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of Engineers
Hydrologic Engineering Center

Generalized Real-Time Flood Control System Model

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14. ABSTRACT

A comprehensive series of interconnected computer models are described which assist water control managers in operating reservoir systems during real-time flood emergencies. The need for and the desirable features of a transportable comprehensive software systems are presented along with a description of the various computer models developed for this purpose by the Hydrologic Engineering Center of the US Army Corps of Engineers. The functions, capabilities and interties of the data management, operation, forecast and display computer modules used in this software system are described and an example application of this system on one of the Corps' reservoir systems is presented.

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US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center
609 Second Street
Davis, CA 95616

(530) 756-1104
(530) 756-8250 FAX
www.hec.usace.army.mil

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GENERALIZED REAL-TIME FLOOD CONTROL SYSTEM MODEL*

by

Bill S. Eichert,[1] M. ASCE and Arthur F. Pabst,[2] M. ASCE

1. Need for and Scope of Real-Time Water Control System

There were over 325 dams operated for flood control by the U.S. Army Engineers in 1978 with an additional 79 under construction. Included in this number are many multipurpose dams which the Corps operates for water supply, water quality and hydroelectric generation. The Corps has expended over 10 billion dollars for flood protection over the years and has estimated the savings in damage prevented at over 40 billion dollars. In order to continue operating the flood control systems with reduced manpower resources and reduced funding, the data collection and operation must be automated as much as possible. A very active program has been going on in the Corps for several years to have hydrometeorological and water resources project data automatically collected and transmitted to Corps' computers. Most newly installed systems rely on satellite relays to obtain the data in a cost-effective manner. Many of our Corps offices are now, or within a few years will be, obtaining most of these data in this manner. With the availability of real-time data, considerable improvements can be made in the forecasting and operations work. The intent of this paper is to provide a summary of some of the work being done by the U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) in Davis, California, to automate this process by developing a set of generalized computer programs. Since the potential applications for this software may require use on many different computer systems, the software is being designed to maximize the transportability of the code to different computer systems. In that most of the Corps offices, including HEC, currently have Harris 100/500 computers, the developmental programming is taking place on that system, but the code is being designed to maximize transportability. Limited machine related code is restricted to a few low-level subroutines that can be provided for other systems as necessary.

Because the software will be applied to many different basins, all of the information about the basin is stored in data files and is not a part of the program code itself.

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[1]Director, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, 609 Second Street, Davis, CA 95616.

[2]Chief, Special Project Branch, The Hydrologic Engineering Center, U.S. Army Corps of Engineers, 609 Second Street, Davis, CA 95616.

2. Overview of Software Components Required

In order to perform real-time reservoir operation, a rather comprehensive system of software is required (see figure 1). Capabilities must exist to allow the following:

a. Entry of data from satellite relay stations, existing data networks, and manual reporting stations,

b. Storage and retrieval of data,

c. Screening, preliminary processing, editing, archiving, and transferring of data between users,

d. Forecasting of future watershed conditions,

e. Operations of reservoir systems,

f. Reporting of information in graphical and tabular formats, and

g. Statistical/economic/utility functions.

The software that is being developed by the HEC addresses each of these areas in varying degrees. Data may be entered in several formats to allow incoming data to be stored in the data storage system. Utilities exist to copy, rename, edit, purge and transfer data stored in the system. The forecasting of future conditions in the watershed is performed by a version of the HEC-1 Flood Hydrograph Package recently adapted to meet real-time forecasting requirements.

Reservoir operation decisions are made by the HEC-5 Reservoir Systems Operation model (titled Simulation of Flood Control and Conservation System) which is capable of operating a system of reservoirs with multiple project purposes.

The graphical and tabular display of observed, forecasted or simulated reservoir operational data is performed by the DSPLAY routine. Statistical, economic and other utility routines are being developed to allow forecast and project operation effectiveness to be evaluated.

The software supervisor routine that provides entry to the various components is entitled System Control (SYSCON). In SYSCON, the user specifies the basin under analysis and the desired forecast time. From SYSCON the user may then gain access to each module desired. Control is transferred from one module to another under direction of the user until all required tasks have been completed.

