# TECHNOLOGY DEVELOPMENT IN WATER RESOURCE MANAGEMENT

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## ABSTRACT

In developed nations, technological advancements rapidly are changing every aspect of our lives: how we work, how we communicate with each other, and even how we are entertained. The influence of technology is readily apparent. The subtleties of technology and its less apparent influences also are tremendous. Advances in computer technology, communications, and manufacturing are affecting all sectors, including engineering. In the arena of water resources, technological advances have helped to not only develop a better understanding of our physical systems but have allowed improved operational and institutional tools to be developed to support water management. These advances have the potential to provide large and meaningful benefits to less developed infrastructures.

The objective of this paper will be to describe several technological advances in water resources, specifically in areas such as Flood Warning, Water Administration, and Multi-Objective Water Management. Examples of technologies implemented which have direct applicability to developing infrastructures are described. Important to the discussion of these advances are the ways in which implementation and use of these technologies can protect and save lives, extend and optimally use limited resources, and provide useful information to assist in the sustainable growth and development of our natural resources.

## FLOOD WARNING

In developed countries flood warning and hydrologic forecasting are integral activities of water and meteorological agencies, often within the jurisdiction of federal agencies. Data collection, meteorological analysis and forecasting, and hydrologic analysis and forecasting can offer information to emergency managers and civil defense agencies to provide lead time for emergency response and potentially even evacuation. The goals of such programs are to protect lives, property, and mitigate disaster. Most flood warning or forecasting programs typically contain a fundamental set of components, all of which are essential to effective disaster mitigation. These components include:

- Automatic Data Collection Networks
- Data Processing and Analysis
- Meteorological and Hydrologic Forecasting (short-term and long-term)
- Information Dissemination

The technology advances in data collection systems have greatly improved water managers' ability to get both real-time and historical data and analysis automatically. Data collection platforms (DCPs) are now affordable; can be placed in remote locations with minimal maintenance; and provide the communications capability either through dedicated phone lines, wireless phone, radio frequency, or even satellite protocols to provide necessary climatological and hydrologic data to support warning, operations, and planning. Additional data sources include radar and satellite imagery. Data collection networks are integral to successful flood warning and forecasting and are typically the first component of a developing system. On the back end of warning systems, the requirements for information dissemination vary widely depending upon objectives of the flood forecasting or warning system, the size of the system, the available technology, and the needed lead times. Examples of information communication systems include a simple messaging from an ALERT protocol data collection system which could automatically page or call an emergency manager when some warning threshold (precipitation depth over some duration might be an example) has been exceeded in the data collection network or as complicated as a hierarchy of warning from responsible agencies to media and civil defense programs. The procedures and communication channels are often described in emergency response plans developed at regional and local scales.

Essential to a flood warning system are the tools and analysis which act upon data collected to provide some

indication of future hydrologic conditions. Here we will examine two types of systems: short-term flash flood forecasting technology often applied in smaller basins where response times are short and personnel resources for operational support are minimal; and a more comprehensive system targeted at larger basins where the objectives are more complicated, the timescales longer, and the institutional and infrastructure requirements greater.

The objective of flash flood forecasting systems is typically to provide near real-time forecasts in areas of fast response. Data processing and time-step intervals may be on the order of minutes. Forecast horizons may be on the order of hours. Applications must integrate with real-time data sources such as ALERT networks or radars and provide automated processing. The systems must often run stand-alone with little or no human intervention. An example of such a system can be found in FLOOD Watch™, a PC-based hydrologic forecasting tool that simulates the hydrologic response of a watershed as function of precipitation input. FLOOD Watch™ employs a variety of models to represent the physical processes controlling water movement. A state-space implementation of the Sacramento model is used to estimate runoff continuously by modeling the soil moisture water balance. The state-space implementation provides an efficient set of algorithms for real-time computation and has been extended to support real-time updating of model states based on streamflow observations. The Kalman filtering updating technique used with the Sacramento model provides an objective and automatic method to ensure that the model states stay on track. FLOOD Watch™ is typically used in conjunction with a database which is populated by a real-time data collection system. Each time the database is updated with new data, FLOOD Watch™ initiates a forecast simulation. An example of FLOOD Watch™ implemented on top of an ALERT data collection network is presented in **Figure 1**.

This type of system can be used to monitor and forecast river and reservoir conditions in basins with short response times. It is an appropriate system for emergency management personnel who are not experts in hydrology and who have a limited amount of time for operational supervision. In addition, it can be used with readily available PC hardware and operating systems.

In large river systems with longer response times, forecasting technology can be used to provide water management benefits as well as flood warning. Hydrologic forecasts are needed for reservoir operation, water supply planning, navigation scheduling, hydropower generation, environmental protection, recreation, and

fisheries management. Forecast time scales vary from hourly to daily to even seasonal. The institutional as well as technology infrastructure requirements of supporting these larger, more complex systems are much greater than the flash flood forecast systems. Data collections systems covering much larger areas must be integrated into the system. An example of the large, multipurpose forecasting technology is the National Weather Service River Forecast System (NWSRFS) developed by the U.S. National Weather Service (NWS). The NWS is the agency responsible for river forecasts and warnings for the protection of life and property as well as to support the management of the nation's water resources. The NWS has recently undertaken a program to advance the technology within its operational forecasting operations. This program is called the Advanced Hydrologic Prediction System (AHPS). Following the Great Flood of 1993 in the central U.S., a demonstration project was initiated in the Des Moines Basin to showcase AHPS technologies. The four initial objectives of this project were to demonstrate new probabilistic long-range forecast products, to integrate long-range meteorological climate forecasts into long-range hydrologic forecasts, to include short-term quantitative precipitation forecasts (QPFs) into the hydrologic forecasts, and to demonstrate a flood inundation mapping technology.

National Weather Service River Forecast System

NWSRFS provides real-time predictions of river flows and other hydrometeorological variables used in river forecasting. The system includes a Calibration System (CS), an Operational Forecast System (OFS), and an Extended Streamflow Prediction (ESP) component. ESP produces probabilistic forecasts of streamflow based on the assumption that historical meteorological data are representative of possible future conditions. **Figure 2** outlines the interactions between the NWSRFS components and databases.

*The Calibration System:* CS is used to perform all the tasks necessary for hydrologic model calibration. These tasks include historical data analysis, computation of mean areal time series of temperature and precipitation, and model parameter estimation. In calibration, model parameters are adjusted until model simulations accurately reproduce historical observations. The model parameters are then used in OFS for operational forecasting.

