OVERVIEW OF THE WATERSHED AND RIVER SYSTEMS MANAGEMENT PROGRAM

Donald Frevert, Hydraulic Engineer, Bureau of Reclamation, Denver, CO, dfrevert@do.usbr.gov; and Harry Lins, Hydrologist, US Geological Survey, Reston, VA, hlins@usgs.gov

ABSTRACT

For a number of years, the Bureau of Reclamation, the US Geological Survey and other partners have worked jointly through the Watershed and River Systems Management Program to support model development for improved river systems management in the western United States. This paper will outline a system of models developed by the Bureau of Reclamation, the US Geological Survey, the University of Colorado and a number of other governmental and university partners. The application of the technology to a number of key issues including drought management in several key western river basins will be discussed.

BACKGROUND

Beginning in January, 1992, the Bureau of Reclamation and the US Geological Survey formulated plans for the Watershed and River Systems Management Program - a cooperative interagency effort to develop and implement flexible and robust river basin management tools for the benefit of managers and decision makers using a data centered approach. In addition to Reclamation and the USGS, a number of other agencies and universities have made substantial contributions to the success of the program.

The goal of the Watershed and River Systems Management Program is to research, develop, and deploy decision support systems to aid water resource managers in achieving an equitable balance among often-competing water resource objectives. As resource managers, we seek such balances by considering three major factors: our stakeholders and their interests; our legal and political constraints; and sound technical information and knowledge. Providing the technical information and knowledge is the focus of this program and forms the foundation upon which the other factors can be considered. It began in 1994 with funding from operations and maintenance; since 1995, it has been funded by the US Bureau of Reclamation's Science and Technology (formerly Research and Technology Transfer), the US Geological Survey's National Research Program, various Regional, District and Area Offices, as well as other collaborators. These other collaborators include the University of Colorado Center for Advanced Decision Support for Water and Environmental Systems (CU-CADSWES), the Tennessee Valley Authority and the Army Corps of Engineers.

The program is designed such that actual river system management issues drive the research and development priorities. This is accomplished by choosing "application basins" to participate in the program for 3 years each. Previously participating basins include the San Juan, the Gunnison, the Lower Colorado, the Yakima, and the Upper Rio Grande. The Truckee and Upper Columbia are currently participating in the program. Subject to decisions by Reclamation, its partners and stakeholders, the Lower Platte River basin might join the program in the near future.

By rotating basin participation, the program is assured of meeting new research and development needs Reclamation-wide. Each basin contributes new resource management issues that define the research and development needs and priorities over that period. Experience to date suggests that it takes the full 3-year time frame to conduct the new research and development, demonstrate the applicability, and deploy the system. This time frame also allows the local offices time to program future funding for their own local maintenance, support, as well as future research and development. To date, all basins that have participated in the Program have chosen to continue funding research and development, as well as maintenance and support.

The decision support system is being developed in a modular framework that allows for utilization of other emerging technologies (e.g., the ET Toolbox and new weather and climate forecasting). The modules are developed to allow for application to *any* river system, while still being able to solve site-specific problems without the need for tailored software programming. As the capabilities of the modules are enhanced and expanded to meet the new research and development priorities, basins already using the modules have ready access to those enhancements.

The primary modules under development are the RiverWare modeling system, the Hydrologic Database (HDB), and the Modular Modeling System (MMS). MMS is a generic, physical process modeling system that can be used to develop models of a variety of physical processes including precipitation-runoff models. The research and development of MMS is handled by the USGS. RiverWare and HDB are being developed at CU-CADSWES.

RIVERWARE

RiverWare is a reservoir and river systems operations and planning modeling tool that allows the user to construct and customize the physical behavior of the river network without the need for software programming. The user further constructs the operating policy for the network and supplies it to the model as "data" (i.e., the policies are visible and capable of being explained to stakeholders; secure, yet able to be modified for policy analysis). RiverWare models can be run at a variety of time steps ranging from 1-hour (detailed operations, hydropower and physical processes) up to annual (long range planning). Among the many successfully deployed RiverWare models are the Colorado River planning model (CRSS), the Colorado River operations model (the Annual Operating Plan), the Upper Rio Grande Water Operations Model, and TVA's water and power scheduling model.

