AD-A138 616 A SOFTWARE SYSTEM TO AID IN MAKING REAL-TIME WATER CONTROL DECISIONS(U) HYDROLOGIC ENGINEERING CENTER DAVIS CA A F PABST ET AL. SEP 83 HEC-TP-89 1/1

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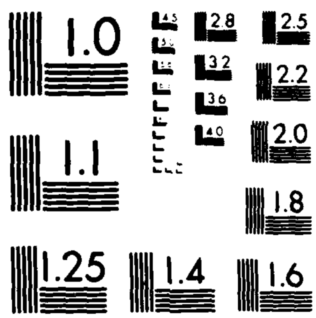

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US Army Corps
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The Hydrologic
Engineering Center

A Software System to Aid in Making Real-Time Water Control Decisions

by

Arthur F. Pabst

John C. Peters

Technical Paper No. 89

September 1983

Papers in this series have resulted from technical activities of the Hydrologic Engineering Center. Versions of some of these have been published in technical journals or in conference proceedings. The purpose of this series is to make the information available for use in the Center's training program and for distribution within the Corps of Engineers.

A Software System to Aid in Making Real-Time Water Control Decisions

By

Arthur F. Pabst[1/] and John C. Peters[2/]

INTRODUCTION

The Corps of Engineers has responsibility for operating numerous water resource systems throughout the United States. A primary purpose of many of these systems is flood control; however most systems are multipurpose with additional project purposes such as hydropower generation, water supply, navigation, water quality enhancement and recreation. Effective operation of a water resource system typically requires (1) timely acquisition of reliable data that reflects the current state of the watershed and water resource system, (2) data analysis and runoff simulation to produce forecasts of runoff, perhaps with and without estimates of the effects of future precipitation, and (3) system analysis to produce optimal operations decisions.

A major advance in automated data collection has occurred in recent years with the use of geostationary satellites for data transmission. A Data Collection Platform (DCP) at a gage (e.g. precipitation or stage gage) contains a microprocessor for storing the data and transmitting it via geostationary satellite to a receiver (downlink) where the data is placed in a computer file. Use of this means of acquiring data is increasing rapidly in the Corps of Engineers and is a primary source of real-time data for a number of water resource systems.

During the last several years the Hydrologic Engineering Center (HEC) has been involved in developing and adapting software for real-time data analysis, short-term runoff forecasting and reservoir system simulation. These software components are part of a comprehensive software system that also includes a specially-designed data storage system, an interactive control interface and a graphical display capability that facilitates interpretation and analysis of observed data and simulation results. The software system, in whole or in part, is intended for use throughout the Corps of Engineers on computers that are dedicated to water control activities. The software is presently being implemented on Harris 100/500 minicomputers.

This paper focuses on the conceptual basis for, and capabilities of, the software system. Illustration of software capabilities is based on application to the 16,900 sq. km. Scioto Basin in Ohio, USA.

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For presentation at the WMO-sponsored Technical Conference on Mitigation of Natural Hazards through Real-Time Data Collection and Hydrological Forecasting, held at Sacramento, Calif. on September 19-23, 1983.

APPROACH

Assuming that raw "real-time" data is available in a computer file, the following tasks are performed:

1. Raw data is decoded to a form with desired engineering units. Data conversions such as stage to discharge and accumulated to incremental precipitation are made. Simple range checks on data validity are performed. Data is interpolated for isolated periods of missing data.

2. The availability of data is assessed. A Data Status Table is generated in which the presence or absence of verified data is indicated for each hydrometeorological station.

3. Based on data availability, a time of forecast is adopted. Choice of forecast time generally involves a tradeoff between data availability and the lag between the current time and the forecast time.

4. Point precipitation data is used to develop hyetographs of subbasin-average precipitation for each subbasin.

5. Automatic estimation of runoff parameters (unit hydrograph, loss rate and base flow) for headwater subbasins is performed.

6. Based on results of parameter estimation, loss rate and base flow parameters are adopted for remaining subbasins.

7. Runoff hydrographs are calculated, routing and combining is performed and calculated hydrographs are blended with observed hydrographs wherever observed data is available. The end product of this step is a set of reservoir inflow hydrographs and hydrographs at downstream control points.

8. Runoff hydrographs from step 7 are used with a reservoir system simulation model to make reservoir release decisions.

9. Results are analyzed using graphical displays. Additional analyses are performed with alternative future-precipitation assumptions and/or operation policies as desired.

SOFTWARE

Key elements of the software system are as follows:

Data Storage System (DSS)

The DSS provides a means for efficient storage and retrieval of hydrologic data. It is used primarily for time series data such as precipitation hyetographs or hydrographs of stage, discharge, storage, etc. DSS and associated utility programs can be used to (1) store and maintain data for multiple users, (2) store input and output data from applications programs, (3) transfer data between programs and (4) display data in graphs or tables.

Field Data Conversion (CONVRT)

This program provides routine transformations of field data into forms required for hydrologic analysis. Cumulative precipitation is converted to incremental precipitation. Water surface stages and elevations are transformed, as appropriate, into discharges and storages based on rating tables. Reservoir inflows are computed from corresponding outflow and storage hydrographs. Screening for data outside reasonable bounds, estimation of missing data elements, and data smoothing are combined with each of the basic transformations as appropriate to provide an automated flow of usable data.