3. Use of Data Storage System

In order for all of the software components to exchange data efficiently, it is desirable for them to be able to

read and/or write information into a common data system. The HEC data storage system (HEC-DSS) was developed a short time ago to enable the major HEC analysis program to exchange data with one another while doing planning and design studies. A logical extension of this has been the employment of this same data storage system in the real-time environment since two of the major analysis programs (HEC-1 and HEC-5) were also needed for the real-time application (see figure 2). The basic concept of the HEC-DSS is to store data in a predefined format and provide sufficent information along with the data to adequately describe it. Thus, the data retains an identity apart from the particular program that wrote it or expects to read it. For example, for standard regular interval time series data, the name of the data record (called the "pathname") contains identifying information as follows:

Pathname Part	Example
a. Project name	SCIOTO BASIN
b. Location	DELAWARE RESERVOIR
c. Type of data	FLOW-RES OUT
d. Starting data	01JAN1982
e. Time interval	3HOUR
f. Plan or version	0900RF+PRE-RELEASE

In addition, "header" information is also transferred containing data units and any other information that might be desirable.

4. User Interfaces

A primary concern in the development of a real-time system is its ease of use. Potential users should not be required to be computer specialists, expert typists, or possess other special skills. The system has been designed to provide human-oriented interfaces between the user and the programs in order to facilitate its use. Commands to the system may be entered through any interactive keyboard terminal. Even though commands have been structured for efficient entry, typing and repetitive entry of data can be a burden on the user. To eliminate this burden, several enhanced user interfaces are provided. As an alternative to keyboard input, the user may select the appropriate command from a command list or menu. The selection is made by simply pointing to the desired entry on a graphics tablet. For example, by pointing at certain areas of menus, data can be displayed, forecasts and reservoir operations can be performed and then reanalyzed with alternative conditions considered. The results of such system operations can be displayed in either tabular or graphical form.

Other enhanced interfaces available to either the keyboard or the menu user are function characters and macro procedures. The function character capability allows any character (letter, number or special character) to be redefined to mean one or more characters. For example, the pound sign # could be redefined to mean an entire command of perhaps 10 to 20 characters. The macro procedure capability allows a series of commands to be stored and invoked by a single command.

When menus, functions and macros are properly implemented, the water control user may direct the complex processing and display of information with comparative ease. Those capabilities requiring graphics input (i.e., menus) and graphics output are, of course, limited to terminals supporting those features. All other capabilities (i.e., functions and macros) are available to any interactive terminal.

Where graphical input is available, it is also possible to input data, such as a discharge hydrograph of desired reservoir releases, by simply sketching it on the input tablet.

5. Forecasting Methodology

The forecasting routines are one of the key elements of the software package and must be executed before the operations module.

Forecasts are required by the operations model for all reservoir inflows and for all uncontrolled local flow locations (those areas which are below reservoirs and above damage centers). The forecast routines utilize real-time information contained in the data base, plus data files for the forecast models describing each individual basin. The forecaster will eventually be able to select the particular forecast model he wishes to use for each forecast location. Models to be made available may include the simple runoff extension, recession and routing techniques available in HEC's "FORCST" model, the "HEC-1" single event forecast optimization model, the North Pacific Division's continuous event model ("SSARR"), and the National Weather Service's real-time continuous event model "CHAT." Currently, the HEC-1 model is the only forecast submodule interfaced to the system. This single event model relies on either an optimization process or user input to define basin parameters. At the beginning of the storm, user input or default values are used. As the storm progresses, the observed and computed runoff are compared for various parameters until a best-fit is obtained. The optimized parameters are then applied to the observed and/or forecasted rainfall to determine the calculated forecast (see figure 3). When the forecast flows do not agree with the latest observed flows, the entire hydrograph is blended

so that the forecast coincides with the most current observed data. The forecasts are obtained by using an interactive preprocessor that edits data interactively and submits an HEC-1 job to execute in a batch mode using model data files. As described earlier, the process of editing, executing and displaying forecast data may be accomplished using the appropriate menu and graphics tablet.