*The Operational Forecast System:* OFS is used to make real-time hydrologic forecasts for periods extending hours or days into the future. The system consists of a number of databases, programs, and utilities that store

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hydrometeorological observations, processed areal time series estimates of precipitation and temperature, network and model parameter information, and current model states. The hydrologic, hydraulic, and utility software that produce the forecasts in NWSRFS are called operations. An operation can be a hydrologic or hydraulic model, a time series computation program, or a statistical computation or display tool. The OFS includes an Interactive Forecast Program (IFP) which is a GUI that lets the forecaster make run-time adjustments to the system in order to fine tune the forecast based on the forecaster's knowledge of the watershed and current conditions.

*The Extended Streamflow Prediction System:* ESP uses the CS historical time series data and the OFS parameters and current conditions to produce long-range probabilistic hydrologic forecasts for user-specified periods. ESP is linked to OFS and CS by databases and basin parameters. ESP uses the basin and network parameters and the current watershed states from OFS combined with the historical time series of precipitation, temperature, and river data from CS. Simulations in ESP start with the current watershed states from OFS. The historical meteorological data time series are then applied to the basin, with each year of historical data producing a simulation trace. Traces are analyzed to produce probabilistic forecasts about watershed conditions ranging from one day to one year in the future based upon current watershed states.

The Extended Streamflow Prediction Analysis and Display Program (ESPADP) was developed as part of AHPS to analyze ESP forecasts and to incorporate both short- and long-range climate prediction and QPF products into hydrologic forecasts. Products generated in ESPADP include time series realizations of future hydrologic conditions, also called traces, probability interval plots, expected value plots, and exceedance probability plots for selected variables over varying time intervals. Temperature, precipitation, river stage, streamflow, and reservoir pool elevation are just a few of the data types that can be analyzed. Users can compare model simulations (conditional simulations), calibration simulations (historical simulations) with observed data sets, and statistics over identical analysis and time intervals. Risk-based forecast information is provided by examination of all the potential realizations, by analysis of exceedance histograms, and by statistical analysis using distributions to describe the forecast simulations. **Figures 3 and 4** demonstrate example ESPADP risk-based analysis output.

*Climatological Adjustments*: ESP provides probabilistic forecasts based on current watershed conditions and historical meteorological data. ESP also provides several mechanisms to incorporate weather and climate forecast information into the analysis. First, ESP allows a QPF to be included directly into the conditional simulation. Within the simulation, the QPF is blended with historical precipitation for the short-duration precipitation forecast using adjustable blend parameters. The blending period provides a smooth transition between future values and the historical data. Additionally, historical years can be weighted differently in the probabilistic analysis if a forecaster has some knowledge about future climate. For example, year weighting could be used to condition the hydrologic forecast to El Niño signatures by excluding or weighting historical years differently. Seasonal snowmelt forecasts can be shaped by forecaster knowledge of historical snowpacks and temperature and precipitation patterns. Automated procedures have also been developed to model adjustments based upon the U.S. Climate Prediction Center (CPC) long-term forecasts for precipitation and temperature.

*Flood Inundation*: Flood inundation technology integrated into geographic information systems (GIS) can provide a valuable linkage between hydrologic forecasting analysis and visualization for emergency management. The NWS has developed tools for overlaying contours of risk of inundation onto digital elevation models (DEM). Other tools have been developed by a number of commercial entities to display inundation over GIS coverage's of cities, floodplains, etc. These dynamic maps can be valuable to emergency response planning and implementation. **Figure 5** demonstrates an example of how flood inundation mapping might be displayed operationally.

Hydrologic forecasts from a system such as NWSRFS provide basic flood warning information and support a variety of water management objectives. This system provides deterministic information for short-term operations and probabilistic information for longer-term operations. The probabilistic forecast information provides the basis for risk-based decisionmaking where decisions are based on the probability of future outcomes and the trade-off of one objective versus another. These systems require a much larger institutional commitment and technical infrastructure to operate and maintain on a daily basis; however, they provide the best possible hydrologic forecast information to support decisions.

## WATER ADMINISTRATION AND PLANNING

As water use and regulation becomes more complex with large managed systems, developing countries must wrestle with approaches for administration and planning of water resources. Many countries have developed both institutional and legal frameworks for the allocation and delivery of water. Often further complicating administration and planning within these legal and institutional frameworks are a mixture of international,

federal, and even local (state/district) control and responsibility.

While technology cannot overcome many of the institutional issues facing developing countries in water management, the integration of technology and tools into administrative and planning systems can provide consistent, reliable, and meaningful information to decisionmakers in a timely manner. The availability of data and the ability to examine and visualize data and examine policy "what if" questions offers water managers the opportunity to look at potential impacts of decisions. There are many examples of administration and planning systems in use in both developed and developing countries. Here we examine the Colorado River Decision Support System (CRDSS), developed and implemented by the Colorado State Engineers office and the Colorado Water Conservation Board - the two primary agencies within Colorado for planning and administering water within the State of Colorado under the Prior Appropriation Doctrine of Western U.S. water law, as well as numerous inter-state agreements and international water treaties.

CRDSS was designed and developed to allow Colorado to enter a new era of water management that emphasizes cooperation among state agencies, water providers, and water users. The CRDSS is a data-centered system that contains historic tabular data such as streamflow, climate and diversions; spatial data such as topography, hydrography, and irrigated acreage; and administrative data such as water rights and water management policies. Data are keyed to locations in the river basin using a GIS. This computer-based system allows decision makers to access water resource data, simulate potential decisions and policies, and examine the consequences with regard to interstate compact policy, water resource planning, and water rights administration.

A Data-Centered Approach

An essential requirement of CRDSS was that various database and modeling components be developed and implemented over time. This required that the database design be scaleable and flexible enough to allow growth and enhancement. A model-generic approach was chosen, in which a core set of data are stored in a central database and are used by one or more applications. In this data-centered approach, the database becomes the repository for key data and consequently helps to maintain quality and consistency. **Figure 6** illustrates the CRDSS data-centered approach where various tools share common data.

In order to implement a data-centered system, there must be enough infrastructure in place to support and allow effective use of the system. The CRDSS database contains all of the key water resources data needed for planning and administrative purposes for the State of Colorado and allows for "one stop shopping" for Colorado water data users. Utilities have been written to format data files for models and provide effective data displays to users. Much of the data is available to Internet users via the CRDSS home page (www.cdss.co.state.us). Utilities are available that allow users to quickly access and format data for use in other applications.

