DECISION SUPPORT SYSTEM FOR A MULTIRESERVOIR SYSTEM OPERATION

E-031

Project Progress Report

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Project Summary

A reservoir system such as the one on the Arkansas River is designed to fulfill a number of objectives such as navigation, flood control, hydropower generation, recreation and water quality management. Operation of such a system to maximize the overall benefits has been a subject of research for a long time, but not many successful stories abound. One reason for the gap between theory of optimization and actual implementation may be the imposition of too much structure when an optimization problem is formed. A second reason may be the lack of communication between the decision maker and analyst. Decision Support Systems are being introduced in the business world to alleviate these two problems. This research attempted to develop a framework for such a decision support system for water release planning.

The developed DSS is fully interactive for analyzing 'what if' scenarios. The system eventually will consider the probabilistic nature of inflows and demands, benefits of various uses of water, constraints imposed on releases for economic/technical/political reasons, and provide release suggestions.

The system has been developed in Encore!, a modeling language based on the spreadsheet concept. In its current form, a data base management subsystem, user interface, report generation, a graphics subsystem and the relationships between some other benefits and releases have been incorporated.

A mainframe version in IFPS was built initially in 1982-83. This report summarizes the microcomputer version which was developed during the 1983-84 academic year. The DSS runs using an IBM-PC with color graphics card and 256K.

INTRODUCTION

Objectives:

The objective of this research is to develop an interactive system for release decisions for a multipurpose reservoir system. The system will consider the probabilistic nature of inflows and demands, benefits of various uses of water, constraints imposed on releases for economic/technical/political reasons, and provide release suggestions.

The interactive nature of the system allows a user to evaluate many 'what if' scenarios. Thus, the system supports the decision-making, rather than make the release decisions. Using this model, the decision maker is able to analyze effects of various uncertainties and action alternatives and then make the final release plans.

Scope and Justification of the Study:

A decision support system reported here is being developed for the Oklahoma portion of the Arkansas River Navigation System. As seen from Figure 1, various benefits such as hydropower generation, navigation, recreation and flood control have all been increasing over the last few years. This clearly establishes the multipurpose nature of the system.

The release decision problem for a multipurpose reservoir is quite complex. First, the timing of the release is important. Every time some water is released, one wonders whether it could have been saved for a later day when its utility may have been higher. Second, the conflicting and multiple uses of water make it even more difficult. For example, the optimal hydropower generation objective may require that water be stored to build a large head and then released during periods of peak demand. Navigation, on

TRENDS IN VARIOUS USES OF THE MCCLELLAN-KERR NAVIGATION SYSTEM

(ALL FIGURES ARE IN THOUSANDS)

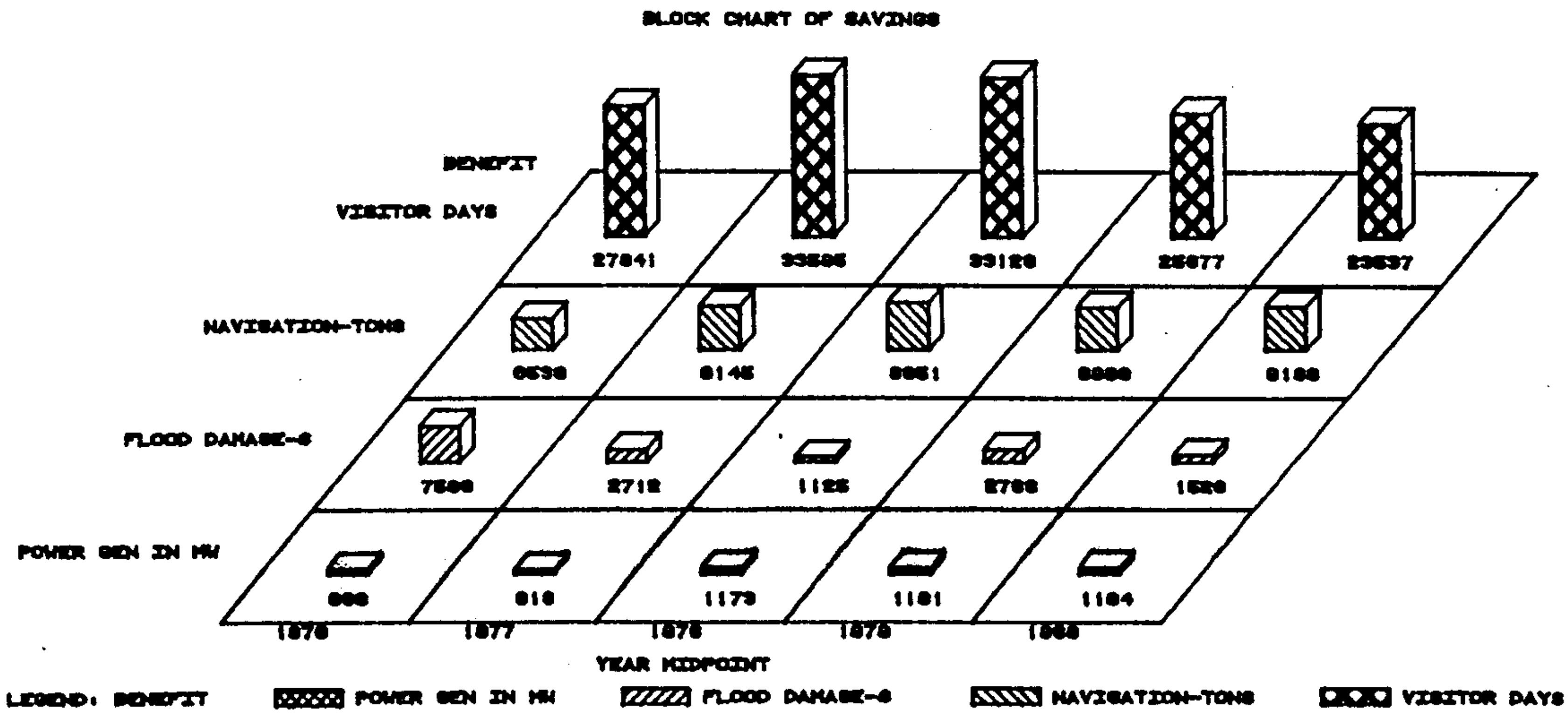


Figure. 1

the other hand, would be better managed by releasing enough water to maintain a stable flow in the channel. The recreation objective may suggest yet another operation plan. Thus the conflicting objectives do make release planning a difficult task. When the interrelationships between reservoirs are to be considered, the problem is even harder. The Oklahoma portion of the McClellan-Kerr Arkansas River Navigation System is such a multipurpose-multireservoir system. The objective of this research has been to develop a system for use in planning releases in Oklahoma.

General Statement of the Problem:

The problem can be briefly stated as follows. Let $\underline{\zeta}$ be the set of inflows, $P(\zeta)$ be the probability distribution of inflows, $\underline{d}$ be the set of demands on water, $P(\underline{d})$ be the probability distribution of the same, $\underline{x}$ be the set of releases, $\underline{s}$ be the set of storage values, and let $B(\underline{s},\underline{x})$ be the overall benefit function as a result of release $\underline{x}$ and storage level $\underline{s}$. Then at any time period t, we have information on $\zeta_1 \ldots \zeta_{t-1}$; $d_1, d_2, \ldots d_{t-1}$; $s_1 \ldots s_{t-1}$; $x_1 x_2 \ldots x_{t-1}$. The problem is to

$$\text{find } x_t, x_{t+1} \ldots .$$

so as to

$$\text{Maximize } B(\underline{x},\underline{s})$$

and also satisfy constraints on

$$\text{demands } d_t, d_{t+1} \ldots .$$

$$\text{and } S_t = S_{t-1} + \zeta_t - x_t .$$

The constraint above is a continuity constraint. A real problem, of course, has constraints relating water levels for downstream reservoirs to releases from upstream reservoirs, upper and lower bounds on storage levels and such.

The problem described above is a sequential decision making problem. Reservoir operators need to plan releases. They use the historical information and determine releases. When new information on inflows is available next month, a set of revised releases can be developed.

