STREAMFLOW FORECASTING USING THE MODULAR MODELING SYSTEM AND AN OBJECT-USER INTERFACE.

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ABSTRACT

The U.S. Geological Survey (USGS), in cooperation with the Bureau of Reclamation (BOR), developed a computer program to provide a general framework needed to couple disparate environmental resource models and to manage the necessary data. The Object-User Interface (OUI) is a map-based interface for models and modeling data. It provides a common interface to run hydrologic models and acquire, browse, organize, and select spatial and temporal data. One application is to assist river managers in utilizing streamflow forecasts generated with the Precipitation-Runoff Modeling System running in the Modular Modeling System (MMS), a distributed-parameter watershed model, and the National Weather Service Extended Streamflow Prediction (ESP) methodology.

INTRODUCTION

Competition among water-resource users in the Western United States has resulted in a need for near-real-time assessment of water availability and use. Coupled hydrologic and water-management models can be used for water-resource planning and operation. Advancements in computer hardware and modeling software have enabled the development of such models. The USGS and the BOR are working collaboratively on a long-term project, termed the Watershed and River Systems Management Program (WaRSMP). The goal of the program is to couple watershed river-reach models that simulate the physical hydrologic setting with routing and reservoir management models that account for water availability and use. Some of the objectives include: (1) improving precipitation and snowmelt simulation to allow more effective and efficient river basin management, (2) determining the available water supply through streamflow simulations, (3) analyzing short-term (12 to 48 hours) water supply, and (4) analyzing probable long-term (1-12 months) water supply for annual operations. The river-management model, *Riverware*, currently being developed for the BOR by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES, 2001) at the University of Colorado, is an object-oriented reservoir and river modeling system designed to support management and planning decisions for reservoir operations and scheduling (http://wwwbrr.cr.usgs.gov/weasel). Included in this modeling framework (but not discussed here) is a hydrologic database to assist in the operation, scheduling, and planning of water resources. This data base consists of real-time data, simulated time series of data, as well as physical characteristic data at all the modeling nodes in the system. The USGS OUI facilitates the coupling of the *Riverware* model with the USGS MMS through data-management interfaces (DMIs) that handle the transfer and reformatting of data among the different systems. Streamflow forecasts are computed using the National Weather Service ESP program.

DESCRIPTION OF SOFTWARE PROGRAMS

The Modular Modeling System and a Geographic Information System

MMS is an integrated system of computer software designed to provide a framework for the development and application of models to simulate a variety of water, energy, and biogeochemical processes (Leavesley and others, 1996). The central model in MMS is the Precipitation-Runoff Modeling System (PRMS) (Leavesley and others, 1983), a physically based, distributed parameter watershed model designed primarily for alpine snowmelt-driven systems with minor surface water-groundwater interactions. In the model, the watershed is disaggregated into individual land units where the runoff response is considered to be homogeneous. These units are called hydrologic response units (HRUs) and are typically based on physiographic characteristics such as soil type and infiltration rate, slope, aspect, land cover/land use, and altitude. MMS uses a library of compatible program modules for simulating a variety of hydrologic and ecosystem processes. A watershed model is created by selectively coupling

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the most appropriate modules from the library to create an "optimal" model for the desired application. Figure 1 illustrates an MMS run-time window where selected variables are displayed graphically during model simulation. Where existing physical process simulation modules are not appropriate, new modules can be developed and added to the MMS. Geographic Information System (GIS) software developed by the USGS and referred to as the GIS Weasel (Viger and others, 1998) is one GIS interface to MMS. The Weasel uses the Arc Macro Language, C and Unix shell scripts to delineate, characterize, and parameterize areas of interest for users with limited GIS experience. The GIS Weasel requires a digital elevation model (DEM) describing topography for the area of interest. Drainage area and stream networks, as well as the HRU are delineated according to several different methodologies. Modeling response units (MRUs) can be delineated according to one of several different methodologies: (1) flow-planes associated with the drainage network; (2) elevation bands; (3) non-contiguous or "pixelated" zones (based on physiographic similarities rather than spatial contiguity; (4) contributing areas associated with a coverage of points (e.g.: stream gages); and (5) integrating pre-existing MRU maps (Viger and others, 1998). Figure 2 illustrates HRU delineation for a watershed in eastern Nevada generated from a stream network based on a user-defined catchment area (method 1).