It is important to note that the implementation of a data-centered approach in the CRDSS has not precluded the use of modular tools. Water resource planning models and other tools can run stand-alone and are not tied directly to the database. This allows for distributed modeling efforts within the user community. In order to promote data sharing, standard data formats for time series and other data have been adopted. The data-centered approach, as adopted for the CRDSS, allows users to access data from a central location but perform analyses using accepted tools in a desktop environment. As a policy, model output is not currently stored in the database but is kept in the standard model output formats. This simplifies model use and database design and decreases the overall size of the database. Exchange of data between models occurs using standard data formats and file translation utilities, where necessary.

Water Resource Planning

A water resource planning tool was implemented with CRDSS and is called StateMod. This tool is a monthly water allocation and accounting model that had been developed by the state beginning in 1986. It is capable of making comparative analyses for the assessment of various historic and future water management policies in a river basin using the Prior Appropriation Doctrine (first in time, first in right). StateMod's operation is governed by hydrology, water rights, and operating rules. It recognizes four types of water rights: direct flow, instream flow, reservoir storage, and operational. Operational rights are used to control complex, multi-structure activities associated with reservoir releases, exchanges, and carrier ditch systems. Key features of the model required to simulate the diverse operating conditions encountered on the western slope of Colorado include the following:

- Simulates tributaries and main stem river systems through the use of a tree-structured network
- Simulates direct flow, instream flow, storage and operation rights under the Prior Appropriation Doctrine as a function of water availability, priority, decreed amount, demand, structure capacity, and location
- Allows reservoirs to be operated with multiple accounts serving multiple users

- Allows instream flows to be operated as a point or river reach
- Simulates a wide variety of operating agreements and exchanges between several users or structures
- For a given structure, simulates one or more water rights, with one or more return flow patterns returning to one or more stream nodes
- Uses an efficient direct solution algorithm that recognizes the impact of a diversion's return flows during the current time step without having to iterate
- Estimates base or natural streamflow from gauged or estimated streamflow, diversion, and reservoir data

Data from the centralized database required in the planning process includes streamflow, diversions, baseflow, demand, and system efficiencies. These data are automatically queried from the database and formatted for planning model use and analysis. The planning tool is based upon a node network topology. The model network describes the physical connectivity of the structures and gauges being modeled. StateMod uses a network file that describes model nodes in an upstream to downstream fashion. **Figure 7** illustrates part of the network for the White River basin. This schematic representation of the network is useful for modeling and can be aligned to closely match the true orientation of the basin. Nodes are labeled with structure identifiers. The figure illustrates the use of stream flow gauges, minimum streamflow reaches, aggregate demands, and baseflow nodes.

**Figure 8** illustrates the Big Picture Plot feature of the StateMod GUI. This graphic shows the difference in diversions between two policy allocation scenarios, with upward bars indicating that a diversion received more water under the second scenario, and downward bars indicating a decrease. The size of the bar indicates the magnitude of the change. Consequently, water resources planning model users are able to see a basin's response to an input change. This type of display illustrates the power of the CRDSS and its potential for helping make decisions at different levels. The Big Picture Plot can be used by managers studying long-term average impacts, whereas hydrograph plots at a gauge might be more useful to someone studying the time varying impact at a location on the river (such as an instream flow study). CRDSS offers display tools for various output levels to satisfy the needs of water managers.

The ability to visualize complex changes in water delivery or use in simple ways provides tremendous benefit to water managers and policy makers when examining changes in operational or legal policy. In developing infrastructures, the ability to explore scenarios of water development allows decisionmakers greater understanding on the impacts of new development and the operations of existing development.

**MULTI-OBJECTIVE WATER MANAGEMENT**

Increased and competing demands on water resources typically result in a proliferation of water development activities in developing countries. A myriad of institutional, organizational, and funding programs often results in fractured water management policies as well as disjointed operation of existing reservoirs, water supply, and irrigation systems. Development of new systems is often planned and implemented with little or no thought to system integration and operation. As a consequence, decisionmakers find it increasingly difficult to operate multipurpose reservoirs and networks of reservoirs.

Technology advances including computational power and efficiencies as well as modeling techniques have resulted in numerous developments in optimization, multi-objective tradeoff analysis, risk analysis, and operations research. These developments have provided the foundation for multi-objective water management of reservoirs and systems allowing for operations which increase reliable yields, increasing power generation and revenues, secure more reliable water supply and irrigation supply, and provide more reliable operation for flood control and environmental considerations such as fisheries and sediment flows.

An example of how risk-based multi-objective analysis supports strategic planning over short-term and long-term horizons can be found in how the Denver, Colorado Water Department operates mountain reservoirs for water supply, power, flood control, fisheries, and recreation benefits. The Denver Water Department is responsible for providing water for the City and County of Denver as well as 40 percent of the surrounding suburbs. To do this, Denver Water owns and manages 11 reservoirs on both the eastern and western slopes of the Continental Divide. Representing nearly half of Denver's raw water supply, Dillon Reservoir (**Figure 9**) is considered one of Denver Water's most important water supply facilities.

Located on the western slope's Blue River (Upper Colorado), with a live storage of 254,036 acre-feet, Dillon reservoir is one of the largest lakes in Colorado. Water is diverted from Dillon Reservoir to Denver Water's treatment facilities via the 23.3 mile-long Roberts Tunnel under the Continental Divide. The water then flows into the North Fork of the South Platte River.

Although built and operated fundamentally for water supply, Dillon Reservoir offers many secondary benefits, including (1) downstream flood reduction for the town of Silverthorne, (2) in-lake recreation (boating, fishing, and camping), (3) downstream fisheries habitat augmentation,

(4) downstream recreation (fly fishing and white water rafting), and (5) hydropower generation.

Forecast Information for Reservoir Operations

Reservoir operators rely on a variety of forecast information as input into the decisionmaking progress. Short-term forecasts (typically three to five days) give reservoir operators important information about reservoir inflows for real-time operations and short-term planning. Typically, short-term forecasts are deterministic in nature and represent the forecaster's best estimate of future reservoir inflow over several days. Extended probabilistic forecasts (1- to 3-month outlooks) give operators important information about the uncertainty and range of forecasts over an extended time horizon. The extended probabilistic forecasts give decisionmakers invaluable information about the distribution of possible reservoir inflows (i.e., timing and magnitude of peak inflow), as well as short-term and seasonal reservoir inflow volumes.