6. Reservoir Operation Methodology

The computation of reservoir releases is made by the HEC-5 model "Simulation of Flood Control and Conservation Systems." Data files for HEC-5 are used to store reservoir configuration, reservoir characteristics and operating criteria for each basin. Forecasts of inflows and local flows needed to determine the reservoir releases are obtained from the HEC-DSS after the forecast routines have been executed. Real-time data representing the system operation during the last few periods can also be taken from the DSS files to provide a continuous display of operation results. The HEC-5 reservoir operation program is executed in batch mode initiated by the interactive HEC-5 PREOP package. The PREOP package also allows interactive changes to be made in the system operations criteria before the HEC-5 execution. Like the FORCST model, the operations routines can be executed from any interactive terminal or by use of a menu which has been set up for the particular basin. Figure 4 shows the operations menu for the Scioto River Basin for the Corps of Engineers Huntington District office. The menu allows the user to change operational parameters, using the PREOP package, by touching descriptive boxes on the left side of the menu (under "RES OP"). After the system has been operated by HEC-5, and the model output has been stored on HEC-DSS, the operation results for any reservoir or control point can be displayed on a graphics device by touching blocks on the right side of the menu. User designed tabular displays, up to seven columns wide, can be displayed as well as graphical plots of up to four different curves using multiple vertical axes such as flow and level (indication of percent storage in various pools) as shown on figure 5. The reservoir releases determined by HEC-5 and shown as FLOW-RES OUT on figure 5 can be overridden by the user through the DSPLAY package by entering desired outflow ordinates through an interactive terminal or by cross hairs on a graphics terminal or by a graphics pen on a graphics tablet. Once the desired releases have been specified for the selected time periods, the HEC-5 model can again be executed and the results displayed for either or both of the operations.

7. Application of System to Individual Basins

Since the system software has been developed as a generalized package of programs, the system can be used on any system of flood control reservoirs as long as the

generalized forecast and operation models have the capabilities, or are modified, to satisfy the types of operational parameters that are important for that basin. All of the information necessary to describe a particular basin is contained in an input file for each analysis program. Data files can be easily created or modified to reflect different systems or different operational or forecasting criteria. The functions, macros and menus used for a basin are defined in data files which can be easily and quickly modified.

In order to apply this system to a particular basin, input files for the forecast and operation models must be prepared to represent the site specific information. The forecast model would require data on the routing and combining operations, as well as unit hydrograph and loss rate parameters. The model would have to be calibrated on several historical floods to determine reasonable parameters and evaluate how forecasts at various points in time during the flood would compare with the observed flood hydrographs. This effort is not a trivial task, however, it is extremely important in order to get reasonable results from the system. The operations model data file would also contain routing criteria, as well as reservoir storage allocation, outflow, capacity, elevation and surface area curves. In addition, system operational parameters and nondamaging channel capacities would be required. After the basic data are assembled, several flood events should be simulated with the model to see if the operational performance is reasonable when using historical data. After a reasonable operation can be obtained using historical flows, the operational model should be executed using the forecasts of past historical flood events for progressive time steps through each flood event.

Prior to, or during, the time when the basic analysis models are calibrated, the data storage system needs to be defined and linked with the automatic data collection system and with any manual data entry procedures. The last step then would be to develop any functions, macros and menus that might enhance user ease in modifying data, executing programs and displaying data.

8. Remaining Work on System Software

While the basic components of the system have been developed and tested on historical data for one basin, and have been demonstrated during a two-week HEC course on Real-Time Water Control (1-12 February 1982), much work remains in implementing the system. The initial real-time use of the system is scheduled for April 1982 on the upper part of the Scioto Basin for the Huntington District, Corps of Engineers, where forecasting procedures have been tested. Three of the largest pieces of software are essentially completed now that the HEC-1 (forecast version), HEC-5 and DSPLAY modules are operational with the data storage system.

Interactive preprocessors are also available to interface to both HEC-1 and HEC-5. However, the desired alternative forecast procedures available through the SSARR and NWS models are planned to be implemented at a later date. Many of the data entry, data maintenance and HEC-DSS utility routines are still only operational for some of the more basic applications. The largest amount of work remaining is on the Data Validation routine which will screen all incoming data for obvious errors, report problems and correct those where possible. This work is scheduled to start in June 1982 and will take about one year. A generalized error analysis routine for forecasts has not been initiated yet, but is currently partially available through the HEC-1 model. While the DSPLAY routine is essentially complete for displaying time series data, non-time series data capabilities need to be developed. In addition, it is desired to provide a spatial display of rainfall, temperature and other parameters over a map outline of the basin. Interfaces of HEC-DSS to other data bases such as TOTAL, System 2000, and CROHMS (used by the North Pacific Division, Corps of Engineers, and others) that may be desired by Corps offices have not been accomplished.

While the system was built in a machine-independent manner by using FORTRAN 77 code where possible, the transportability of the system has not been validated to date.