This problem of decisions regarding water releases from each reservoir of the system for different purposes has received a great deal of attention. The problem has been solved using simulation or various optimization techniques. The reported applications of simulation include Thomas and Fiering (1982) and Fiering and Jackson (1971). Applications of optimization techniques include linear programming [e.g., Nayak and Arora (1971), Houck (1979)]; dynamic programming [e.g., Young (1967), Heidari et al., (1971)]; nonlinear programming [e.g., Peters et al., (1978), Hanscom et al., (1980)]. As pointed out by Becker, et al., (1976), most of the developed methods are primarily for the optimization of reservoir operations for planning and design purposes, and the problem of real-time operation of a multipurpose, multireservoir system is still being studied.

Despite a large body of literature concerning application of optimization techniques to reservoir operation problems, there appears to be a wide gap between the studies and applications. A large part of this gap may be attributed to the fact that in applying an optimization technique, too much structure is forced into the problem. A reservoir management problem is not as well structured as we like to think it is. Forcing a structure onto this problem requires that we make certain stringent assumptions, which may make the results unusable by field personnel. On the other hand, if all of the "reality" were to be taken into account in the formulation, an optimization problem would either be unsolvable or it may not be solvable for real time use. Thus, an unstructured approach to the problem may be more appropriate, even at the cost of optimality.

A second requirement for successful application appears to be that the system has to be interactive so that the user can try various scenarios and then make a decision. As noted by Joshi (1980) and many other management scientists, implementation of a decision is more likely if the decision is made by the implementor. Thus, the two key features of a successful application seem to be: (i) solving an unstructured problem, and (ii) an interactive mode of decision making.

Decision Support Systems are beginning to find widespread applications in the business world recently. As defined by Keen and Scott Morton (1978), Decision Support Systems are interactive computer based systems, which help decision makers utilize data and models to solve unstructured problems. The aim of this research has been to develop such a system for the water management problem.

Modeling Approach:

A number of decision support system generators have been introduced within the last few years. These modeling systems feature an English-like programming language, an interactive mode of operation and built-in financial and mathematical functions. Some of these languages also allow for risk analysis through Monte Carlo simulation, 'what if' interrogation, and goal seeking. Traditionally these systems have been used for financial planning, capital budgeting, planning for financial requirements, mergers and acquisitions, and lease vs. purchase analysis. These analyses are facilitated by the row and column logic where the rows define variables and the columns represent time periods. The model consists of mathematical relationships for computing the values of variables as time passes. The risk analysis and 'what if' features enable the user to analyze the effects of various uncertainties. The natural language program appears to the user as a concise statement of the problem. Thus he can alter not only the values of variables, but also the perceived relationships between variables of the model.

One such modeling language is the Interactive Financial Planning System (IFPS). This DSS generator is fully interactive, and very easy to use. We developed the prototype of the DSS using IFPS. However, IFPS is available only on mainframe computers. A microcomputer version is available, but in a stripped down form.

Microcomputers have gained a lot of popularity in the last two years. They offer a low cost machine dedicated for one's use. They also allow a greater amount of control on the peripherals such as the CRT, printer, plotter, etc., than is possible using mainframe computers. These computers are inherently interactive, so they make it easier to develop decision support systems. For this reason, a microcomputer based DSS was designed and developed during the course of this project.

The microcomputer based DSS was developed using an IBM-PC with 640K and a color monitor. The basic software used was Encore!, a UCSD-p system based DSS tool. Encore! was chosen over IFPS/Personal because of its better graphics features and command control language.

MODEL DEVELOPMENT

The first step in developing the system was to prepare a complete requirements definition, i.e. what will this DSS be able to do? The following section summarizes the capabilities of the system. Not all of the features discussed here have been implemented yet; the model is expected to be completed this year. The following section describes the various components of the model followed by a report on the current state of the DSS.

General Description of the System:

The DSS is being developed for the Oklahoma portion of the McClellan-Kerr Arkansas River Navigation System. It is a multipurpose, multireservoir system. A schematic of the system highlighting the reservoirs under consideration is given in Figure 2.

In its current form, the model will provide support for planning releases over an intermediate term. The model assumes a monthly time step and can help plan releases over a 12-month period.

The DSS can be used by a nonprogrammer to evaluate the effects of various release plans on benefits such as hydropower, recreation, and navigation. The user can also access and update the historical data files, generate statistical summaries of the same, and plot the results graphically.

Components of the DSS:

The decision support system is termed Water Resource Planning DSS (WRP-DSS) in what follows. This decision support system, like a typical DSS, consists of six modules, all of which are programmed in one modeling language, Encore!. A relationship between Encore! and the six modules is shown in Figure 3. A brief description of each follows.

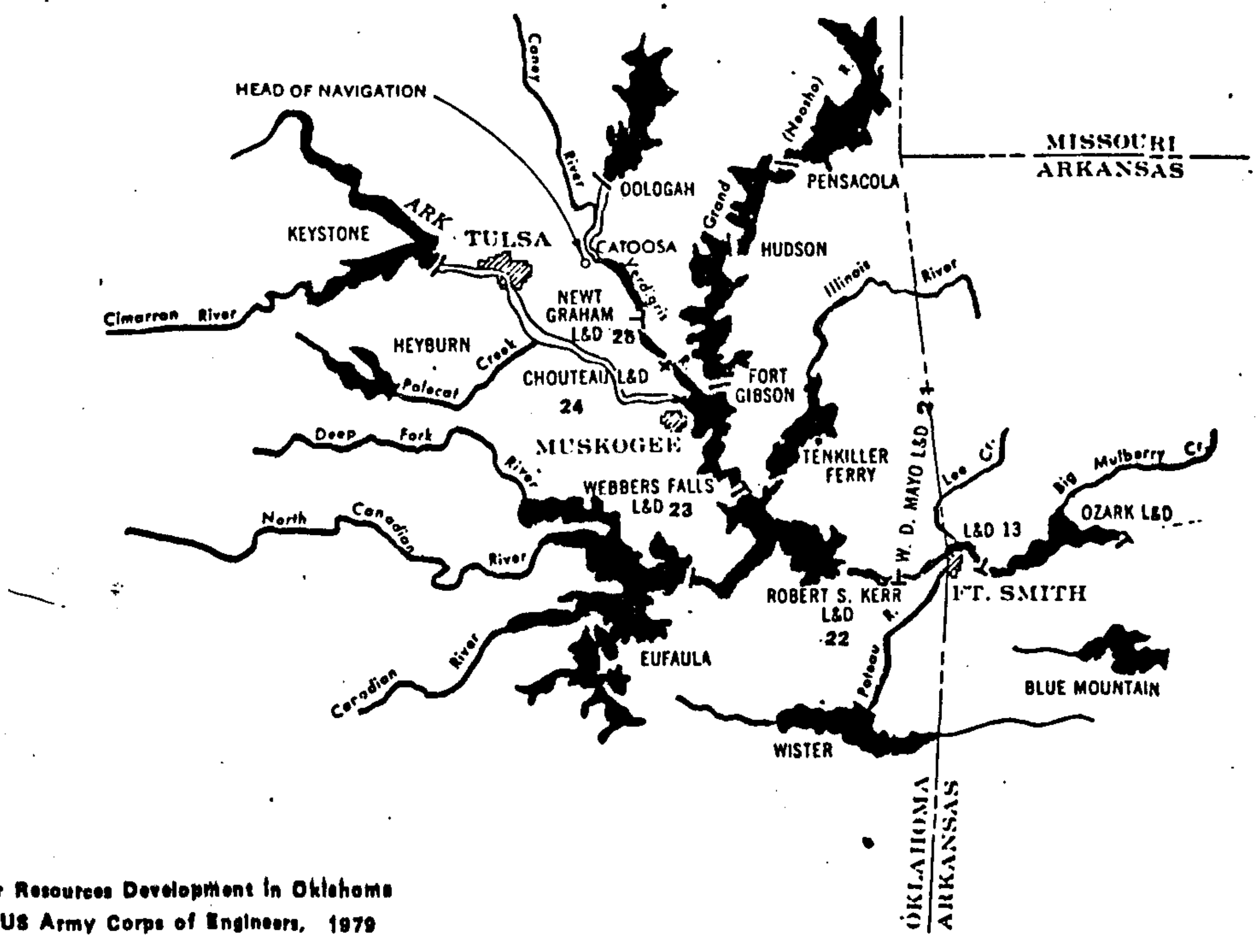
The Model:

The model is the heart of the system. This is where all of the main calculations are performed. The model consists of all of the interrelationships between the variables. The release plans are considered the decision variables. All the other variables are affected by the release values, directly or indirectly. The model is provided with a historical probability distribution of inflows, estimated relationships between outflows, storage

Figure 2

McCLELLAN–KERR ARKANSAS RIVER

NAVIGATION SYSTEM



SOURCE: Water Resources Development in Oklahoma
The US Army Corps of Engineers, 1979

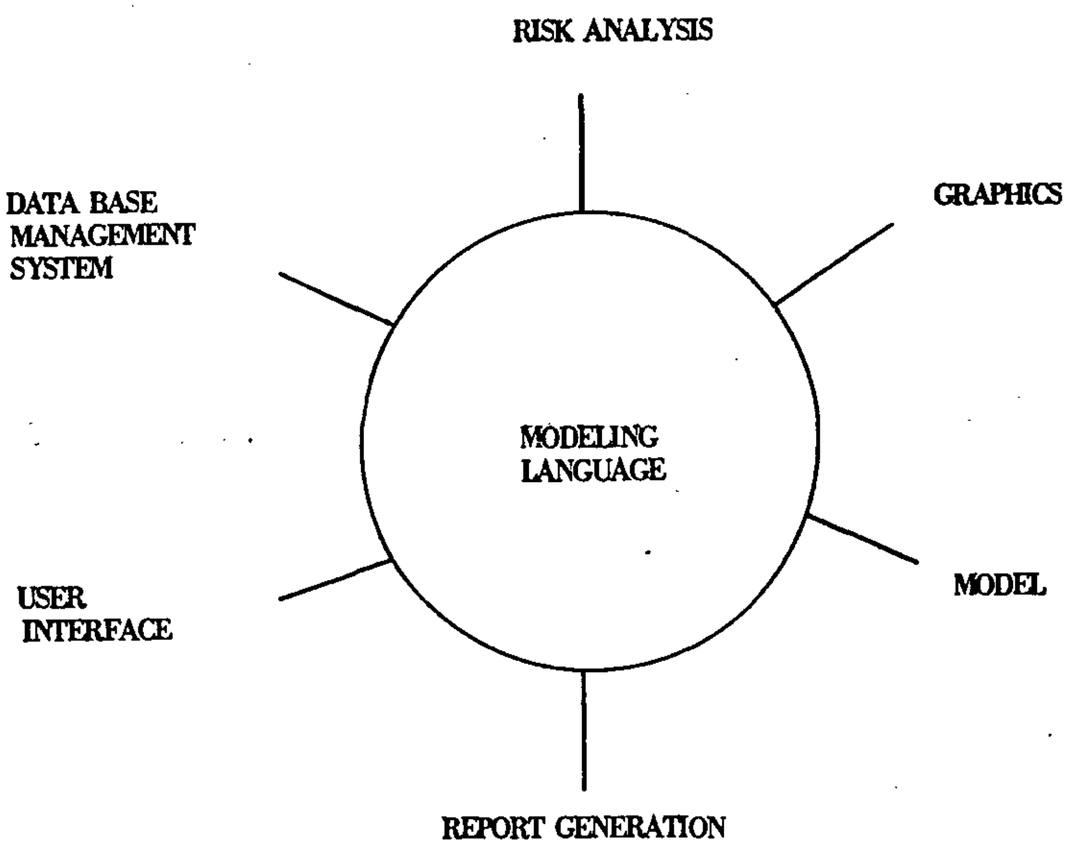


Figure 3: Components of WRP--DSS

levels and benefits generated each month, forecasts of certain variables and data on minimum demand constraints. The model can be run in two modes: deterministic and stochastic. In the deterministic mode only a mean value of inflow is assumed. In contrast, the stochastic mode consists of generating random values of inflow over many successive trials. For a given sequence of inflows and outflows, the model computes values of all benefit levels and also indicates whether the constraints are being satisfied.

A user can simply change the assumptions in the model and run it for a different set of inflows or releases. Since Encore! is a very high level language, it is very easy for a decision maker to understand the assumptions of the model and modify them if he wishes to investigate the effects of change in this relationship.

User Interface

Easy interrogation of the model is made possible through a friendly user-interface. The user, for the most part, does not have to learn Encore! in order to use this DSS. Yet, other features of Encore! are available to the user by entering just one command. This is accomplished by using the EXEC subsystem of Encore!

The interfaces developed by the EXEC subsystem let the user select an option from the menus when the user begins a session. The first menu lets him decide whether he wants to analyze the whole system, or just one reservoir at a time. In the latter case, the user has to select the reservoir. The second level menu then gives the user the option to access historical data bases, solve and produce reports using the model, interrogate the model for 'what if' analysis, or generate graphics. In any of these modes, the user can access other powerful features of Encore! Some sample menus are described in a sample session of the DSS.

Data Base Management System

The Encore! matrix options are employed along with the EXEC files to provide a data base management system within the WRP-DSS. The model needs a lot of data items such as historical storage levels, inflows, visitor days, power generation characteristics, etc., for future projections. A complete system is available to the user for accessing and updating the stored data. The user can insert new actual values in the data files through a very friendly user-interface. The data files are also available for development of statistical summaries and graphical reports.

Risk Analysis

As mentioned in the description of the model, a Monte Carlo simulation can be performed for risk analysis due to uncertainty in the values of realized inflows. Monte Carlo simulation consists of randomly generating a value of a subject variable which follows a particular probability distribution, measuring its impact and repeating this experiment over many trials. One can employ frequency analysis to consider the effects of the uncertainty.

WRP-DSS is set up for both deterministic and stochastic approaches. A lot of statistical analysis has been done to develop the cumulative probability distributions of inflows into the reservoirs for each month. These cumulative density functions are being included in the Encore! model for model for each season. These seasons have been defined as groups of months, based on similar inflow characteristics. A typical cumulative density function for inflows is shown in Figure 4. Probability distributions of demands will be analyzed and added to the model in the near future. The IFPS version of the DSS has full risk analysis features. The microcomputer version including this feature is still under development.