In the United States, the NWS issues short-term deterministic forecasts for over 3,000 forecast points daily. For many reservoir decisionmakers, these forecasts provide essential information used in immediate real-time operational decisions. In addition to short-term deterministic forecasts, the NWS also provides a number of longer-range forecast products for reservoir planning. Seasonal forecasts of water supply used in the western United States are prepared by the NWS and the Natural Resources Conservation Service (NRCS). These forecasts provide a most probable volumetric outlook along with reasonable minimum and maximum volumes. The reasonable minimum and maximum volumes represent inflow volumes that are expected to be exceeded 90 percent and 10 percent of the time, respectively.

An important forecast product used in reservoir operations and developed by the NWS is the ESP forecast. ESP, described previously, provides probabilistic, or risk-based, information to reservoir operators. These probabilistic inflows are conditional and reflect the future variability of inflow based on current hydrological conditions. Once streamflow realizations have been generated, a forecaster can use the ESPADP to generate other helpful products.

Following is an example of a reservoir optimization model that uses ESP realizations of reservoir inflow to optimize operations at the multipurpose Dillon Reservoir.

Multi-Objective Optimization

A wide variety of reservoir optimization models exists to help decisionmakers formulate reservoir release strategies. Each of these models provides different levels of information and utility, depending on reservoir system characteristics and operating goals. A Stochastic Linear Binding Method (SLBM) and a stochastic linear reservoir optimization model were developed to aid the operators of the multipurpose Dillon Reservoir.

The stochastic linear reservoir optimization model was created to aid decisionmakers with both short-term (one week) and long-term (seasonal) reservoir regulation decisions. The model helps reservoir decisionmakers explicitly quantify the benefits and risks associated with different operating policies by identifying tradeoffs of operating benefits. With stochastic ESP inflows available for input, the reservoir optimization model was formulated as a multi-objective stochastic linear programming model, running on a daily time step. The tradeoff curve depicted in **Figure 10** illustrates a set of non-dominated optimal solutions for Dillon Reservoir. Each point on the curve defines an optimal alternative operating policy, with each point representing the starting point for preferences between two conflicting objectives. **Figures 11 and 12** demonstrate the results for a single point on the tradeoff curve where the operating policy minimizes flood risk by initially releasing 1,800 cubic feet per second (cfs). The resulting discharge and storage under this policy, however, increase the risk or probability of not meeting a different, non-commensurate objective.

The use of multi-objective tools to help manage multipurpose reservoirs provides additional information to project operators which can greatly enhance yield, power revenues, and help minimize flood control and other objectives. The use of hydrologic forecast information can provide additional information into reservoir operations which allow better decisions to be made in the near-term which have longer-term effects. Furthermore, adding a probabilistic component to the analysis gives decisionmakers risk-based information upon which to make decisions, greatly enhancing their ability to understand the inherent tradeoffs they must make.

**CONCLUSION**

Tremendous advances are being made in technology across all avenues of society. Advances in computers, communications, and software have allowed tremendous developments in tools and systems for water resource applications. Advances in flood warning systems, water administration and planning, and multi-objective water management have direct applicability to the infrastructures and processes of countries that are developing and expanding water resources capacity. The implementation of these technologies can have direct impact on saving and protecting lives and property, extending and optimally using limited resources, and providing useful information

to assist in the sustainable growth and development of natural resources.

**Daniel J. Epstein**    Mr. Epstein is a civil/software engineer specializing in project management, software design and development, water resources engineering, and hydrologic modeling. He has designed, developed, and implemented large computer applications for both real-time hydrometeorological operations as well as for planning purposes. He has experience in integrated decision support systems, including databases, geographic information systems, animation, and web application development. Mr. Epstein's computer engineering experience includes design, development, quality assurance, project management, system administration, database administration, and system utilities development. As a project manager, Mr. Epstein has extensive experience coordinating interdisciplinary software and engineering applications. He designs and coordinates development cycles to ensure quality products and client satisfaction.

**Larry E. Brazil**    Dr. Brazil is the president and chief executive officer of Rti Riverside Technology, inc.). He specializes in the development and evaluation of water management projects. In his technical role as a water resources engineer, he is involved in decision support system development, deterministic and stochastic hydrologic modeling, hydrometeorologic forecast system design, and data analysis. He spent 11 years at the Hydrologic Research Laboratory of the National Weather Service where he developed and implemented components of real-time hydrometeorological monitoring and forecasting systems. Dr. Brazil's experience in water management has included technical assistance in forecasting water availability for operational purposes, such as irrigation management, hydropower production, and water supply. Applications of his work also have included use of hydrometeorological forecast information for disaster and emergency response and preparedness. Dr. Brazil has 26 years of experience and has published over 40 papers in his areas of expertise.