It is anticipated that within a year this system will be fully operational on three or four basins in the United States. Initial efforts on the Trinity River in Texas and the Scioto Basin in Ohio will provide the necessary experience to make this system easy to transport to other flood control systems.

9. Anticipated Use of Software

The U.S. Army Corps of Engineers has approximately 50 offices involved in real-time flood control activities covering perhaps 250 basins. Each of these offices are autonomous and develop or use techniques developed by others at their own discretion. Many Corps offices have expressed a strong desire to have this system, along with some locally developed programs, implemented for their use.

There are also non-Corps offices participating in flood control activities, including other federal agencies, such as the Bureau of Reclamation, state agencies and local governments. One such organization, the Salt River Project in Arizona, is currently using an earlier, more limited version of this system. We are hopeful that at least 50 basins in the United States will be adapted to this system of software in the next 10 years.

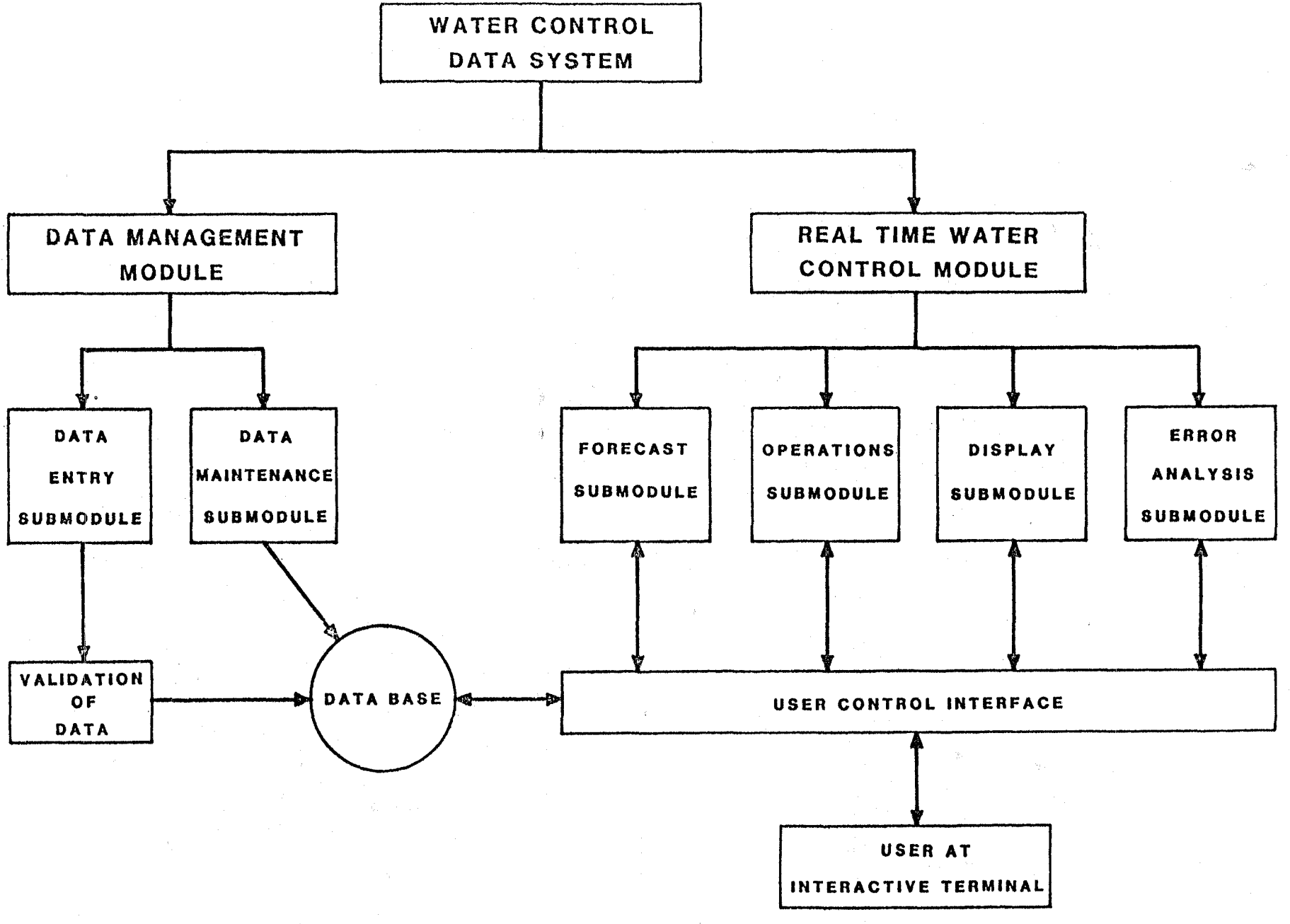

WATER CONTROL DATA SYSTEM
DATA MANAGEMENT MODULE
REAL TIME WATER CONTROL MODULE
DATA ENTRY SUBMODULE
DATA MAINTENANCE SUBMODULE
FORECAST SUBMODULE
OPERATIONS SUBMODULE
DISPLAY SUBMODULE
ERROR ANALYSIS SUBMODULE
VALIDATION OF DATA
DATA BASE
USER CONTROL INTERFACE
USER AT INTERACTIVE TERMINAL

