Technical Progress Report

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Use of Produced Water in Recirculating Cooling Systems at Power Generating Facilities

Deliverable Number 9

Progress Report for ZeroNet Amendment

Robert Goldstein and Kent Zammit, EPRI Project Manages
3412 Hillview Ave.
Palo Alto, CA 94304-1395

Abstract

During the past six months, the WSAC pilot was purchased, designed, constructed and shipped to the Public Service New Mexico San Juan Generating Station for installation and testing during the 3rd Quarter of 2005.

Watershed characteristics, land use, and meteorological, observed streamflow, diversion, point source, and reservoir data have been collected from diverse sources and fed into the Watershed Analysis Risk Management Framework (WARMF). As part of the ZeroNet application of WARMF to the San Juan Basin, a new ZeroNet Module was developed in WARMF (Figure 2.6). The ZeroNet module is accessible through the *Module* menu item in WARMF. The main structure of the ZeroNet module is a series of steps, 1 through 6, which guide the user through setting up simulations and viewing model output. The purpose of the new module is to guide stakeholders through the simulation of various water sharing agreement scenarios and test how well these management scenarios meet water supply criteria throughout the Basin. The hydrological component of WARMF has been calibrated for the San Juan Basin. Verification exercises were performed by comparing model simulations for time periods that were not included in the calibration with flow observations. Work has been initiated on integrating WARMF into the Quick Scenario Tool (QST) and Knowledge Base that are being developed by Los Alamos National Laboratory and the University of New Mexico. The ZeroNet Quick Scenario Tool (QST) uses system dynamics modeling for rapid analysis and visualization. The ZeroNet Knowledge Base serves to organize and archive data in easily accessible digital libraries, and to share data from diverse sources and for diverse uses. Input and characterization data for scenarios for the San Juan Basin of extended drought, warmer climate and vegetation change have been initiated. Presentations were prepared for upcoming American Society of Civil Engineers and American Water Resources Association Conference.

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Executive Summary

During the past six months, the WSAC pilot was purchased, designed, constructed and shipped to the Public Service New Mexico San Juan Generating Station for installation and testing during the 3rd Quarter of 2005.

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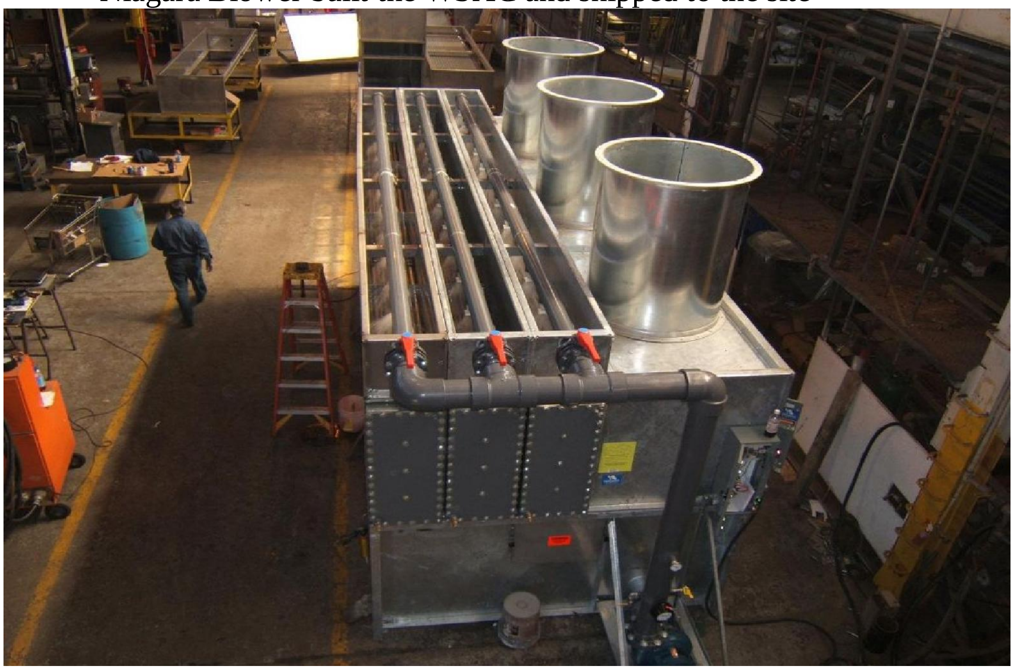
Pilot Testing of a Wet Surface Air Cooler for Water Conservation in Utility Cooling

During the past six months, the WSAC pilot was purchased, designed, constructed and shipped to the Public Service New Mexico San Juan Generating Station for installation and testing during the 3rd Quarter of 2005.

Details of the work completed include:

- EPRI issued contracts to Mike Difilippo for testing and engineering services
- EPRI issued a contract to Niagara Blower for design, construction and delivery of the pilot WSAC
- The design of the WSAC was iterated several times to provide adequate capabilities within the given budget
- Construction drawings were finalized and approved
- Niagara Blower built the WSAC and shipped to the site



- Foundation work completed at site
- WSAC delivered April 14, 2005

Commissioning of the WSAC is expected to occur by the end of May, with testing on cooling tower blowdown to commence when the site begins seeing peak summer temperatures.

ZeroNet Decision Support

1 Introduction

Rapid population growth and severe drought are impacting water availability for all sectors (agriculture, energy, municipal, industry, etc.) particularly in arid regions. New generation decision support tools, incorporating recent advances in informatics and geographic information systems (GIS), are essential for responsible water planning at the basin scale. The ZeroNet water-energy initiative is developing a decision support system (DSS) for the San Juan River Basin, with a focus on drought planning and economic analysis. The ZeroNet DSS provides a computing environment with three major components: Watershed Tools, a Quick Scenario Tool (QST), and a Knowledge Base. The focus of this progress report will be primarily on the ZeroNet Watershed Tools, based in Watershed Analysis Risk Management Framework.

The ZeroNet Watershed Tools, based in the Watershed Analysis Risk Management Framework (WARMF), provide two sets of capabilities: 1) capabilities to model surface flows, both the natural and controlled, as well as water withdrawals, via an engineering module, and 2) capabilities to analyze and visualize results via a stakeholder module. A new ZeroNet module for WARMF enables iterative modeling and production of "what if" scenario libraries to examine consequences of changes in climate, landuse, and water allocation. To date, completed tasks include populating WARMF with input data for the San Juan (e.g. meteorology, land use, streamflow, diversions, reservoir releases) and calibrating the hydrologic model for the period of 1990-1994. A verification was also performed for the time period of 1990-2004, with special emphasis placed on representative wet (1993), normal (1998) and dry (2002) years. The majority of the ZeroNet Module development has been completed, and several initial scenarios have been run in WARMF. Ongoing work includes continued development of the ZeroNet module, with a new scenario tool which permits construction of climate and management scenarios based on historical climate and flow data.

2 ZeroNet Watershed Tools

2.1 <u>Watershed Tools Design Background</u>

The Watershed Analysis Risk Management Framework (WARMF) watershed tools calculate surface and subsurface flows, as well as water quality (Chen et al. 2001, Keller 2000, 2001, Weintraub et. al. 2001) (Figure 2.1). WARMF has been applied to over fifteen watersheds in the United States and internationally. In addition to simulating flow, WARMF simulates water quality constituents including temperature, total suspended solids, coliform bacteria, biochemical oxygen demand (BOD), dissolved oxygen (DO), nutrients (phosphorus and nitrogen), chlorophyll, and others. WARMF was originally designed to support modeling and planning for total maximum daily loads (TMDLs), the amount of a particular pollutant that a particular stream, lake, estuary or other water body can handle without violating state and federal water quality standards. Application of

WARMF for the ZeroNet Initiative focuses primarily on surface flow scenarios under a series of climate and management regimes.

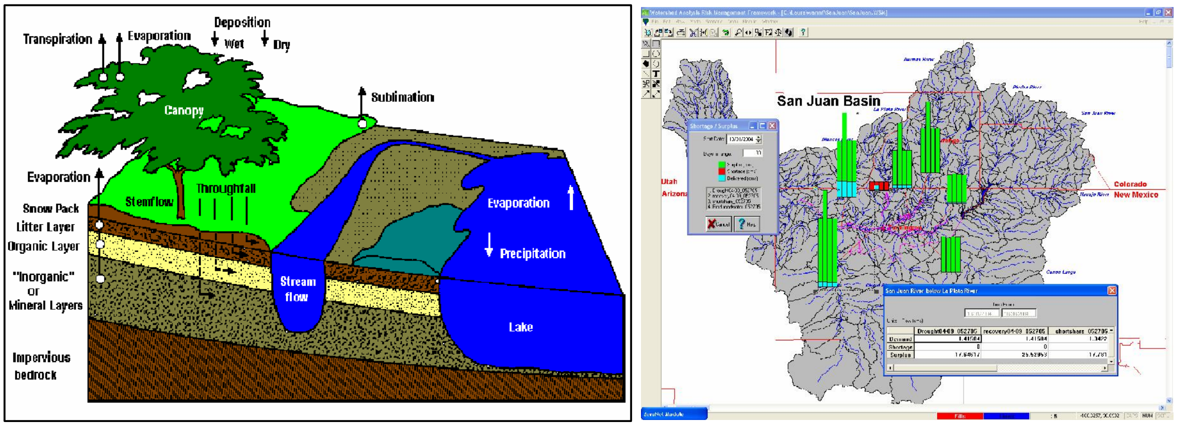


Figure 2.1. The WARMF watershed tools include process models to simulate freshwater flow (left) and access via a graphical user interface (right).

