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APPLICATIONS OF COMPUTER GRAPHICS IN NATIONAL WEATHER SERVICE RIVER FORECASTING

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INTRODUCTION

The National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), is responsible for providing hydrologic information and forecasts for watersheds and rivers throughout the United States. The main NWS hydrologic offices are 13 River Forecast Centers (RFC's) and the Office of Hydrology (O/H) at the central NWS headquarters in Silver Spring, Maryland. The RFC's are located throughout the United States, as shown in Figure 1, and provide hydrologic forecasts for over 2,500 forecast locations. The RFC's are staffed by professional hydrologists responsible for the preparation of river forecasts to be used for issuing flood forecasts and warnings and for input to daily operational decisions concerning water supply, reservoir operation, power production, irrigation, navigation, recreation, and water quality. Seasonal snowmelt forecasts also are issued for areas where snowmelt constitutes a major portion of the streamflow.

Demands for weather-related information and services have increased during the last two decades. The National Weather Service has managed to meet these increased demands through reappropriation of staffing and advancements in data collection, analysis, and prediction methods. Current Federal Government staff reduction policies probably will make increases in future services dependent on the use of improved high-speed computer equipment. The Hydrologic Research Laboratory (HRL), a part of the O/H, conducts research in support of RFC activities. The mission of the HRL is to advance the state-of-the-art of hydrologic forecasting. Since the late 1960's this advancement has focused within the context of developing the NWS River Forecast System (NWSRFS), a system of hydrologic computer models and data handling and display facilities to aid real-time hydrologic forecasting. Several publications have been written describing the development of NWSRFS and some of its uses; (1), (2), (3), (4), (5), and (6).

The advent of complex computer models has created an environment in which river forecasters often supply to and receive from computers vast amounts of information. The computer industry has directed an extensive development effort toward improving the interaction between computer users and computers. Computer-generated graphics is one product of this development which has the potential to be especially useful in hydrologic forecast procedures. This paper examines some of the current and future applications of computer graphics in NWS river forecasting.

RIVER FORECASTING

A river forecaster's responsibilities typically include data collection, river forecasting, forecast dissemination, calibration of hydrologic simulation models, and development of procedures to improve forecasts. All of these activities generally require some type of computer interaction. The link between the river forecaster and the computer is an important element in today's hydrologic forecasting procedures. Although forecasting procedures vary considerably among the RFC's, the most commonly used mode of interaction with the computer is the batch program. Advancements which enhance the forecaster-computer interface should improve the overall forecasting effort (7).

RFC's receive input to their operational river forecast system through a number of sources. Data are received through telephone calls from observers, teletype information from other offices, communication links with automatic and interrogated gages,

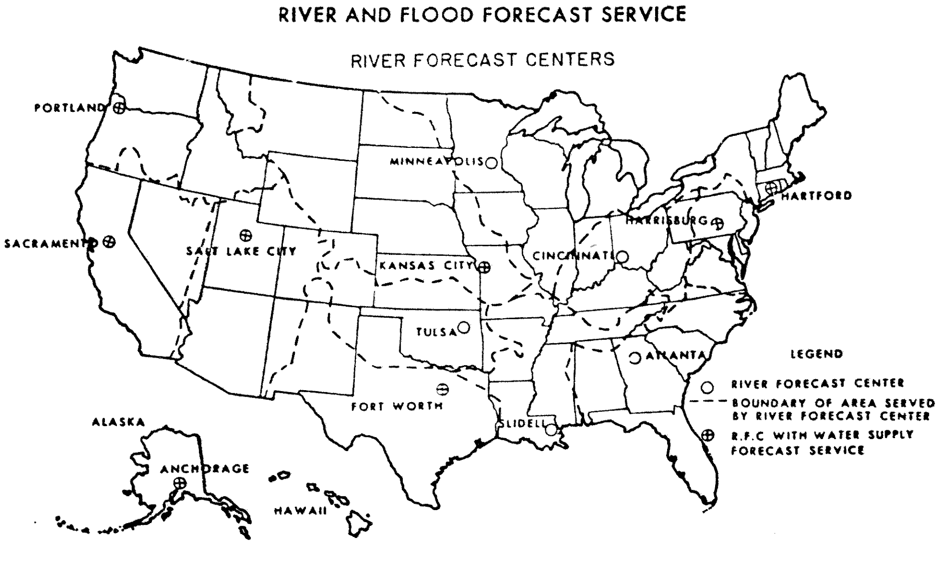

Figure 1. The 13 NWS River Forecast Centers and their respective forecast areas.