CUMULATIVE PROBABILITY FUNCTION OF INFLOWS

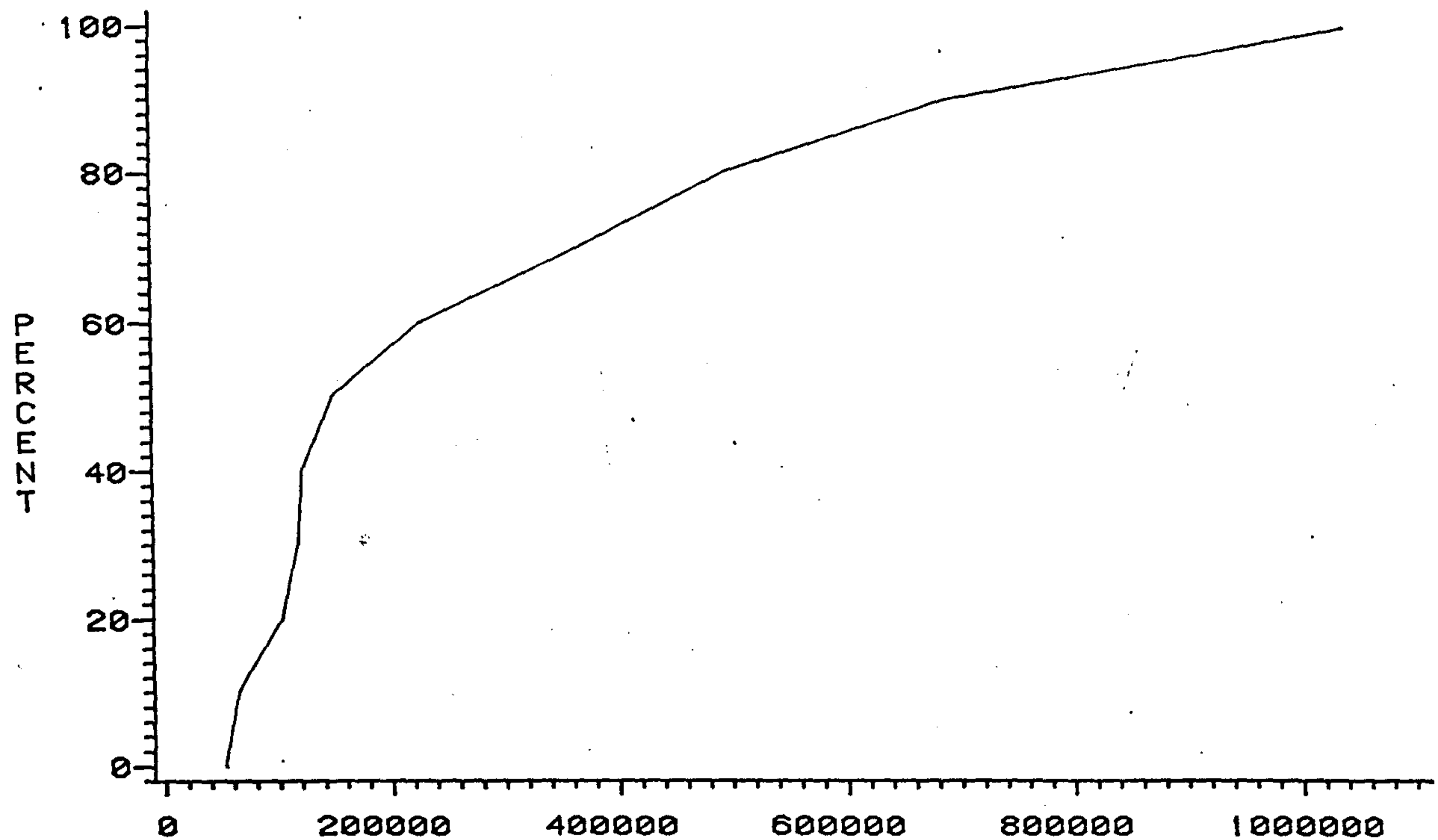


FIG. 4 - INFLOWS IN ACRE FEET
SEASON ONE FOR KEYSTONE (ST16420)

Report Generation

A very powerful report generator is available within Encore! It can be used to design customized reports. Since WRP-DSS can be used in deterministic or stochastic modes, two report writers are already built into the system. A deterministic report is a very neatly formatted report, which can be used for final presentation, etc. A stochastic report gives frequency analysis of observed values of a set of selected variables. Both reports automatically print the values of variables for 12 months, starting with the current month. A sample of the deterministic report is given in Table 1.

Graphics

The graphics subsystem has been implemented. This system has the ability to plot selected benefits over time, plot histograms of values realized in a Monte Carlo simulation, plot pie charts of various benefits at a given time, etc. The visual aid should help a release planner in decision making. Examples of the types of plots which are available are given in the description of the sample session.

Progress Report on the WRP-DSS:

As noted in the previous section, all sections except the risk analysis subsystem have been implemented to some extent. The report generator and data base management modules have been incorporated fully.

The user-interface has also been developed to control interaction with the DSS. As is usually the case with such systems, all of these modules are evolving. Once a complete system is in place, it will be demonstrated to the release decision makers and appropriate changes will be made to make the system even more useful.

KEYSTONE LAKE
One Year Monthly Projection

	May 72	Jun 72	Jul 72	Aug 72
Inflows (acre-ft)	656,548	656,548	212,779	148,103
Monthly avg storage (acre-ft)	522,741	564,289	603,952	629,393
Monthly avg water level	719.1	720.8	722.5	723.4
Planned release (acre-ft)	610,000	620,000	170,000	140,000
Recreational Benifits:				
Expedted monthly visitation %	100.00	100.00	100.00	100.00
Projected normal visitor days	4,700.8	4,128.8	4,553.0	3,714.6
Adjusted visitor projection	4,700.8	4,128.8	4,553.0	3,714.6
Navigation costs:				
Two million ton miles per day	$2,000	$2,000	$2,000	$2,000
Total navigation system cost	$1,290,871	$1,290,840	$1,289,338	$1,289,233

	Sep 72	Oct 72	Nov 72	Dec 72
Inflows (acre-ft)	148,103	150,804	150,804	147,614
Monthly avg storage (acre-ft)	617,496	626,950	667,754	666,963
Monthly avg water level	723.0	723.3	724.8	724.8
Planned release (acre-ft)	180,000	100,000	120,000	180,000
Recreational Benifits:				
Expedted monthly visitation %	100.00	100.00	100.00	100.00
Projected normal visitor days	1,986.7	1,722.1	272.0	793.5
Adjusted visitor projection	1,986.7	1,722.1	272.0	793.5
Navigation costs:				
Two million ton miles per day	$2,000	$2,000	$2,000	$2,000
Total navigation system cost	$1,289,400	$1,289,090	$1,289,163	$1,289,400

	Jan 73	Feb 73	Mar 73	Apr 73
Inflows (acre-ft)	147,614	147,614	420,632	420,632
Monthly avg storage (acre-ft)	664,577	677,191	736,314	791,946
Monthly avg water level	724.7	725.2	727.2	729.1
Planned release (acre-ft)	120,000	150,000	300,000	430,000
Recreational Benifits:				
Expedted monthly visitation %	100.00	100.00	100.00	100.00
Projected normal visitor days	753.3	875.3	2,196.6	2,828.8
Adjusted visitor projection	753.3	875.3	2,196.6	2,828.8
Navigation costs:				
Two million ton miles per day	$2,000	$2,000	$2,000	$2,000
Total navigation system cost	$1,289,163	$1,289,268	$1,289,827	$1,290,307

Note: Visitor projections are in thousands of visitor days.
Note: Water level is in feet above M.S.L .

Considerable progress has been made in developing the relationships between release and/or water level variables and benefits. Navigation and recreation benefit equations have been incorporated into the model. A description of our approach to this follows:

Recreation Benefits

Considerable research has addressed the question of recreation benefits. No single method has been available to measure the value of recreation. For a summary of the widely used methods, see Sharda (1983). The same report also describes the efforts to relate recreation visitor days to water level for various reservoirs in Oklahoma. Time-series analysis was used to analyze the recreation and water level data. The project was sponsored by the Office of Water Research and Technology, Department of the Interior.

Recreation benefits in this model are measured only on a visitor day basis. Since there is no uniformly accepted measure of the worth of each visitor day, we let the decision maker make a subjective judgment as to whether having an extra 30,000 visitor days is worth 10,000 MW of power. This is a two-edged sword. On the one hand, the user does not get to look at all of the benefits in the same units based on some arbitrary values of worth of water for various uses. At the same time, there is no research indicating that the decision maker is able to make optimal tradeoffs between a megawatt of power and a thousand visitor days. The model reported here does not compute all of the benefits in the same units because such relations are not fully available. More work in this area is clearly necessary.

The approach to estimate recreation benefits is as follows. Using the historical month visitor-day data, Box-Jenkins time series models were developed. These models relate the value in month t to values in some previous months and the errors in previous forecasts. The final models for the seven reservoirs are listed in Table 2. The forecast for visitor days in each month is then adjusted by a percent factor. The percent factor is based on a set of relationships developed by Coomes et al. (1979). They estimated a relation between pool elevation and percent of normal monthly visitation for each of the lakes included in our model. One such relationship which is programmed in the model is given in Figure 5.

To summarize this module, the model takes beginning storage, estimated inflow, proposed release and computes ending storage. This is converted into pool elevation using a capacity table. Through an equation, a percent factor is obtained for the corresponding pool elevation. This factor is multiplied with the recreation visitor day forecast to obtain the effective visitor days. The visitor days forecast is based on an equation which may include some previous historical values and errors in earlier forecasts. The same process is repeated for each month for each of the seven reservoirs included in the model.

