Upper Rio Grande Water Operations Model: a Tool for Enhanced System Management

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Abstract—The Upper Rio Grande Water Operations Model (URGWOM) under development through a multi-agency effort has demonstrated capability to represent the physical river/reservoir system, to track and account for Rio Grande flows and imported San Juan flows, and to forecast flows at various points in the system. Testing of the Rio Chama portion of the water operations model was completed in March 1998. Results indicate that RiverWare software can be used to model the entire upper Rio Grande system. Model development is in progress on the mainstem of the Rio Grande.

The process of moving water through the Rio Grande basin has become increasingly complex. In 1996, six federal agencies recognized the need for a tool that could help them make timely decisions and improve storage and delivery operations in the Upper Rio Grande Basin for more effective and efficient system management. They needed a computer model with accounting and forecasting capability that could simulate near real-time reservoir operations. The agencies agreed in a memorandum of understanding to cooperate to develop a model for the upper Rio Grande basin from the headwaters in Colorado to Fort Quitman, Texas and to provide access to actual, forecasted, and planned reservoir and river operational data through a unified data base for data management and information sharing among basin stakeholders.

As a result of 1997 model scoping and coordination activities with other basin interests, the cooperating agencies finalized a plan for development of the Upper Rio Grande Water Operations Model (URGWOM). The plan identified computer software (RiverWare) and associated hardware that could be used in developing the model and outlined the tasks and schedule for model development.

Cooperative Effort

Since 1996, the Bureau of Reclamation (Reclamation), U.S. Fish and Wildlife Service, U.S. Geological Survey (U.S.G.S.), Bureau of Indian Affairs, the International Boundary and Water Commission (U.S. Section), and the U.S. Army Corps of Engineers (Corps) have partnered to develop the model. The cities of Albuquerque and Santa Fe, Rio Grande Restoration, Sandia and Los Alamos National Laboratories also entered into this partnership in 1997. Other entities, as well, have contributed to the effort through technical review and outreach support.

The cooperative spirit of this effort is exemplified by the co-located modeling team with members from Reclamation, U.S.G.S., and the Corps working together and sharing a melange of computer equipment and also by the technical review team made up of stakeholders, interested individuals, and state, local, and federal agency staff who have contributed many hours of technical review of the test case.

Rio Chama Test Case

To test that RiverWare was capable of simulating the entire Upper Rio Grande surface water system, the software was first tested on the Rio Chama. This stream reach was selected because of its operational complexity. It includes a transmountain diversion, three reservoirs with complex operational criteria and accounting procedures. Because it has relatively simple river reach conditions and reasonable availability of data, it was a good test of the capabilities of the software.

RiverWare

RiverWare is a generic reservoir and river system modeling software that can be readily customized to fit a specific river basin. It has been in development since 1993 and is the result of a continuing collaborative effort by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado, the Bureau of Reclamation and the Tennessee Valley Authority.

RiverWare is object oriented, meaning that the software has objects that represent features of the basin visually on a computer screen such as reservoirs, confluence's, gaging stations, river reaches, diversions, data, etc. Objects contain user selected physical process methods and numerical data. For example, the modeler can specify different routing method categories for a stream reach object: "no routing", time lag, Muskingham-Cunge, kinematic wave, etc. Variables called "slots" contain all the data that are required or generated by the object. In the case of a stream reach, a reach object may contain slots for inflow ,return flow, outflow, and other data.

The software is referred to as data-centered because data supplied to the model defines the specific river and reservoir system. It is also rule-based; operating policies are incorporated into the model with a rules language. RiverWare uses the operational rules to make decisions during a simulation. None of these customizing features requires a change in the hard code of the software so it is easily modified for changes

In: Finch, Deborah M.; Whitney, Jeffrey C.; Kelly, Jeffrey F.; Loftin, Samuel R. 1999. Rio Grande ecosystems: linking land, water, and people. Toward a sustainable future for the Middle Rio Grande Basin. 1998 June 2-5; Albuquerque, NM. Proc. RMRS-P-7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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in policies or addition of new objects as the basin changes. Since the data and rules defines the specific system, the Rio Chama test case model was developed by entering Rio Chama data and rules.