and radar and satellite sources. The Automation of Field Operations and Services (AFOS) system, discussed later in this paper, also will provide a data communication interface useful to river forecasting. Data currently are processed for most of the RFC's in the NOAA central computer (IBM 360/195) located at Suitland, Maryland, into a format acceptable for input to the operational river forecast program. An example of this transformation is the computation of mean areal precipitation values from point precipitation values. This procedure typically is performed by most RFC's by submitting the data to the computer for input to a batch preprocessing program. Forecast programs are subsequently run using the mean areal precipitation values as inputs to the computation of simulated hydrographs for the various forecast locations. Calibration of the hydrologic simulation models used for forecasting requires many of the same steps as running the forecast program, i.e., data preparation and processing, and submitting batch programs to compute simulated hydrographs. Most of the output for both the forecast and the calibration programs currently is in the form of tables and graphs on a line printer.

COMPUTER INTERACTION

Procedures for collecting, analyzing, and displaying data; processing data for use in the forecast program; computing forecasts; and calibrating models are undergoing changes. Interactive computer programming techniques and computer-generated graphics currently are being incorporated into forecast and calibration procedures. Although much of the work is still in the early stages, the potential of these computer tools appears to be substantial. Some interactive systems with graphics capabilities already exist to help the forecaster display available data and perform interactive computations. The AFOS equipment has been installed in the RFC's and currently is being implemented. AFOS will provide RFC's with a limited amount of on-site interactive computing capability. The NOAA central computer facility also has an interactive time-sharing system which can be used with graphics terminals to produce interactive graphical displays. In the past, use of this interactive part of the central system for hydrologic applications has been mainly for research and development work by the HRL. RFC's have used the NOAA central computer primarily for processing batch programs. Another system, for which a prototype currently is being developed, is being designed to improve the RFC's on-site interactive computer capabilities. When completed, the prototype computer system will include an Interactive Calibration Program (ICP) that a forecaster will be able to use to select an appropriate set of parameter values for the NWSRFS hydrologic simulation models. Ultimately, when installed in the RFC's, the computer system will allow the forecasters to run data processing, calibration, and operational forecast programs interactively and generate graphical output. These systems are discussed in more detail in the following sections.

RFC Uses of AFOS graphics

The NWS has spent much of its resources since the mid-1970's in the development of a nationwide Automation of Field Operations and Services. AFOS is a system being installed at major NWS offices, including RFC's, which will facilitate data communications and display and dissemination of many types of hydrometeorological products. The AFOS system provides text editing and some interactive graphics capabilities. AFOS includes communications circuits which connect the various NWS facilities (including the NOAA central computer facility, Weather Service Forecast Offices, Weather Service Offices, Weather Service Meteorological Observatories, and River Forecast Centers). Each system includes an on-site site host computer and graphical display equipment (8). The discussion of the applications of AFOS will be limited in this paper to those utilized by the RFC's.

Computer-generated graphics is an integral part of AFOS. Graphical output data presently are generated and stored for display on the AFOS equipment by two means. The first method consists of receiving over the AFOS circuit static display information generated by the NOAA central computer. The second technique involves running programs on the AFOS central processing unit (CPU) to generate graphical displays. Display data from both sources are stored by the host computer on an AFOS data base until needed. The AFOS graphics equipment includes an Interactive Display Generator DGS-800 with a console-mounted cathode ray tube (CRT) display, also called graphics display module (GDM), developed by Western Development Laboratories (9). The host computer retrieves coded alphanumeric and graphics data from the AFOS data base and sends the information to the GDM through a high-speed, direct-memory access interface. These data are stored and operated on by a high-speed graphics display generator to produce up to three overlaid images on a CRT monitor. Firmware within the GDM controls texture (solid, dashed, or dotted lines) selection, overlay imagery, zoom, translation, and clipping on the CRT display. The display generator is a refresh raster scan device with 768 x 1024 picture elements. Four zooms ranging from 4:1 to 25:1 are possible. A graphics interface provides a high-speed data path between the AFOS central processing unit (CPU) and the GDM; and performs status polling of the GDM, interrupts of the CPU, and transfer of data.