Navigation Benefits

As in recreation, there is no agreement among researchers on the value of navigation. Perhaps a large chunk of the navigation benefits are long-term and fixed, because it stimulates industry growth and makes low cost transportation possible. A reservoir operator only needs to make sure that the releases are enough to maintain navigation depths. It would seem that the navigation objective presents some constraints rather than the opportunity to optimize. However, if the navigation charges were set by freight companies in a competitive environment, the lower freight costs would increase the savings in transportation even further. Reservoir operators can contribute to

Table 2

Univariate Time Series Models for Visitor Days

Reservoir	Model
Keystone	$y_t = 0.2\ y_{t-1} + y_{t-12} - 0.2\ y_{t-13} + e_t - 0.48\ e_{t-12}$
Oologah	$y_t = y_{t-12} + e_t - 0.462\ e_{t-12}$
Hulah	$y_t = 0.539\ y_{t-1} + y_{t-12} - 0.5397\ y_{t-13} + e_t + 0.945\ e_{t-12} + 8.1626$
Fort Gibson	$y_t = 0.4\ y_{t-1} + 1.33\ y_{t-12} - 0.4\ y_{t-13} - 0.33\ y_{t-24} + e_t - 0.94\ e_{t-12}$
Tenkiller	$y_t = y_{t-12} + 0.65\ y_{t-1} - 0.65\ y_{t-13} + e_t - 0.55\ e_{t-12}$
Eufaula	$y_t = y_{t-1} + 0.4\ y_{t-12} - 0.4\ y_{t-13} + 0.15\ y_{t-24} - 0.15\ y_{t-25} + 0.45\ y_{t-36}$
	$- 0.45\ y_{t-37} + e_t - 0.68\ e_{t-1}$
Wister	$y_t = 0.606\ y_{t-1} + y_{t-12} - 0.606\ y_{t-13} + e_t - 0.55\ e_{t-12}$
Heyburn	$y_t = y_{t-12} - y_{t-24} + e_t - 0.405\ e_{t-1} - 0.352\ e_{t-12} + 0.1428\ e_{t-13}$