Areal Precipitation Analysis (PRECIP)

This program is used to calculate subbasin-average precipitation from observed gage data. Subbasin-average rainfall is calculated as the weighted average of rainfall that is estimated at up to five points (nodes) in a subbasin. Rainfall at a node is calculated as the weighted average of rainfall measured at gage sites. One to four gages are used for each node. The gages are selected as the nearest reporting gage in each quadrant with respect to North-South and East-West axes through the node. Weights used in calculating rainfall at a node are inversely proportional to the square of the distance between the node and a gage. The weights used can vary each time interval depending on the number and location of gages reporting that interval. Subbasin hyetographs calculated by PRECIP are stored in a DSS file for subsequent use for runoff forecasting.

Streamflow forecast (HEC1F)

This program is a modified version of computer program HEC1, a primary capability of which is to calculate runoff from complex (multi-subbasin) watersheds using the unit hydrograph approach and hydrologic routing methods. HEC1 is widely used for planning studies and other applications, and runoff parameters for use in the program have been derived for numerous locations throughout the USA. However it is a "single-event" model; there is no capability for maintaining a continuous accounting of soil moisture. Forecast accuracy is therefore likely to be low early in an event, especially for situations where substantial uncertainty is associated with loss rate estimates. However, later in an event when it becomes possible to calibrate parameters to an observed stream rise, forecast accuracy is improved and should be commensurate with accuracy obtainable with more complex continuous simulation models.

Application of HEC1F to produce short-term runoff forecasts in a multi-subbasin watershed is generally implemented as a two-step process. The first step is to estimate runoff parameters and calculate discharge hydrographs for gaged headwater subbasins. Automatic estimation capabilities are used to derive best fit values for loss rate, unit hydrograph and base flow parameters. Constraints are used to restrict derived values to physically reasonable limits. The parameter estimates for headwater basins provide useful information to aid in establishing loss rate and base flow parameters for remaining (non-headwater) subbasins.

The second application of HEC1F is made to accomplish the following: (1) discharge hydrographs are calculated for all non-headwater subbasins using user-defined runoff parameters, (2) hydrographs are routed and combined throughout the basin and (3) hydrographs are blended at each gage prior to subsequent routing and combining operations. Blending consists of replacing the calculated hydrograph ordinates with observed hydrograph ordinates up to the time of forecast, and providing a smooth transition back to the calculated hydrograph over five future time periods following the time of forecast. Forecasted discharge hydrographs calculated with HEC1F are stored in a DSS file for subsequent use in establishing reservoir release decisions.

Reservoir Operation (HEC-5)

This program is designed to simulate the sequential operation of a system of reservoirs of any configuration. Reservoir releases are determined by the program in accordance with constraints at downstream control points while keeping the system "in balance". A wide variety of factors that affect release decisions can be accomodated, including channel capacities at downstream control points, emergency conditions requiring prereleases, minimum-flow requirements, etc. Reservoir inflow hydrographs and hydrographs of uncontrolled runoff for downstream control points are obtained from preceding HEC1F applications via a DSS file. Output from HEC-5 such as hydrographs of discharge, reservoir stage and storage are written to a DSS file for subsequent display and analysis.

Model Control (MODCON)

This is an interactive, executive program designed to facilitate use of other components of the software system. The program can be used to specify the magnitude of input parameters for PRECIP, HEC1F and HEC-5. For example, values for loss rates, future precipitation or specified future reservoir releases can be easily established with MODCON. MODCON also has the capability to create and send off (for execution) batch jobs that involve the sequential execution of a series of modelling programs, for example - PRECIP, HEC1F (first application), HEC1F (second application) and HEC-5. Summary displays of data status, input-parameter status, job status and program output can be viewed. It is also possible to execute the DSPLAY program to view plots or tabular displays of virtually any variables of interest, including observed data and results of precipitation-runoff and reservoir system simulations.

Graphical Display (DSPLAY)

This is an interactive program that provides a quick and simple means of displaying, in graphical or tabular form, data stored in a DSS file. The graphics capabilities permit the plotting of several curves on one graph, use of a split-screen option for showing plots on each half of a graph, capabilities for shading graphs, overlaying grids,etc.

SCIOTO BASIN APPLICATION

Illustration of application of the software system will be made with reference to the Scioto River Basin, for which the software system is presently operational. Fig. 1 is a map of the basin. There are four Corps of Engineer reservoirs, the primary purpose of which is flood control. However the reservoirs are also operated for water quality and other purposes. Data Collection Platforms at the reservoirs and at precipitation and stream gages throughout the basin transmit data via geostationary satellite to a downlink and computer in Cincinnati, Ohio. Data is "sensed" each hour and transmitted to Cincinnati at 4-hour intervals. The Scioto reservoir system is operated by personnel of the Huntington District Office of the Corps of Engineers, located in Huntington, West Virginia. The observed data is transmitted automatically at fixed intervals from the computer in Cincinnati to a computer in the Huntington District Office, where forecasts and operational decisions are made.