Figure 1

HEC DATA STORAGE SYSTEM

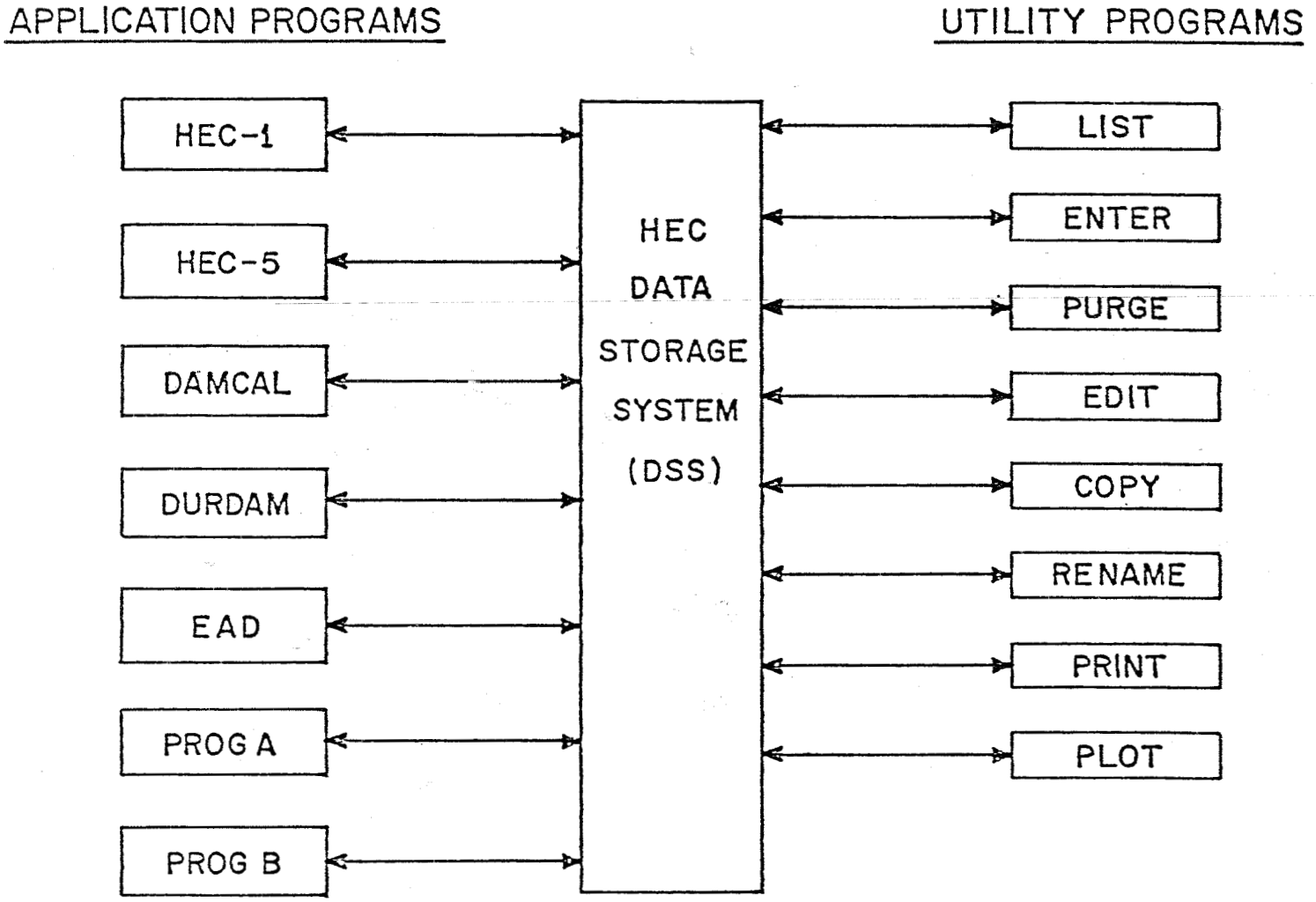


Figure 2

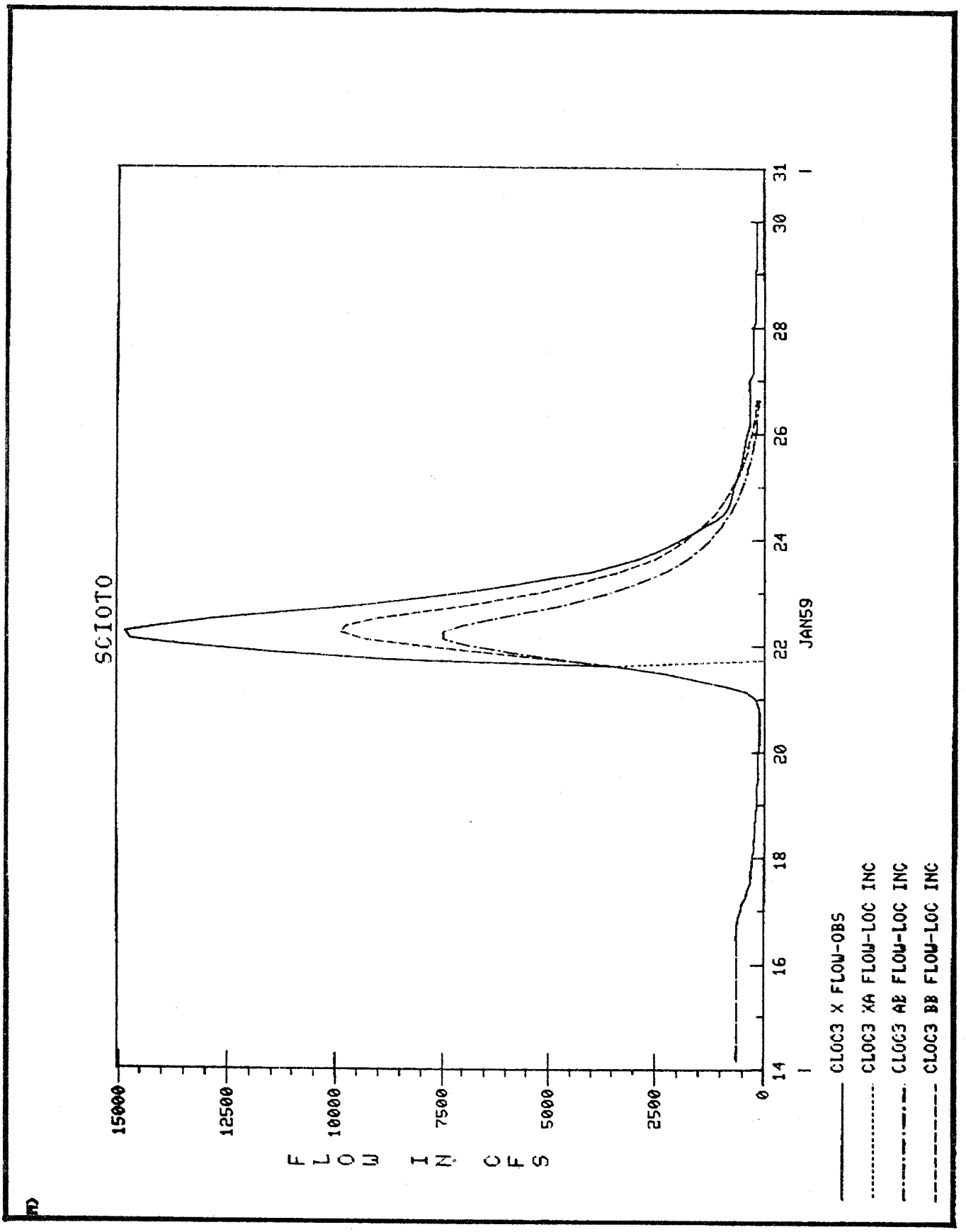

SCIOTO
FLOW IN CFS
15000
12500
10000
7500
5000
2500
0
14
16
18
20
22
24
26
28
30
31
JAN59
CLOC3 X FLOW-OBS
CLOC3 XA FLOW-LOC INC
CLOC3 AE FLOW-LOC INC
CLOC3 BB FLOW-LOC INC