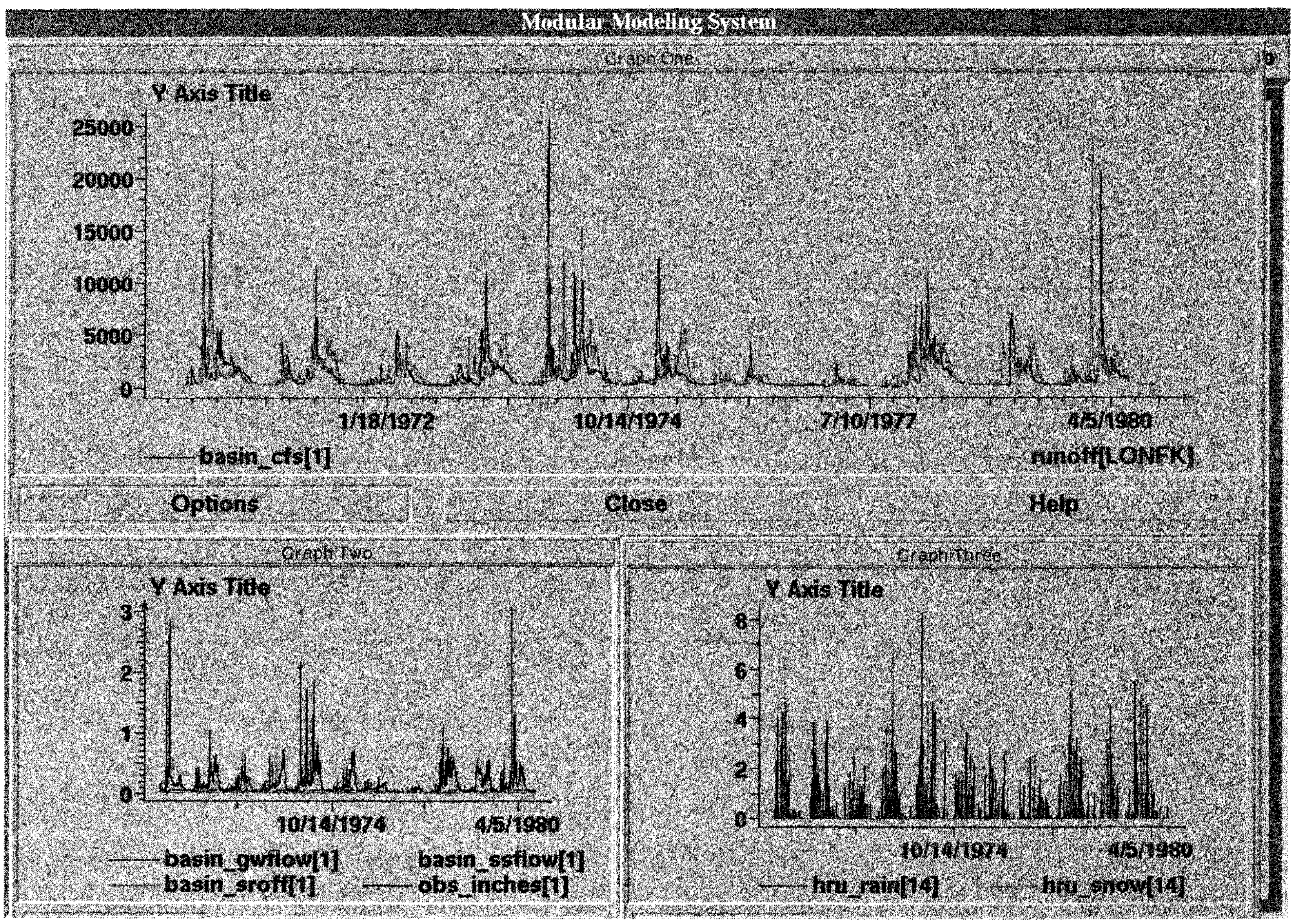

Figure 1. An example of an MMS run-time window for the Lower North Fork of the Feather River, Calif., for water years 1970-80. The insets illustrate a simulated versus observed hydrograph (graph 1), shallow subsurface-, groundwater, and surface-water runoff components of the simulated hydrograph (graph 2), and simulated rain and snow component for an individual HRU [14] (graph 3).