Program MODCON is entered and a Data Status Table (Fig. 2) is obtained. A time of forecast based on data availability is selected and input to MODCON. Input parameters for PRECIP, HEC1F and HEC5 are set. The status of the parameters can be reviewed by calling for a Model Status Table (Fig. 3).

The execution command in MODCON is invoked to create and send off a batch job for processing. The job may involve execution of PRECIP and HEC1F (first application) to provide a set of parameter estimates for headwater subbasins. Or the job may also involve the second application of HEC1F and execution of HEC-5 for making the operational release basins. While a model job is in execution, other tasks can be performed, such as checking the status of the water resource system by viewing plots of observed precipitation and streamflow. Fig. 4 shows a DSPLAY-generated plot of observed discharge hydrographs for four locations on the main stem of the Scioto River. Fig. 5 shows observed precipitation hyetographs for two field gages.

The progress of the modelling job in execution can be monitored and results can be viewed following completion of each component of the job. Fig. 6 shows hydrographs of inflow, outflow and storage for a reservoir. The outflow hydrograph was determined by HEC-5. Fig. 7 shows two forecasted and the observed discharge hydrograph at a downstream control point. One forecast is based on the assumption of no future precipitation whereas the second forecast is based on having 13 mm of rainfall over the basin during a 12-hour period following the time of forecast.

Analysis of information such as that shown in Figs. 6-7 provides a means for interpreting simulation results. Based on such an analysis, the water control manager may decide that there is sufficient information to make operational decisions, or it may be desired to make additional runs to reflect alternative watershed, precipitation or operational conditions.

MAN-MACHINE INTERFACE

An interactive terminal with a keyboard is a common input device for a computer. Some terminals with input graphics capabilities, such as the Tektronix 4014, also permit the use of a graphics tablet as an input device. A "menu" can be created to overlay on the tablet, and capability can be provided to enable an input command, or a series of commands, to be generated simply by touching the appropriate location on the menu.

Fig. 8 illustrates such a menu for the Scioto Basin. MODCON commands can be implemented by touching rectangular command boxes on the left side of the menu. For example, to obtain the table shown in Fig. 1, the box labeled Data Status would be touched. Plots can be generated with the right side of the menu by touching in sequence the location (on the schematic diagram), the desired variable (e.g. reservoir outflow) and PLOT.

The boxes labeled [illegible] through M11 at the bottom of the menu invoke "macros" for automatic generation of a single or a series of plots of prespecified variables. Fig. 4 and 5 were obtained with such macros.

SUMMARY AND PLANS FOR FUTURE DEVELOPMENT

A comprehensive software system has been developed to aid the water control manager in making operational decisions. The software encompasses components for data conversion and screening, estimation of subbasin-average hyetographs, short-term runoff forecasting and reservoir system simulation. A Data Storage System designed for efficient handling of time series data provides a means for transferring data between analysis components. A graphics program enables interpretation and analysis of observed data and simulation results. An interactive executive program greatly facilitates utilization of the software system.

Experience to date has shown that a major limitation in forecast capability is the estimation of spatial and temporal distribution of rainfall. The use of radar imagery to better define rainfall distribution appears to be a promising development that should be operational in the next year or two. As more experience is acquired in application of the software system, it is likely that substantial enhancements will be made to various components of the system. The modular structure of the system is such that alternative components can readily be substituted or added into the system.