Figure 3

SCIOTO RIVER BASIN OPERATIONS MENU

4 JAN 1982

HARDCOPY	RUN	KEYBOARD	7	8	9	CARRIAGE	A	B	C	D	E	F	G	H	I	J	K	L	M
COED	LEARN	DEL CHARACTER	4	5	6	RETURN	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
JCL	STORE	DEL LINE	1	2	3	000	SPACE												
	ECHO ON / ECHO OFF	ALL	YES	NO	0	.	000,000	,	/	?	*	+	-	=	"	'	#	$	%	&

RES OP
INFILE=DEFAULT
JOB VARIABLES
T1 | T2 | T3
RATIO
CONTINGENCY FACT
FORESIGHT
PRE-RELEASE OPT
J1 | J2 | J3 | J8
RESERVOIRS
INITIAL STORAGE
INITIAL RELEASE
RATE CHANGE RISE
RATE CHANGE FALL
CONTINGENCY FACT
FORESIGHT
RES OP LOC
RL | RO | RS | RQ
RE | RD | R2
CONTROL POINTS
MAX Q/STAGE
CP | ID | RT

TIME SERIES

START TIME & DATE
PER
TIME INTERVAL
IN | QA
BF

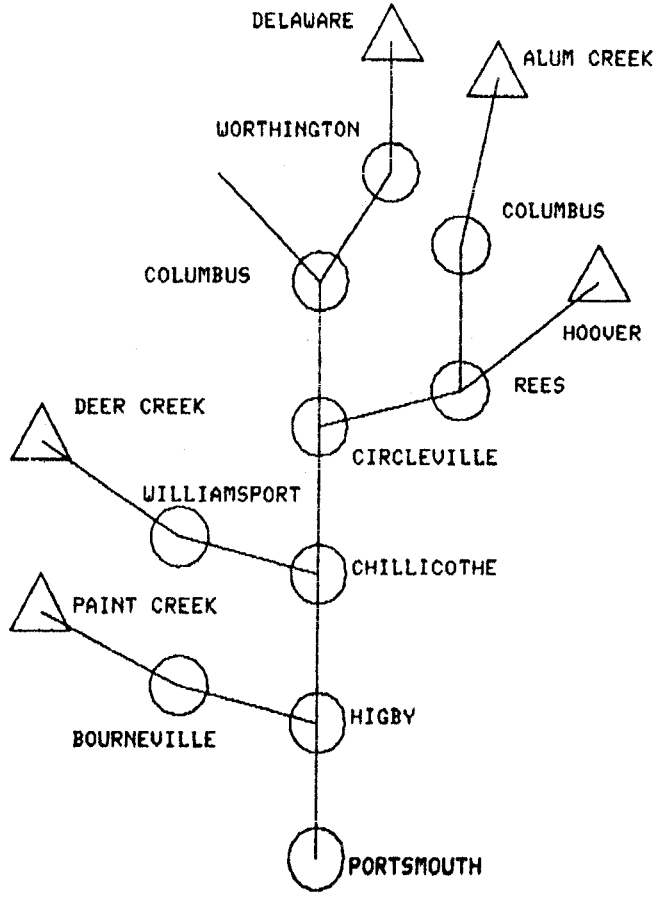