WARMF currently consists of five integrated modules (Engineering, Consensus, TMDL, Data, and Knowledge). Enhancements of WARMF in support of the ZeroNet Initiative include iterative modeling and production of "what if" scenario libraries to examine consequences of changes in climate, landuse, and water allocation. This is being accomplished by development of a ZeroNet module, a batch scenario tool, and improvements to the Engineering and Knowledge modules. Although the Consensus and Data modules of WARMF will be used during the WARMF application to the San Juan basin, no modifications to these modules are planned.

The Engineering module of WARMF contains a dynamic watershed simulation model that calculates daily surface runoff, ground water flow, non-point source loads, hydrology, and water quality of river segments and stratified reservoirs. In WARMF, a watershed is divided into a network of land catchments, river segments, and reservoir layers. Land catchments are further divided into land surface and soil layers. These watershed compartments are seamlessly connected for hydrologic and water quality simulations. The land surface is characterized by its land uses and cover, which may include forested areas, agriculture lands, or urbanized cities. Daily precipitation, which includes rain and snow, is deposited on the land catchments. WARMF performs daily simulations of snow and soil hydrology to calculate surface runoff and groundwater accretion to river segments. The water is then routed from one river segment to the next downstream river segment until it reaches the terminus of the watershed. The associated point and nonpoint loads are also routed through the system. Heat budget and mass balance calculations are performed to calculate the temperature and concentrations of various water quality constituents in each soil layer, river segment, and lake layer. WARMF provides a robust framework to address the complex issues proposed by the ZeroNet project. Although no major algorithm changes are anticipated for the Engineering module, several small enhancements were completed. These include the ability to divert water from a reservoir, and the implementation of a minimum flow requirement.

2.2 Data Inputs for Watershed Tools

2.2.1 Watershed Characteristics

The USEPA BASINS framework (USEPA 2004) was used to extract watershed data for the 12 Hydrologic Unit Codes (HUCs) in the San Juan Basin. These data included Digital Elevation Model (DEM) data, National Hydrography Dataset (NHD) stream networks, land use, and cataloging unit (HUC) boundaries. The data were processed within BASINS to generate 12 delineated watershed areas for import into WARMF. During this step, several shape files were corrected for stream linkage issues. The watershed delineations were set to include enough resolution for calibration against all available USGS stream gaging stations. Higher resolution was implemented in the northern parts of the basin where wetter conditions occur and most diversion activity exists. To improve computational speed, a lower resolution was implemented in the southern, more arid portions of the basin. A shape file downloaded from the NHD website (http://nhd.usgs.gov/) was used defined the boundaries for 4 reservoirs modeled within WARMF (Navajo Reservoir, Lemon Reservoir, Vallecito Reservoir, and Farmington Lake). After delineating subwatershed areas in BASINS, subbasin, stream, and lake shape files were imported into WARMF to create a San Juan Basin map in the graphical user interface (GUI) (Figure 2.2). Upon import, land catchments, river segments and lakes were linked to form a hydrologic network. Each entity was populated with data which originated from DEM or NHD data or was calculated by BASINS during the delineation process (e.g. such as area, slope, elevation, aspect, channel bathymetry, and stream name.)

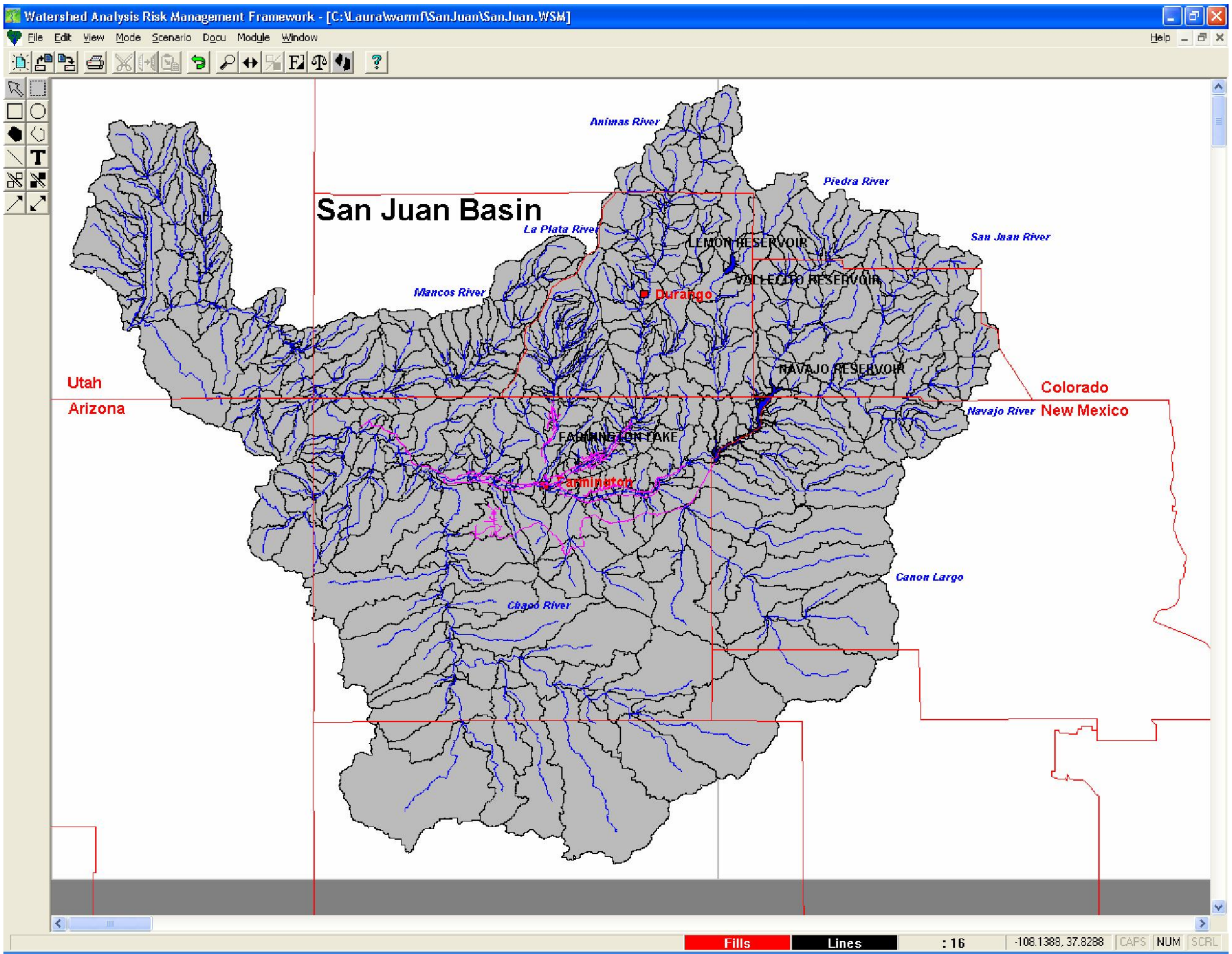


Figure 2.2. San Juan Basin Map as shown in the WARMF Graphical User Interface

2.2.2 Land Use

The default land use data extracted using BASINS 3.0 is the Geographic Information Retrieval and Analysis System (GIRAS)Landuse/Landcover data for the Conterminous United States by quadrangles at scale 1:250,000. The data set is mainly based on imagery collected from mid 1970s to early 1980s. One problem with using this dataset is that it misclassifies a large agricultural region within the Navajo nation lands south/southeast of Farmington, NM.. Therefore we used another dataset the National Landuse Cover Data (NLCD) that has a finer spatial resolution of 30m and is derived from the early to mid-1990s Landsat Thematic Mapper (TM) satellite data (Figure 2.3). The new dataset shows a significant amount of crop circles within the Navajo Irrigation project area. This NLCD data set was produced by the U.S. Geological Survey (USGS) as part of a cooperative project between the USGS and the U.S. Environmental Protection Agency (USEPA). The TM data are acquired by the Multi-Resolution Land Characterization (MRLC) Consortium, which includes USGS, USEPA, the U.S. Forest Service, and the National Oceanic and Atmospheric Administration. In this project, the downloaded Geo-Tiff files were first converted into grids in Arcview and further converted into shapefiles and clipped with watershed boundaries before importing into WARMF.