**Gerald N. Day**    Dr. Day is the director of water management and forecasting. He specializes in watershed modeling and streamflow forecasting. Dr. Day has extensive experience in implementing river forecasting technology in the U.S. and around the world. Since joining Rti, he has capitalized on his knowledge of forecasting technology to support the development of decision support systems for water management. Prior to joining the firm, he spent 13 years at the National Weather Service Hydrologic Research Laboratory, where he served as the Water Resources Forecasting Project Area Leader. In this role, he was responsible for development and operational support of the National Weather Service Extended Streamflow Prediction system, which provides probabilistic forecasts of streamflow at time scales ranging from one week to several seasons. These forecasts help water managers make complex decisions involving competing objectives of water resource systems. Dr. Day has 25 years of experience and has published over 20 papers in his areas of expertise.
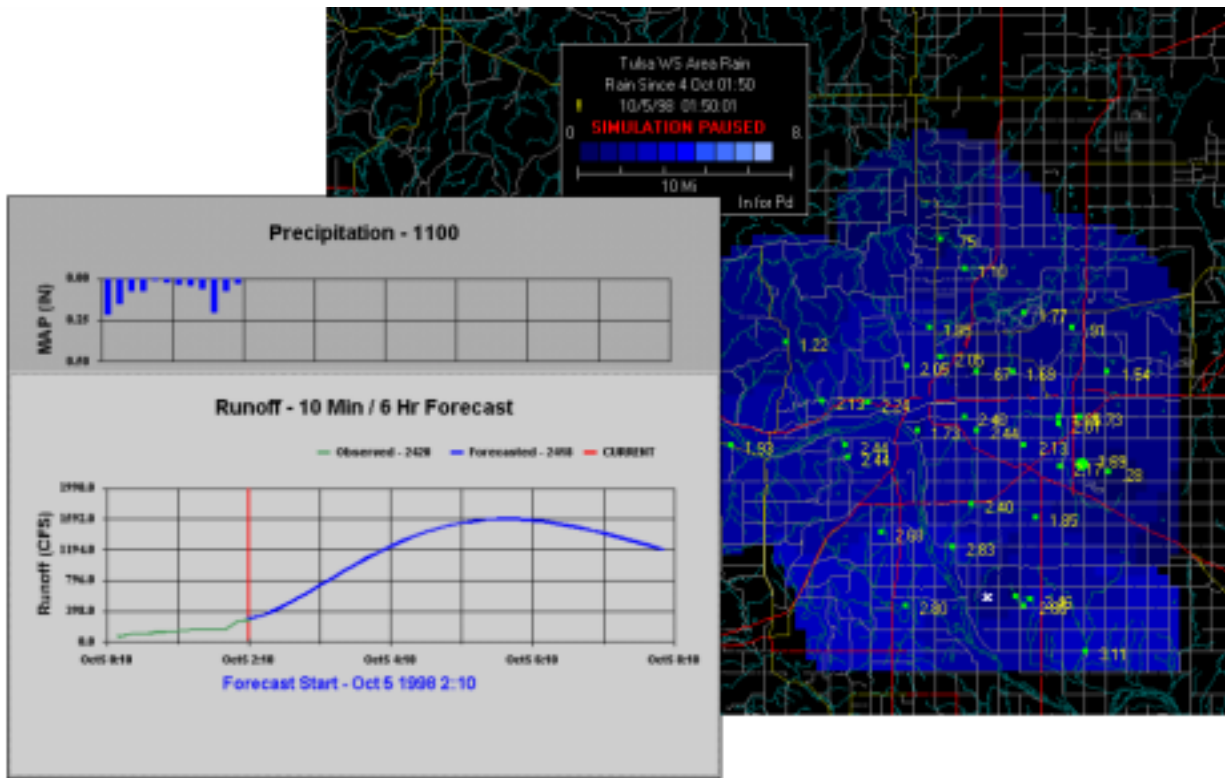
Figure 1. FLOOD Watch Flood™ Forecasting Using ALERT-based Data Collection Network
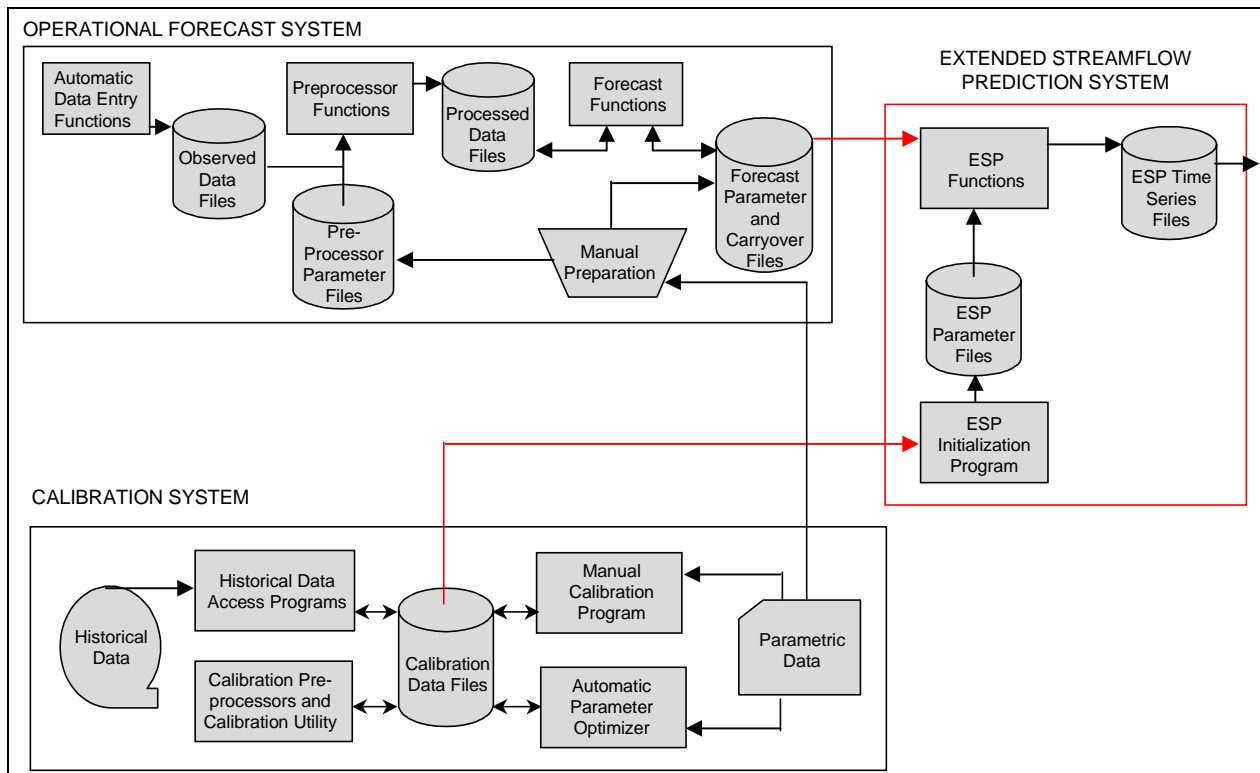Source: RTi
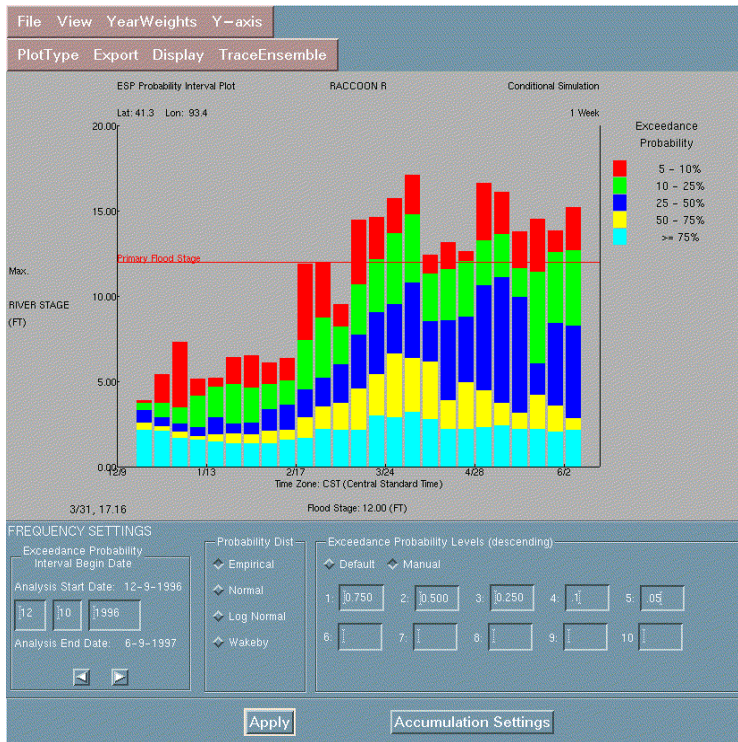


