

C STEP 14
C ESTIMATE EVAP FOR MONTH
C
STUG = 0.5 * (START(JM) + RCAP(JM))
CALL AREA (STUG,ISURA,JM)
IJA(JM) = ISURA + EVAP(JM,MN) + ROFF
STUG = 0.5 * (START(JM) + RMIN(JM))
CALL AREA (STUG,ISURA,JM)
IJK(JM) = ISURA + EVAP(JM,MN) + ROFF
STUG = 0.5 * (START(JM) + OPRLRULE(JM,MN) + RCAP(JM))
CALL AREA (STUG,ISURA,JM)
IC(JM) = ISURA + EVAP(JM,MN) + ROFF

C STEP 15
C SET UP BOUNDS FOR DESIRED STORAGE ARCS
C BASED ON RULES - PRICE ARCS FROM RANK
C INPUT - CALCULATE BOUNDS FOR FINAL STORAGE ARCS
C
IAT = IAT + IA(JM)
MIPOL = MIN(MIPOL,LO(NP))
LO(NP) = IB(JM) + MIPOL
IF (LO(LT,LT,LO(NP))) LO(NP) = LO(LT,LT,LO(NP))
IF (LO(NP),LT,LO(NP)) = 0
LO(NN) = 0
HI(NP) = OPRLRULE(JM,MN) + RCAP(JM) + IC(JM)
COST(NP) = 1.0 - OPRLRULE(JM,MN)
HI(NM) = 1.0 - OPRLRULE(JM,MN) + RCAP(JM) + IA(JM) - IC(JM)

C 90
C IF (HI(NM).LT.0) HI(NM) = 0
C IF (HI(NP).LT.LO(NP)) GO TO 410
C HI(NP) = LO(NP)
C HI(NM) = RCAP(JM) - HI(NP)
C IF (HI(NM).LT.0) HI(NM) = 0

C 410 CONTINUE
FLO(NM) = FLOW(L)
LO(MARC - 3) = LO(MARC - 3) + LO(NP)

C 420 CONTINUE

C SUBROUTINE OPERATE 73/73 OPT=2 TRACE FTN 4.6+452 78/85/10. 13.11.59
C SET UP BOUNDS IN INCOME BALANCE ARCS
C
FLOW(MARC - 3) = ISUR
HI(MARC - 3) = IOT+ IAT
FLOW(MARC) = ISUR
HI(MARC) = FLOW(MARC)
LO(MARC) = FLOW(MARC)

C STEP 17
C SET UP DEMAND ARCS AND PRICE
C ACCORDING TO RANK
C
C SET LIMITS ON DEMAND ARCS
C
DO 430 L = L7, LB
JM = NF(L)
HI(L) = USE(JM)
COST(L) = - (1000 - DEMR(JM, LRULE) * 10)
MAXD = MAXD + HI(L)
320 CONTINUE
430 CONTINUE
440 CONTINUE
HI(NARC - 1) = MAXD
IF (LOPT.EQ.1 AND ITER.GE.1) GO TO 480
325 C
C
STEP 18
SET UP SPILL ARCS AND PRICE ACCORDING TO ORDER
330 C
C
SET LIMITS ON SPILL ARCS
330 MAXS = 0
DO 470 L = LB, LA
JM = NF(L)
MTX = 0
335 C
C
DO 450 K = 1, KS
IF (JM.EQ.SP(K).AND.MS.ME.0) MTX = 1
IF (MTX.EQ.1) GO TO 460
450 CONTINUE
K = 0
340 KS = K
HI(L) = ITOT * 10 * MTX
COST(L) = HTX * 10000 * (1 + KS)
MAKS = MAKS + HI(L)
345 C
C
GO TO 480
470 CONTINUE
HI(NARC - 2) = MAKS
350 C
C
480 CONTINUE
STEP 19
CALL NETWORK FLOW ALGORITHM
350 CALL SUPERK
355 IF (.NOT.FESIBL) GO TO 770
NTIME = 2
360 C
C
IF (LOPT.EQ.1) CALL CHANNS (RHS, ITER, IDONE, L7, LB, MAXD, IV)
C
IF (IDONE.EQ.0) GO TO 440
365 C
C
SUBROUTINE OPREAD
368 DO 490 L = 1, ML
73/73 OPT=2 TRACE
FLOW(L) = FLOW(L) - INT(XCLIL(L, RHS))
490 CONTINUE
490 CONTINUE
IF (.NOT.FLAG.EQ.0) GO TO 530
490 CONTINUE
500 CONTINUE
DO 520 L = 1, NL
DO 510 J = 1, NJ
IF (JDN(J).EQ.0) GO TO 510
IF (LHOM(E(L, 2), EQ.0)) ITHRU(IDSTRM(J)) = ITHRU(IDSTM(J)) + FLOW(L)
1 CONTINUE
510 CONTINUE
GO TO 540
520 CONTINUE
IF (JFLAG.EQ.1) AND (IRTH.EQ.0)) GO TO 540
ITERI = 1
530 IF (IRTH.EQ.0) GO TO 550
CALL RTFLOW (MOM, IV, JFLAG, ICMPY, JDNY, J7, LB)
IF (JFLAG.EQ.0) GO TO 290
GO TO 550
540 IF (ITERI.LE.0) GO TO 550
ITERI = 1
GO TO 290