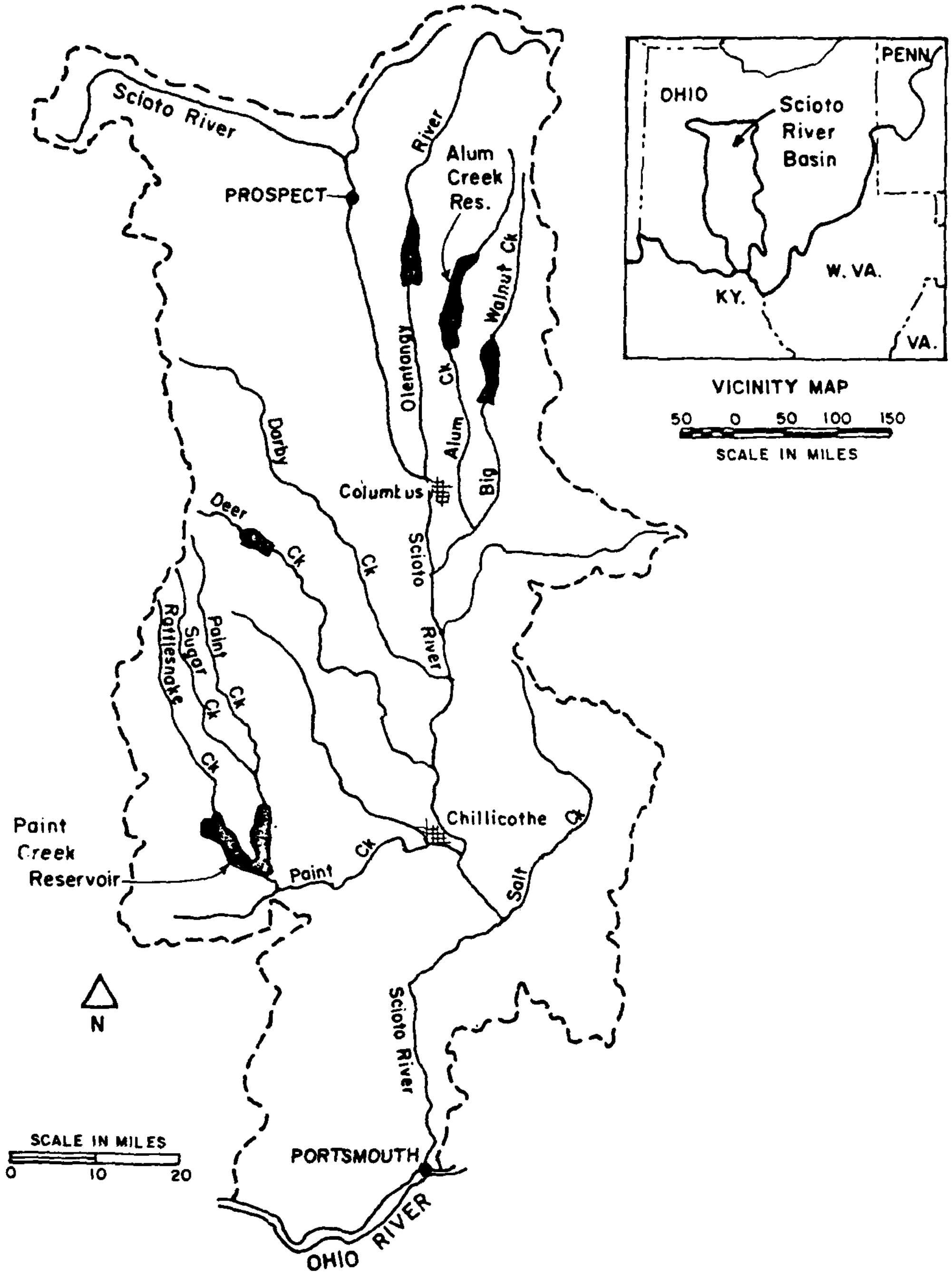

Figure 1. MAP OF SCIOTO RIVER BASIN

DATA STATUS FOR DSSFILE 0000DAT*MASTDB
SCIOTO 05MAY83 15:40:36
1HOUR INTERVALS

			03MAY83				04MAY83				05MAY83		
LOCATION	PARAMETER	HR	20	24	4	8	12	16	20	24	4	8	12
			* * * PRECIPITATION GAGES * * *										
ACSE3	PRECIP-INC		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XX--
CTSH2	PRECIP-INC		----	----	----	----	-XXX	----	----	----	----	-XXX	----
DCSOF	PRECIP-INC		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
DDOD2	PRECIP-INC		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
GRFH2	PRECIP-INC		----	----	----	----	-XXX	----	----	----	----	-XXX	----
NBKD3	PRECIP-INC		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XX--
OCTG1	PRECIP-INC		----	----	----	----	----	----	----	----	----	----	----
PCSOF	PRECIP-INC		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
			* * * RESERVOIR INFLOW * * *										
ACSE3	FLOW-RES IN		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
DCSG2	FLOW-RES IN		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
DDOD2	FLOW-RES IN		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
PCSI2	FLOW-RES IN		----	----	----	----	----	----	----	----	----	----	----
			* * * RESERVOIR OUTFLOW * * *										
ACSOF	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXX-
DCSOF	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXX-
DDOOF	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXX-
PCSOF	FLOW		----	----	----	----	----	----	----	----	----	----	----
			* * * HEADWATER STREAMFLOW GAGES * * *										
CTSH2	FLOW		----	----	----	----	XXXX	----	----	----	----	XXXX	----
DYDG2	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
GRFH2	FLOW		----	----	----	----	XXXX	----	----	----	----	XXXX	----
KLAD3	FLOW		----	----	----	----	----	----	----	----	----	----	----
MTSF2	FLOW		----	----	----	----	----	----	----	----	----	----	----
			* * * DOWNSTREAM STREAMFLOW GAGES * * *										
BMRI2	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
BRPH2	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XX--
CHSH3	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
CISG3	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
CLAF3	FLOW		XXXX	XXXX	XXX-	----	----	----	----	----	----	----	----
CLSF4	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XX--
DUSE2	FLOW		----	----	----	----	----	----	----	----	----	----	----
HIGH3	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XX--
PCSI2	FLOW		----	----	----	----	----	----	----	----	----	----	----
REWF3	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
WMTH2	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	X---
WOOE2	FLOW		XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XX--

TOTAL NUMBER OF STATIONS = 33

Figure 2 Data Status Table

```
========== MODEL CONTROL (MODCON) ==========
I>STATUS
STATUS

BASIN               SCIOTO

FORECAST              DAY    TIME    DATE
                      THU    1200   05MAY1983

PPT ALTERNATIVE        B

LOSS RATES            ZONE     STRTL   CNSTL
                       1         .3     .015
                       2
                       3

HEC-1F BASE FILES   IBASXI  IBASAL  IXXXAE  IXXXAF

HEC-5 BASE FILE     IBASAFA

OPERATION ALT.         A

BATCH JOB OUTPUT      OFF

MASTER DATA BASE   0000DAT*MASTDB

========== MODEL CONTROL (MODCON) ==========
I>FUTURPPT
FUTURPPT

                    FUTURE PRECIPITATION
         ALTERNATIVE B      ALTERNATIVE C      ALTERNATIVE D
 ZONE      PPT       HR       PPT       HR       PPT       HR

  1         1        12        1        24
  2
  3
```