PLOT OF NORMAL MONTHLY VISITATION VS WATER LEVEL

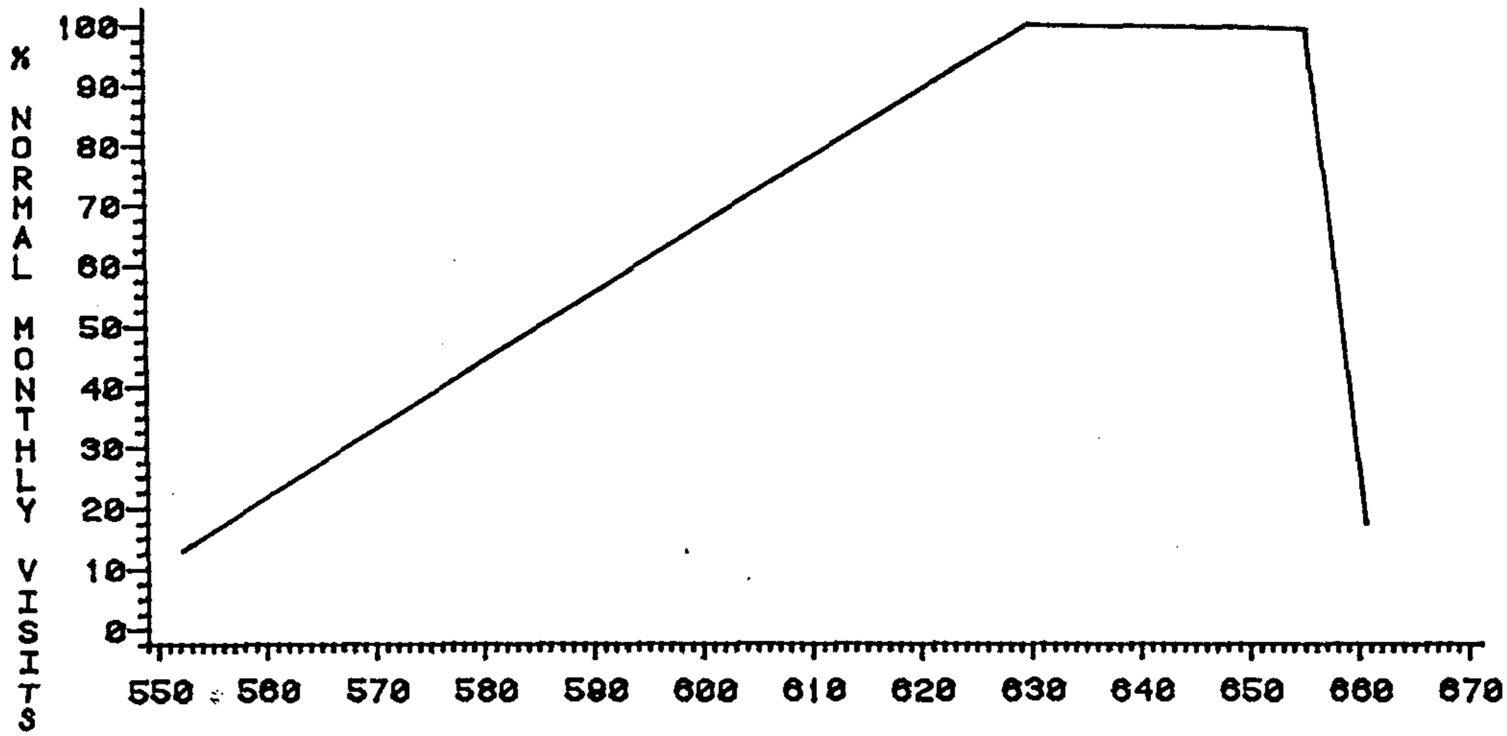


Figure. 5

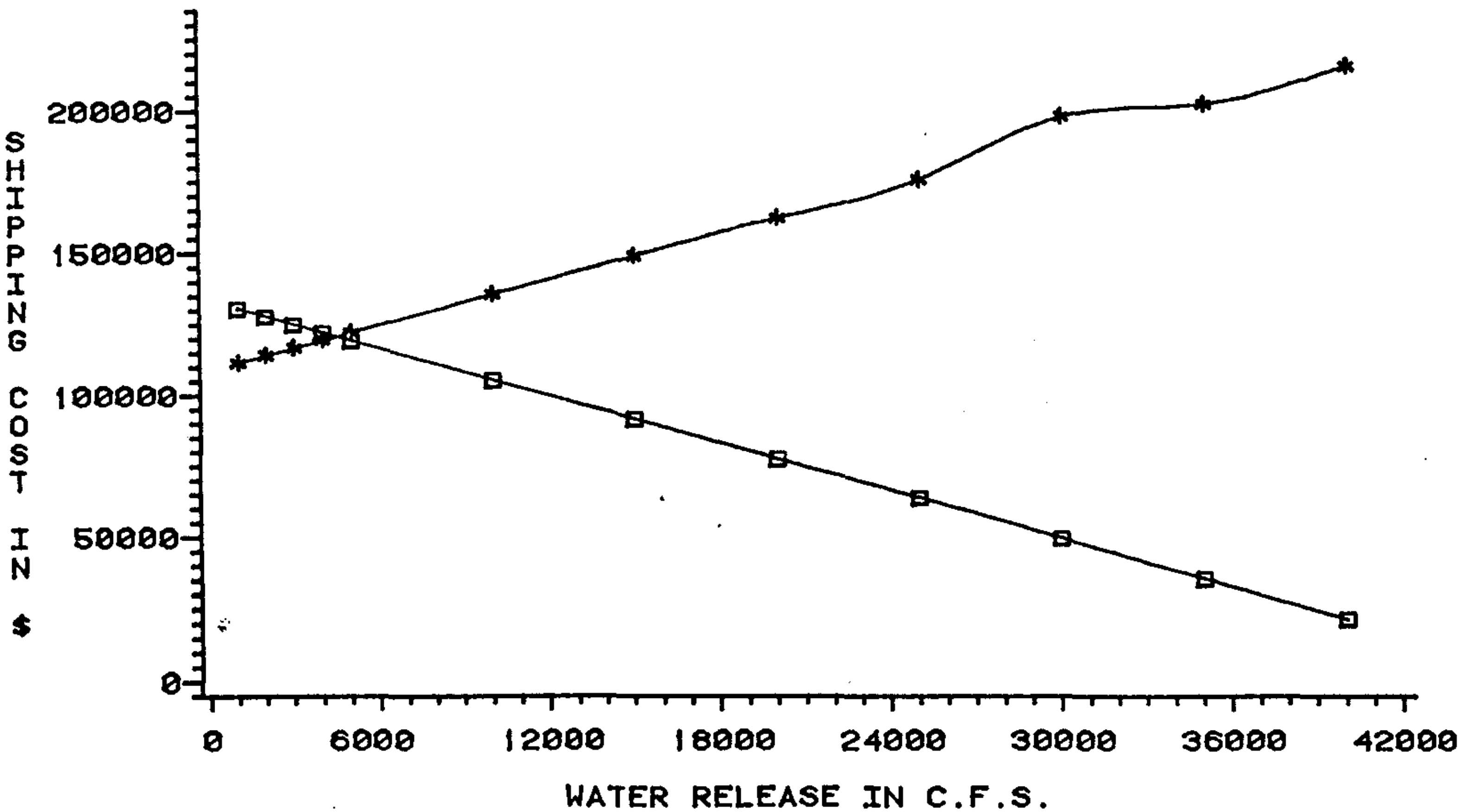
lowering the freight rates by helping to reduce the navigation costs of barge operators. This is possible if regulation of releases affects the travel time of a towboat. A limited study for just two reaches of the system [Singh (1983)] shows that the travel time of a towboat is related with flow rate positively in the upstream direction and negatively in the downstream direction. The relationship is stronger when the navigation channel is narrow than when the navigation channel passes through a reservoir. This relationship was extended for a typical trip (with average tonnage, boat size and hp) to estimate the fuel and labor costs of a trip. Based on 1981 data, this was used to estimate the navigation costs affected by the releases. A graphical representation of the relationship is given in Figure 6. Table 3 gives the same relationship in more detailed form. It is clear that the navigation costs are largely constant and are affected only slightly by a substantial change in release. However, this is included in the model to give the user another perspective.

The cost function described above includes only fuel and labor costs. The flow changes in the navigation channel also affect dredging costs, which are not insignificant. Coomes et al. (1979) took the dredging costs into account and estimated the total costs of shipping two million ton-miles per day, as affected by flow. The model also incorporates this relationship. This gives the user one more criterion to base his decision on. The user-friendliness of Encore! makes it very easy to modify the model for getting additional perspectives. The above proves it.

Modules Under Development:

The model is evolving to be a more detailed DSS. Work is in progress to add the risk analysis module. The model is being enhanced to include

NAVIGATION COST FUNCTION
(TRAFFIC BETWEEN CHOUTEAU AND NEWT GRAHAM)



LEGEND: Upstream Traffic *-*-*-* Downstream Traffic ⊡-⊡-⊡-

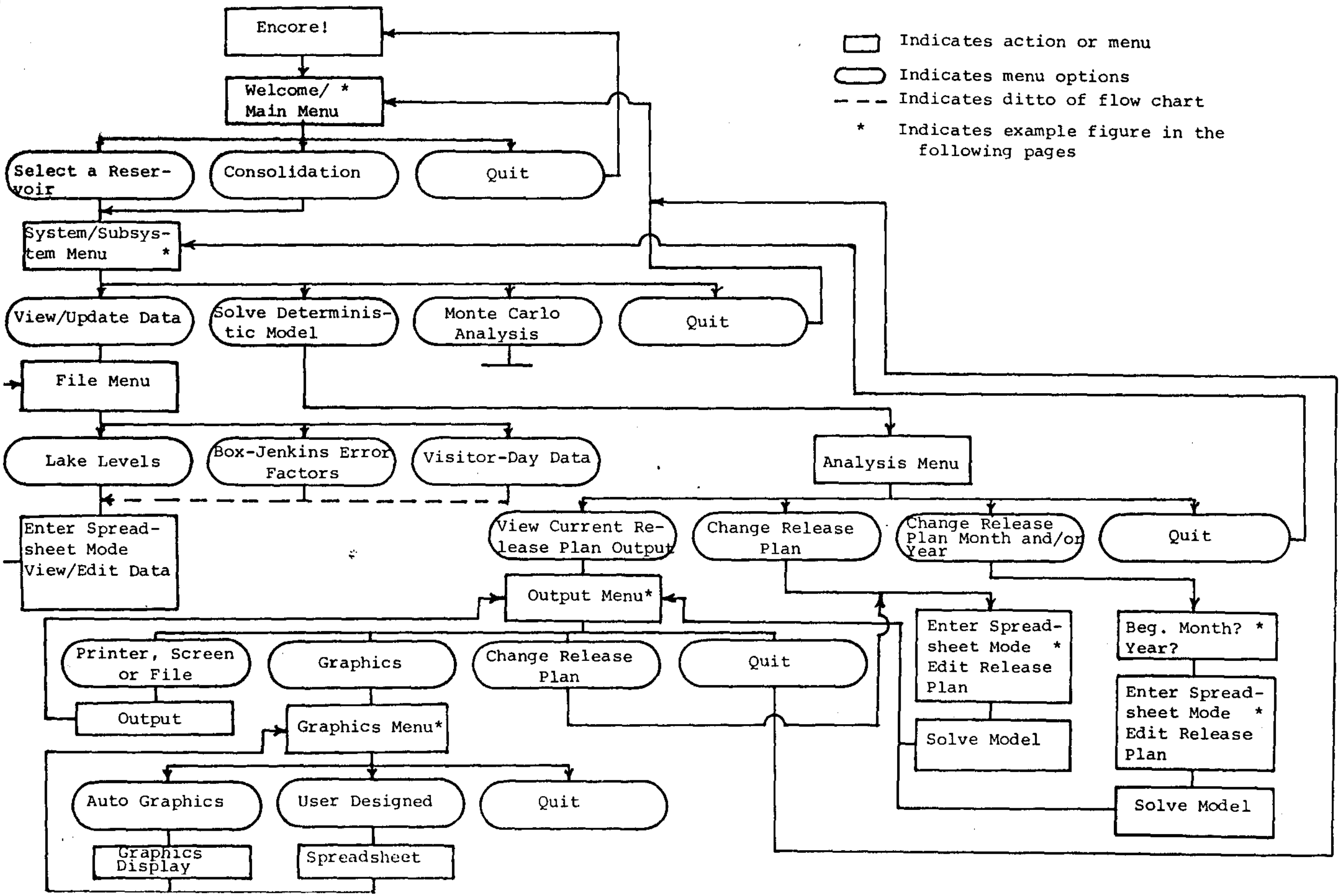
Figure. 6

hydropower generation, floods prevented as related to discharge from the reservoirs. Inclusion of each relationship requires a complete development; which is why it has taken so long. The completed model will also include the interrelationships of flows between reservoirs.

A SAMPLE RUN OF WRP-DSS

The following pages document a sample run of the decision support system in its current form. Since it is programmed in a natural language-type modeling system, most of the session is self explanatory. Figure 7 gives a general flow diagram of the DSS.

Figure 7. Flow Diagram of WRP-DSS



MAIN MENU

1) Keystone (ST16420)
2) Oologah (ST17130)
3) Hulah (ST17250)
4) Fort Gibson (ST19350)
5) Tenkiller (ST19750)
6) Eufala (ST24480)
7) Wister (ST24800)
8) Arkansas River System (consolidated)

- Selection of 1 through 7 will take the user into a submenu for that particular lake. There the user may elect to update historical data, solve the model, or when equipped, implement monte carlo analysis of the model.