The software also has multiple calculation methods that can be selected to customize the physical behavior of an object. For example, there are about eight different calculations available to chose from for calculating spills from a reservoir, everything from no spill to a complex combination of regulated spill plus bypass plus unregulated spill calculation. In the specific case of Abiquiu Reservoir, the no spill calculation was selected to represent the real situation. After the objects are put into a workspace and the appropriate methods are selected they can be linked together to form a river basin network.

The most recent improvement to RiverWare was the addition of the water accounting function. Each object has accounts slots for accounting data.

Conceptual Model Development

The Technical team began model development of the Rio Chama by describing the existing physical and water accounting systems, graphically and in text, to serve as a basis for the construction of the model in RiverWare. Public technical review and comments on the conceptual model documents were provided by the Technical Review Committee.

Physical Model

The physical model of the test case is a rule-based simulation of the physical system of the Rio Chama. The model simulates the physical system from the top of the basin, starting with the San Juan diversions and continuing downstream to the confluence of the Rio Chama with the Rio Grande at Chamita. Figure 1 shows the topology or layout for the Rio Chama in RiverWare. The Technical Team built the computer version by constructing each object separately: first, reservoirs; then, river reaches; followed by confluence's and diversions. Each object was verified by comparing to historical data. After all objects were built, verified and linked together, the over all model was checked against records for a period from January 1985 to July 1996. Simulated results closely matched actual records. The resultant physical model represents the Rio Chama physical system and is the basis for the test case accounting and forecasting models.

Accounting Model

The accounting model incorporates water ownership and accounting functions into the physical model. It is essentially a data processing and reporting application of the model structure. The layout for the accounting model is displayed in figure 2. Since the water input data for San Juan Chama Project accounting is measured at the outlet of the Azotea tunnel, the San Juan diversions are not shown as objects in the topology for the accounting model. However, the rest of the physical model structure is used in the accounting model.

The accounting model solves for inflow since the releases from the reservoirs are measured and are direct inputs to the model. It is designed to perform the same operations that Reclamation's daily water operations programs perform, and to eliminate many of the hand calculations that are presently needed to distinguish San Juan water from Rio Grande. Additionally, it can simulate the two types of water accounting in the river reaches between reservoirs. By mid 1999, the model will also be capable of simulating San Juan Chama contractors accounts.

Forecast Model

The forecast model is used to simulate the operation of the river and reservoir system by determining releases and storage for a desired forecast period. Since it is based on the physical model, includes the accounting functions of the accounting model, and the rules based upon water operations regulations, constraints and preferences, it is a very powerful tool to understand the system. The topology of the forecast model is shown in figure 1.

Forecasted inflow hydrographs at all of the forecast points and the initial conditions of the reservoirs are required inputs to the model. The forecast model using the rules, simulates how varying hydrologic conditions upstream may affect water operations downstream. It simulates most routine water operations and clearly defined special operations, including emergencies, thus giving water managers the ability to make timely decisions.

Test Case Results

Figures 3, and 4 display few differences between the test case model and Reclamation's daily program calculations of inflow and precipitation at Abiquiu Reservoir for 1985 to 1996. Comparisons of the two methods gave similar results for outflow, and evaporation at Abiquiu and at the other reservoirs.

Figure 5 shows the cumulative differences between the two methods in storage at Abiquiu Reservoir. The total cumulative difference between using the model to compute storage versus using the daily programs is about 46 acre feet, a small cumulative error for 10 years of record. Total storage capacity for Abiquiu Reservoir at elevation 6220 feet is 189,307 acre feet.

The test case model forecast of total outflow at Abiquiu Reservoir is compared with historical data for a 10-month period of record in figure 6. The model simulations for San Juan outflow and Rio Grande outflow also closely duplicate the historical data. Historical time series data were used as inputs at the upstream forecast points for these simulations.

Testing, therefore, indicated that the software RiverWare successfully modeled the Rio Chama and could be used on the mainstem of the Rio Grande. Since the test case contained most of the physical components such as diversions, river reaches, confluences, and hydropower that will be encountered in the remainder of the upper Rio Grande Basin, a great number of operational rules and accounting relationships have already been worked out to some degree for the mainstem model development.