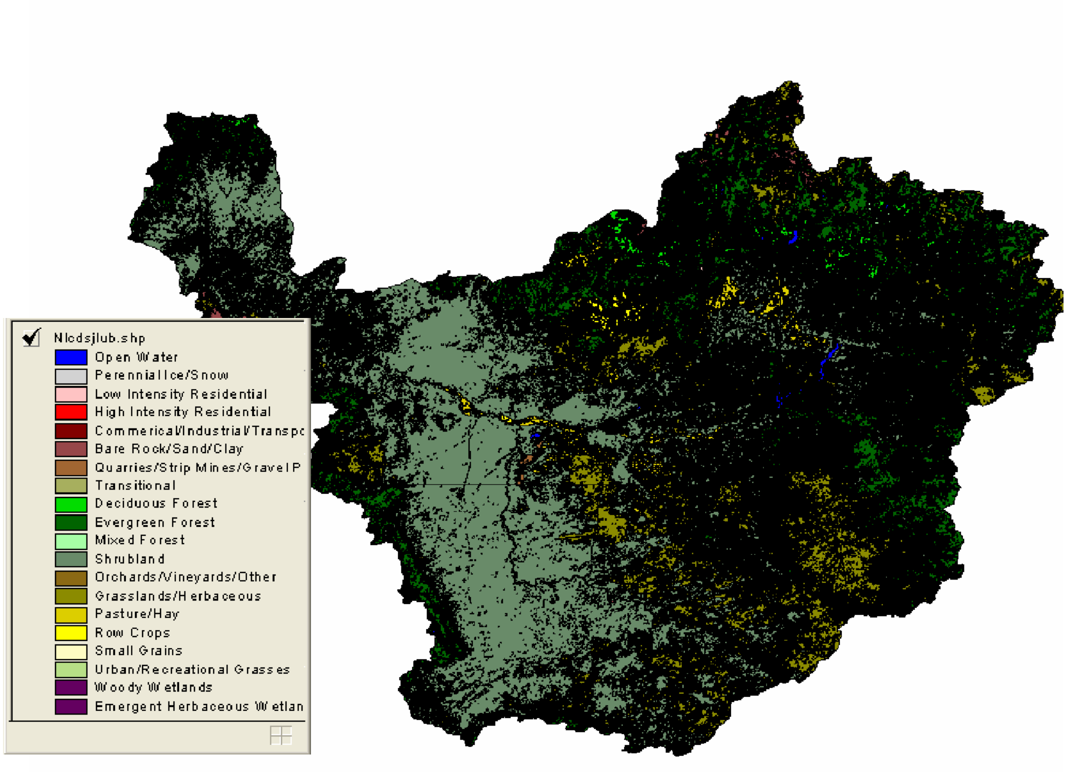


Figure 2.3. National Land Cover Data (NLCD) used in WARMF

The NLCD is based on a 21-Class classification system. Upon importing into WARMF, these 21 categories of land use were reclassified into 17 land use categories in WARMF (Table 2.1).

Table 2.1. Re-classification of NLCD land use categories into WARMF land use categories

NLCD classification keys	WARMF classification keys
Water	
11 Open Water	17 Water
12 Perennial Ice/Snow	17 Water
Developed	
21 Low Intensity Residential	12 Low Intensity Residential
22 High Intensity Residential	13 High Intensity Residential
23 Commercial/Industrial/Transportation	14 Commercial/Industrial
Barren	
31 Bare Rock/Sand/Clay	16 Barren
32 Quarries/Strip Mines/Gravel Pits	16 Barren

33 Transitional	16 Barren
Forested Upland	
41 Deciduous Forest	2 Deciduous
42 Evergreen Forest	1 Coniferous
43 Mixed Forest	3 Mixed Forest
Shrubland	
51 Shrubland	4 Shrubland
Non-natural Woody	
61 Orchards/Vineyards/Other	9 Orchard
Herbaceous Upland	
71 Grasslands/Herbaceous	5 Rangeland
Herbaceous Planted/Cultivated	
81 Pasture/Hay	6 Pasture/Hay
82 Row Crops	7 Row Crops
83 Small Grains	8 Small Grains
84 Fallow	10 Fallow
85 Urban/Recreational Grasses	11 Urban
Wetlands	
91 Woody Wetlands	15 Wetland
92 Emergent Herbaceous Wetlands	15 Wetland

2.2.3 Meteorology

Meteorological data for 45 stations located within the San Juan watershed were obtained for input to WARMF. Data includes daily values for precipitation, min/max air temperature, cloud cover, wind speed, air pressure, and dewpoint temperature. The sources of data include the National Climate Data Center (NCDC) global summary of the day, NCDC cooperative data and National Resources Conservation Service (NRCS) SNOwpack TELemetry (SNOTEL). NCDC global summary of the day data set contains records for all the variables, while SNOTEL data set and NCDC cooperative data contain only measurements for precipitation, min and max air temperature. Appendix A provides a table listing all meteorology stations, data sources, station locations, and periods of record.

2.2.4 Observed Streamflow

Streamflow data for 39 USGS gauging stations located in the San Juan Basin (Figure 2.4) were downloaded from the USGS website and processed for input into WARMF. These data were used for comparison during hydrology calibration. Due to constraints of resources, WARMF modeling effort was focused on the New Mexico portion of the watershed. Observed streamflow data for 6 CO / NM stateline locations (Mancos.orh, LaPlata2.orh, Animas4.orh, LosPinos2.orh, Piedra.orh, SanJuan2.orh) were used to establish model boundary conditions. Recorded streamflow data was set to be prescribed flow at these 6 tributary locations, and WARMF simulated the streamflow for all downstream locations based on meterology, soil hydrology and historical diversions. A table listing all observed streamflow stations, data sources and periods of record is provided in Appendix A.

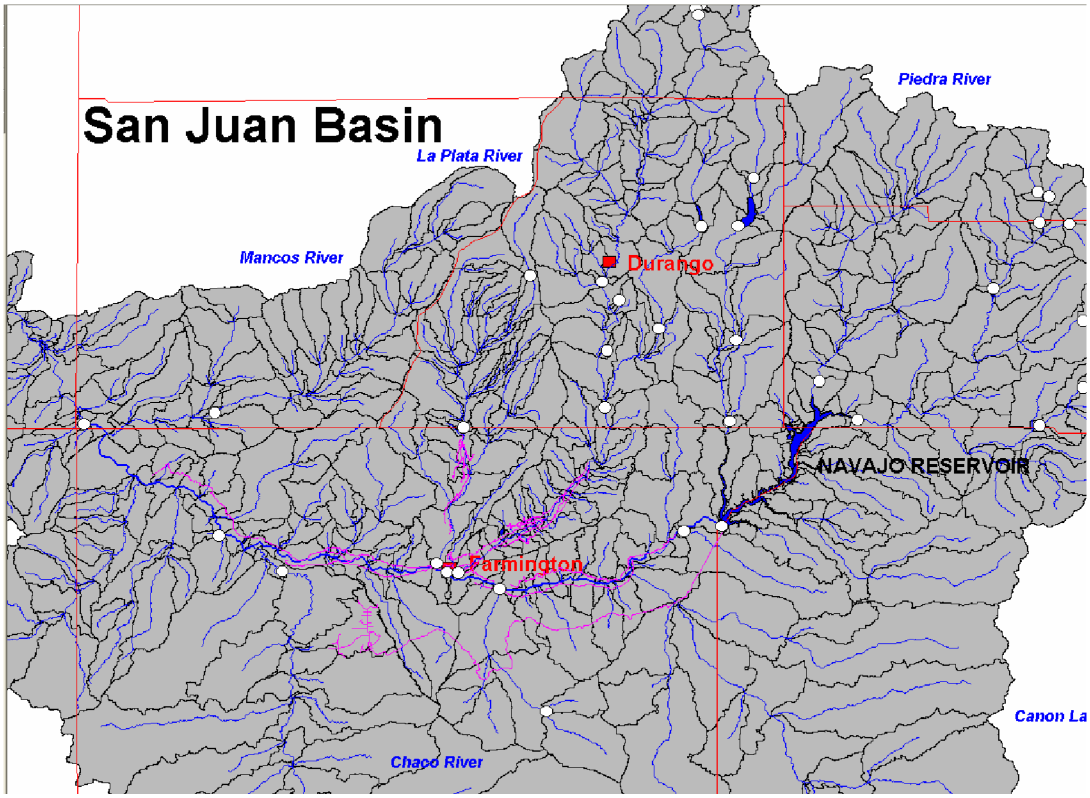


Figure 2.4. Locations of USGS gauging stations.