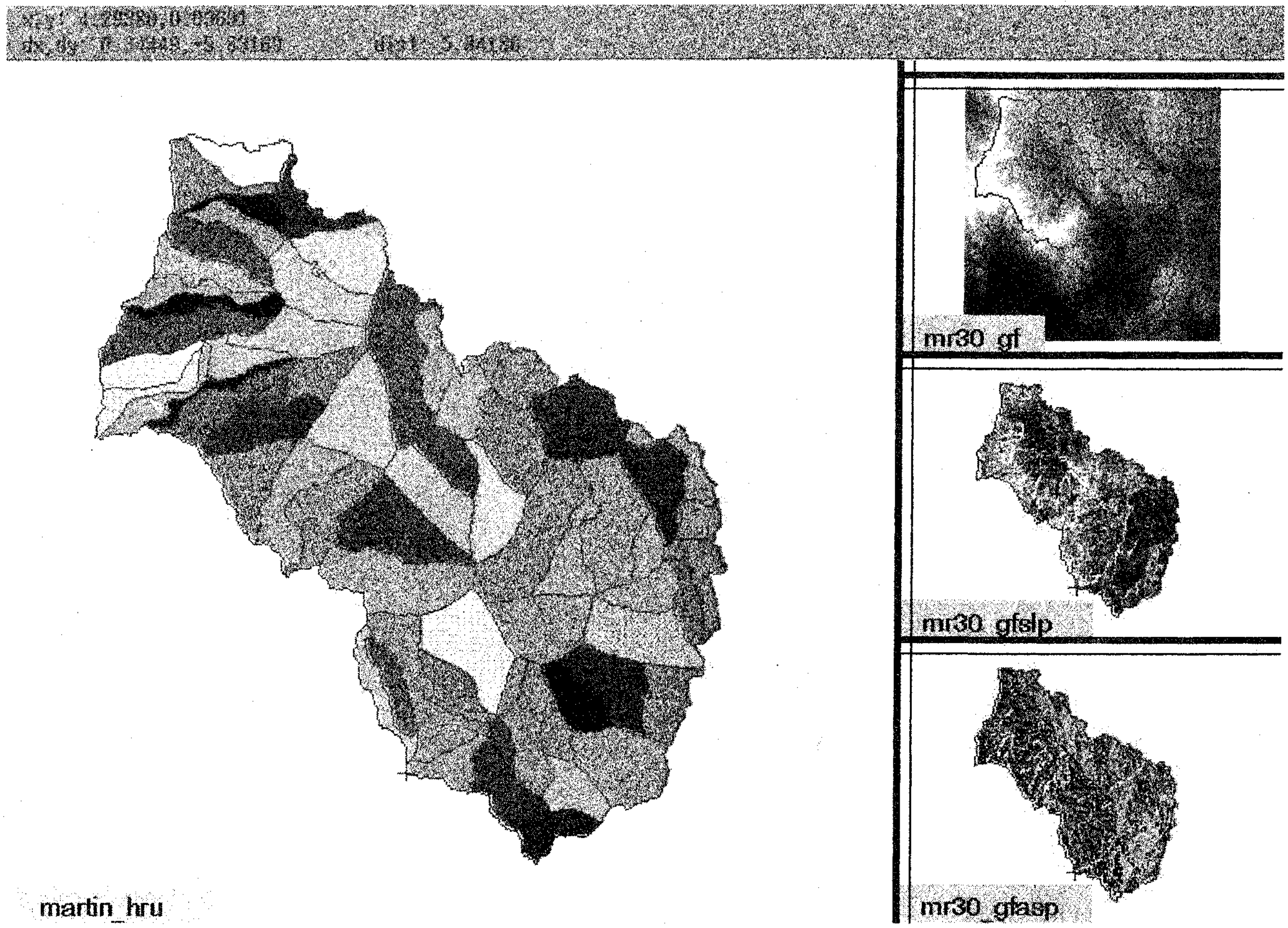

Figure 2. An example of a window from the GIS Weasel illustrates (on the left) hydrologic response units for Martin Creek watershed, eastern Nevada; the three insets (on the right) show altitude coverages, slope, and aspect of the same basin.