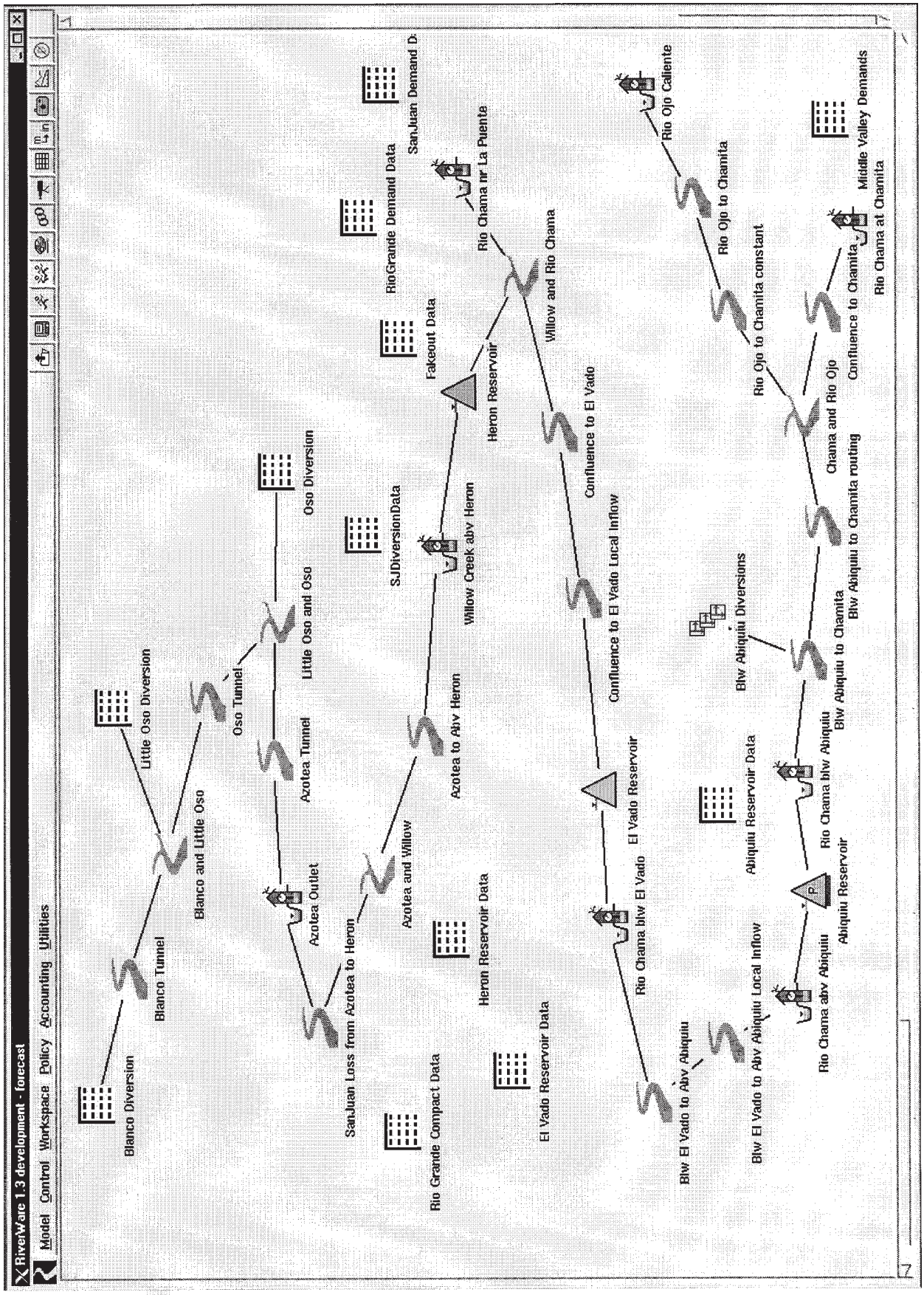