The AFOS equipment can support static and dynamic displays. Currently, most of the effort is being placed on static display products (10). A set of map backgrounds, on which graphics products can be overlayed, is stored at each AFOS site. Storage of the map backgrounds at each site reduces redundance of data flowing on the communication circuits. Each AFOS product contains a set of text and/or vector commands, which when displayed over the appropriate background, represents a meteorological or hydrological event. In order to fully utilize AFOS in a hydrologic environment, RFC's have developed programs which utilize data bases from other agencies to develop map backgrounds at the meso- or river basin scale. An example of a map background of the State of Utah, illustrating potential flash flood area rankings, is shown in Figure 2.

Dynamic graphics is being used with AFOS on a limited basis. A simplified interactive streamflow forecast program, based on a simple temperature index model which relates temperatures with snowpack conditions, is being run presently on the AFOS CPU at the Colorado Basin RFC. Output hydrographs from the program can be displayed on the GDM where the simulated hydrograph can be compared with the observed data. Adjustments can be made to the simulated hydrograph by positioning the cursor over the location where a forecaster wants the simulated values to be moved. The CPU uses the cursor position to redraw the hydrograph vectors and update

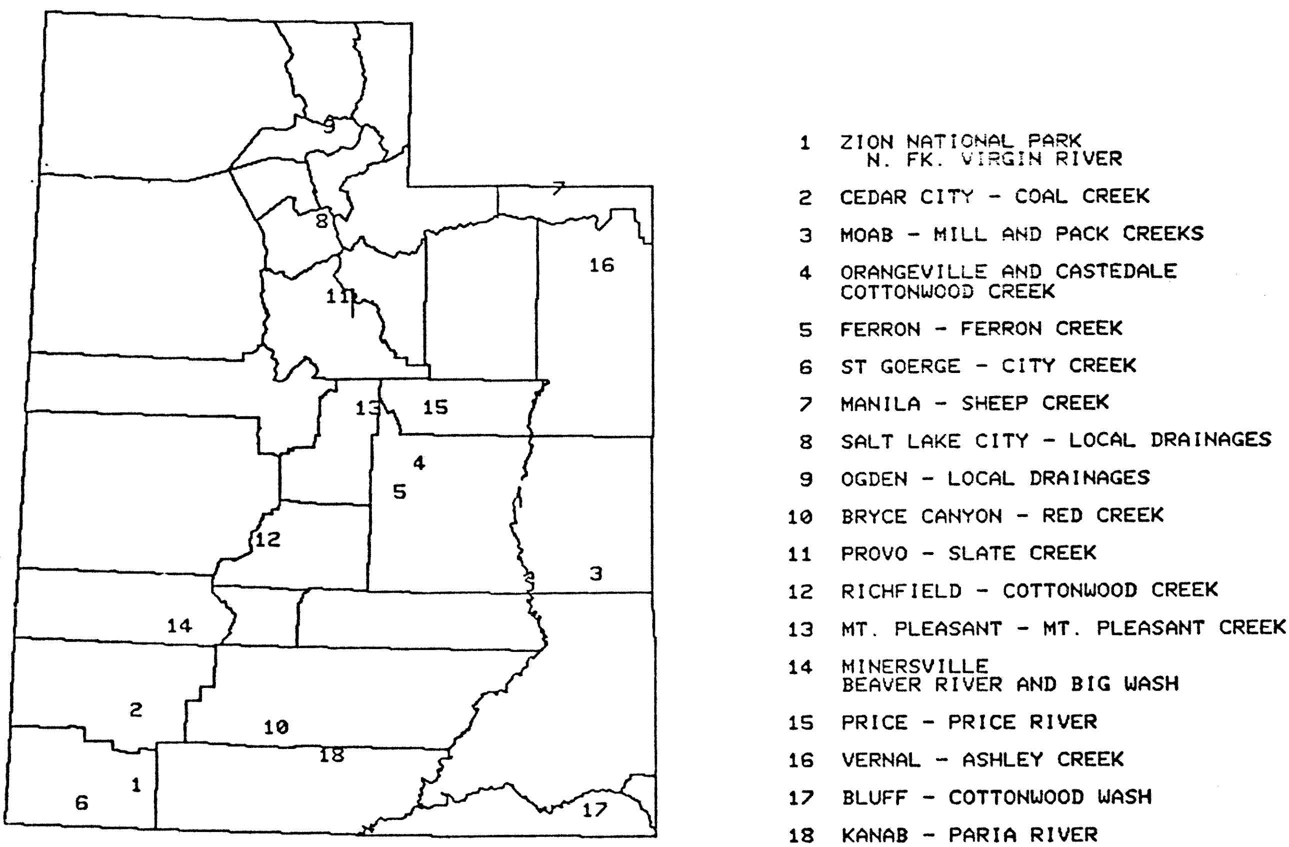

Figure 2. AFOS display showing potential flash flood area rankings for Utah.