Figure 3   Model Status Table

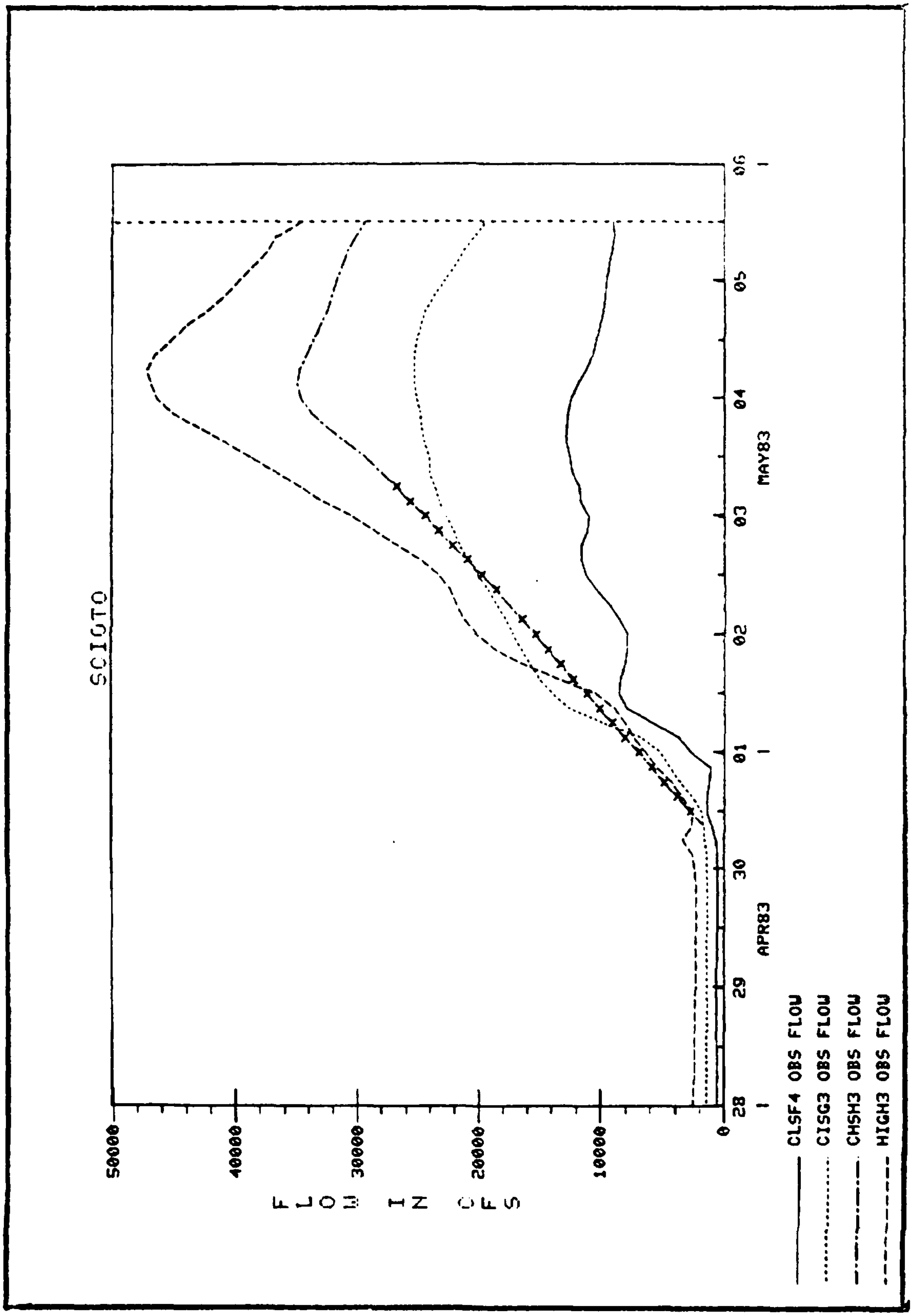

Figure 4 Mainstem Observed Flow Hydrographs