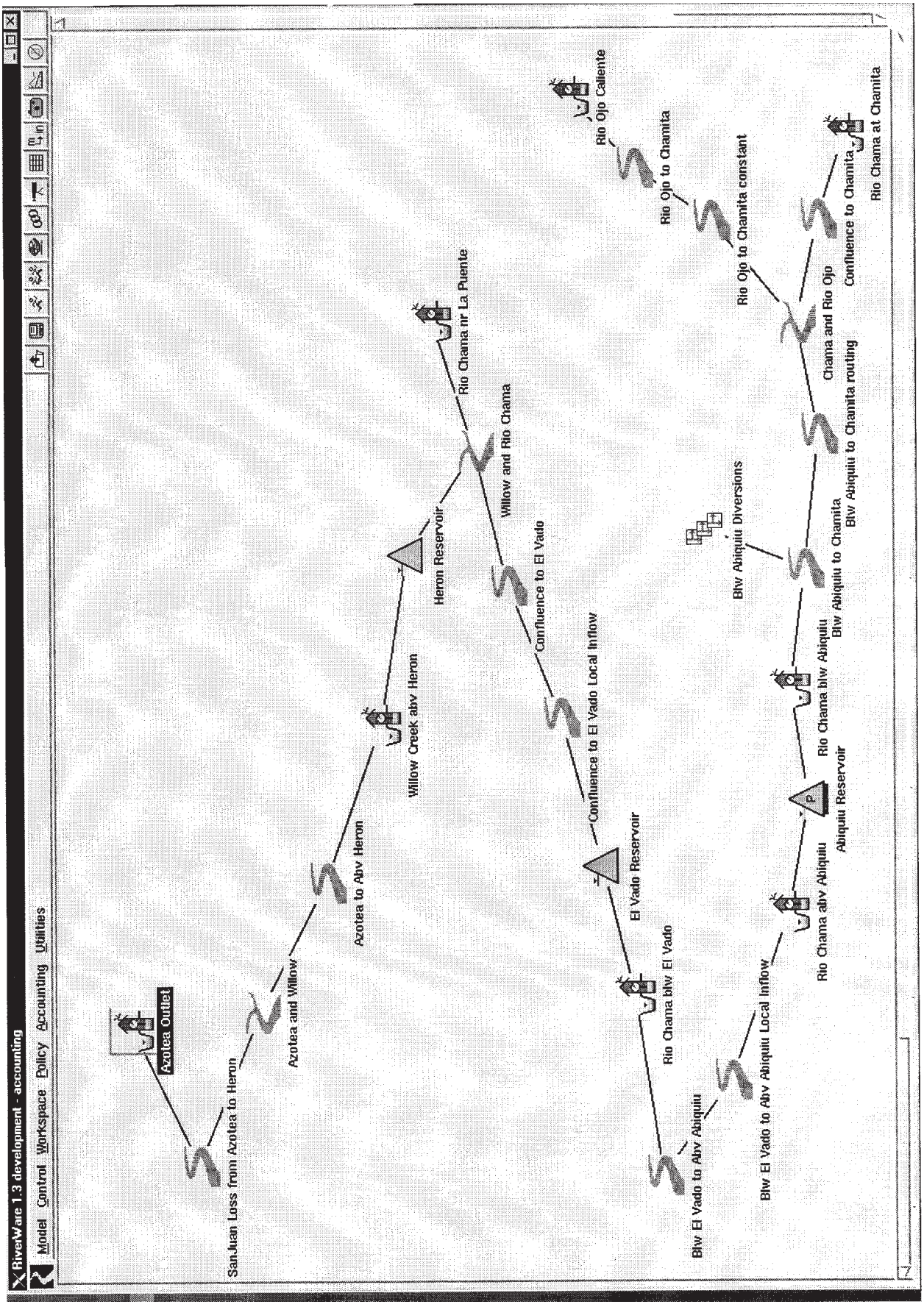