Figure 2. NWSRFS Process and Components
Source: RTi

Figure 3. ESPADP Histogram Plot - 14th Street, Des Moines, IA
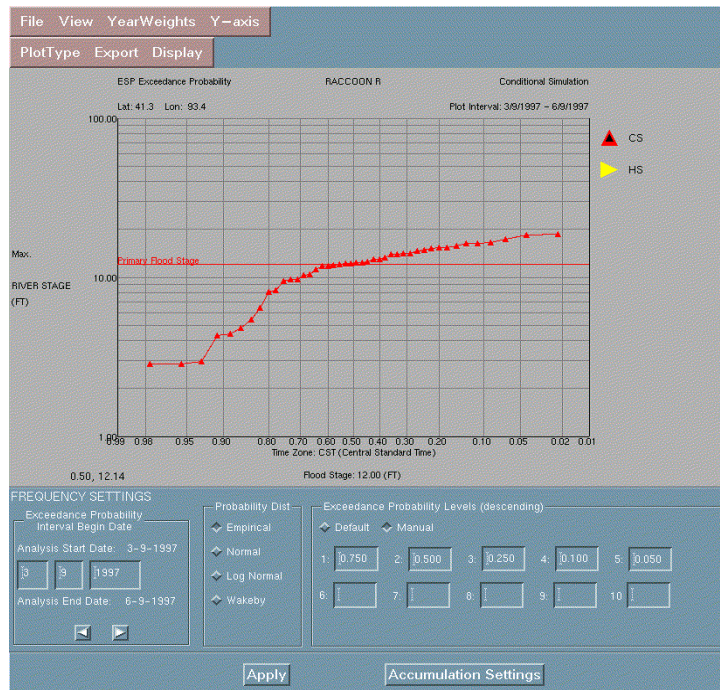Source: RTi



Figure 4. ESPADP Exceedance Probability Plot - 14th Street, Des Moines, IA
(60-day forecast, March 9, 1997 to June 9, 1997, a maximum river stage exceedance probability)
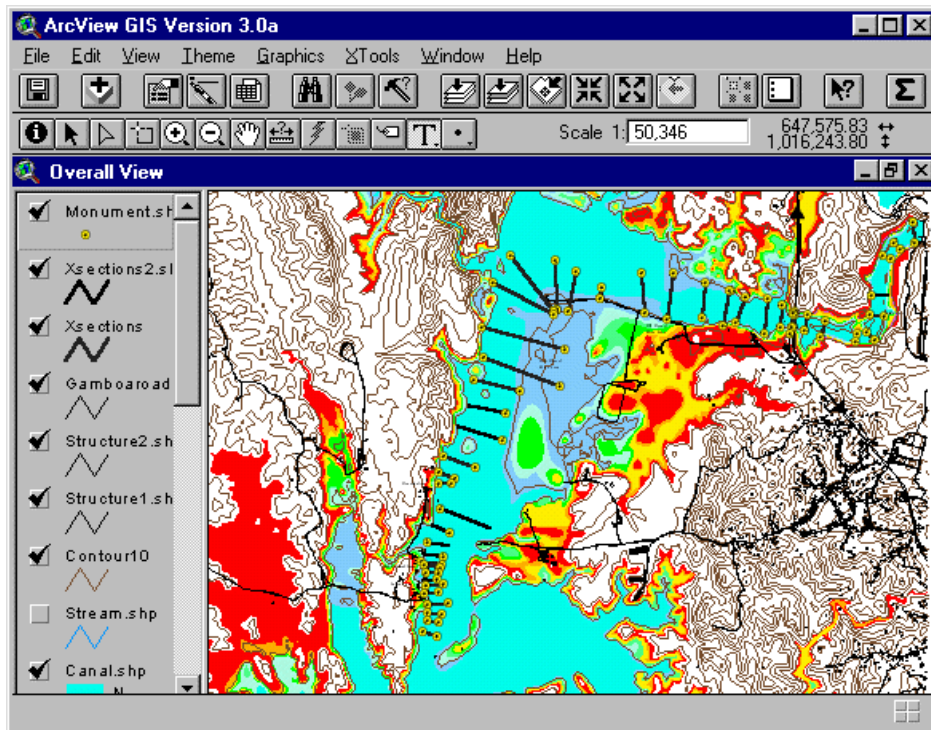Source: RTi

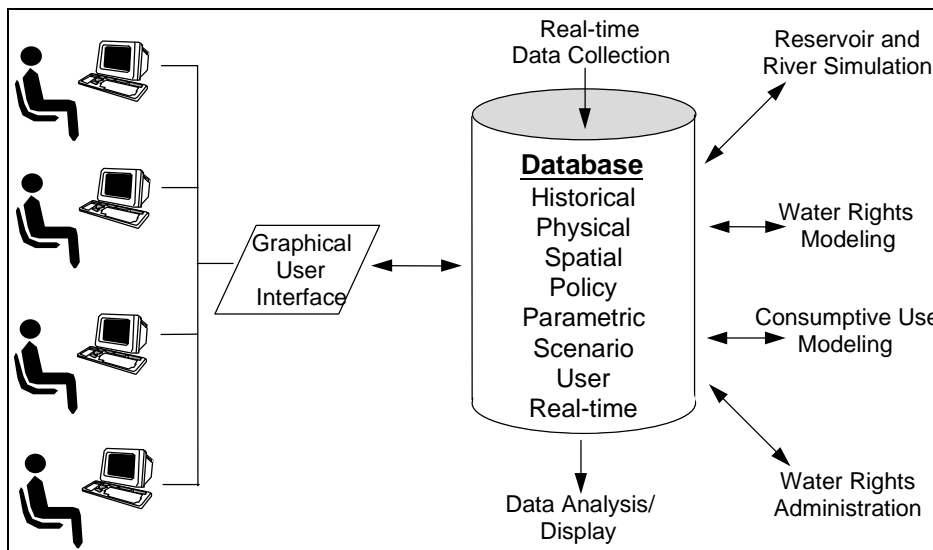Figure 5. Flood Inundation Map - Chagres River below Madden Dam
Source: RTi