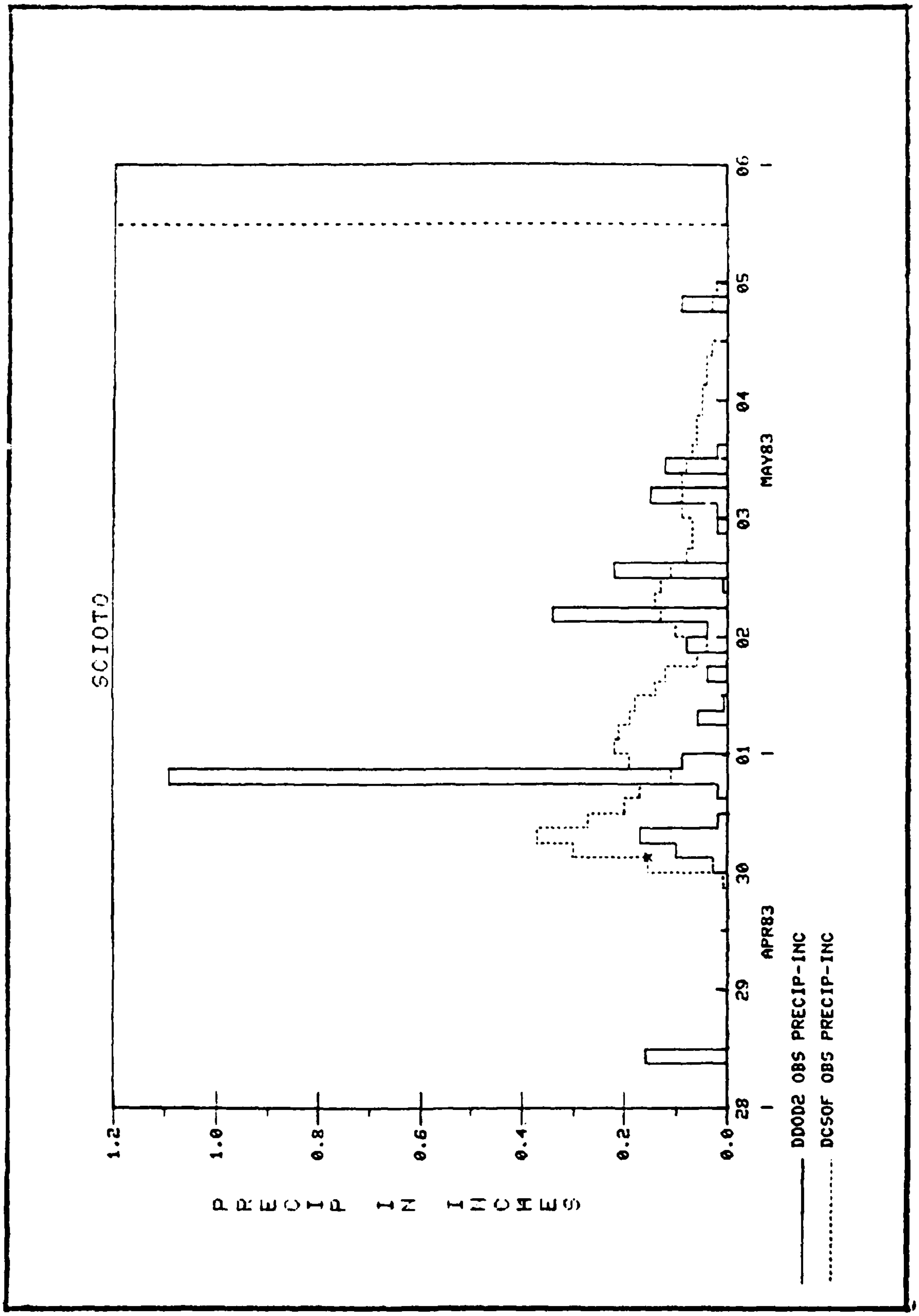

Figure 5 Observed Hyetographs

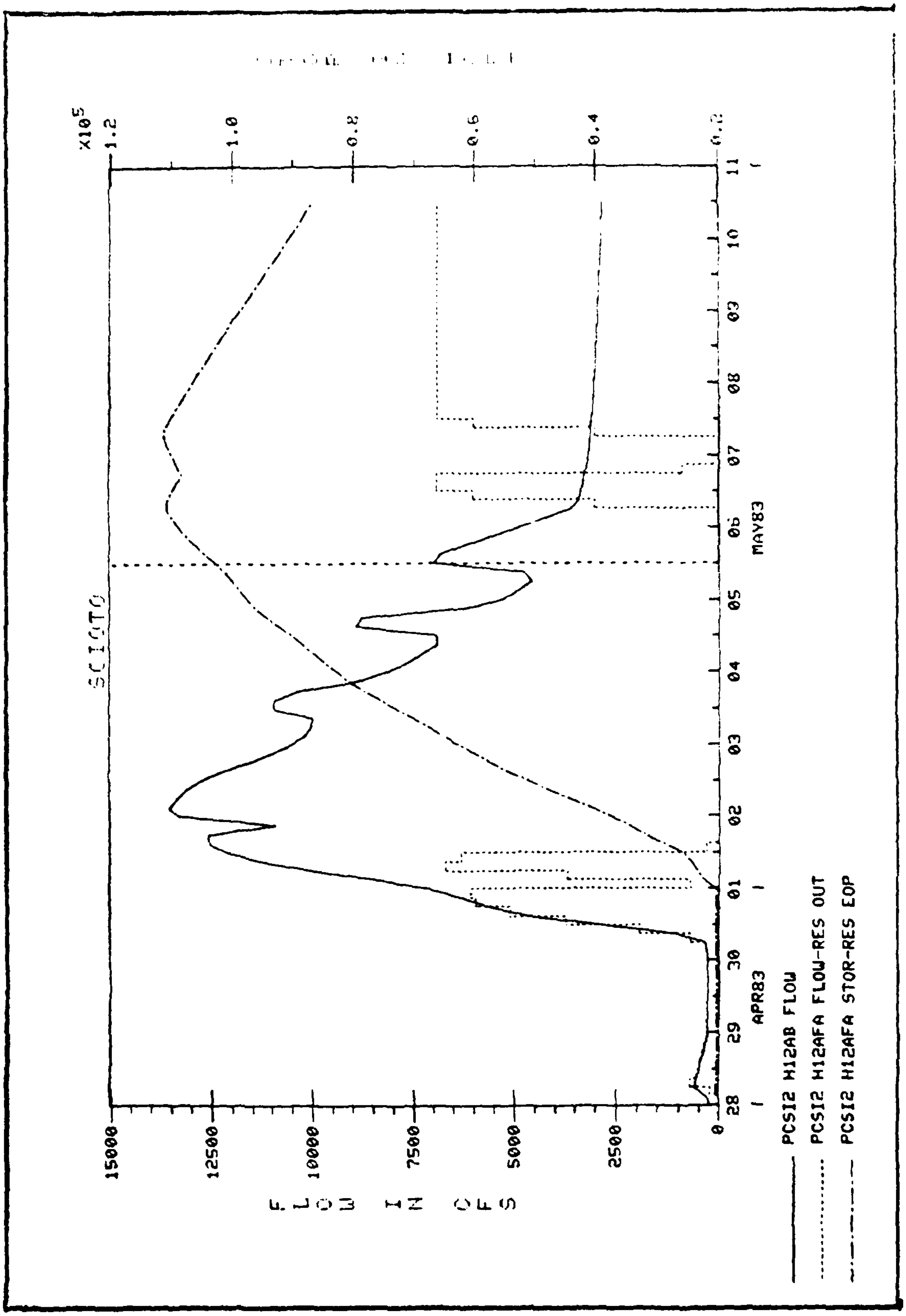

Figure 6 Reservoir Inflow, Outflow and Storage