RiverWare 1.3 development - forecast
Model Control Workspace Policy Accounting Utilities
Blanco Diversion
Little Oso Diversion
Blanco Tunnel
Blanco and Little Oso
Oso Tunnel
Azotea Tunnel
Little Oso and Oso
Oso Diversion
Azotea Outlet
Sanjuan Loss from Azotea to Heron
Azotea and Willow
Azotea to Abv Heron
SJDiversionData
Willow Creek abv Heron
Fakeout Data
RioGrande Demand Data
SanJuan Demand D
Rio Chama nr La Puenta
Heron Reservoir
Willow and Rio Chama
Rio Grande Compact Data
Heron Reservoir Data
El Vado Reservoir Data
Confluence to El Vado
Confluence to El Vado Local Inflow
Rio Chama blw El Vado
El Vado Reservoir
Rio Ojo Caliente
Rio Ojo to Chamita
Blw El Vado to Abv Abiquiu
Abiquiu Reservoir Data
Blw Abiquiu Diversions
Rio Ojo to Chamita constant
Blw El Vado to Abv Abiquiu Local Inflow
Rio Chama abv Abiquiu
Abiquiu Reservoir
Rio Chama blw Abiquiu
Blw Abiquiu to Chamita
Chama and Rio Ojo
Blw Abiquiu to Chamita routing
Confluence to Chamita
Middle Valley Demands
Rio Chama at Chamita