Figure 6.  CRDSS Data-centered Approach
Source: RTi
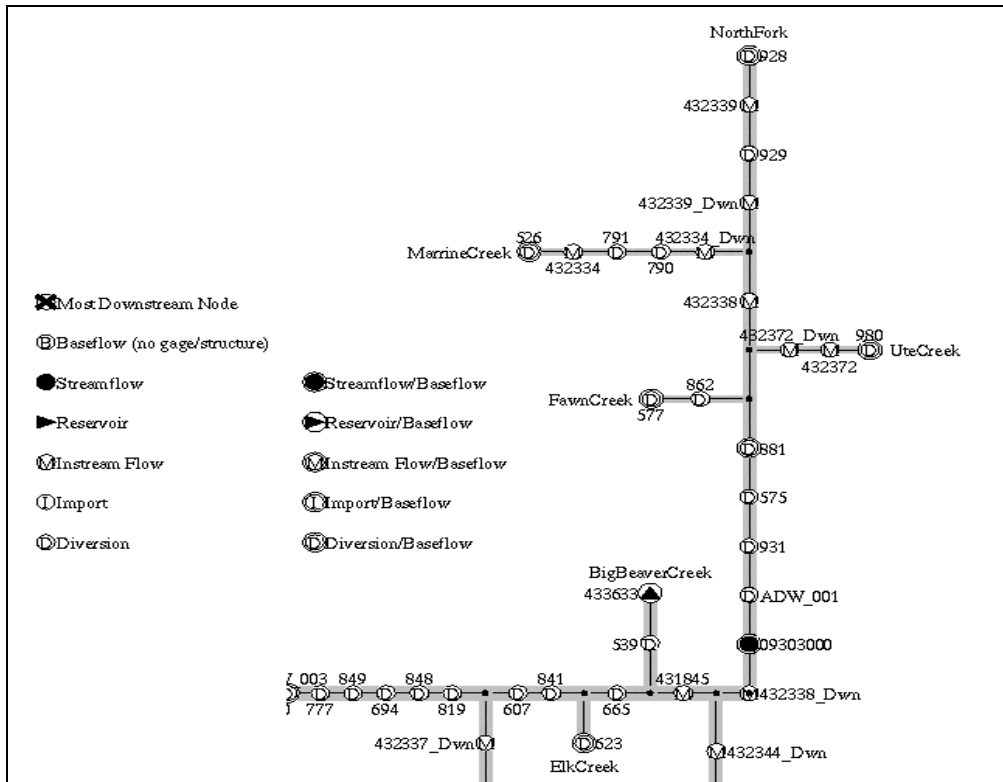
Figure 7.  Example of Part of a StateMod Network Diagram - the North Fork of the White River
Source: RTi
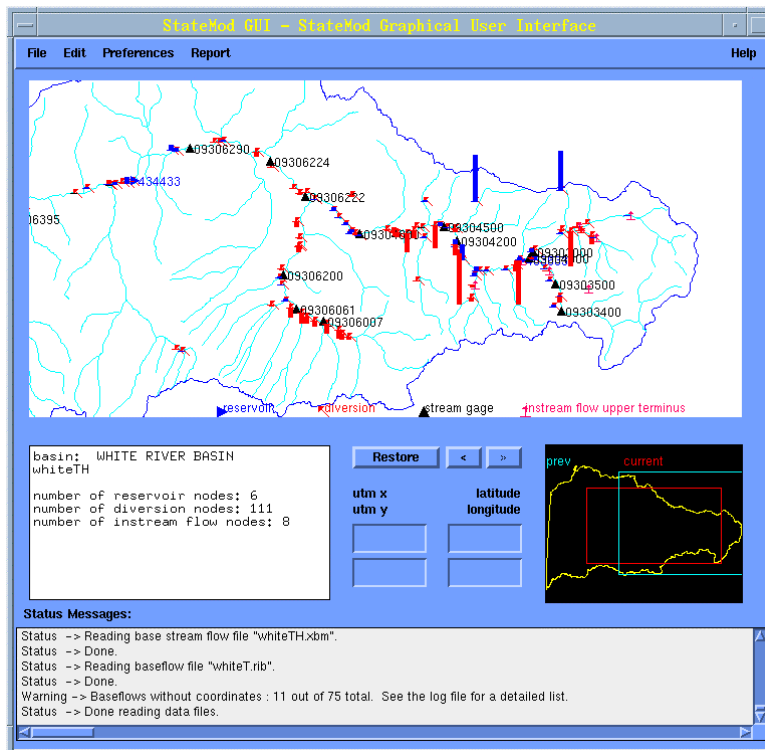