Object User Interface

The OUI is a map-based interface for models and data. It provides a common interface to run hydrologic models as well as acquire, browse, organize, and select spatial and temporal data. OUI allows for the integration of spatial and temporal information, is configured by the user, not the developer, and runs the hydrologic models in the background using database-management interfaces. No new spatial information is created in OUI. It facilitates the querying and displays data output from the user's data directory. Figure 3 illustrates the OUI using data for the Feather River Basin. Several options within the program are for displaying data, for example, flow duration curves, error plots, simulated and observed hydrographs in addition to tabular statistical output.

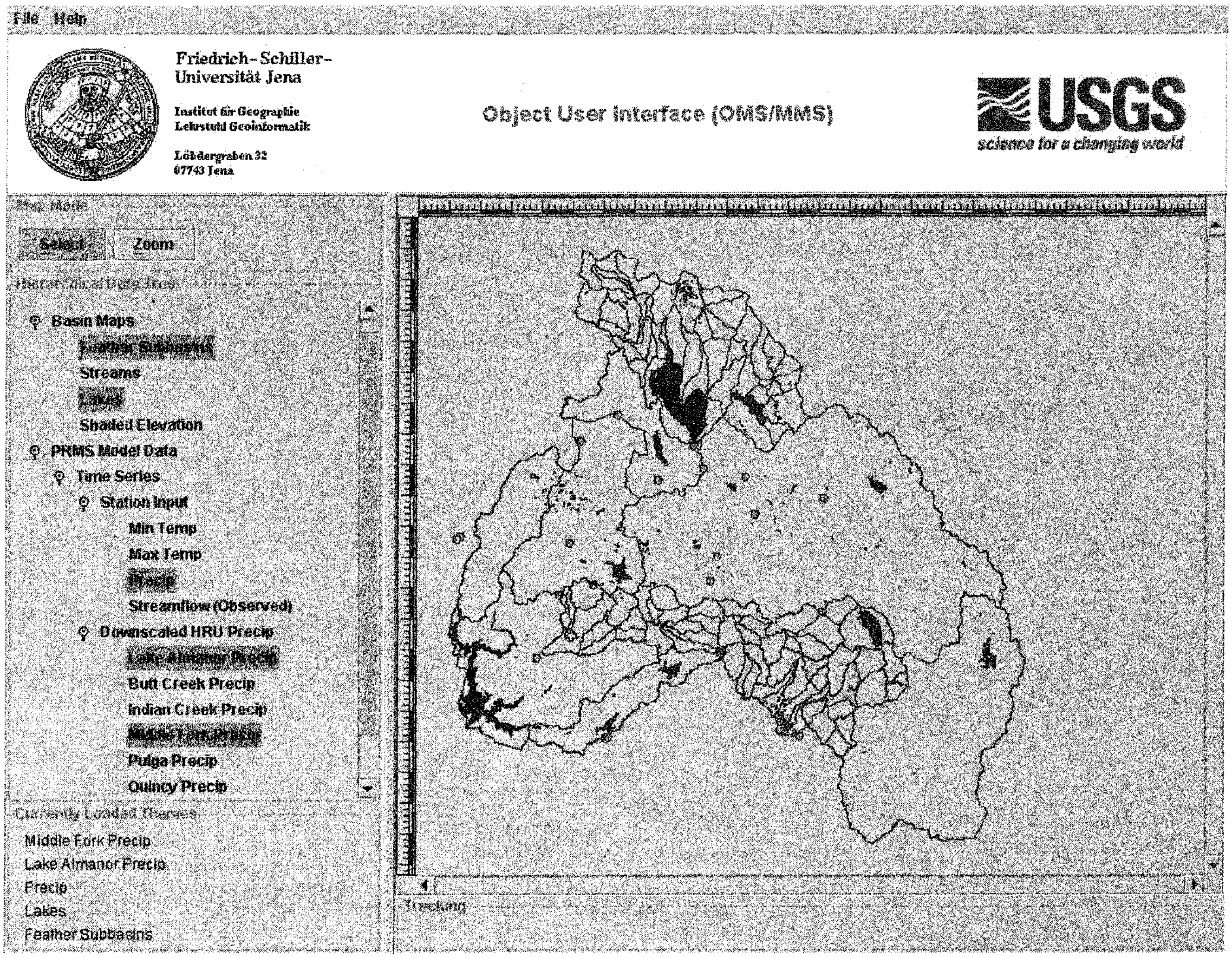

Figure 3. An example window using an Object-User Interface that shows data from the Feather River Basin. Also shown are 7-modeled subbasins, the lake network, precipitation stations, and the HRU boundaries for Lake Almanor (upper portion) and Middle Fork (lower portion) of the Feather River Basin.

Streamflow Forecasting

The methodology for generating streamflow forecasts as incorporated into MMS is the ESP program (Day, 1985). Many water-management agencies in the United States and abroad use ESP for estimating streamflow volumes from monthly to seasonal periods. The ESP methodology assumes that the historic climate is a good analogue for the future climate. The calibrated watershed model is run typically from late summer of the previous water year to the day prior to the beginning forecast date, thereby establishing an initialization period (figure 4). One streamflow trace is simulated for each historic year of climate data using the current watershed conditions as the initial conditions for each simulation. Ensembles of streamflow traces are analyzed statistically to produce a probabilistic forecast for each output variable of interest. The USGS has developed a graphical-user-interface program, ESPTOOL, to visualize the different streamflow traces and their associated probabilities. ESPTOOL outputs summary tables of forecasted volumes, volume and peak flow rank, exceedance probabilities, and date of peak flow. Included in MMS is the ESP module, that runs when the ESPTOOL program is executed, allowing the user to compute forecasts for several basins in an iteractive mode. Typically the forecasting agencies produce and publish the 10-50-90 percent exceedance probabilities. ESPTOOL allows the user to view all associated probability volumes for a given river basin. Given the current climatic information made available to the public by the various climate forecasting agencies, water managers often have indications, as early as the prior summer, as to the dominant precipitation pattern expected the following season and can determine whether the precipitation pattern resembles an El Nino, La Nina, or neither. The ESPTOOL user can select a subset of years resembling either one of these patterns (figures 5 and 6) or the more general patterns resembling negative or positive pacific decadal oscillation indices.