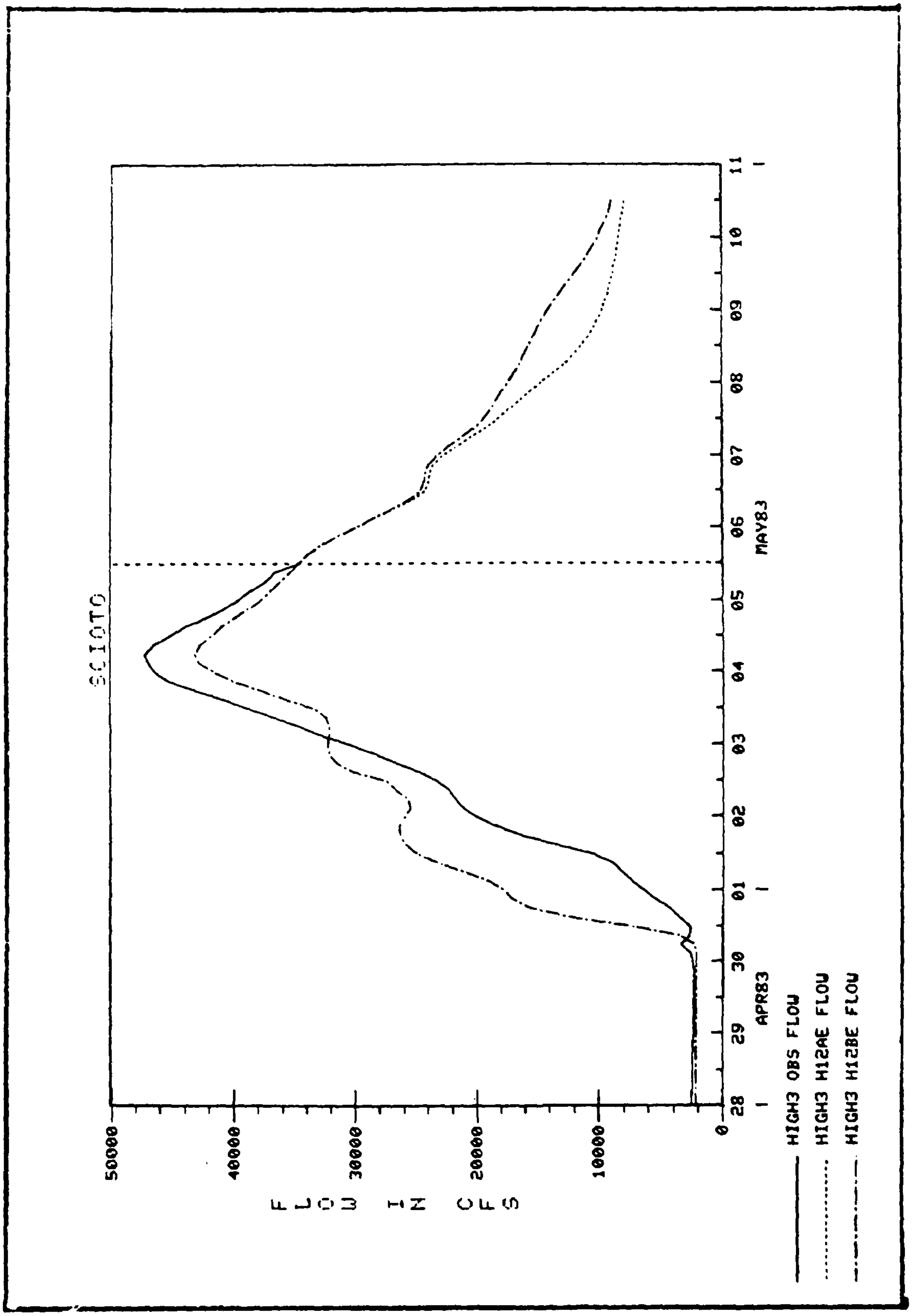

Figure 7 **Observed and Forcasted Flow With and Without Additional Precipitation**