Figure 1


RiverWare 1.3 development - accounting
Model Control Workspace Policy Accounting Utilities
Azotea Outlet
San Juan Loss from Azotea to Heron
Azotea and Willow
Azotea to Abv Heron
Willow Creek abv Heron
Heron Reservoir
Rio Chama nr La Puente
Willow and Rio Chama
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Confluence to El Vado Local Inflow
El Vado Reservoir
Rio Chama blw El Vado
Blw El Vado to Abv Abiquiu
Blw El Vado to Abv Abiquiu Local Inflow
Rio Chama abv Abiquiu
Abiquiu Reservoir
Rio Chama blw Abiquiu
Blw Abiquiu Diversions
Blw Abiquiu to Chamita
Blw Abiquiu to Chamita routing
Chama and Rio Ojo
Rio Ojo Caliente
Rio Ojo to Chamita
Rio Ojo to Chamita constant
Confluence to Chamita
Rio Chama at Chamita

Figure 2

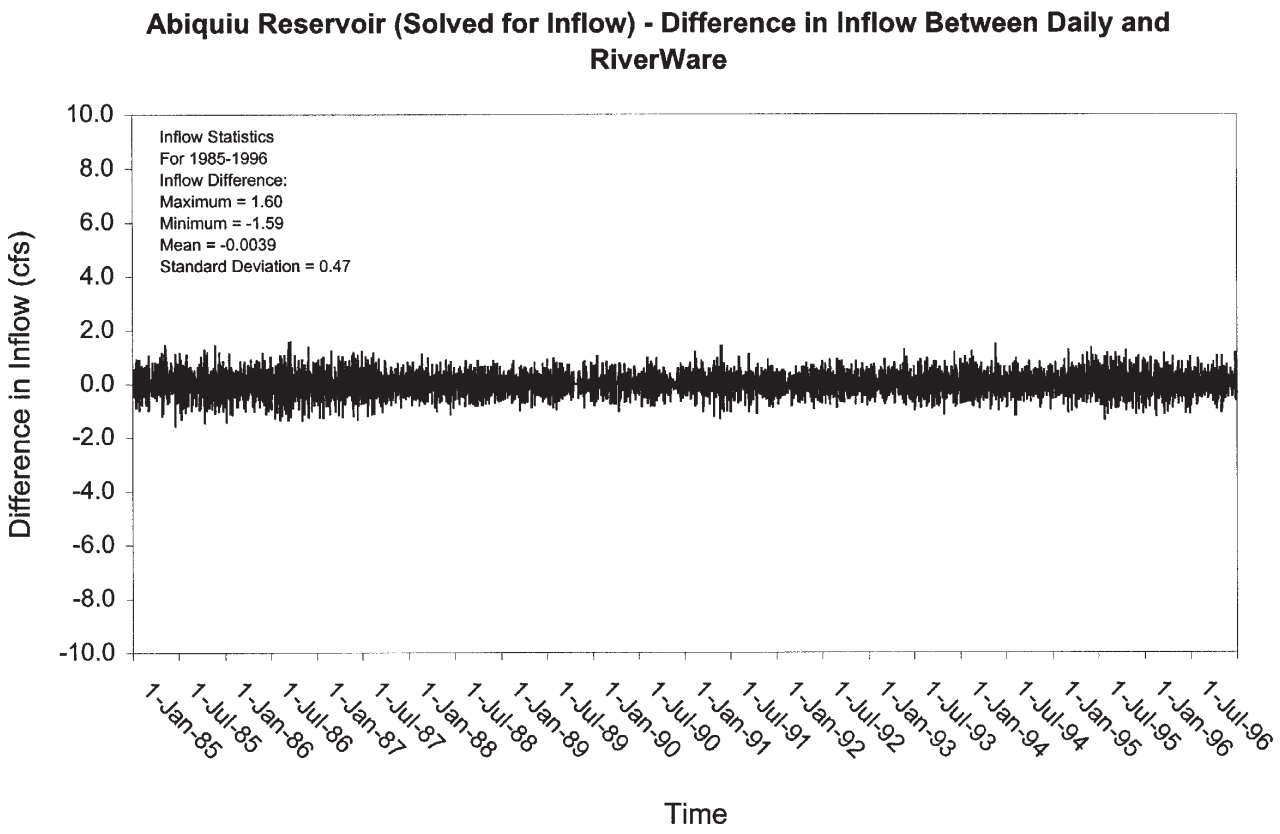

Figure 3

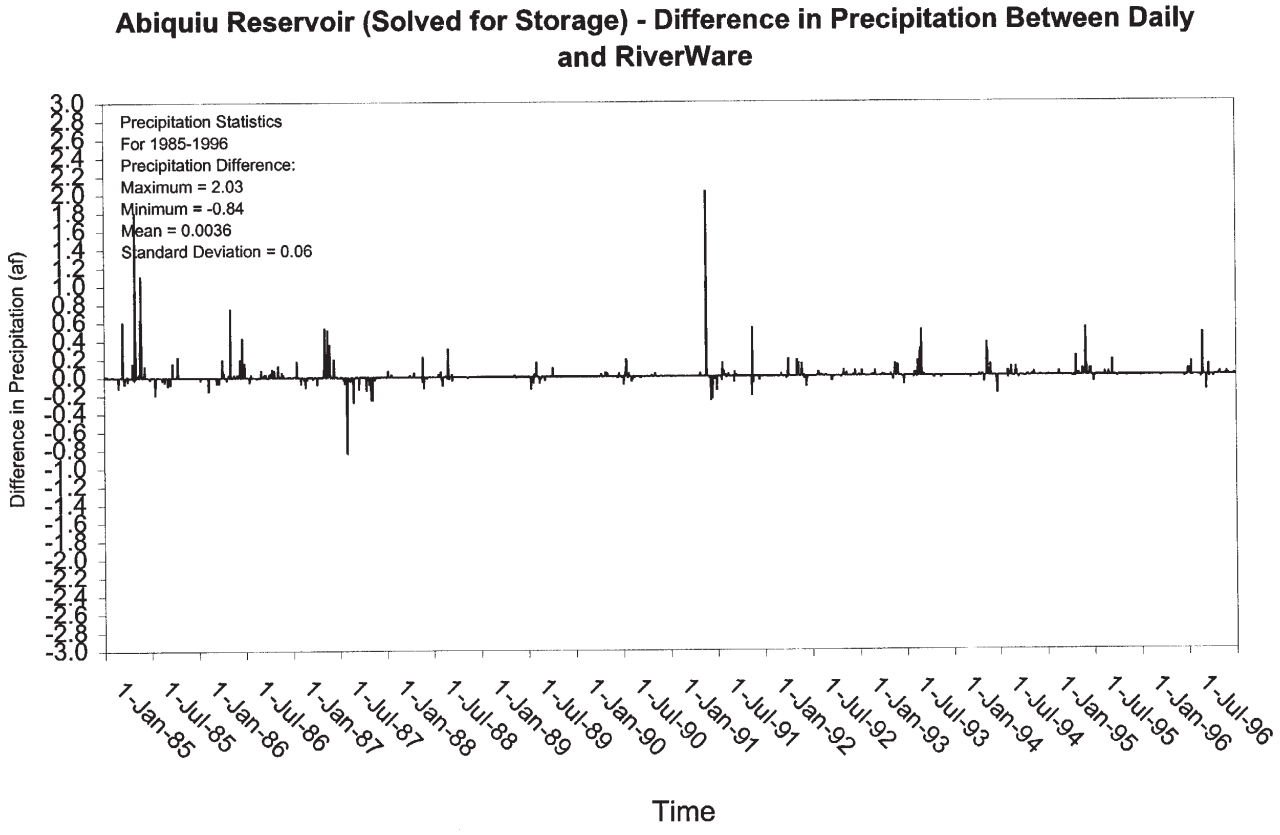

Figure 4

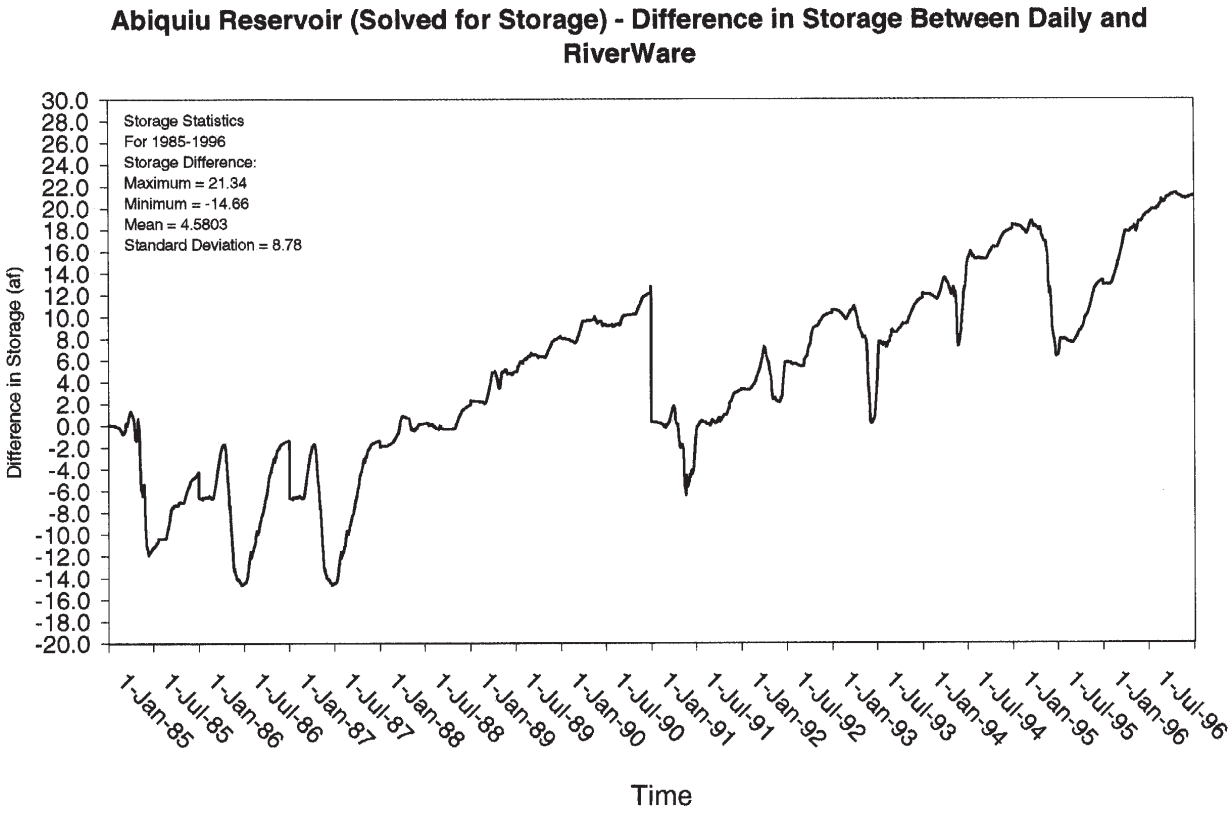

Figure 5

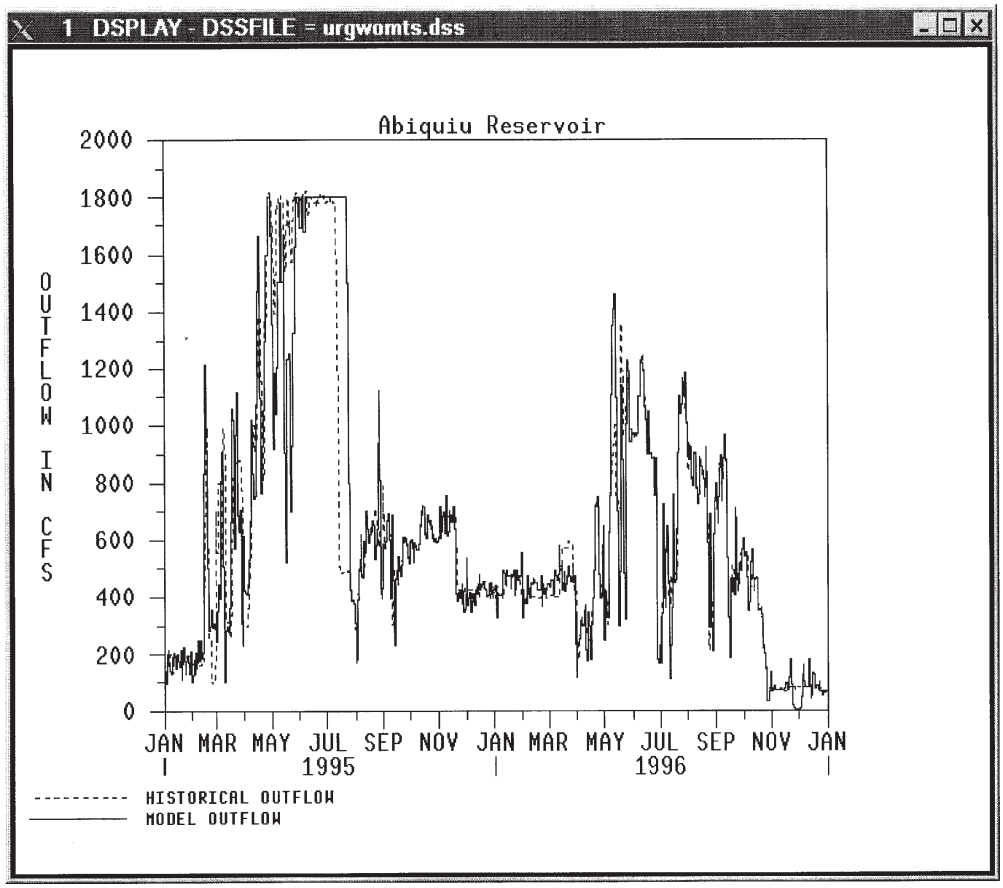

Figure 6

Mainstem Model Development