SYSTEM/SUBSYSTEM MENU

1) Look at/update historical data.
2) Solve deterministic model.
3) Solve stochastic (monte carlo) model

- Selection of "1" will take the user into the spreadsheet mode. In this mode, the various data matrices can be accessed and edited. Selection of "2" will take the user to the analysis menu, and the the selection of "3" will allow monte carlo analysis when equipped to do so.

1. would you like to view the current
   release-plan output ?
2. change the release plan, month, and/or year ?
3. just change the release plan ?

select 1..3

- This analysis menu gives the user the option of studying the current release-plan output before changing the values of the decision variables.

- Or the user can initiate solving the model by selecting 2 or 3.

```
Beginning month (number) of projection is ?  5

Beginning year of projection is ?  1972
```

- This is an example of the prompt initiated by selecting "2" of the previous menu.

When ready, you will be entering the
'spreadsheet' mode. There you will be
able to view, enter, or change, the
monthly release plan for the coming year.
Keep in mind that column one represents the
first month in your twelve month
release projection.

Type <space bar> to continue -->

- At this point, the user leaves the automated portion of the program and enters the spreadsheet mode where he is able to edit the release plan matrix. Upon leaving the spreadsheet mode, the automated program will automatically resume. In future versions, it is planned that the release-plan selection and editing will also be automated so as to increase user friendliness.

```
---------------------------------------------------------------
! Spreadsheet ("Q" returns to Main Encore Menu)!
! Data Logic Analysis Window Matrix mp Graphics!
! Enter 1st character of Command Q-Quit H-Help !
!---------------------------------------------!
!                           1        2        3   !
! 1 PLANNED RELEASE   230,000  350,000  450,000 !
! 2                         0        0        0 !
! 3                         0        0        0 !
! 4                         0        0        0 !
! 5                         0        0        0 !
! 6                         0        0        0 !
```

- An example of the spreadsheet mode and partial view of the release plan data matrix. At this point, the user would use the spreadsheet functions to view and edit the matrix.

1. would you like a hard copy, screen display, or create a text file of the calculated results ?
2. a graphical display of some of the calculated results ?
3. change your release plan ? (processing time after edit: 2.6 minutes)
4. return to main menu ?

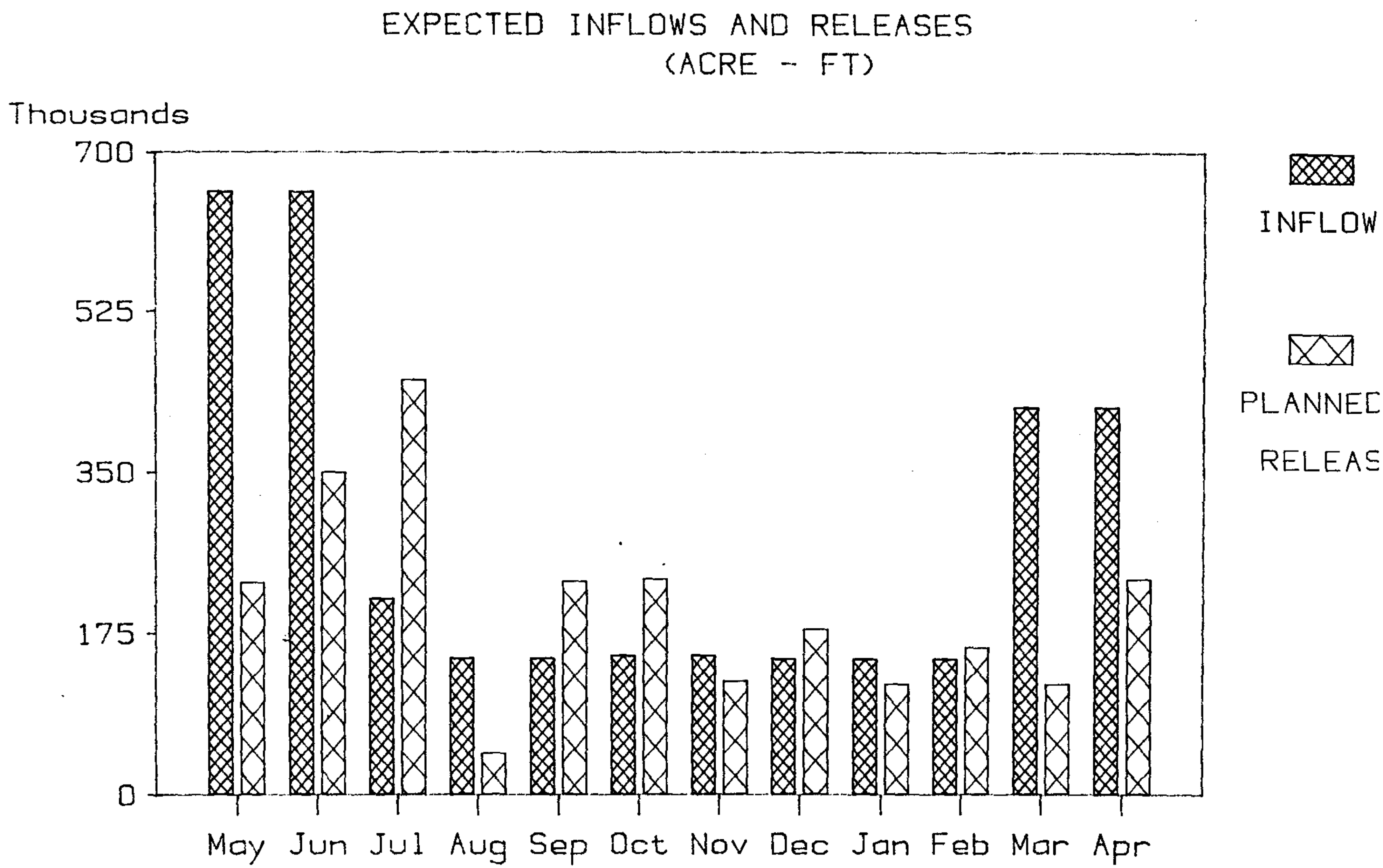
select 1..4

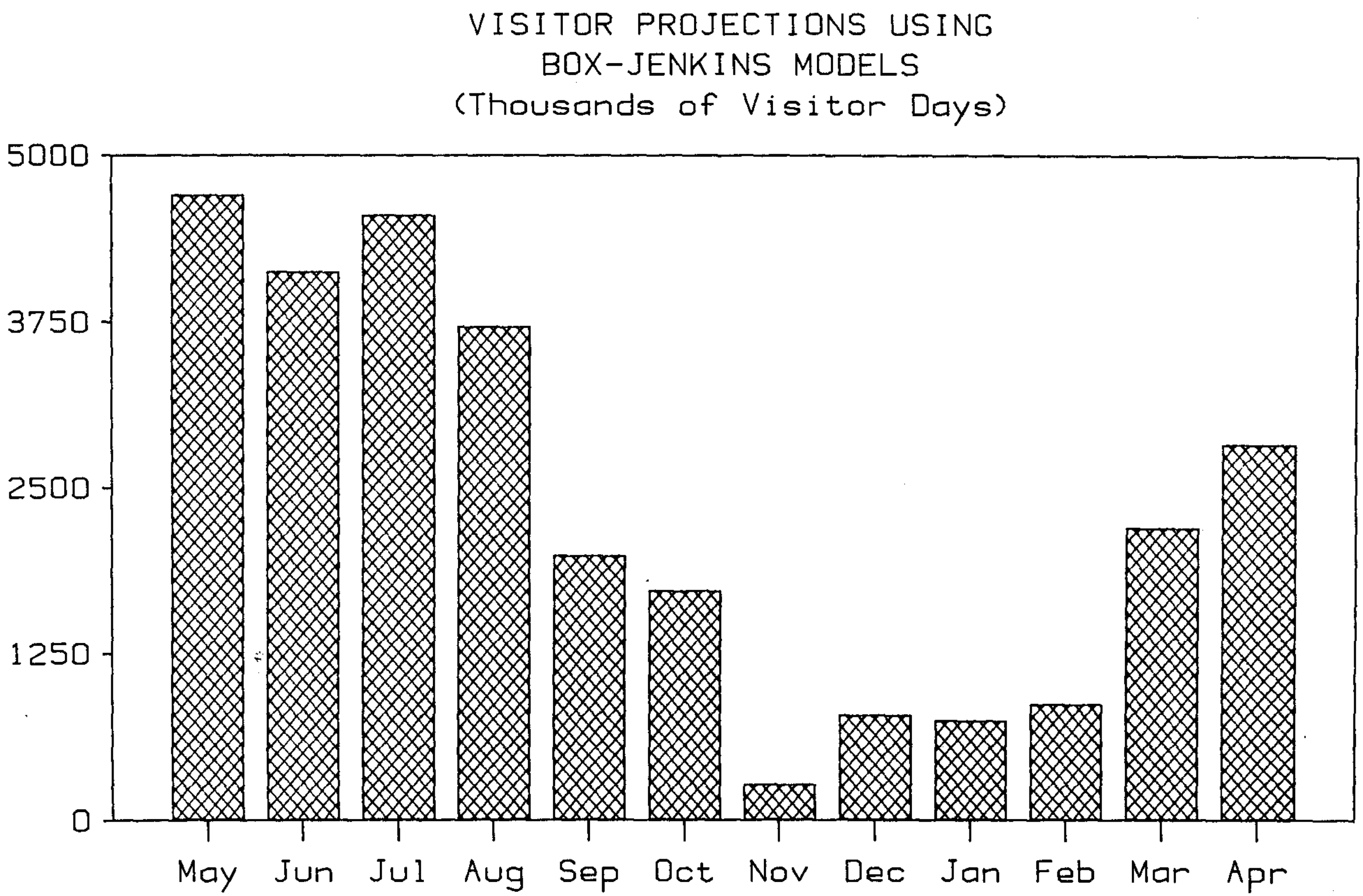
- This is the output menu which appears at the end of the model run, or if the user wishes to study the current output before running the model.