Users are allowed to customize the appropriate physical processes to suit each basin feature by use of a variety of objects which represent several types of reservoirs, diversions, ground water storage, power plants, river reaches, stream gages and other physical features. Operating policies

are expressed as user defined data which allows for easy modification to reflect updates and other changes.

RiverWare offers the flexibility to perform pure simulation, rule based simulation, optimization and water accounting analyses. RiverWare is used in Reclamation's Upper and Lower Colorado Regions and also in the Albuquerque, Upper Columbia and Lahonton Basins Area Offices. It is also used extensively by the Tennessee Valley Authority. More detailed information about RiverWare can be found in Zagona, et al (2001).

HYDROLOGIC DATA BASE

The Hydrologic Data Base (HDB) is an Oracle-based, data management system that can serve as the center of the decision support system. It provides a reliable and consistent view of the historical, current, and future state of the river system incorporating time series data, physical data, forecasts and results of model runs. HDB supports data loading from a variety of external sources, provides easy access for near real-time quality control, and is easily interfaced to a variety of modeling packages. Due to its use of standard, state-of-the-art database technology, HDB can utilize a wide variety of query and reporting tools, many of which require no development (i.e., they are "off-the-shelf").

For the Reclamation offices where it is utilized, HDB has the goal of consolidating existing data, helping to insure complete, consistent and reliable collection, storage and documentation, being available as the "database of record" to help document how and why operational decisions were made, allowing user access at any time interval to the original source data and providing for an automated generation of time aggregated summary data.

HDB is fully deployed at both the Bureau of Reclamation's Upper and Lower Colorado Regional offices and also in the Upper Columbia Area office.

MODULAR MODELING SYSTEM

The Modular Modeling System (MMS) focuses on the precipitation – runoff process and is designed to allow a user to selectively couple the most appropriate process algorithms from applicable models to suit the desired application In cases where existing algorithms are not well suited, there is the potential to develop new algorithms and add them to the system. This approach offers substantial flexibility to accommodate the user's needs and constraints. MMS consists of three major components: Pre-processing routines, the model and post-processing routines.

The first component (pre-processing) focuses on spatial and time series data for use in model applications. The second (modeling) component encompasses tools used to develop and apply models. A module library includes modules for simulating water, energy, chemical and biological processes. The third (post-processing) component includes tools to display and analyze model results. Additional information about MMS is provided in Leavesley, et al (1998).

OTHER TOOLS

In addition to RiverWare and HDB, a number of other river basin models are used in various other Reclamation offices. These include the Stochastic Analysis, Modeling and Simulation (SAMS) program, the Agricultural Water Resources Decision Support (AWARDS) program and some other river basin models such as MODSIM and CALSIM.

The SAMS program offers the capability to analyze historically observed runoff patterns, generate equally likely traces which can be used to consider future events and provide statistical analyses of both historically observed and generated flows. Both the Boulder Canyon Operations Office and the Lahonton Basins Area Office plan to utilize SAMS in conjunction with RiverWare to help formulate long term operational decisions. A more extensive description of SAMS and its capabilities is provided in Salas, et al (2005).

The AWARDS – ET Toolbox package provides near real time information on crop water demands for use by private sector and government water managers. Efforts are currently underway to couple AWARDS – ET Toolbox with RiverWare on the Upper Columbia, Yakima and Rio Grande Basins. More extensive information about AWARDS – ET Toolbox is provided in Brower and Hartzell (1998).

Some other river basin modeling tools being used by Reclamation outside of the WaRSMP program include MODSIM and CALSIM. MODSIM is a network model which gives special attention to water rights and allocation issues. MODSIM is often run on a monthly basis, but also offers capabilities to run on shorter time steps. A more detailed description of MODSIM is offered in Larson, Labadie and Baldo (1998). MODSIM is utilized by Reclamation on the Snake River basin and also in other locations. Other governmental and private entities also utilize MODSIM. CALSIM was originally developed by the California Department of Water Resources and is also used by Reclamation for management of the Central Valley Project.