2.2.5 Diversions

Controlled diversions for municipal, agricultural and industrial use are an important set of input data for WARMF. Several organizations assisted Systech Engineering to obtain data related to diversions and irrigation in the San Juan basin.

Map of Diversions

Eric Chavez of the San Juan Water Commission (SJWC) provided GIS data showing the location of diversions in New Mexico. In addition, Shawn Williams (San Juan Basin Water Master) provided a similar coverage. This information was cross referenced with a National Hydrography Dataset (NHD) GIS coverage to develop a GIS shape file showing all NM diversions in the San Juan Basin (Figure 2.5). This shapefile was imported into WARMF.

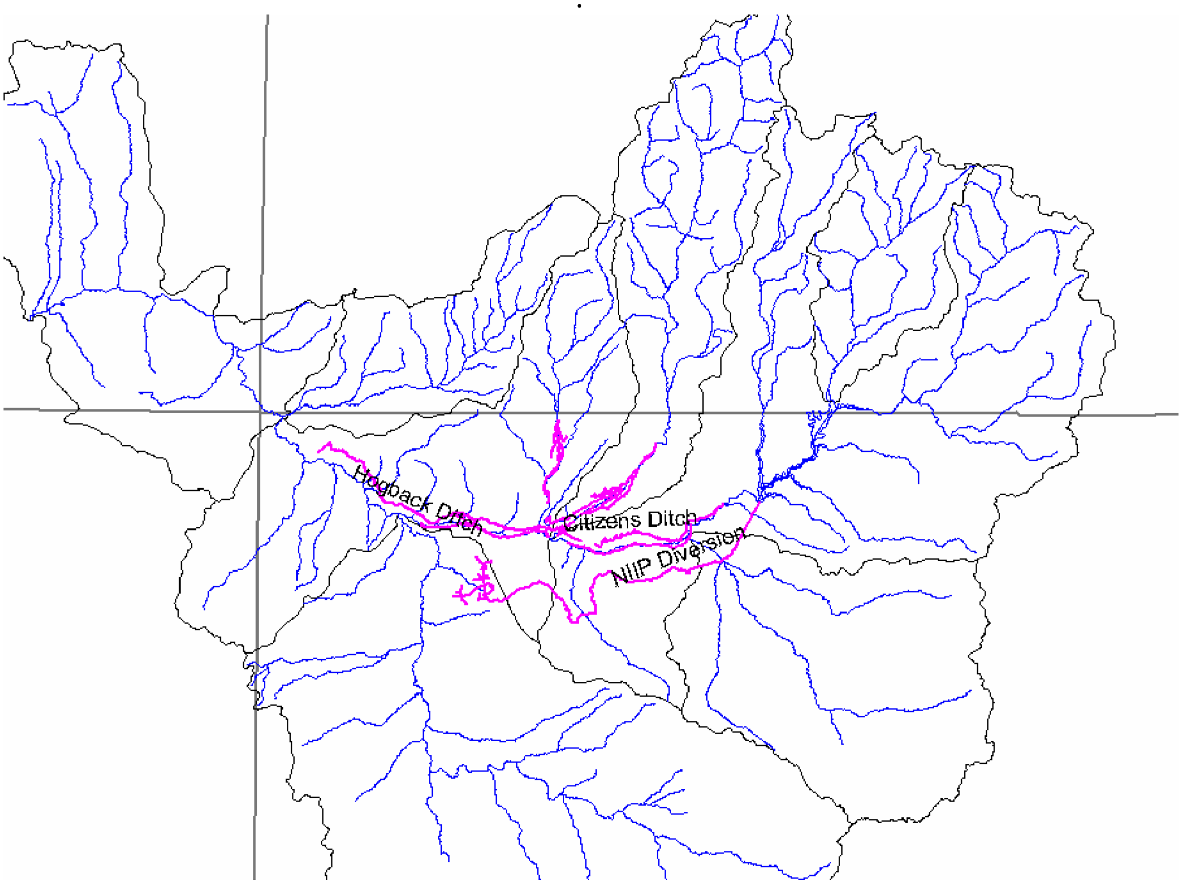


Figure 2.5. New Mexico Diversions in the San Juan Basin

New Mexico Diversions

The New Mexico portion of the San Juan Basin contains 51 municipal, industrial, and agricultural diversions. WARMF requires historic diversion records for all diversions. John Simons and Dave King of the U.S. Bureau of Reclamation (USBR) provided general diversion information in the basin. Mr. King also provided historical data for 4 major New Mexico diversions (Navajo Indian Irrigation Project - NIIP, Hammond Project, Four Corners Power Plant, San Juan Generating Station). Additional data for Four Corners Power Plant and San Juan Generating Station were obtained from Rob Ashman (PNM). As well, data for NIIP, Hogback, and Fruitland diversions were obtained from www.sanjuanflows.org. Shawn Williams, (Water Master), provided data for agricultural diversions. A complete list of San Juan Basin New Mexico diversions is provided in Appendix A.

For most of the municipal and industrial diversions, data records are available from 1988 with some as far back as 1976. For the Navajo Nation diversions, Fruitland and Hogback only have records for 2003 and 2004. Therefore, records from these two years were repeated for the previous years. Detailed monthly data for the NIIP diversion starting in

1976 was available from USBR and the daily data from 1990 to current were obtained from www.sanjuanflows.info. For most of the agricultural diversions, there were no diversion records except an adjudicated maximum value. In this case, we assumed the diversion to be equal to this value during the irrigation months of April to October and this pattern was repeated for each year. Beginning in 2004, some of these agricultural diversions were measured on a daily basis. The daily diversion records obtained in 2004 were repeated for all the previous years.

Irrigation of Agricultural Diversions

For WARMF modeling, it was assumed that 30% of diversion water is lost from ditches during transport (Williams 2003). Therefore only the remaining 70% of diversions was applied to the agricultural lands. The lost water was applied to shrub or rangeland land use. The landuse map (Figure 2.3) and the GIS layer of ditches (Figure 2.5) were used to infer which watersheds are irrigated by certain ditches. The diverted water was then distributed among these watersheds based on the agricultural land area of each watershed. For example, from the landuse map, we inferred that Cedar Hill ditch irrigates watershed 474 and watershed 475. Based on the agricultural (i.e. pasture/hay land use) areas in these two watersheds (0.165 km^2 and 0.724 km^2, respectively; estimated by WARMF upon importing the land use data), we determined 13% of the diverted water to be irrigated in watershed 474 and 57% to be irrigated in watershed 475. In the case when 2 or 3 ditches pass through one same watershed, we assumed each ditch irrigates ½ or 1/3 of the agricultural area in the watershed.

Colorado Diversions

Ray Alvarado and Doug Stencel of the Colorado Department of Water Resources (CO DWR) provided GIS data from their website for diversion locations, land use, flow stations, etc. A CD of data has been purchased from CO DWR which contains historical data for all Colorado diversions in the San Juan basin. Diversions for Colorado are currently not imported into WARMF. If the domain of the modeling effort expands to include the Colorado portion of the San Juan Basin, the data will then be imported.

2.2.6 Point Sources

Data for seven (7) of the largest point source dischargers in the New Mexico portion of the San Juan basin were obtained from the Water Master, PNM or EPA Permit Compliance System (PCS) database. Appendix A provides a table of these dischargers, NPDES permit numbers, geographic location, permitted flow, and source of data. For all dischargers, data was available on a monthly basis.

2.2.7 Reservoir Data

Reservoir data was downloaded from the USBR website for 3 reservoirs located in the San Juan basin: Navajo Reservoir, Lemon Reservoir, and Vallecito Reservoir (http://www.usbr.gov/uc/crsp/GetSiteInfo). The data includes daily estimated reservoir inflow, reservoir release, storage, and surface elevation. Records were downloaded for 1990 through October 2004. Reservoir bathymetry data for all three reservoirs was obtained from John Simons of USBR. Release and bathymetry data for Farmington Lake were obtained from the City of Farmington via the Water Master.

2.3 <u>ZeroNet Module for Watershed Tools</u>

As part of the ZeroNet application of WARMF to the San Juan Basin, a new ZeroNet Module was developed in WARMF (Figure 2.6). The ZeroNet module is accessible through the *Module* menu item in WARMF. The main structure of the ZeroNet module is a series of steps, 1 through 6, which guide the user through setting up simulations and viewing model output. The details of the ZeroNet module design can be found in the Watershed Tools Design document, available via the team page of the ZeroNet website (http://zeronet.lanl.gov).