the forecast. When the changes are complete and the forecaster is satisfied with the forecast at the present geographical location, the forecaster enters a command to route the flows downstream and the adjustment process can be repeated at the downstream forecast point. This procedure allows for increased product reliability since changes to the simulation are immediately seen in a graphical representation. Another dynamic graphics application is contouring. A program has been written to accept coordinates from the cursor position so that contours for data such as observed precipitation can be generated or adjusted by the user. Automatic contouring programs also are available.

Many of the capabilities that AFOS brings to hydrologic forecasting are yet to be explored. Applications programs have been written or will be written soon for statistical analyses, flash flood guidance, rating table generation, and double mass plotting.

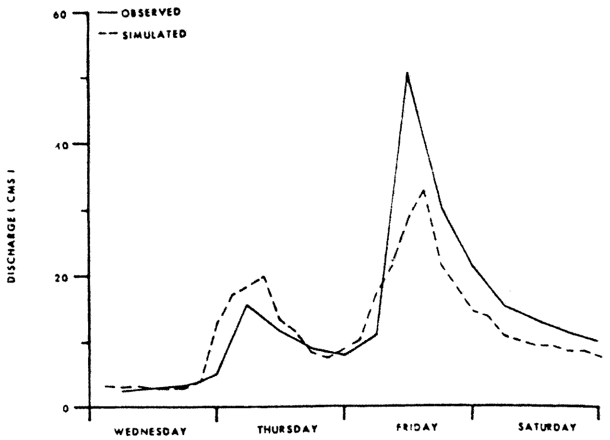

Figure 3. IFC display of observed and simulated hydrographs with no input modifications (6).

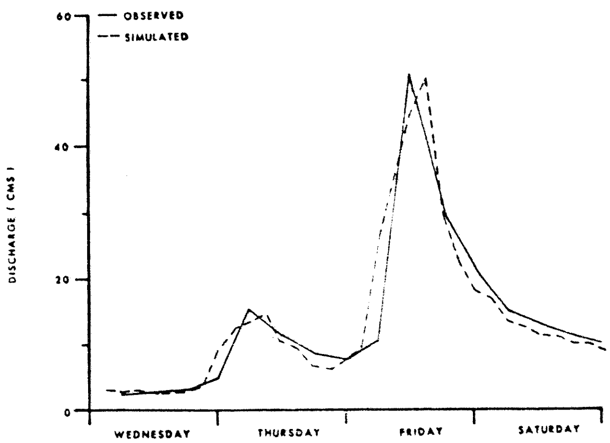

Figure 4. IFC display of observed and simulated hydrographs showing results of adjustment to input (6).

Research and Development Graphics

The NOAA central computer facility has time-sharing facilities which can be used to run interactive computer programs with graphical input and output. A number of projects have been undertaken in the HRL in an effort to develop computer graphics techniques which may be useful to RFC's. One such project consisted of digitizing map backgrounds using a digitizing tablet to examine experimentally various map background configurations of river basin boundaries for RFC use.

The HRL computer graphics equipment currently consists of a Tektronix 4014 terminal, two digitizing tablets (40" x 30" and 11" x 11"), a hard copy unit, and a 300/1200 baud modem. Programs written for use with the HRL equipment range from simple programs that produce x-y plots of data to complex interactive programs which could be adapted to operational river forecasting.