Following the completion of the test case in March 1998, the Technical Team began the conceptual model of the mainstem. Expected completion date of a functioning, but not exhaustively calibrated and verified basic water operations (or "backbone") model of the upper Rio Grande is Fall 1999. The fully refined model completion date is approximately 2002.

Data Base and Other Tools

While URGWOM is under development, the Technical Team is utilizing the Corps Data Storage System (DSS) to format and store data. The team has written data management interface programs (DMI)s that interface the time series data stored in DSS with the Rio Chama model for use in testing and calibrating. The same will be done for the mainstem since DSS is easy to use. Part of the Technical Team is investigating needs and requirements for an URGWOM Data Base. The Corps Hydrologic Engineering Center provided a cursory screening of data base alternatives. Their preliminary report indicated that Reclamation's HDB has potential to serve URGWOM's ultimate data storage needs.

An URGWOM data base will store time series data, spatial data, and accounting data. A unified data base will provide a source of data for and from URGWOM that will be accessible for use by anyone needing the data. It will be a resource for other models such as planning models, as well as a source of data for URGWOM model applications.

Water Operations Review

One of the applications of URGWOM is the Upper Rio Grande Basin Water Operations Review (Water Operations Review). This is a joint effort with Reclamation to take an integrated look at the system. Part of this effort will be to develop supplemental tools or models, that with input from URGWOM, can determine what effects potential water operations changes have on riparian vegetation, aquatic communities, endangered species, cultural resources, and other basin resources. The review will likely be a five-year effort, starting in 1999.

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