C C C C C C
385 BUILD SHORTAGE ARRAY
C C C C C C
385 STEP 20
DO 560 L = L7, LB
JN = NF(L)
390 ISHTM(JN, ND) = MI(L) - FLOW(L)
C C C C C C
395 BUILD SPILL ARRAY
C C C
405 C C C C C C
405 STEP 21
DO 570 L = L9, LA
JN = NF(L)
410 ISPIL(JN, ND) = FLOW(L)
C C C C C C
415 C C C C C C
415 STEP 22
C C
420 C C C C C C
420 DO 580 L = L3, L4
JN = NF(L)
430 LM = L + NJ
STEPDN(JN) = FLOW(L) + FLOW(LM)
440 EUPT(YN) = IA(JN)
IF (FLOW(L).EQ.0) EUPT(JN) = IB(JN)
IF (FLOW(L).EQ.0) EUPT(JN) = IC(JN)
IF (STN(JN).LT.0) STN(JN) = 0
C C C C C C
445 C C C C C C
445 CALUULATE FINAL RES STORAGE
C C C C C C
450 C C C C C C
450 CALCULATE MONTHLY EVAP. AND SET MONTHLY EVAP. ESTIMATE
C C C C C C
460 C C C C C C
460 DO 590 L = L3, L4
JN = NF(L)
470 LM = L + NJ
480 STNEN(JN) = FLOW(L) + FLOW(LM)
490 EUPT(JN) = IA(JN)
500 IF (FLOW(L).EQ.0) EUPT(JN) = IB(JN)
510 IF (FLOW(L).EQ.0) EUPT(JN) = IC(JN)
520 IF (STN(JN).LT.0) STN(JN) = 0
C C C C C C
525 C C C C C C
525 CALUULATE MONTHLY EVAP. AND DETERMINE
C C C C C C
530 RES. ENDING STORAGE
C C C C C C
SUBROUTINE OPERATE 73/73 OPT=1 TRACER FTM 4.6+452
78/05/10. 13.11.52
ICM > 0
JN = NF(L)
IF (RCAP(JN).LE.0) GO TO 660
EUP = EUPT(JN)
STEP = STEND(JN)
500 IF (STEP.GT.RCAP(JN)) STEP = RCAP(JN)
STUG = (STEP + START(JN)) *.5
CALL AREA (STUG, ISURA, JN)
ETEMP = 0.0
IAREA(JN) = ISURA
IF (EUP(JN,NOM)) 600, 640, 660
600 ETEMP = ISURA * EUPT(JN,NOM) + ROFF
IF (ABS(ETEMP - EUPT.LT.5.0)) GO TO 640
ICM = ICM + 1
IF (ICM.LE.100) GO TO 630
WRITE (KOUT,610) JN,ETEMP,EUP,ISURA,START(JN),STEND(JN)
610 FORMAT (5X,JN=13,5X,STUF(Temp,F18.4,5X,EMEUP,F18.4,5X,EMISURA)
110,7MSTART =.110,BSTEND =.110)
WRITE (KOUT,620) IY,MOM,STEP
620 FORMAT (/,,1310)
CALL EXIT
630 CONTINUE
EUP = ETMP
STEP = STEND(JN) - EUP
445 IF (STEP.LT.0) STEP = 0
GO TO 690
STEP = ETMP
440 STEND(JN) - STEP
450 IF (STEP(JN,LT.0)) STEND(JN) = STEP
460 IF (STEN(JN,GT.RCAP(JN))) STEND(JN) = RCAP(JN)
EUPT(JN) = STEP
600 CONTINUE
STE 25
BUILD PRINT-ARRAY WITH MONTHLY DATA
650 DO 700 J = 1,NRES
ICAP(J,MOM,1) = START(J)
1C0 ICAP(J,MOM,2) = USE(J)
ICAP(J,MOM,3) = IAREA(J) + ROFF
ICAP(J,MOM,4) = EUPT(J)
ICAP(J,MOM,5) = ISMTH(J,MOM)
ICAP(J,MOM,11) = ISPIL(J,MOM)
ICAP(J,MOM,12) = STEND(J)
ICAP(J,MOM,13) = OPRMA(LAULE,J,MOM) + RCAP(J) + ROFF
700 CONTINUE
C
C
C
STEP 26
SET UP UPSTREAM AND DOWNSTREAM FLOWS
470 IF (MR.EQ.0) GO TO 670
475 C
C
C
C
SUBROUTINE OPRATE

DO 660 L = 1, NR
   LNKFLD(L, ROM) = FLOW(L) / COMFLO
   IF (LMODE(L, 1), EQ, J) IDM = IDN + FLOW(L)
   IF (LMODE(L, 8), EQ, J) IUP = IUP + FLOW(L)

DO 660 L = LB, ML
   LNKFLD(L, ROM) = FLOW(L) / COMFLO
   IF (LMODE(L, 1), EQ, J) IPD = IPD + FLOW(L)
   IF (LMODE(L, 2), EQ, J) IPI = IPI + FLOW(L)

CONTINUE

ICAP(J, ROM, 9) = IPI
ICAP(J, ROM, 10) = IPD

CONTINUE

C 670 IF (MC.EQ.0) GO TO 690
   DO 680 L = LB, ML
      LNKFLD(L, ROM) = FLOW(L) / COMFLO
      IF (LMODE(L, 1), EQ, J) IPD = IPD + FLOW(L)
      IF (LMODE(L, 2), EQ, J) IPI = IPI + FLOW(L)
   CONTINUE

C 680 CONTINUE

C 690 CONTINUE

ICAP(J, ROM, 9) = IPI
ICAP(J, ROM, 10) = IPD

C 700 CONTINUE

C 710 CONTINUE

C 730 CONTINUE

C 500 CONTINUE

C 710 CONTINUE

C 510 CONTINUE

C 720 CONTINUE

C 730 CONTINUE

C 520 CONTINUE

C 740 CONTINUE

C 750 CONTINUE

C 530 CONTINUE

STEP 27
CALCULATE AVER. AND MAX FLOWS

STEP 28
ADD MONTHLY AMOUNTS FOR YEAR TOTALS

STEP 29
IF ONE PASS OR CONVERGENCE AND PRINT  OPR 5310
YEAR-CALL YEARLY PRINT ROUTINE  OPR 5328

KEY = 1  OPR 5330
CALL OUT2 (IV)  OPR 5340

IV = IV + 1  OPR 5359
IF (IV.LE.NYEAR) GO TO 170  OPR 5369

SUBROUTINE OPERATE  73/73  OPR+2 TRACE  FTM 4.6+452  79/05/10. 13.11.59

STEP 30  OPR 5410
CALL ROUTINE TO ADJUST ANNUAL DEMAND  OPR 5420
AT YIELD NODE IF NECESSARY  OPR 5430

IF (IQUIT.EQ.0) GO TO 780  OPR 5440
CALL ADJUST (IV, IQUIT, ICMT)  OPR 5450
GO TO 160  OPR 5460

760 CONTINUE  OPR 5470

STEP 31  OPR 5500
PRINT ARC DUMP IF SOLUTION INFEASIBLE  OPR 5510

RETURN  OPR 5520

770 WRITE (KOUT, 780) IV, MON, (L, NF(L), NT(L), LO(L), HI(L), FLOW(L), COST(L))  OPR 5530
1.1 = 1.3ARC  OPR 5540
780 FORMAT (11I8, 2D10.8, NSOLUTION INFEASIBLE, .5H YEAR, .1H, MONTH, 13H (31)  OPR 5550
10H LINK FROM TO LO HI FLOW COST */(30P)  OPR 5560
215, 4110))')  OPR 5570