One program written last year combined interactive computer graphics and estimation theory into an interactive hydrologic forecast program (7). The program was used to show how these two tools could be used in conjunction with a simple existing forecast model to make reservoir forecasts. The graphical output from the program consisted of plots of observed and/or simulated reservoir inflow, outflow, and storage volumes and their respective standard deviations.

More recently, the Interactive Forecast Component (IFC), which employs interactive graphics procedures, was developed in HRL (6). Work began in 1979 on a project to develop a version of the National Weather Service River Forecast System, called NWSRFS Phase II, which would be more comprehensive and flexible. The Forecast Component (FC), which is the part of NWSRFS Phase II containing the hydrologic functions necessary to simulate a river system, is essentially complete. The IFC is an interactive version of the FC and can be used to simulate a portion of a river system, display the hydrographs graphically, make adjustments to the input, rerun the simulation model, and continue making adjustments until the simulation is acceptable. Figures 3 and 4 show typical observed and simulated hydrographs before and after making adjustments, respectively. This sequence of simulation-adjustment-resimulation can be continued throughout sections of a river system until the entire river basin has been simulated. The IFC currently is used only as part of a research project but could easily be adapted to operational use once Phase II of NWSRFS is implemented and when more interactive computing capabilities, such as those described in the following section, become available to RFC's.

Future Graphics Capabilites

A computer system being designed as a prototype for future systems to be located within each RFC currently is being developed under contract with The Analytical Sciences Corporation (TASC). The purpose of the system is to give each RFC enough on-site computing capabilities to run NWSRFS at a data transmission rate fast enough to allow generation of complex dynamic graphics. The prototype system will consist of a virtual memory computer, a magnetic tape drive, two disk drives with disks of 80 and 300 megabytes, a printer/plotter, two alphanumeric terminals, and a color raster refresh graphics terminal with zoom and scroll capabilities. The on-site systems will be used for operational forecasting and calibration of hydrologic models. The type of graphics displays will range from plots of simulated and observed hydrographs to maps of flood inundation areas. The system to be eventually installed in RFC's will be dependent on the evaluation of the performance of the prototype and available funds.

Calibration of hydrologic models is an area where the potential benefits of using interactive graphics are high. A program will be produced as part of the prototype contract to interactively calibrate the NWSRFS simulation models. The Interactive Calibration Program (ICP) is being developed to allow users to calibrate hydrologic forecast models in a more efficient manner than is currently possible with the batch versions of the calibration programs. The initial version of ICP should provide the user with the capability to perform simulations, display the results graphically, change parameters in the models, and quickly rerun the simulation models to observe the effects of the parameter adjustments.

ICP will be capable of generating a number of types of computer-generated displays. The most basic display will be a general two-dimensional plot of time series data. These data can be observed values or any simulated time series that have been stored on the system. The display used most often during calibration will consist of a plot of simulated and observed hydrographs.

The soil moisture accounting model currently used as a part of NWSRFS is a modified version of the Sacramento model (11). The model is a conceptual representation of the layers in the soil mantle. The model divides the soil vertically into two main soil moisture accounting zones. The total simulated runoff from an area consists of the sum of the runoff contributions from each component of the model. Calibration of the soil moisture model is often a complex process. Displays are being included in ICP to enable users to better understand the model. One of the hydrograph display options will include a plot of the runoff components which contribute to the total streamflow, so that the user can quickly see which portion of the model is generating runoff. Another option available to the user will be a dynamic display of a schematic diagram of the soil moisture model. The diagram will show the zones in the model filling and depleting as the program cycles through a simulation period. Another display will show a plot of the percolation function being used during simulation. Plots of various statistics computed for the observed and simulated flows also can be displayed. Eventually, an automatic parameter optimization option will be added to ICP, and the displays of the results will include three-dimensional plots of parameter values versus statistics to show response surfaces.

CONCLUDING REMARKS

Computer graphics provides a means by which a river forecaster will be able to display observed and forecast hydrometeorological information, map backgrounds for forecast areas, simulated and observed hydrographs and detailed plots to aid in the calibration of hydrologic models. When used with interactive programming techniques, computer-generated graphics should help save forecast time and improve forecast accuracy. Future research in river forecasting should include the development of interactive programming techniques and the utilizion of new computer interaction devices to improve the forecaster-computer interface.

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