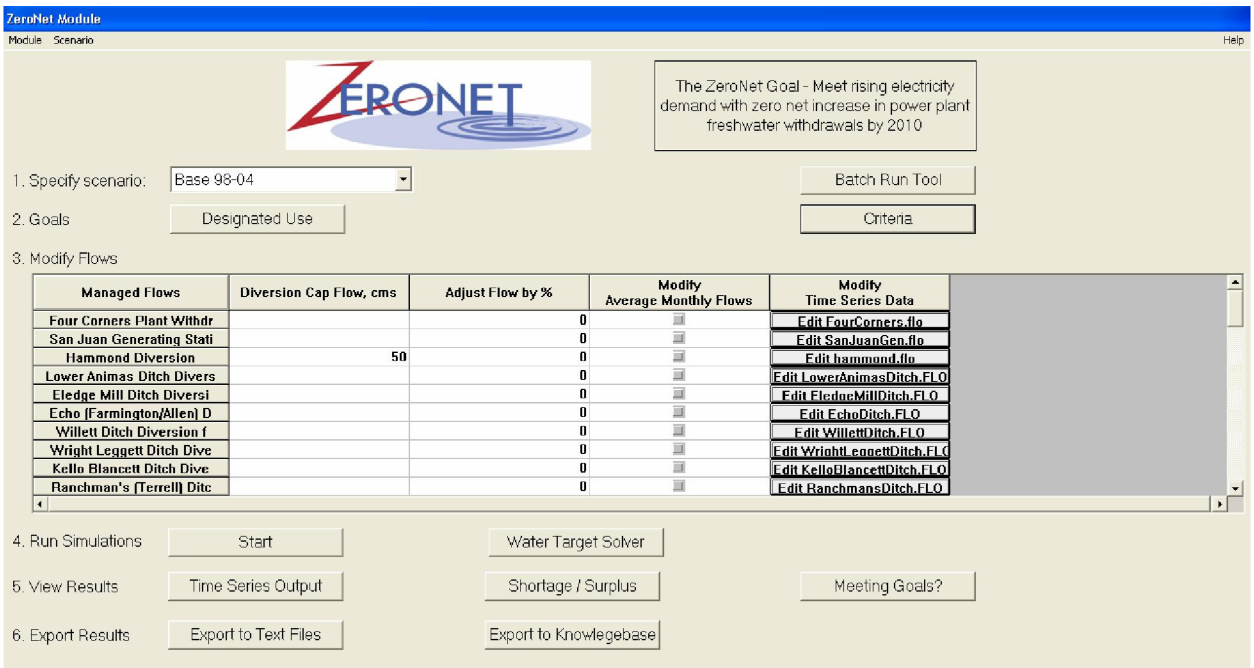


Figure 2.6. Graphical User Interface of the ZeroNet Module

To date, several ZeroNet Module components have been developed. In Step 1, users may use a pull down menu to select a scenario for simulation. The batch scenario tool is currently not active.

In Step 2 (Goals), the *Designated Use* button will pop up a watershed map where users may select a region where one or more designated use applies. Then, selecting the *Criteria* button activates a dialog where flow or elevation criteria can be set for each designated use. For the San Juan Basin, the designated use of Fish Habitat was set along the San Juan River below Navajo Reservoir. Minimum flow criterion of 250 cfs (7.08 cms) was set for San Juan River from Navajo Reservoir to Farmington. Likewise a minimum flow criterion of 500 cfs (14.18 cms) was set for San Juan River downstream of the City of Farmington. A designated use for Minimum Reservoir Level was also set for Navajo Reservoir. A minimum elevation of 1825.8 m (5990 ft) was set as the criterion.

This is the minimum operating level of Navajo Reservoir in order for the water level to be above the NIIP outlet works.

For Step 3 (Modify Flows), a spreadsheet was developed which shows the list of Managed Flows in the basin. Subsequent columns contain functions for modifying managed flows in order to simulate a proposed management condition. In column 2, a diversion cap flow can be set for any diversion. By setting this cap in the spreadsheet, the model will override the historical diversion with the cap value if the historical diversion exceeds the cap. In column 3, the prescribed diversion flows can be adjusted by a set percentage. By assigning a weighting factor in this column, historical diversions will be increased or decreased by the specified percent. The pattern of diversion will remain the same. Column 4, Modify Average Monthly Flows, is not currently functional. In column 5, time series data containing prescribed diversion or reservoir release flows can be modified via the Data Module. This is activated by selecting a file listed in column 5 of the spreadsheet

In Step 4 (Run Simulations), the *Start* button provides a linkage to the simulation control dialog within the Engineering Module that allows the user to select the time period and watershed regions for simulation and start the simulation.

Several tools in Step 5 (View Results) facilitate the viewing of model output. The first button, *Time Series Output* links back to the Engineering Module of WARMF where time series output for flow and reservoir elevation can be viewed by clicking on stream or reservoir locations. The second button, *Shortage / Surplus*, will bring up a GIS map for the user to view shortage/surplus at various locations in the watershed (Figure 2.7). By clicking at a location on the map, a bar chart will pop up to show the magnitude of demand, shortage and/or surplus in terms of water volume (m^3). The volume water delivered (based on demand) is shown as a blue bar. If there is a surplus of water beyond the demand, it will be shown as a green bar. If a shortage occurs where a full diversion could not be taken since not enough water is available, a shortage bar will appear shaded in red. The user may specify the time period for which to calculate the demand, shortage and surplus for each location and multiple scenarios may be viewed together. The numeric values of each bar chart are displayed in a spreadsheet when a bar chart is selected. The third button, *Meeting Goals?*, allows users to view compliance and/or violation of criteria with respect to beneficial uses via a red/green color coded map. Figure 2.8 provides an example of a projected drought scenario where Navajo Reservoir is violating the designated use and minimum elevation criteria (shaded red), however the San Juan River downstream of the reservoir is meeting the designated use and minimum flow criteria (shaded green).

In Step 6 (Export Results) the *Export to Text Files* button opens a postprocessor where flow, elevation, shortage, and surplus output can be exported for various scenarios and various watershed locations in the form of text files.

Development of the ZeroNet module is ongoing. Additional tasks that must be completed for in the ZeroNet Module are discussed in Section 2.6, Future Tasks.

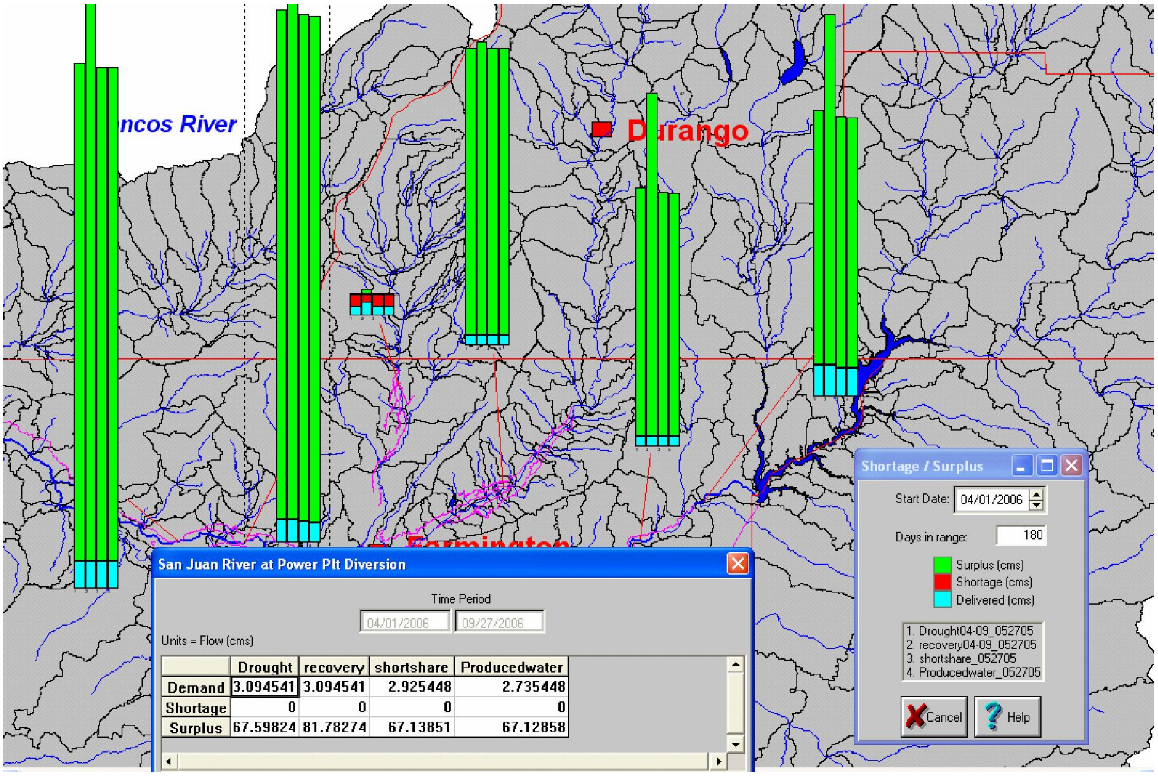


Figure 2.7 Screen capture of WARMF showing Shortage / Surplus bar charts for several river locations in the San Juan Basin.