RETURN  OPR 5580

SUBROUTINE OUT1  73/73  OPR+2 TRACE  FTM 4.6+452  79/05/10. 13.11.59

SUBROUTINE OUT1  OPR 5619
INTEGER  OPR 5629
1   CNAME, ACTAB, DEXT, DMIN, DMAX  OPR 5639
2
5 COMMON /CONTROL/  OPR 5640
1 LNAME, LMIN, LMAX, LMID  OPR 5650
3 MNAME, MMIN, MMAX, MMID  OPR 5660
5 COMMON /RESULT/  OPR 5670
1 RNAME, RMIN, RMAX, RMX  OPR 5680
3 RPAIRS, RPAIRS(40,2), RCAP(40)  OPR 5690
5 COMMON /PSTAG/  OPR 5700
1 PSTAG(40), ACTAB(10,18), DSTART(40,10),  OPR 5710
4 DMIN(10,18), DMIN(10,18), DMIN(10,18),  OPR 5720
8 COMMON /YPCT/  OPR 5730
1 SMIN(40,18), SMAX(40,18), PPAIRS(40)  OPR 5740
4 COMMON /LINK/  OPR 5750
1 NODE(50,5), CNAME(50)  OPR 5760
20 COMMON /CONFAC/  OPR 5770
1 AMACI, AMESI, AMESI  OPR 5780
5 COMMON /CRTFT/  OPR 5790
1 CNAME, CRNAME  OPR 5800
20 COMMON /MTR/  OPR 5810
1 4
2 COMMON /URULE/, JESUOL(10)     OTI 0210
1 COMMON /ADAATS/, NARC, MAX, FES1IL, OTI 0220
1 COMMON /HTIME/, HT(50), OTI 0230
2 COMMON /DLISN/, FL8IT(50), OTI 0240
2 COMMON /NHDN(40), IDSTM(40), ITLMF(40), OTI 0250
1 COMMON /VIRR/, CMAV(50), OTI 0260
1 COMMON /DXDATA/, XLOR(50), XLL(50,12), LOPT, OTI 0270
1 COMMON /TOL/, TLAT1, ITLM, OTI 0280
2 COMMON /MEG/, MLAGS, A(I10,15), OTI 0290
1 COMMON /HMEQ(10), JrRTF(10,15), JrRTF(0), JrRTF(10,200), OTI 0300
2 COMMON /HMEQ(10), JrRTF(10,15), JrRTF(0), JrRTF(10,200), OTI 0310
1 COMMON /HMEQ(10), JrRTF(10,15), JrRTF(0), JrRTF(10,200), OTI 0320
1 COMMON /DOUT/, DOUT(2), OTI 0330
2 COMMON /DOUT/, DOUT(2), OTI 0340
1 COMMON /DOUT/, DOUT(2), OTI 0350
1 COMMON /DOUT/, DOUT(2), OTI 0360
1 COMMON /DOUT/, DOUT(2), OTI 0370
1 COMMON /DOUT/, DOUT(2), OTI 0380