Figure 8.  StateMod GUI Big Picture Plot
Source: RTi

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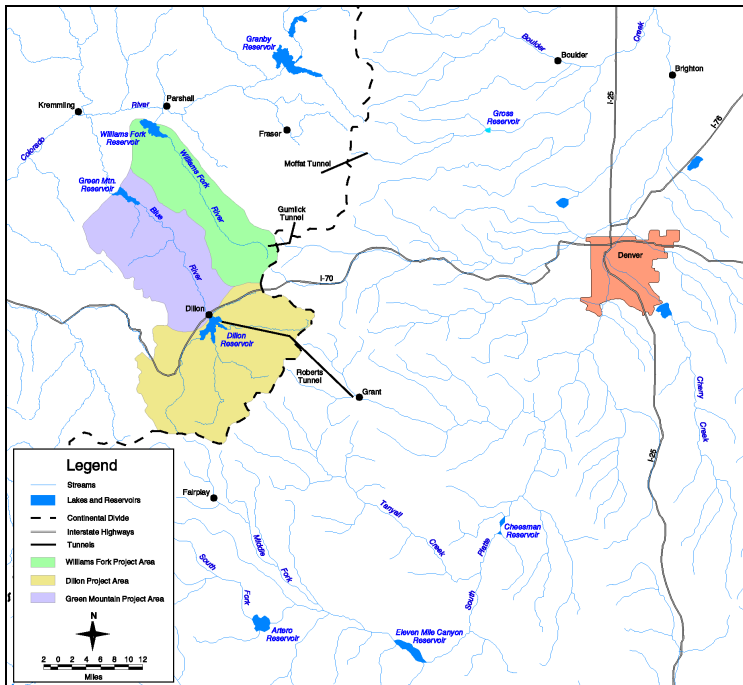
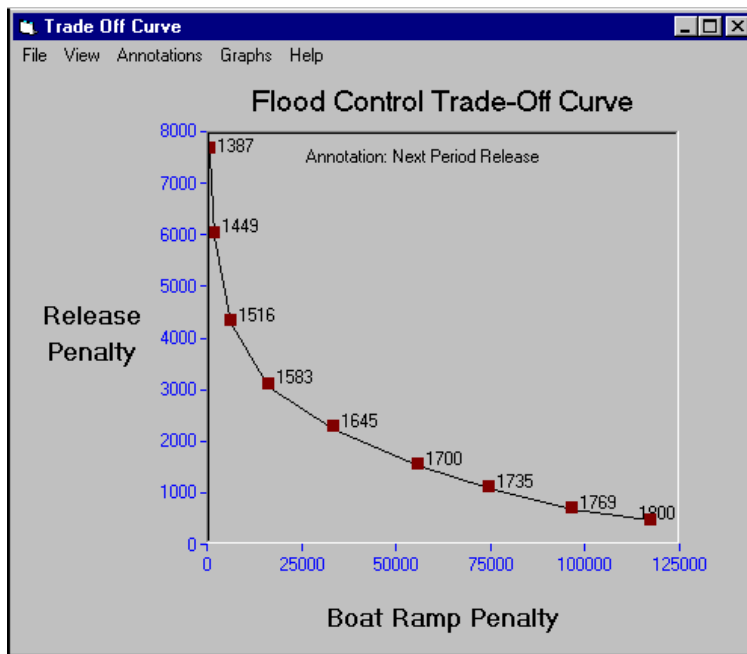Figure 9. Dillon Reservoir
Source: RTi



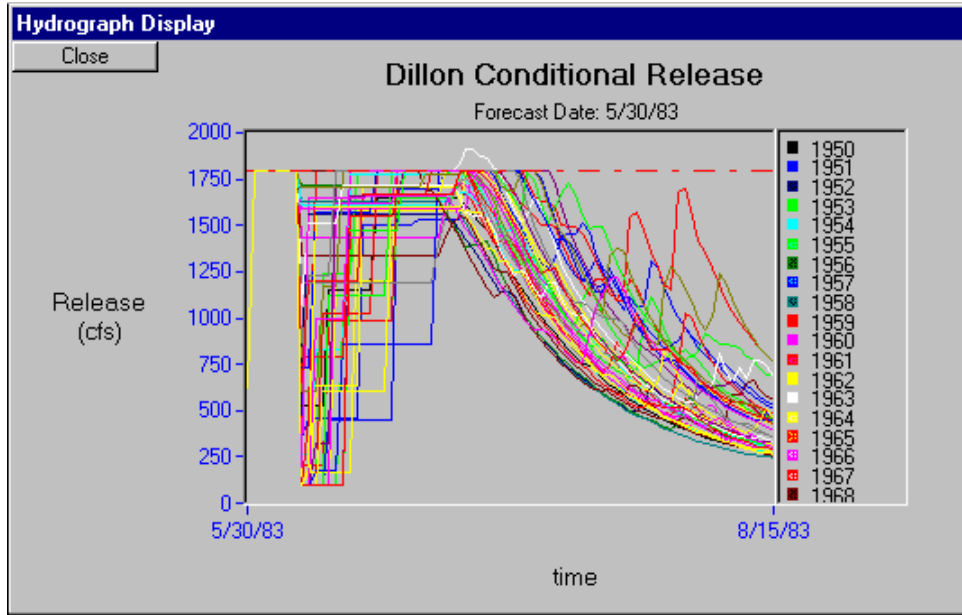Figure 10. Tradeoff Curve
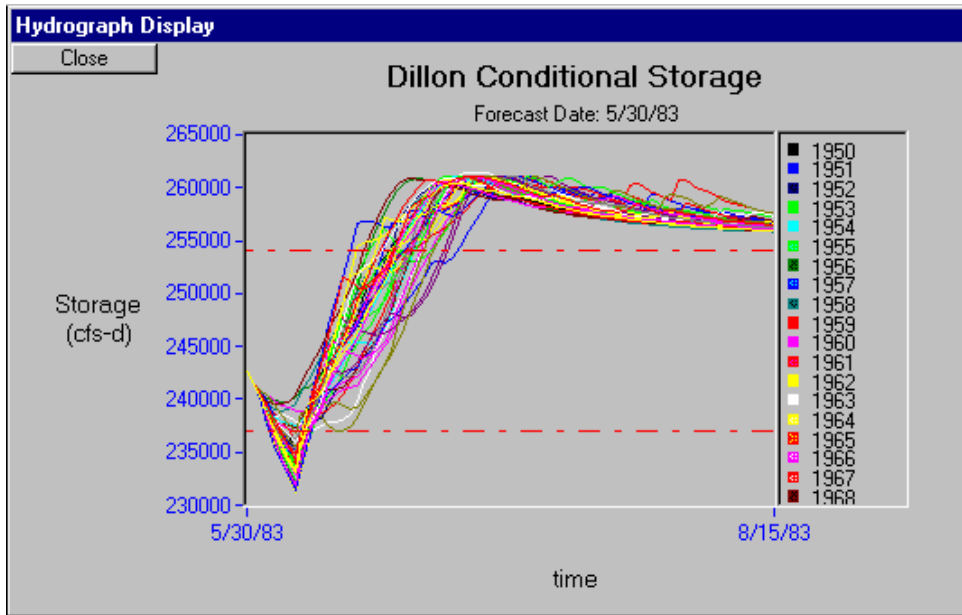Source: RTi

Figure 11. Release Realizations for 1,800 cfs
Source: RTi



Figure 12. Storage Realizations for 1,800 cfs
Source: RTi