LOCATION=
PARAMETER=
DATE=
TIME INTERVAL=
VERSION=

CARD FIELDS

1	2	3	4
5	6	7	8
9	10		

AIDS

JAN	FEB	MAR	APR
MAY	JUN	JUL	AUG
SEP	OCT	NOV	DEC
HOUR	DAY		



DSPLAY	
LIST	
FETCH	RESET
LOC,#	TIME
PLOT	TABLE
SPLIT	FINISH

CONTROL POINT

INC LOCAL	#
CUM LOCAL	#
NATURAL Q	#
REGULATED Q	#
STAGE	#
Q SPACE	#
Q BY U/S RES	#

RESERVOIR

INFLOW	#
OUTFLOW	#
STORAGE	#
POOL ELEV	#
CASE	#
LEVEL	#
EQ LEVEL	#

Figure 4

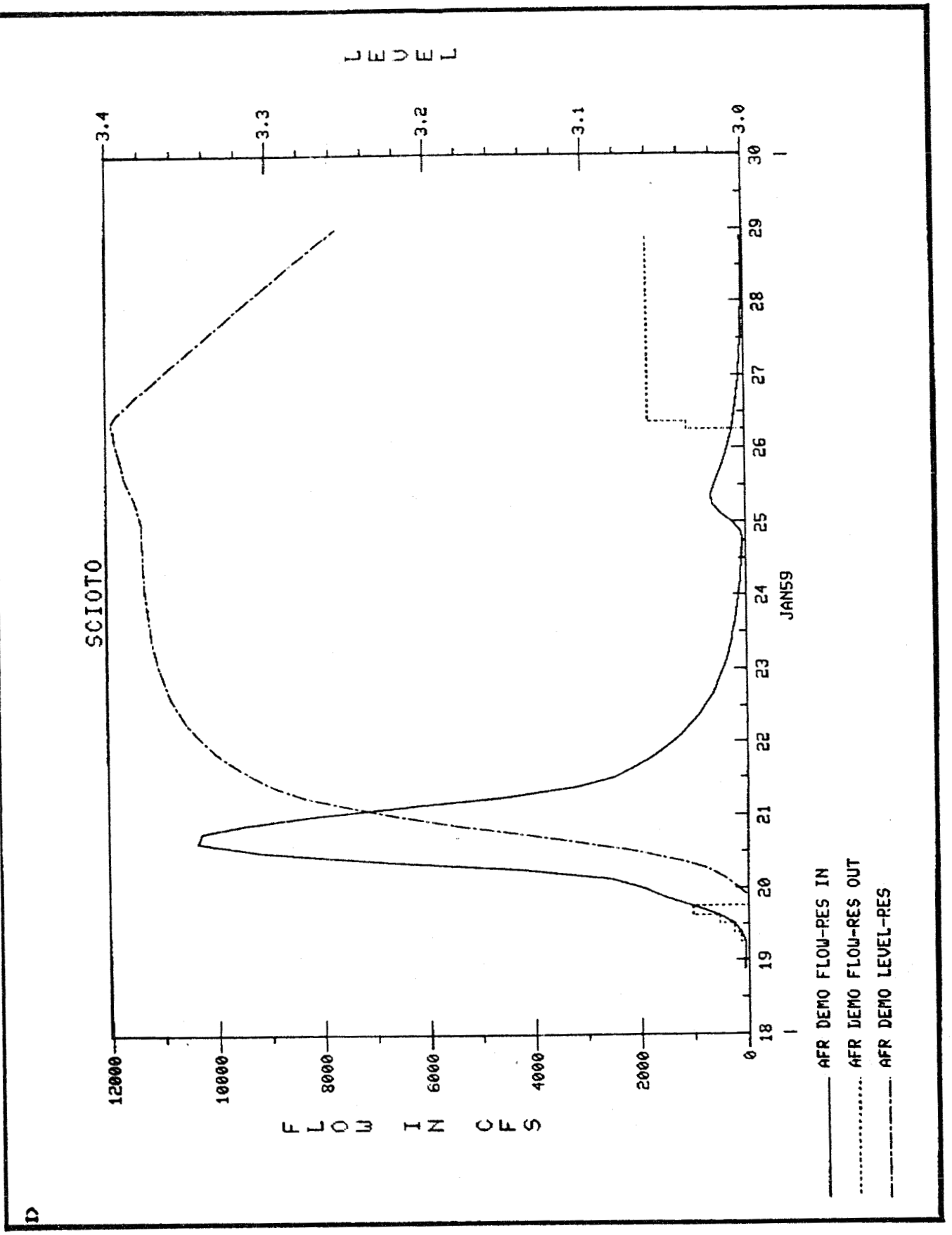

SCIOTO
LEVEL
FLOW IN CFS
12000
10000
8000
6000
4000
2000
0
3.4
3.3
3.2
3.1
3.0
18
19
20
21
22
23
24
25
26
27
28
29
30
1
JAN89
AFR DEMO FLOW-RES IN
AFR DEMO FLOW-RES OUT
AFR DEMO LEVEL-RES

Figure 5

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