III = 2
PRINT OUT ALL INPUT INFORMATION

100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0390
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0400
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0410
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0420
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0430
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0440
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0450
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0460
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0470
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0480
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0490
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0500
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0510
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0520
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0530
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0540
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0550
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0560
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0570
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0580
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0590
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0600
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0610
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0620
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0630
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0640
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0650
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0660
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0670
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0680
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0690
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0700
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0710
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0720
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0730
100 FORMAT (1H1//10X, IBMURER BASIN SIMULATION PACKAGE, 10X, 42HAPRX: ORI 0740
DO 250 L = 1, NL
  IF (MOD(L,20).NE.8) GO TO 190
  WRITE (KOUT,140) TITLE
  WRITE (KOUT,180) 
  190  IF (NMAU.EQ.8) GO TO 230
  DO 220 LL = 1, NUMAU
    IF (LMAU(LL).EQ.L) GO TO 200
    GO TO 220
  200  WRITE (KOUT,210) L,(LMAU(LL),1=1,2),CMIL(L),XCMIL(L),COST(L)
  GO TO 250
  220  CONTINUE
  WRITE (KOUT,240) L,LMODE(L,1),I = 1,2,CMA(L),CMIL(L),XCMIL(L),COST(L)
  240  CONTINUE
  WRITE (KOUT,250) (SP(I),I = 1,HS)
  250  CONTINUE
  WRITE (KOUT,260) (1,IMP(I,K),IDIMP(I,J,K),J = 1,12)
  260  CONTINUE
  WRITE (KOUT,270) IMP(I),IDIMP(I,J,K),IDIMP(I,J,K),J = 1,12
  270  CONTINUE
  WRITE (KOUT,280) IMP(I),IMP(I),IDIMP(I,J,K),IDIMP(I,J,K),J = 1,12
  280  CONTINUE
  WRITE (KOUT,290) IDIMP(I,J,K),IDIMP(I,J,K),J = 1,12
  290  CONTINUE
  WRITE (KOUT,300) IMP(I),IMP(I),IDIMP(I,J,K),IDIMP(I,J,K),J = 1,12
  300  CONTINUE
  WRITE (KOUT,310) (JESVOL(I),I = 1,HSRS)
  310  FORMAT (/10X,25HSRS
  AVLO = MARGLO I 100.
  AHI = MARGHI I 100.
  WRITE (KOUT,320) AVLO,AHI
  320  FORMAT (/10X,2H'MARGLO',DEFNED AS BETWEEN,M.F.1,5H, AMD,M.F.1,5H)
  330  GO TO 300
  340  FORMAT (/10X,5HSRS ,AVG, AND ESRS WILL NOT BE CALCULATED)
  350  FORMAT (/10X,5HSRS ,AVG, AND ESRS WILL NOT BE CALCULATED)
  360  WRITE (KOUT,370) CONFLO,CONFUP,CONDE
  370  FORMAT (/10X,10HSRS ,MULTIPLES CAPACITIES BY, M.F.1,5H)
  SUBROUTINE OUT1 73/73 OPT+2 TRACE FTH 4,9-122 73/06/19. 13.11.59
  1//15X,25HSRS
  25 BY 15X,25HSRS
  350  FORMAT (/10X,5HSRS ,DESIGNED OPERATING LEVELS WILL BE INPUT FOR EACH)
  360  WRITE (KOUT,370) CONFLO,CONFUP,CONDE
  370  FORMAT (/10X,10HSRS ,MULTIPLES CAPACITIES BY, M.F.1,5H)
  SUBROUTINE OUT1 73/73 OPT+2 TRACE FTH 4,9-122 73/06/19. 13.11.59
  1//15X,25HSRS
  25 BY 15X,25HSRS
  350  FORMAT (/10X,5HSRS ,DESIGNED OPERATING LEVELS WILL BE INPUT FOR EACH)
  360  WRITE (KOUT,370) CONFLO,CONFUP,CONDE
  370  FORMAT (/10X,10HSRS ,MULTIPLES CAPACITIES BY, M.F.1,5H)
31)  WRITE (KOUT,390)  OTI  1200
320)  FORMAT (112X,11HNAME DAY WET)   OTI  1300
330)   DO 420 J = 1,NJ                  OTI  1310
340)   DO 420 INJ = 1,NHD              OTI  1320
350)   IF (J - NMDR(INJ)) 420,440,420    OTI  1330
360)  430)  WRITE (KOUT,400) J,(DEMR(J,K),K = 1,12J),(DEMR(J,I),I = 1,3)  OTI  1340
370)  440)  FORMAT (/10X,2X,i12,10X,12F7.4,3X,3I4)    OTI  1350
380)  420)  CONTINUE                  OTI  1360
390)  420)  GO TO 500                 OTI  1370
400)  430)  WRITE (KOUT,440)                  OTI  1380
410)  440)  FORMAT (/10X,31HMANUAL RANKING FOR DEMAND MODES)    OTI  1390
420)   DO 430 J = 1,NJ                  OTI  1400
430)   DO 430 INJ = 1,NHD              OTI  1410
440)   IF (J - NMDR(INJ)) 430,450,430    OTI  1420
450)  450)  WRITE (KOUT,460)                  OTI  1430
460)  460)  FORMAT (/)                       OTI  1440
470)   DO 470 I = 1,NYEAR              OTI  1450
480)   WRITE (KOUT,490) J,I,DEMR(J,I)    OTI  1460
490)  490)  FORMAT (15X,9HMODE NO.,12,3X,4HYEAR,13,3X,7HRANK = ,13)    OTI  1470
500)  490)  CONTINUE                  OTI  1480
510)  500)  WRITE (KOUT,510)                  OTI  1500
520)  510)  FORMAT (/10X,30X,4HDEvised MONTHLY STORAGE LEVEL (PERCENT FULL))    OTI  1510
530)   120X,4HNAME/10X,4HRESEVOIR NO. )               OTI  1520
540)   IF (JALLY.GT.0) GO TO 540        OTI  1530
550)   DO 520 J = 1,NRES                OTI  1540
560)   IF (MOD(J,2).EQ.0) WRITE (KOUT,100) TITLE         OTI  1550
570)  520)  WRITE (KOUT,520) J,(COM(L),LPRR(L,J,I),I = 1,12),0PRR(L,J),L = 10J170    OTI  1560
580)  520)  CONTINUE                  OTI  1570
590)  520)  GO TO 590                 OTI  1580
600)  530)  DO 550 J = 1,NRES                OTI  1590
610)   WRITE (KOUT,550)                 OTI  1600
620)  550)  FORMAT (/)                       OTI  1610
630)   IF (MOD(J,2).EQ.0) WRITE (KOUT,100) TITLE         OTI  1620
640)   DO 560 L = 1,NYEAR              OTI  1630
650)   WRITE (KOUT,570) J,L,(OPRR(L,J,I),I = 1,12),0PRR(L,J)        OTI  1640
660)  560)  FORMAT (11X,12,3X,4HYEAR,12,2X,12F7.4,5X,14)         OTI  1650
670)  560)  CONTINUE                  OTI  1660
680)  560)  WRITE (KOUT,560)                  OTI  1670
690)  560)  FORMAT (/)                       OTI  1680
700)  570)  WRITE (KOUT,600)                  OTI  1690
710)  600)  FORMAT (/48X,33HRESEVOIRS AREA - CAPACITY TABLES/ )        OTI  1700
720)   K = 0                                                  OTI  1710
730)   NP = 0                                                 OTI  1720
740)   310)  K = K + 1                                             OTI  1730
750)   310)  M1 = M2 + 1                                       OTI  1740
760)   310)  M2 = M1 + 1                                       OTI  1750
770)   IF (M1.GT.MRES) M1 = 0                              OTI  1760
780)   IF (M2.GT.MRES) M2 = MRES                          OTI  1770
790)   IF (M1.EQ.0) GO TO 650                            OTI  1780
800)   IF (K.GT.1) WRITE (KOUT,100) TITLE            OTI  1790
810)  SUBROUTINE OUT 73.73 OPT-II TRACE               FTH 4.6+452         7/9/85/10. 15.11.58
820)  WRITE (KOUT,620) (KRS,KRS = M1,M2)                 OTI  1810
830)  620)  FORMAT (10X,6(4X,13HRESEVOIR NO.,13)/3X,3HPOINT,2X,6SX,4HAREA,1XOTI  1820
1,2X,BLSCAPACITY)
DO 630 NPT = 1,NNPAIRS
630 WRITE (KOUT,640) NPT, (ACTAB(JN,NPT,KK),JN = 1,2), KJ = 1,110
GO TO 610
650 CONTINUE
IF (IRN.FEQ.0) RETURN
WRITE (KOUT,100) TITLE
LAGS = 2 + MLAGS + 2
DO 700 I = 1,NEQU
    IDUMB = HDNBMU(I)
    WRITE (KOUT,660) I,MLAGS,1,IRTFT(I)
700 WRITE (KOUT,660) I,1,IRTFT(I)
660 CONTINUE
RETURN
END

SUBROUTINE OUT2
73/73 OPT=2 TRACE
FTN 4.6+652
70/05/10 13.11.50

SUBROUTINE OUT2 (IV)
INTEGER TOTLS, P
INTEGER RCAP, RAIN, FSTART,
1 2 CRAXU, ACTAB, DEN, DEMR,
3 CRAXU, RAIN, DEN, FSTART,
5 COMMON /CTRL/ KIN, KOUT, KAEP
1 COMMON /PRT/ IPRT, ILM, ITOY
1 COMMON /PM/ MJ, MRES, MNUC
1 2 MC, MC, MC, MC,
1 2 MV, MV, MV, MV,
1 NR, NR, NR, NR,
1 COMMON /PRNT/ ICAP(40,12,13), TOTLS(40,29,12)
1 COMMON /RESV/ RHME(40,29,12), RCAP(40), RAIN(40), FSTART(40)
1 2 OPDH(29,12), SP(18), DEMR(40,12), DENR(40,12),
3 EWAP(10,12), IP(2), DEM(40,12), DERN(40,12)
4 COMMON /UNIT/ LMKFL(50,13), LMKFAL(50,13)
1 COMMON /V/ HMKF(40,40), IMTR(40,40), ITRT(40,40)
1 COMMON /DATA/ XLCQF(50), XCLQ(50,12), LOPT,
2 TOL, TOL, TOL, TOL,
2 COMMON /R/ NJEQ(10), IRTFT(10,15), JRTFT(10), IRFT(10,10,15)
2 IDIV(10,15), INTL(10,10,15)
30 C C
STEP 01