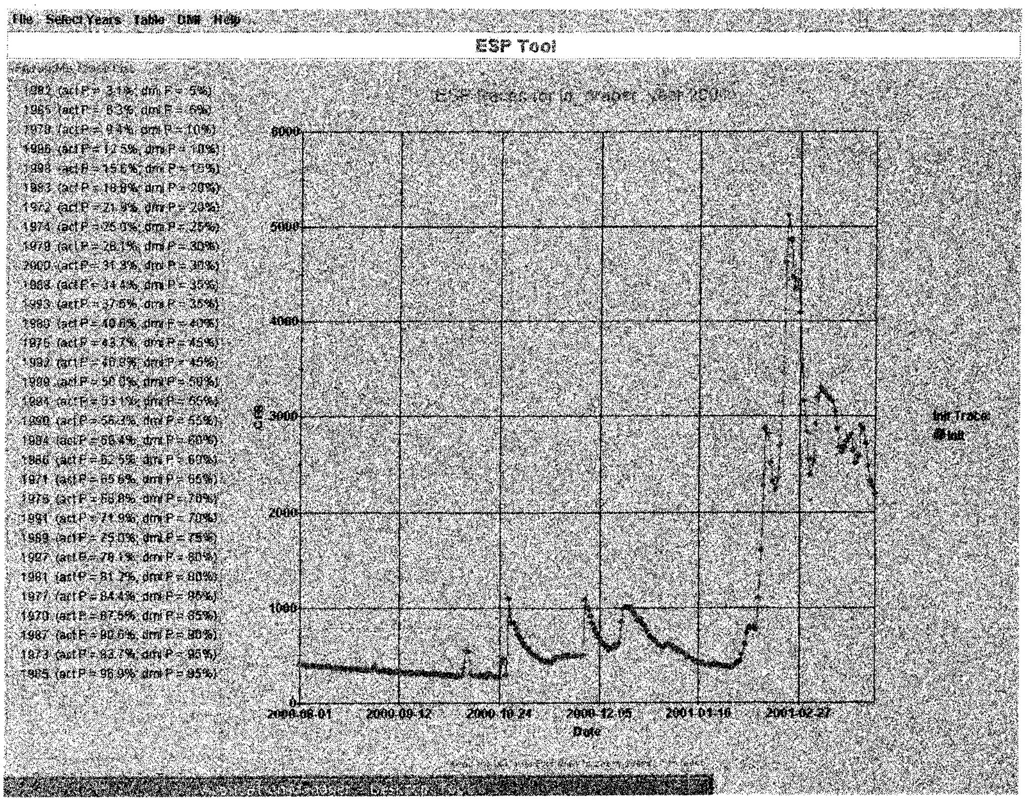

Figure 4. An example window from ESPTOOL illustrates the initialization period used in forecasting runoff for the Lower North Fork Feather River.

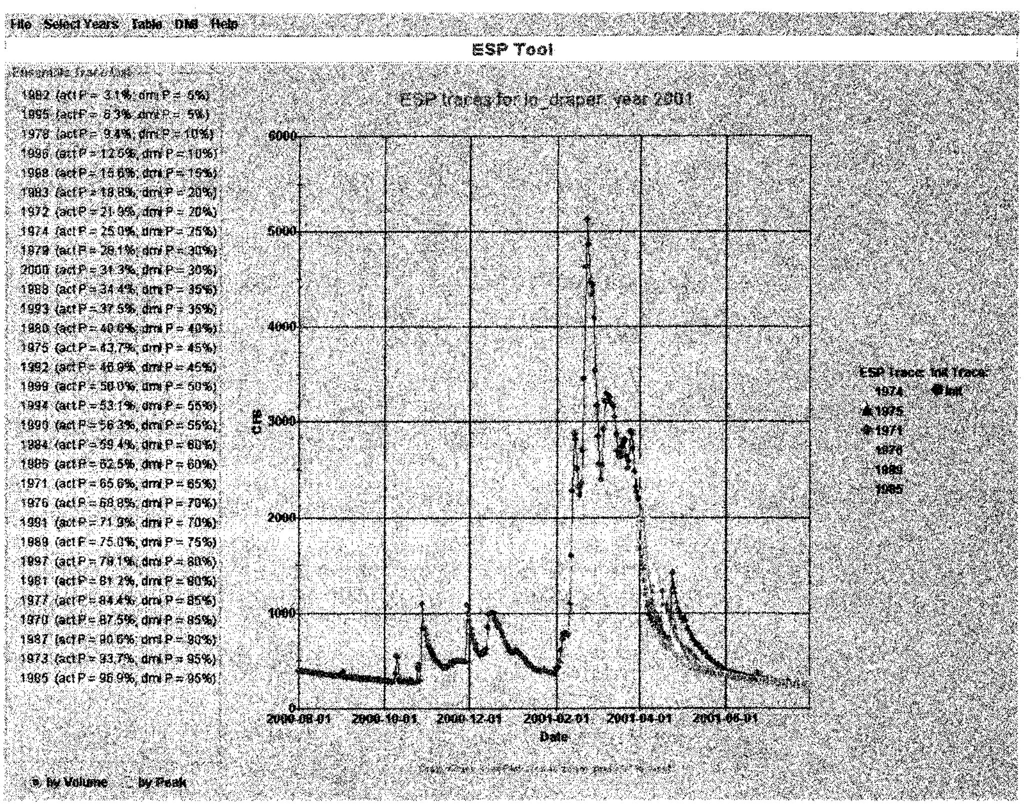

Figure 5. An example window from ESPTOOL illustrates the forecasted streamflow traces for the La Nina years (1971, 1974, 1975, 1976, 1985, and 1989).