CASE STUDIES

A prolonged drought has impacted much of the United States – including the west – since the late 1990's and use of decision support tools developed under the Watershed and River Systems Management Program has been critical to water resource managers in western river basins. The following will outline a number of key applications of this technology including, but not limited to, the impacts of the drought in the western United States and the use of decision support tools to mitigate these impacts.

Colorado River Basin

The Colorado River basin covers more than 200,000 square miles including parts of seven states and the Republic of Mexico. It provides water for irrigation of more than one million acres in southern California and southwestern Arizona and it also serves as a source of

municipal water for more than 16 million people. A series of compacts and treaties divides the waters of the Colorado among the seven basin states and Mexico.

The majority of the water of the Colorado River system originates as snowmelt and flows through a complex system of reservoirs and diversions prior to its use for either agricultural or municipal purposes.

Operations of the Colorado River system are governed by "the Law of the River" and these constraints have significantly impacted operational decisions. Some of the key components of the Law of the River include the Colorado River Compact of 1922, the Boulder Canyon Project Act of 1928, the Mexican Water Treaty of 1944, the Upper Colorado River Basin Compact of 1948, the Colorado River Storage Project of 1956, the Arizona vs California Supreme Court Decision of 1964, the Colorado River Basin Project Act of 1968 and Minute 242 of the US-Mexico International Boundary and Water Commission of 1973. These components have a major impact on operational decisions that must be made.

Since 1999, water levels in the major reservoirs on the Colorado River system have declined rapidly due to consistently low runoff, steady demands and the treaty and compact obligations dictated by the Law of the River. Lake Powell contents, shown in Figure 1, have dropped from near capacity levels in the summer of 1999 to less than 40 percent of capacity in January, 2005.

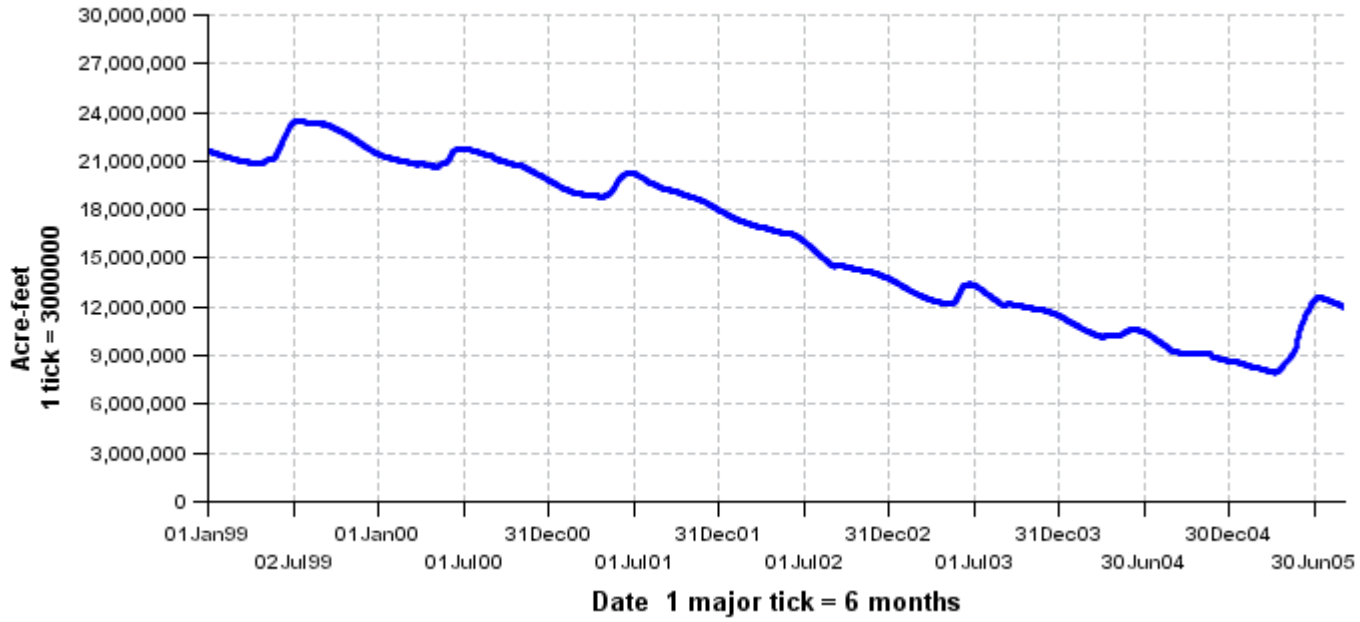

Figure 1 – Lake Powell Contents – courtesy of Bureau of Reclamation, Upper Colorado Regional Office