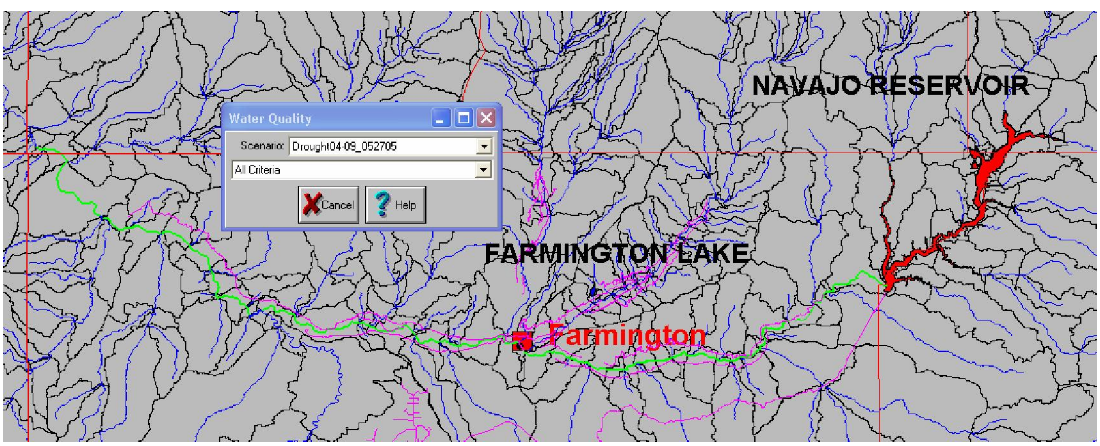


Figure 2.8. Screen capture of WARMF showing compliance and violation if designated uses for Navajo Reservoir and the San Juan River.

2.4 <u>Calibration Watershed Tools</u>

After WARMF was set up and adapted to the San Juan Basin, model calibration was performed. The hydrological calibration of flow was performed using an upstream to downstream approach. Important hydrology calibration parameters include precipitation weighting factors, evaporation coefficients, soil field capacity and saturated moisture content, snow melt coefficients, and hydraulic conductivity. Precipitation weighting factors translate the amount of precipitation that occurs at the weather station to the amount falling on a specified land catchment. This factor accounts for any elevation differences between a land catchment and the assigned meteorology station location. The factor is modified in conjunction with the evaporation coefficient so that the correct amount of precipitation is applied to the catchments to produce the right amount of runoff by WARMF. Snowmelt coefficients control the rising limb of the hydrograph in the spring. Field capacity, horizontal and vertical hydraulic conductivity, and saturated moisture of the soil control the recession limb of the hydrograph and the dynamic fluctuations between storms. WARMF contains a hydrology autocalibrator utility to aid the user in hydrology calibration. After setting initial parameter values, minimum / maximum values and maximum increments for designated parameters, WARMF will perform a set of iterative simulations adjusting parameters up or down within the specified range until the error between simulated and observed flow is minimized. After inspection, these “autocalibrated coefficients” may be accepted by the user for model input. Since only hydrology was considered for the project, a water quality calibration was not conducted.

After simulations are complete, time series model output can be viewed through the Engineering Module by double-clicking catchment, river or lake locations on the map. The plots will show simulated versus observed results for flow and each water quality parameter as well as the goodness of fit in terms of relative error, absolute error, Root Mean Square (RMS) error and correlation coefficient (r^2).

2.4.1 Calibration

The hydrology in the New Mexico portion of the San Juan Basin is highly influenced by the large number of diversions in this region. Many of these diversions are not well monitored and therefore uncertainty in diversion records could influence the hydrology calibration. Therefore, as a preliminary calibration step, we performed a hydrology calibration in an upstream watershed (Upper Vallecito watershed; Figure 2.9). Although this watershed is in Colorado and therefore outside of the spatial scope of this project, it is upstream of all diversions and is therefore a good section to calibrate and establish reasonable values for model calibration parameters which impact hydrology simulations. During the calibration process, soil thickness, hydraulic conductivities, soil field capacity, saturated moisture content, and snowmelt coefficients were the main parameters adjusted. The calibration period is 1990-1994. The calibration results provided a relatively good match with the observed values (Figure 2.10-2.13).

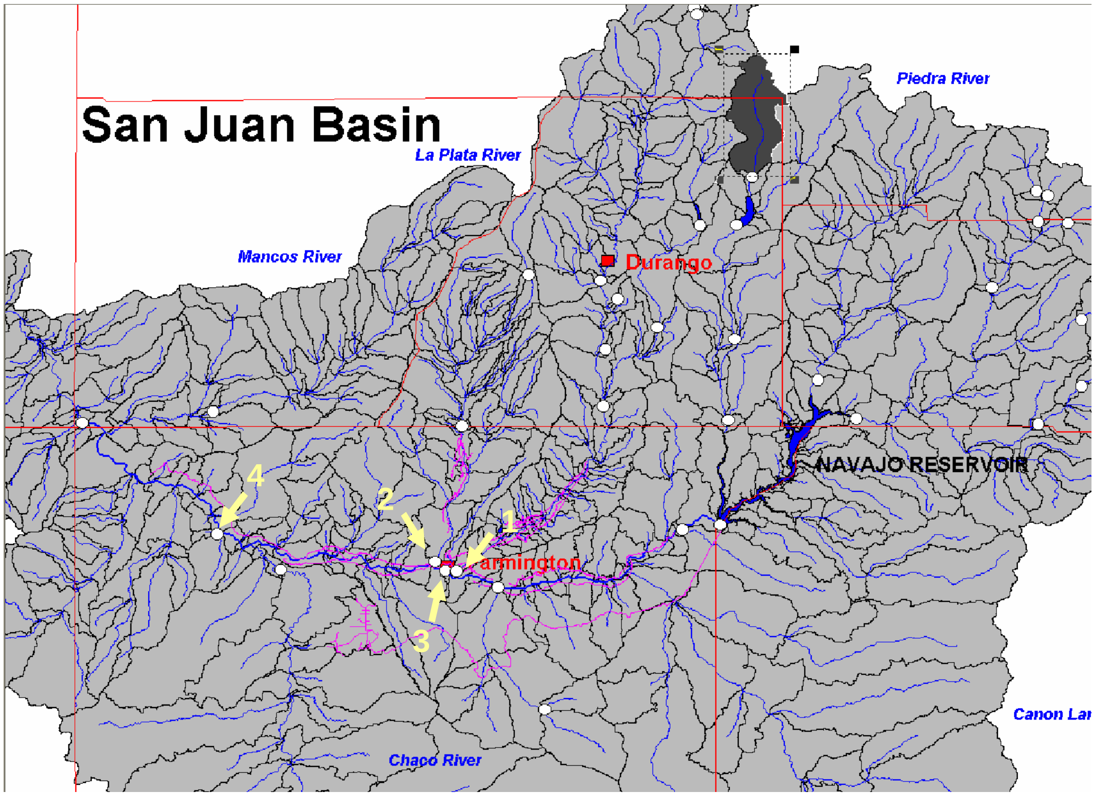


Figure 2.9. San Juan Basin map showing locations for calibration: Upper Vallecito Watershed (shaded dark gray), Animas River above Farmington Glade (1), La Plata River at San Juan (2), San Juan River at Farmington (3), and San Juan River at Shiprock (4).

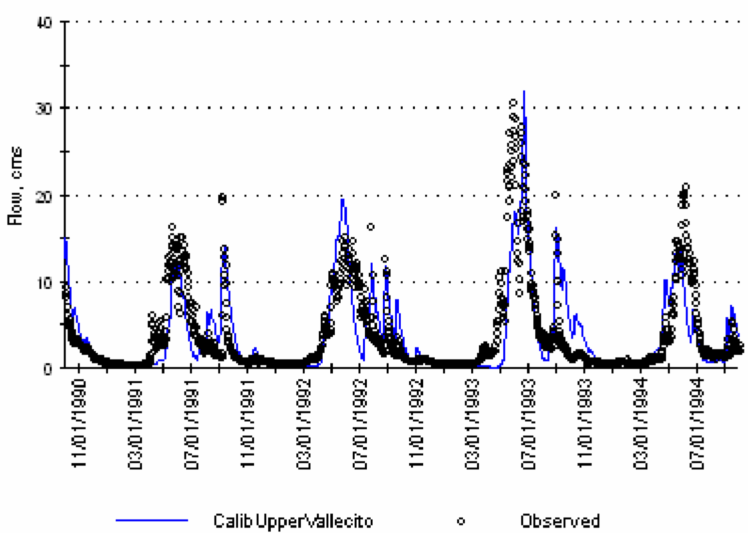


Figure 2.10. Simulated and Observed Stream Flow of Vallecito Creek.