85   WRITE (KOUT,250) (I,1 = 1,12)
250   FORMAT (1X,6HSEASON,BX,12(12,7X),15H,1V,1HBLINK NO.)
     X = 0.0.
    DO 270 I = 1,12
     X = X + FLOAT(LNKFLO(I,1)) / 12.
    CONTINUE
270   FORMAT (1X,6HSEASON,BX,12(12,7X),15H,1V,1HBLINK NO.)
     X = X * 0.499999
     LNKFLO(L,13) = IFIX(X)
    WRITE (KOUT,260) L,(LNKFLO(L,1),I = 1,13)
260   FORMAT (KAPE,280) IV,L,(LNKFLO(L,1),I = 1,13)
     WRITE (KOUT,280) (XCLL(L,1),I = 1,12)
280  FORMAT (215,1318)
     IF (LJFT) 320,330,300
300  WRITE (KOUT,310) (XCLL(L,1),I = 1,12)
     IF (IJFT.EQ.0) RETURN
310  FORMAT (1X,4X,4HLoss,12F5.0,/) 1000
     IF (IJFT) RETURN
320  CONTINUE
100  IF (IJFT) RETURN
     WRITE (KOUT,330)
330  FORMAT (/1X,23HRETURN FLOWS CALCULATED,/) 3000
     IEIG = (IV - 1) * 12 + 1
     JEND = IEIG + 11
     DO 370 I = 1,JEND
370   FORMAT (1X,4X,4HLoss,12F5.0,/) 1000
     WRITE (KOUT,340) I,JFTFT(I)
340  FORMAT (/1X,25HRETURN FLOW EQUATION NO. (J),13,B5H,12(1X,13))
     RETURN
110  WRITE (KOUT,350) (J,J = 1,12)
350  FORMAT (1X,6HSEASON,BX,12(12,7X),/) 1100
     WRITE (KOUT,360) (I,JFTFT(I),J = IBEG,IEDEL)
     RETURN
360  FORMAT (1X,7X,1318)
370  CONTINUE
115  RETURN
120  RETURN
125  RETURN
130  RETURN
END
SUBROUTINE OUT3  73/73  OPT-2 TRACE  FTM 4.6+452  79/05/16  13.11.59
1
SUBROUTINE OUT3
  INTEGER
  COMMON /CTRL/ KIN , KOUT , KAPE1 
1   COMMON /IPMAT/ IPMAT , IVLD , ITOV 
5   COMMON /PRAV/ NJI , NRES , NJUNC 
1   COMMON /MC/ MC , MYEAR 
5   COMMON /T/year/ INI , TITLE(20)
10   COMMON /PMAS/ HMAS 
15   COMMON /LHKFLO/ LNKFLO(50,13)
20   COMMON /TOL5/(40,18,13)
25   COMMON /TOL5/(80,13)
30   COMMON /TOL5/(120,13)
35   DIMENSION NMA(2), NMAX(2)
40   DIMENSION DMA(2)
45   DATA NAME /HLINKAGE /, MMAX /HMAP/, HMAP /, HMAH /, HMAH /, HMAH /
50   DMA 0
55   IPTO 0
60   IPTO 0
65   IPTO 0
70   IPTO 0
IPTOD = 0
IPTOS = 0
IPTOL = 0
IPTOG = 0

STEP 01
PRINT OUT YEARLY DATA FOR ALL NODES

DO 100 KY = 1,NYEAR
   WRITE (KOUT,100) TITLE,DNN(2),KY,DNN(1)
   DO 10 J = 1,NJ
      WRITE (KOUT,160) J,(TOTLS(J,KY,M),M = 1,2),(TOTLS(J,KY,4),TOTLS(J,KY,6),M = 11,12)
   END

STEP 02
PRINT OUT NODE DATA FOR ALL YEARS

DO 100 J = 1,NJ
   WRITE (KOUT,100) TITLE,DNN(1),J,DNN(2)
   DO 100 KY = 1,NYEAR
      WRITE (KOUT,160) KY,(TOTLS(J,KY,M),M = 1,2),(TOTLS(J,KY,4),TOTLS(J,KY,6),M = 11,12)
   END

100     CONTINUE

STEP 03
FIND YEARLY AVERAGES

IPTOU = IPTOU/NYEAR
IPTOD = IPTOD/NYEAR
IPTOS = IPTOS/NYEAR
IPTOE = IPTOE/NYEAR
IPTOL = IPTOL/NYEAR

SUBROUTINE OUT3

IPTOD = IPTOD/NYEAR
IPTOS = IPTOS/NYEAR
IPTOE = IPTOE/NYEAR
IPTOL = IPTOL/NYEAR

WRITE (KOUT,100) IPTOU,IPTOD,IPTOS,IPTOE,IPTOL

120   CONTINUE
KY = 100000
WRITE (KOUT,130) TITLE,DMA(2),KY,DMA(2) 073 0750
130 FORMAT (1H/DESIGN//SPACE//DESIGN//SIMULATION PERIOD TOTAL SUMMARY//,ACT
14,13//5X,4,13H START DEMANDS,13H START,13H UNREG. FLOW,13H EVAPORATION,13H SYSTEM LOSS,13H ENDING STRG.) 073 0770

DO 170 KY = 1,NVEAR
    DO 150 J = 2,N
        DO 140 N = 1,12
            TOTLS(1,KY,N) = TOTLS(1,KY,N) + TOTLS(J,KY,N)
        140 CONTINUE
    150 CONTINUE
170 CONTINUE

WRITE (KOUT,160) KY, (TOTLS(1,KY,N),N = 1,2), TOTLS(1,KY,4), TOTLS(1,KY,N), N = 11,12
160 FORMAT (5X,14,7113) 073 0930

DO 180 IPTO = IPTO + TOTLS(1,KY,1)
    DO 170 IPTO = IPTO + TOTLS(1,KY,2)
        DO 160 IPTO = IPTO + TOTLS(1,KY,4)
            DO 150 IPTO = IPTO + TOTLS(1,KY,6)
                DO 140 IPTO = IPTO + TOTLS(1,KY,11)
                    DO 130 IPTO = IPTO + TOTLS(1,KY,12)
130 CONTINUE
140 CONTINUE
150 CONTINUE
160 CONTINUE
170 CONTINUE
180 CONTINUE