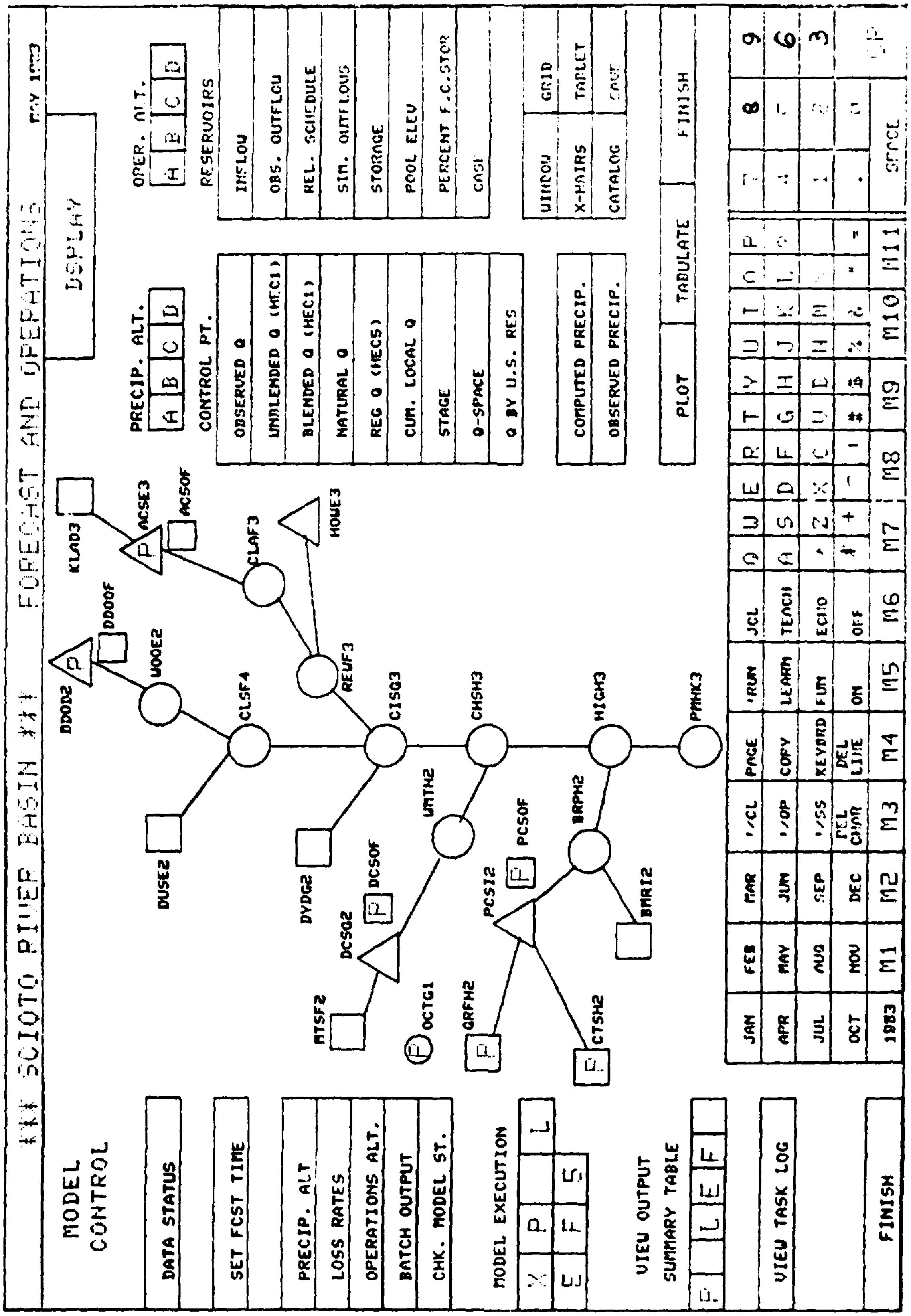

Figure 8   Scioto Forecast and Operations Menu

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Paper No. 89	2. GOVT ACCESSION NO. AD-A138616	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A SOFTWARE SYSTEM TO AID IN MAKING REAL-TIME WATER CONTROL DECISIONS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Arthur F. Pabst John C. Peters		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Corps of Engineers The Hydrologic Engineering Center 609 Second Street, Davis, CA 95616		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE September 1983 13. NUMBER OF PAGES 15
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution of this publication is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the World Meteorological Organization (WMO) sponsored Technical Conference on Mitigation of Natural Hazards through Real-Time Data Collection and Hydrological Forecasting, held at Sacramento, Calif. on September 19-23,1983.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

WATER CONTROL, FLOOD FORECASTING.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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