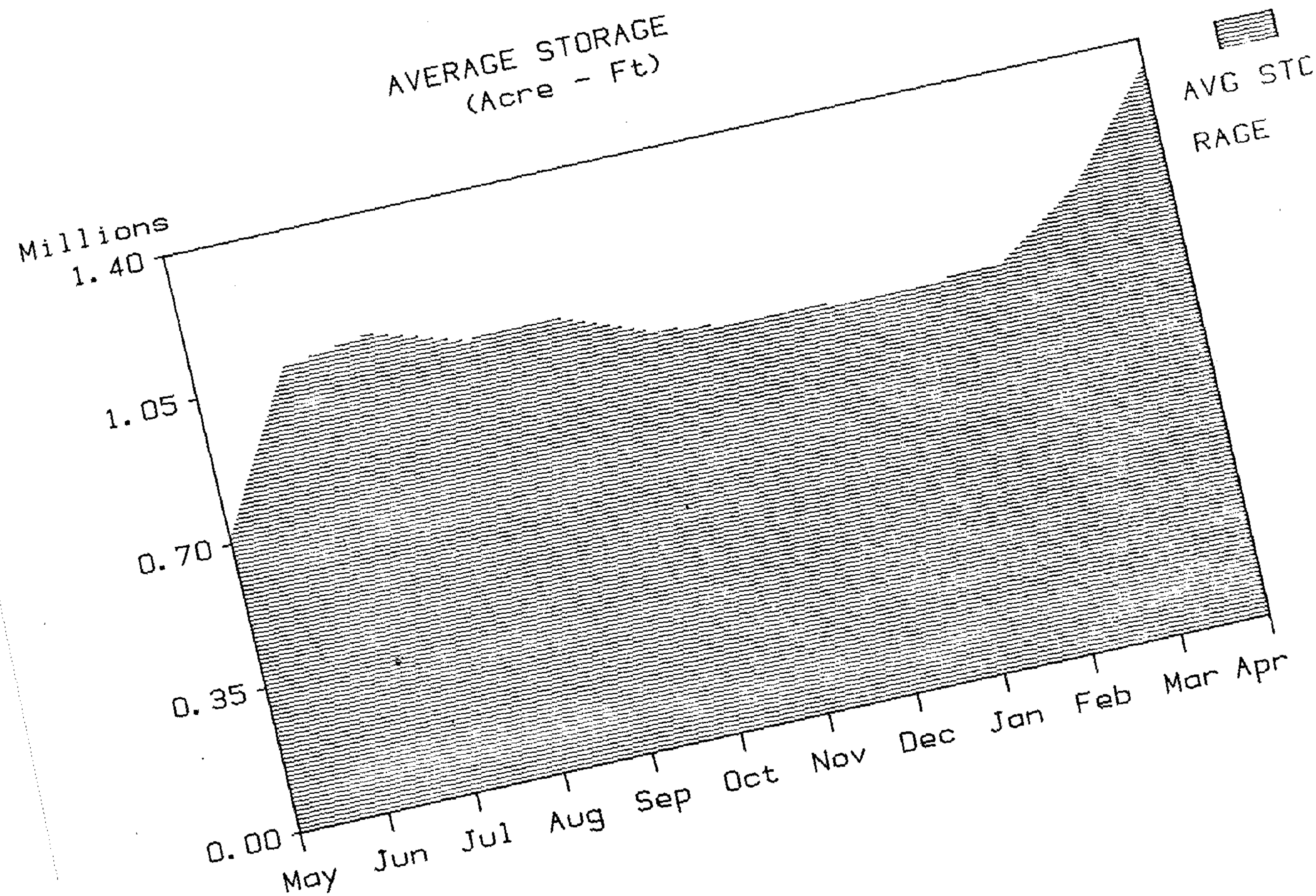
This display is a sequence of graphs for many variables of interest. Of course, you can design your own graphs by using the Graphics option on the spreadsheet menu. Enter 1 if you would like to see the graphics, 2 to look at the spreadsheet and graphics options, or 3 to return to the output menu.

Please enter your choice now
select 1..4

- This graphics submenu offers the user an automated graphics display, or the option of composing selected graphs from the output matrix.


EXPECTED INFLOWS AND RELEASES
(ACRE - FT)
Thousands
700
525
350
175
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
INFLOW
PLANNEC
RELEAS


VISITOR PROJECTIONS USING
BOX-JENKINS MODELS
(Thousands of Visitor Days)
5000
3750
2500
1250
0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr



AVERAGE STORAGE
(Acre - Ft)
AVG STC
RAGE
Millions
1.40
1.05
0.70
0.35
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr

APPLICATIONS OF THE RESEARCH

Potential Beneficiaries:

The immediate beneficiaries of this research are likely to be the operators of the reservoir system in Oklahoma. They will have an easy to use, release planning tool which can be used to develop a lot of 'what-if' scenarios before making release plans. The interactive nature of the system should enable them to look at many more alternative courses of action than would otherwise be possible. A better reservoir release planning would, of course, be eventually to the benefit of the taxpayers of Oklahoma.

Secondary beneficiaries of such a system would include other researchers in the area and reservoir operators elsewhere who may use this as a building block and develop more comprehensive systems.

Contributions of the Research:

The study has demonstrated the viability of application of a spread sheet modeling system to the reservoir management problem. It is, to the best knowledge of the originators of Encore!, the first such application. The work required to build the model resulted in time series analysis of recreation data, development of a relationship between navigation costs and flow rate, and acquisition of a large water related data base which is available to other researchers for further work.

Publications Resulting from the Project:

(i) El-Tayeb, M., Sharda, R. and Karreman, H. F., "An Adaptive Control Approach Applied to a Single-Reservoir Operation Problem," under review at the Journal of Water Resources Planning and Management Division, ASCE.

(ii) Singh, S. K., "Effect of Flow Regulation on Navigation Costs," Unpublished M.B.A. Thesis, O.S.U., July 1983. (A paper will be submitted to Review of Regional Economics).

(iii) Sharda, R. and El-Tayeb, M., "A Comparison of Some Reservoir Management Models," to be submitted to Water Resources Bulletin.

Meetings Attended:

Paper (i) was presented at the National ORSA/TIMS Conference, November 1983. A second paper describing this system will be presented at the International Symposium on Microcomputer Applications.

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