WRITE (KOUT,180) IPTO, IPTO, IPTO, IPTO, IPTO
180 FORMAT (15X,13PERIOD TOTALS,3X,5113) 073 1040

DO 190 IPTO = IPTO/NVEAR
    DO 180 IPTO = IPTO/NVEAR
        DO 170 IPTO = IPTO/NVEAR
            DO 160 IPTO = IPTO/NVEAR
                DO 150 IPTO = IPTO/NVEAR
150 CONTINUE
160 CONTINUE
170 CONTINUE
180 CONTINUE
190 CONTINUE

WRITE (KOUT,190) IPTO, IPTO, IPTO, IPTO, IPTO
190 FORMAT (15X,13PERIOD AVERAGES,3X,5113) 073 1140

DO 210 L = 1,NL
    WRITE (KOUT,200) TITLE, NMA, (J,J = 1,12)
210 FORMAT (1H/DESIGN//SPACE//DESIGN//SIMULATION PERIOD TOTALS,1X,NMA,1X),(13MONTHLY TOTALS) 073 1210

SUBROUTINE OUT7 73/73 OPT-2 TRACE
    FTM 4.6/468 79/06/10.13.11.69

1 FLOW//1X,1X,GSEAISON,4X,12(12,7)//1X,GAIN,1X,GAIN,1X,MNEM NO.) 073 1210
210 WRITE (KOUT,220) L,LMNAY(L,1),N = 1,12
220 FORMAT (1X,5X,12,3X,5119) 073 1220

DO 230 L = 1,NL
    IF (L.EQ.1) WRITE (KOUT,200) TITLE, NMA, (J,J = 1,12)
230 WRITE (KOUT,220) L,LMNAY(L,1),N = 1,12
RETURN 073 1230
SUBROUTINE RIGHT (1,INDEX)
COMMON /CTRL/ KIN, KOUT, KAPE, KAPE
COMMON /DATA/ NR, NM, FESIBL
COMMON I2,E4, I3, M(500), NC(500), JSAVE(500)
COMMON IU5(I4), LABL(E4), NODE(E4), MIDL(E4)
COMMON JAV1(1000)

10 MID = MID(I)
IA = NODE(I)
DO 100 II = IA,MID
IF (MIR(II) - INDEX) 100,130,100
100 CONTINUE

15 KWAY = 1
110 WRITE (KOUT,100) I,INDEX,KWAY
IFROM = NODE(I)
ITO = NODE(I + 1) - 1
WRITE (KOUT,120) IFROM,MIDL(I),ITO,(K,MIR(K),K = IFROM,ITO)

20 FORMAT (3J6/2016)
RETURN

25 ITEM = MIR(MID)
MIR(MID) = INDEX
MIR(II) = ITEM
RETURN

ENTRY LEFT
MID = MIDL(I) + 1
IB = NODE(I + 1) - 1
DO 140 II = MID,IB
IF (MIR(II) - INDEX) 140,150,140

140 CONTINUE
KWAY = 2
GO TO 110

150 ITEM = MIR(MID)
MIR(MID) = INDEX
MIR(II) = ITEM
MIDL(I) = MID
RETURN

160 FORMAT (5H NODE,IS,H ARC,IS,H LOST ON SHIFT,14,4H LOC,14)
ENTRY DUPO
ID = INDEX
MILINES = 1
WRITE (KOUT,210) ID
WRITE (KOUT,210) M, I, J, L, K
GO TO 110

KOST = JSAVE(M)
KWMR = KOST(M)

END
150  CONTINUE
  RTF  0380
160  CONTINUE
  RTF  0330
170  CONTINUE
  RTF  0400
  DO  180  I = 1, MEGU
     RTF  0410
   IRTF(I,JROMY) = IRTF(I,JROMY) + IRTF(I,JROMY) * FLOAT(IADD(I,1))
     RTF  0420
   DO  190  N = 1, MLAGS
      RTF  0430
     IRTF(I,JROMY) = IRTF(I,JROMY) + IRTF(I,JROMY) * FLOAT(IADD(I,N + 2))
      RTF  0440
    1
     IRTF(I,JROMY) = IRTF(I,JROMY) * FLOAT(IADD(I,N + 2))
     RTF  0450
     2
   180  CONTINUE
     RTF  0460
190  CONTINUE
  RTF  0470
200  IF (ICOMV.EQ.1) GO TO 220
  RTF  0450
  DO  210  I = 1, MEGU
     RTF  0540
    IRTF(I,JROMY) = IRTF(I,JROMY)
     RTF  0550
  210  CONTINUE
     RTF  0560
   IFLAG2 = 0
     RTF  0530
   ICOMV = 1
     RTF  0540
   RETURN
     RTF  0550
220  IFLAG2 = 1
     RTF  0560
   DO  230  I = 1, MEGU
     RTF  0570
    IRTF(I,JROMY) = IRTF(I,JROMY) - IRTF(I,JROMY)
     RTF  0580
   230  IF (IDIF(I).LE.1) GO TO 220
     RTF  0590
   IFLAG2 = 0
     RTF  0530
   RETURN
     RTF  0540
480  SUBROUTINE RTFLOW
     RTF  0600
   73/73  OPT-2  TRACE
     RTF  4.6+452
   FTH  75/95.10. 13.11.59
     RTF  250
   IR(I) = IRTF(I,JROMY)
     RTF  0610
230  CONTINUE
     RTF  0620
   IF (ICOUNT.GT.10) GO TO 240
     RTF  0630
   RETURN
     RTF  0640
240  WRITE (KOUT,250) ROM, IV
     RTF  0650
   250  FORMAT (1H-, 5H, WARNING, RETURN FLOW WILL NOT CONVERGE MONTH ,
       12,6H YEAR ,12,/)  
     RTF  0670
   RETURN
     RTF  0680
650  MBACK = MLAGS - JROMY + 1
     RTF  0700
   HPAST = MLAGS - MBACK
     RTF  0710
   DO  320  I = 1, MEGU
     RTF  0720
    IDIOM = MIDBOG(I)
     RTF  0730
   DO  300  J = 1, MLAGS
     RTF  0740
    IFX = IRTF(I,J)
     RTF  0750
   IADD(I,1) = IADD(I,1) + IPAST(I,1)
     RTF  0760
   IF (HPAST.EQ.0) GO TO 280
     RTF  0770
   DO  270  N = 1, HPAST
     RTF  0780
    IADD(I,N + 1) = IADD(I,N + 1) + IPAST(I,N)
     RTF  0790
   IF (N + M = M + 1) IRTF(I,JROMY) = 0
     RTF  0800
   270  CONTINUE
     RTF  0810
   280  DO  290  N = 1, MBACK
     RTF  0820
    IADD(I,1) = IRTF(I,JROMY) + IDIOM(I)
     RTF  0830
   IADD(I,MLAGS + M + 1) = IRTF(I,N)
     RTF  0840
   290  CONTINUE
     RTF  0850
   IF (M + 1) IRTF(I,JROMY) = IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) + IRTF(I,JROMY) = 0
     RTF  0860
   DO  310  N = 1, MLAGS
     RTF  0870
    IADD(I,MLAGS + M + 1) = IRTF(I,1)
     RTF  0880
   310  CONTINUE
     RTF  0890
   320  CONTINUE
     RTF  0900
310 CONTINUE
320 CONTINUE
GO TO 200
95 END