	CalibUpperVallecito	Observed
Mean	3.817	3.982
Minimum	0.0901	0.481
Maximum	31.9	30.87
# Compare Pts	1461	1461
Relative Error	-0.164	0
Absolute Error	2.14	0
RMS Error	3.44	0
r squared	0.579	1

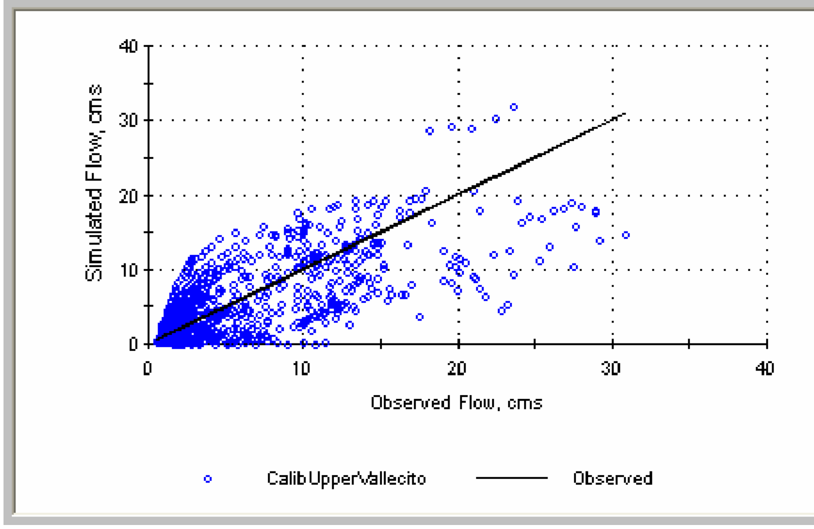


Figure 2.11. Correlation Statistics of Simulated and Observed Flows of Vallecito Creek

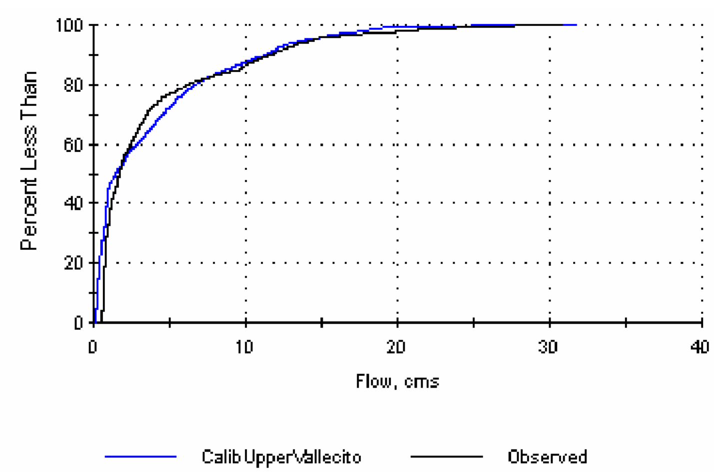


Figure 2.12. Frequency Distribution of Simulated and Observed Flow of Vallecito Creek

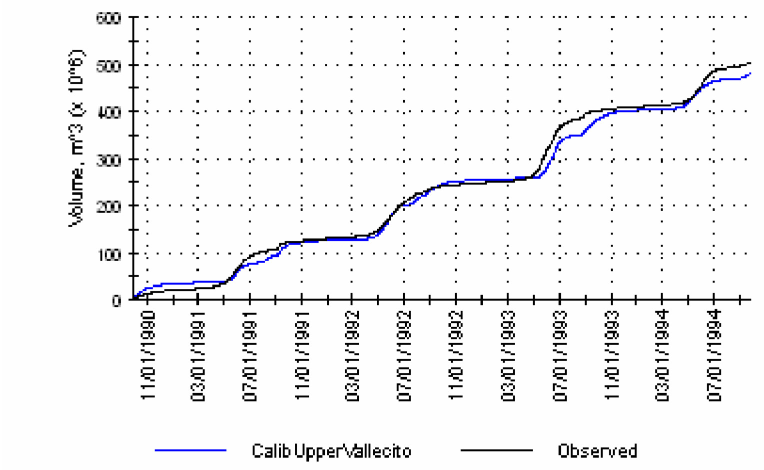


Figure 2.13. Cumulative Hydrograph for Simulated and Observed Flows of Vallecito Creek

Hydrologic parameters derived through this preliminary calibration process were used as initial values for the rest of the San Juan Basin. The Upper Vallecito watershed has relatively high elevation and the hydrology is significantly influenced by snow and snowmelt. Therefore the hydrology in Upper Vallecito watershed is expected to be slightly different from the lower portion of the San Juan Basin. When applying parameters derived from Upper Vallecito watershed to the rest of the basin, initial moisture contents and field capacity were further adjusted. Similarly the calibration for the rest of the basin was done for the period of 1990-1994. Comparison of simulated versus observed streamflow was made for several locations in the basin: Animas River above Farmington Glade, La Plata River at San Juan, San Juan River at Farmington, and San Juan River at Shiprock (Figure 2.9). Appendix B provides detailed calibration results for each location.

2.5 Verification of Watershed Tools

After calibration model verification was performed by running the model for the period of 10/1984-9/2004. During this simulation, model coefficients were the same as was established during the calibration step. Three locations were chosen for comparison of simulated versus observed flow: Animas River above Farmington Glade, San Juan River at Farmington, and San Juan River at Shiprock. We further compared simulated versus observed flow under three different climate conditions, a wet year (1993), a normal year (1998) and a dry year (2002) at each location. Details of the model verification are provided in Appendix C.

2.6 Remaining Tasks for Development of Watershed Tools

Several tasks remain for the development of the WARMF ZeroNet module. These items are listed below:

- Batch Scenario Tool. The batch scenario tool will enable a user to sample historical years of data to set up a long term simulation. The 20 years of available meteorological data for the San Juan Basin will be ranked based on precipitation and then grouped into 3 main categories: wet, normal, and dry. Each category will be represented by equal precipitation percentile ranges: 0-33 for dry, 33-67 for normal, and 67-100 for wet. Upon selecting the *Batch Tool* feature, the user will be prompted to select the number of years for simulation (1 to 40). Then, a spreadsheet will pop up where the user can select a pattern of proposed met conditions to simulate and any proposed change in temperature for each year (Table 2.2). Then, for each scheduled year, WARMF will randomly sample this sequence of years from historical years. The sampling will be done based on grouping of historical years into wet/normal/dry categories. After sampling each year, WARMF will create the needed input files for meteorology, reservoir releases, diversions, point sources and upstream boundary conditions. It will link the sampled years together to create a continuous simulation and save results in standard WARMF output files. Multiple iterations of the historical sampler simulations can be run to produce a probabilistic distribution of results.
- Monthly Flows. A mechanism will be developed in the *Modify Flows* spreadsheet where users can modify diversion and release flows on a monthly basis.
- Target Water Solver (optional task). This will be a tool to back calculate adjustments to prescribed diversions and reservoir releases that are required in order to meet specified storage and flow criteria. The development of this feature is dependent on project resources.
- Knowledge Module Enhancements. Proposed enhancements to WARMF's Knowledge Module include: 1) creating new categories for file organization (Project Background, Data Sources, Related Web Links, etc), 2) adding the capability to insert a hyperlink instead of a file name, and 3) adding a place to briefly describe the file or link that is being stored in the knowledge module
- Unit Conversion Tool. To ease the interpretation of WARMF output into English units, a unit conversion tool will be developed. This tool will be accessible from the main menu of WARMF (either the *Edit* or *View* headings). The tool will allow users to first select a parameter type (e.g. flow, length, volume, etc). Then a single value can be entered with the input units. After selecting the output units, and clicking on calculate, WARMF will calculate the value in the new units.

Table 2.2 User specified schedule of climate conditions

Year	**Conditions**	**Temperature Variation (+/- ° C)**
1	Wet	0
2	Dry	1
3	Dry	2
4	Dry	2
5	Dry	3
6	Dry	3
7	Normal	0
8	Wet	0
9	Wet	0
10	Wet	0
11	Dry	2
12	Dry	2
13	Dry	2
14	Normal	2
15	Wet	0
16	Normal	0
17	Dry	0
18	Wet	0
19	Wet	0
20	Normal	0

3 Linkage with other Decision Support Tools

In addition to the ZeroNet Module enhancements and the application of WARMF to the San Juan Basin, development of WARMF, a linkage is being made between WARMF and the other decision support tools (Quick Scenario Tool and Knowledge Base) to develop a San Juan Scenario Library.