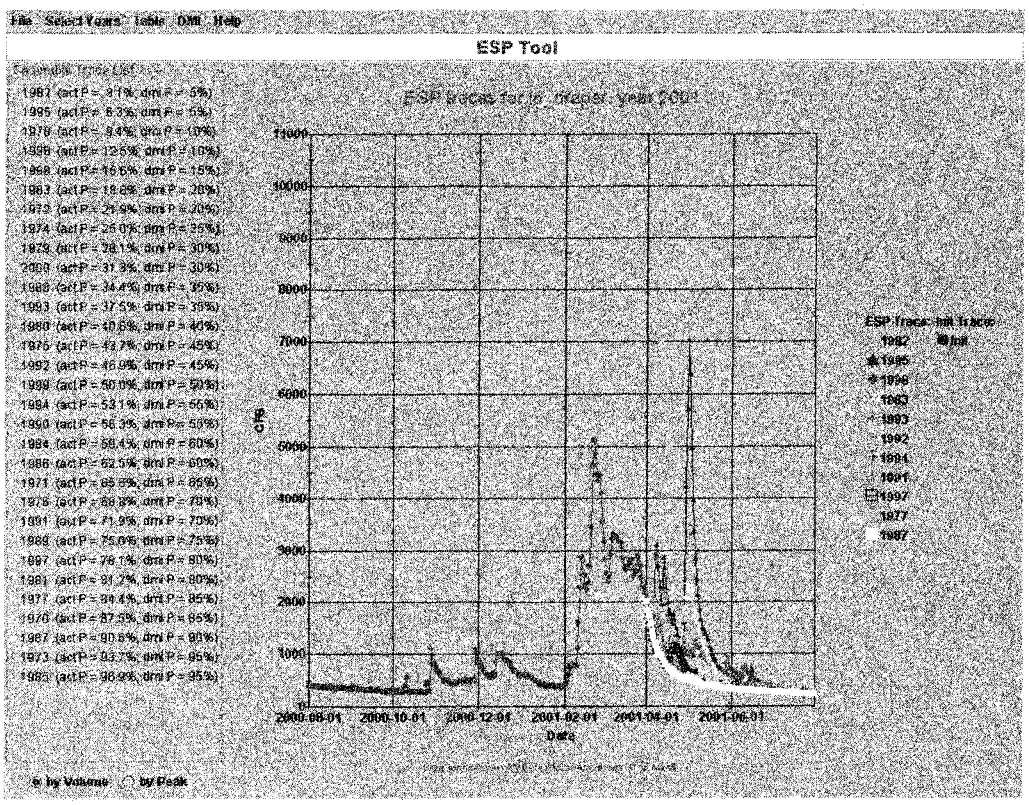

Figure 6. An example window from ESPTOOL illustrates the forecasted streamflow traces for the El Nino years (1977, 1982, 1983, 1987, 1991-95, 1997-98).

SUMMARY

The MMS and associated software programs for basin characterization and streamflow forecasting currently are being implemented in several large river basins in the Western United States. One of the goals of the WaRSMP program is to provide water-resource managers with the computing capability to run the watershed and river optimization and management models with near real-time hydroclimatic data. In addition, the OUI can be used as a stand-alone map-based data tree for simply accessing and displaying data or more configured to run the hydrologic and forecasting models as a design support system. In the latter mode, the execution of the models essentially becomes transparent to the user while providing the means to view and analysis the extensive database associated with running multiple models interactively. The USGS has made available to the public an Internet site where information, documentation, and source code for MMS and the GIS Weasel may be obtained. The URL address for MMS is http:///wwwbrr.cr.usgs.gov/mms, and for the GIS Weasel, http:///wwwbrr.cr.usgs.gov/weasel. In addition, the Natural Weather Service ESP program has been incorporated into MMS as a separate module. The graphic user interface, ESPTOOL, displays the selected streamflow traces and their associated probabilities.

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