SUBROUTINE SETNET 73/73  OPT-2 TRACE  FTM 4.6+452  73/05/19, 13.11.59

1 SUBROUTINE SETNET
COMMON /CONTROL/ KIN, KOUT, KAPE1, SET 0010
1 KAPE4
COMMON /PARAM/ MJ, MRES, MUMC, SET 0020
2 NL, NC, NYEAR, ND, SET 0030
3 NR, NPAIRS
COMMON /LINE/ LNODE(50,2), CNCA(50), CMCA(50), SET 0040
COMMON /DATA/ MMAX, MRES, MNUC, MFC, MESI, SET 0050
10 NTME, NT(500), M(500), H(500), SET 0060
2 NTME, NT(500), NT(500), NT(500), SET 0070
10 NTME, NT(500), NT(500), NT(500), SET 0080

STEP 01
SET UP ALL FROM AND TO NODES BY LINK NO. SET 0100

15 DO 100 L = 1, NL
20 NT(L) = LNODE(L,1)
30 NT(L) = LNODE(L,2)
100 CONTINUE

STEP 02
SET UP ALL INITIAL ARCS SET 0200

25 NARC = NL
35 N = MJ + 1
45 DO 120 K = 1, N
50 NARC = NARC + 1
60 NF(NARC) = N
70 NT(NARC) = K
120 CONTINUE

STEP 03
SET UP ALL DESIRED STORAGE ARCS SET 0300

35 N = MJ + 2
45 DO 120 K = 1, N
50 NARC = NARC + 1
60 NF(NARC) = K
70 NT(NARC) = N
120 CONTINUE

STEP 04
SET UP ALL FINAL STORAGE ARCS SET 0400

45 DO 120 K = 1, N
50 NARC = NARC + 1
60 NF(NARC) = K
70 NT(NARC) = N
120 CONTINUE

50 C
KPOY = 0
KBRK = 0
IP = 0
MMS = 0

20 IFL = 0
NII = 0
NII = NII + 1
IF (NII .GT. CT) GO TO 130
DO 100 I = 1, NII

25 NMODE = 0
100 CONTINUE
DO 110 M = 1, NII
DO 110 NII = 1, M

30 J = NA(NII)
IIFL = MC(NII)
KOST = JSAVE(NII)
NMODE = NMODE + 1
NMODE = NMODE + 1
MII = MII + 1
KOS(NII) = KOST

35 KOS(NII) = - KOST
JC(NII) = JSAVE(NII) - IIFL
JC(NII) = IIFL - ILO(NII)

40 CONTINUE
DO 120 I = 1, NII
120 JSAVE(NII) = NMODE
GO TO 160

130 CONTINUE
DO 140 I = 1, NII
140 CONTINUE
DO 150 M = 1, NII
MC(NII) = JSAVE(NII) - IIFL
MC(NII) = IIFL - ILO(NII)

50 CONTINUE
150 CONTINUE
160 CONTINUE

60 SUBROUTINE SUPERK 73/73 OPT=2 TRACE FTM 4.6+52 70/06/19. 13.11.50

65 KL = 1
DO 170 K = 1, NII
JK = NODE(K)
NMODE(K) = KL
JC(K) = KL

170 CONTINUE
170 MIDL(K) = KL - 1
DO 520 L = 1, NR
LL = L + 1, NR
J = MAIL(L)
I = MR(L)
KOST = KOS(L)
N = MC(L)
LO = - MC(LL)

30 CC
RIGHT=2 LEFT=1
CC
MAIN = 2
MIRROR = 2
IF (KOST) 190, 190, 190
190 IF (K) 210, 210, 220
190 IF (K) 210, 210, 220
210 IF (K) 220, 220, 220
220 IF (K) 230, 230, 230
230 IF (K) 230, 230, 230
240 MIRROR = 1
250 IF (MAIN.EQ.2) GO TO 250
250 II = JUW(I)
250 MIR(J) = L
250 JUW(I) = II + 1
250 GO TO 250
260 II = MIDM(I)
270 MIR(J) = L
270 MIDM(I) = II - 1
270 IF (MIRROR.EQ.2) GO TO 270
270 II = JUW(I)
270 MIR(J) = LL
270 JUW(I) = II + 1
270 GO TO 270
280 II = MIDM(J)
290 MIR(J) = LL
290 MIDM(J) = II - 1
290 CONTINUE

110 ********************************************
110 GO - SUPERFILTER
110 ********************************************
115 MD = INFIN
115 MAIN LOOP (1800)
115 MIRZ = MR 2
120 DO 1130 MAIN = 1, NR
SUBROUTINE SUPERK 73/73 OPT-8 TRACE
FTM 4.3+458 79/05/10. 13.11.59
120 MAIN = MAIN + NR
120 DO 1130 MIRZ = 1, 2
1130 IF (MODE.EQ.2) GO TO 300
1130
II = MAIN
J2 = MAIN
GO TO 310

300 II = MAIN
J2 = MAIN

310 IF (NClII)) 350,330,330
320 IF (NClJJ)) 340,1120,1120
330 IF (KOS(II)) 340,329,329

IS, IT = START, END NODE MOS, JS, JT = ARC, MIRROR ARC MOS
FOR ARC NEEDING FLOW INCREASE
WANT TO INCREASE FLOW, START LABELING AT JJ