Reclamation managers in Boulder City, NV and Salt Lake City, UT have effectively used RiverWare, MMS and the Hydrologic Data Base to meet downstream demands and requirements – even with very limited resources. Although the end of the drought has not yet been reached, much of the success Reclamation managers have had in dealing with the drought to date is directly attributable to these tools.

Reclamation is in the first year of a collaborative effort with Colorado State University to enhance the drought analysis capabilities of the SAMS package. That effort is focused on the Colorado River basin and is expected to be completed in the fall of 2007. The expanded capabilities of SAMS are expected to be useful in a number of other river basins including some managed by Reclamation and some managed by other entities.

Decision support tools, including RiverWare, also played a critical role in completion of the Environmental Impact Statement for the Colorado River Interim Surplus Criteria as outlined in US Department of the Interior (2000). This report represented the culmination of an extensive collaboration between the federal government, state and local government and many diverse stakeholder groups with an interest in Colorado River basin issues.

Upper Rio Grande Basin

The Upper Rio Grande Basin covers about 30,000 square miles above Fort Quitman, Texas. Like the Colorado River basin, runoff is heavily dependent on snowmelt. The extended drought has been especially difficult for water users in this normally arid region, where two thirds of the basin has an average annual precipitation of less than 15 inches and runoff in the last four years has consistently been far below normal.

Operations in the basin are governed by the 1938 Rio Grande Compact which divides the river's waters between Colorado, New Mexico and Texas. Approximately 90 percent of the water in the basin is used for agriculture and nearly all of the remaining water supply is used for municipal purposes.

The interagency Upper Rio Grande Water Operations Modeling (URGWOM) effort involves the Corps of Engineers, the Bureau of Reclamation, the US Geological Survey, the International Boundary and Water Commission, the Fish and Wildlife Service and the Bureau of Indian Affairs, along with several state and local entities.

River managers from the Corps and from Reclamation have effectively used RiverWare and MMS to manage the system during this drought. In addition, Reclamation stakeholders have found the AWARDS – ET toolbox technology to be very useful in scheduling their water deliveries throughout the drought.

One major byproduct of the work on the Rio Grande basin has been the development of the hypothetical simulation capabilities for RiverWare. This allows (as one example) the modeler to efficiently simulate the impacts of changes in reservoir releases at downstream locations during

flood scenarios. This improved capability has been useful to managers on the Rio Grande and on other basins as well.

Truckee River Basin

During the past several years, a multifaceted effort has been undertaken to employ decision support system tools on the Truckee River basin. These include RiverWare, MMS and, in the future, the Hydrologic Data base. Priorities range from more efficient and effective daily river operations to insuring long term survivability of endangered species and delivery of required water supplies for agricultural and municipal purposes.

Further information on this effort is discussed in several papers including Boyer et al (2006), Coors et al (2006), Mann et al (2006) and Rieker et al (2006).

FUTURE PRIORITIES

Although the existing tools have performed well in managing water resources for the ongoing drought, a number of priorities remain to be addressed. These include research and development to better model surface water and ground water interactions, linkages to water quality models and water accounting issues.
As has been the tradition of the program, new capabilities will be developed on a need driven basis. Future funding and support is anticipated from the USGS National Research Program, from selected regional and area offices in the Bureau of Reclamation and from selected offices in the Corps of Engineers. Some of the ongoing efforts are discussed by Zagona et al (2006).

CONCLUSIONS

Decision support systems have been effectively utilized to manage water resources during drought on several major river basins in the western United States. Case studies describing the use of tools developed under the interagency Watershed and River Systems Management Program and their use by managers on the Colorado and Rio Grande basins show not only the benefit of these tools during drought conditions – but also the need for continual maintenance and improvements to the tools.

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