340 IS = NA(JZ)
JS = II
IT = NA(II)
JT = JZ
GO TO 360

WANT TO DECREASE FLOW, START LABELING AT II

350 IT = NA(JZ)
IS = NA(II)
JS = JZ
JT = II

LABELING PROCEDURE

360 IPL = 1
IPLL = 1
IPS = 0
MUMS + 0
LABL(IT) = JS
IW(IPL) = IT

370 KLAB = KLAB + 1
GO TO 390

380 IF (IPS = IPL) 390,640,390
390 GO TO 390

400 DO 420 JJ = IB, IE
J = MIR(JJ)
MNODE = NA(JJ)
IF (LABL(MNODE)) 420,410,420

410 LABL(MNODE) = J
IW(IPL) = MNODE
IF (MNODE = IB) 420,430,480

420 CONTINUE
GO TO 390

BREAKTHROUGH BREAKTHROUGH BREAKTHROUGH

430 KBK = KBK + 1
FIRST RETRACE

K = 0

NOW = IS

IJ = LABI(NOW)

JI = IJ - HR

IF (JI) 550, 550, 550

JI = JI + MR2

NEXT = HAJI(JI)

K = K + 1

IF (KOS(JI)) 480, 480, 480

MET = MC(JI)

JAU(K) = MET

GO TO 480

MET = MC(JI)

JAU(K) = MET

1ALPHA = MINB(IALPHA,MET)

IF (NEXT - IS) 500, 510, 500

NOW = NEXT

GO TO 480

SECOND RETRACE

K = 0

NOW = IS

IJ = LABI(NOW)

JI = IJ - HR

IF (JI) 530, 530, 530

JI = JI + MR2

NEXT = HAJI(JI)

K = K + 1

MC(JI) = MC(IJ) - IALPHA

MET = MC(JI)

METNU = MET + IALPHA

MC(JI) = METNU

IF (KOS(JI)) 580, 580, 580

IF (MET) 580, 580, 580

IF (METNU) 580, 580, 580

CALL LEFT (NOW, JI)

CALL RIGHT (NEXT, IJ)

IF (NEXT - IS) 610, 620, 610

NOW = NEXT

GO TO 580

ERASE LABELS AND GO FOR O-K CHECK

GO TO 580
DO 630 I = 1, IPL
   J = IV(I)
   LABL(J) = 0
   GO TO 310  
C
C POTENTIAL CHANGE
C
SUBROUTINE SUPERK 73-73 OPT=2 TRACE
FTN 4.6+452
75/05/10. 13.11.50

KPOT = KPOT + 1
KSET = MUNS
MEMLAB = 0
MUNS = 0
INTHRU = 0
MIN = INFIN
NEW = MUNS
MUNS = MMAXA + 1
IF (KSET) 748, 749, 650
   IF (NEW - MAXA) 668, 669, 690
   IF (MMAX - MMAXA) 670, 671, 690
   MMAX = MMAXA
   DO 680 K = MMAX + 1, MMAXA
      IF (LABL(K)) 682, 683, 690
      IF (LABL(KX) 686, 687, 690
   CONTINUE
5S
DO 710 K = 5L, 1
   KK = JMAX
   KMAX = MAXA(KK)
   IF (LABL(KK)) 720, 721, 730
   IF (LABL(KX) 724, 725, 730
   MUNS = MUNS + 1
   JMAX(MUNS) = KK
   MINM = MIN(MIN, KOS(KK))
   GO TO 730
5M
CONTINUE

FIND MIN(C-DOR) OVER SET S

DO 820 LL = IPL, IPL
   LL = IVLL
   JMAX = MIGM(L) + 1
   JMAX = NODE(L + 1) - 1
   IF (JMAX - JMAX) 760, 761, 820

760 DO 810 KK = JNID, JRT
    810  K = MIN(KK)
    820  I = HHRC(K)
    830  IF (LABEL(I)) 810, 770, 810
    770  IF (HC(K)) 780, 790, 790
    780  IF (KOS(K)) 800, 800, 790
    790  NUMS = NUMS + 1
    800  JMN(JMN) = K
    810  MIN = MIN(MIN, KOS(K))
    820  GO TO 810
    830  NUMS = NUMS - 1
    840  JMN = JMN + 1

300 SUBROUTINE SUPERC 7/3/73 OPT=2 TRACE FTP 4.6+152 79/05/10 13.11.59

320 DO 950 I = 1, NUMS
    950  IF (JMN) 950, 950, 325
    960  JI = JMN(I)
    970  JI = JI + 1
    980  IF (JI) 990, 990, 910
    990  JI = JI + 1
    325  KOST = KOS(JI) - MIN
    330  KOST(JI) = KOST
    340  CALL LEFT(MN(JI), JI, JI)

330 NODE(JM) = NA(JI)

340 CONTINUE
IF (MODS - MAXA) .GT. 970,970,1050
DO 1040 I = MODS,MAXA
   JJ = JU(I)
   JJ = JJ - WP
   IF (JJ) 980,980,990
   JJ = JJ + WP
   KOSTA = KOS(JJ)
   KOST = KOST - MIN
   KOS(JJ) = KOST
   KOS(JJ) = - KOST
C
C CHECK FOR MIRROR LEAVING MU STATE
C CHECK LATER FOR COMBINING IF-CHECKS HERE

1000 IF (KOSTA) 1040,1000,1000
1010 IF (KOST) 1040,1020,1020
1050 IF (MC(JJ)) 1040,1050,1050
360 CALL RIGHT (NW(IJ),JJ)
SUBROUTINE SUPERK  T3/73  OPT-2 TRACE
FTM 4.6+452  78/05/10. 13.11.59

1040 CONTINUE
C
C OUT-OF-KILTER CHECK

365 IF (MC(JJ)) 1000,1050,1050
1050 IF (MC(JJ)) 1000,1050,1050
1070 IF (KOS(I)) 1000,1070,1070
C
C BREAKTHROUGH CHECK

370 IF (JTHRU) 1090,1000,1090
1090 IF (IPS - IPL) 370,370,370
1100 DO 1110 I = 1,1PL
   J = IU(I)
   J = IU(I)
   1110 LABEL(J) = 0
1120 CONTINUE
1130 CONTINUE
C
C
380 DO 1140 I = 1,WP
   KOS(I) = KOS(I) - ISAVE(I)
   MC(I) = MC(I) - MC(I)
   TOTAL = TOTAL + MC(I) & ISAVE(I)
1140 CONTINUE
C
C
C END
APPENDIX E

ACKNOWLEDGMENT OF RESEARCH BY WATER COMMISSIONER,
DISTRICT NO. 3
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
Water Commissioner, District No. 3
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