The ZeroNet Quick Scenario Tool (QST) uses system dynamics modeling for rapid analysis and visualization. Uses include drought planning, economic analysis, evaluation of management alternatives, and risk assessment. To date, completed tasks include planning of the QST design, incorporation of stakeholder input, collection of key data (stream flows, water demands, etc.), development of the prototype QST model using system dynamics approaches. Distribution curves were fit to historical stream flow data and capabilities were develop for stochastic generation of inflows. Municipal water demands were estimated based on population, per-capita water usage, and price elasticity. Agricultural water demands were estimated based on crop types, acreages, yields, and prices. Energy water demands were estimated using energy production, profits, and efficiency of water use. Capabilities were developed to simulate reservoir operations and estimate evaporation for the Navajo reservoir. Ongoing work includes incorporation of design enhancements based on stakeholder input, calibration of stream flows, validation, development of a user interface, and elaboration of the demand modeling.

The ZeroNet Knowledge Base serves to organize and archive data in easily accessible digital libraries, and to share data from diverse sources and for diverse uses. To date, completed tasks include planning of the Knowledge Base design, initial development of the San Juan Data Library for input to WARMF and the QST, and initial development of the San Juan Scenario Library for output from WARMF and the QST. Preliminary scenarios project future reservoir water budget under several climate and management scenarios. Ongoing work will focus on completion of the prototype San Juan Data Library and San Juan Scenario Library, and development of gateway tools to facilitate data flow to and from the Knowledge Base. The San Juan Scenario Library will include simulations concerning extended drought, increased temperature, vegetation change, and economic implications.

3.1 San Juan Data Library Development

Input data for the Watershed Tools and the QST are being compiled and placed in an Access database. This San Juan Data Library brings together disparate data necessary for our models, and of high value for stakeholder use (watershed characteristics, meteorology, observed streamflow, diversions, reservoir levels…).

3.2 San Juan Scenario Library Development

Initial development of the San Juan Scenario Library is focused on development of three sets of scenarios: 1) extended drought (3-10 year duration), 2) increase temperature (1-10 degrees C) and 3) vegetation change (increased xeric vegetation and forest thinning).

Preliminary Drought Scenarios

Based on record from a NCDC station near Farmington (Farmington 4 NE), annual rainfall during 2000-2004 were among the lowest throughout the record period of 1976-2004. Therefore this period is considered as a drought period. As a result, elevation of Navajo Reservoir has dropped nearly to the minimum level. In this case, WARMF was used to project the reservoir water budget during 2005-2009 under four hypothetical climate and management scenarios: 1) extended drought; 2) extended drought with shortage sharing; 3) extended drought with shortage sharing and produced water; 4) recovery from drought (Figure 3.1).

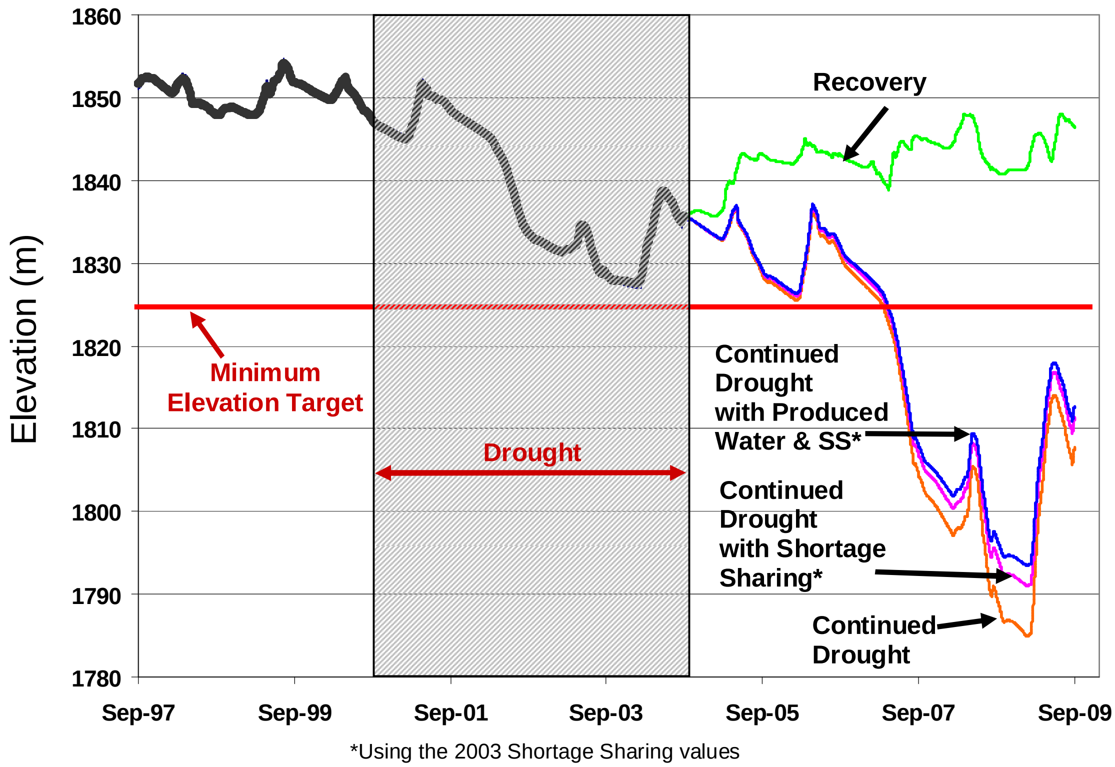


Figure 3.1. Navajo Reservoir levels based on historical data until present, and projected into the future under three scenarios: continued drought, drought with shortage sharing (2003 values), and recovery.

Extended Drought Scenario. The first preliminary scenario was formulated by assuming the drought conditions during 2000-2004 will go on for another five years. Therefore climate records for 2000-2004 were repeated for 2005-2009. Under the continued drought scenario, predicted lake elevation continues to decrease and will be well below the target minimum elevation (Figure 3.1, orange line).

Extended Drought with Shortage Sharing. The second preliminary scenario was developed to begin to evaluate the benefit of shortage sharing among the water users. The scenario was formulated by assuming continuous drought similar to 2000-2004 and with the shortage sharing actions taken in 2003 repeated for 2005-2009. The shortage sharing occurred in 2003 included a 6.8% reduction in total annual agricultural diversions and 5% reduction in power plant diversions. Particularly, these reductions took place in Citizen, Hammond, Farmers Mutual, Fruitland, Jewett Valley and Hogback ditches, mostly in April and September. The pattern of reductions in diversions are assumed to be the same for 2005-2009. The Navajo reservoir release for this period was adjusted to reflect the shortage sharing. The results indicated that with shortage sharing in place, although reservoir elevation is still below minimum target level, the elevation will be higher than the drought scenario without shortage sharing (Figure 3.1, purple line).

Water Savings from Produced Water Scenario. The third preliminary scenario demonstrates the benefit of using produced water in power plant cooling. By using produced water in power plant cooling, power plants will divert less water from the river and therefore influence the reservoir release. This scenario is formulated by assuming 5000 acre feet decrease in power plant diversion, and therefore the reservoir release was adjusted to reflect this decrease in diversion. The results indicated with reuse of produced water, lake elevation will show further increase from the drought scenario (Figure 3.1, blue line).

Recovery Scenario. The fourth preliminary scenario involving recovery evaluates whether reservoir levels will recover under normal climate conditions. Based on meteorological data from the same NCDC station (Farmington 4NE), annual rainfall during 1991-1995 could be generally considered as typical. Therefore we repeated climate records of 1991-1995 for the period of 2004-2009 to formulate the recovery scenario. The results indicated under the normal climate condition, the lake elevation will recover, not to the level before the onset of drought, but will remain above minimum target level (Figure 3.1, green line).

4 Professional Meetings and Presentations

Rich, P.M., L.H.Z. Weintraub, M.E. Ewers, T.L. Riggs, and C.J. Wilson. 2005. Decision support for water planning: the ZeroNet water-energy initiative. Proceedings of the American Society of Civil Engineers - Environmental & Water Resources Institute (ASCE-EWRI) "World Water and Environmental Resources Congress 2005: Impacts of Global Climate Change", May 15-19, Anchorage, AK. LA-UR-05-1068.

Weintraub, L.H.Z., L. Chen, P.M. Rich, J.Herr, R.Goldstein. 2005. Evaluating Climate Change and Water Management for the San Juan Basin using WARMF. Abstract submitted to American Water Resources Association (AWRA) 2005 Annual Conference, November 7-10, 2005, Seattle, WA.

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Rich, P.M., L.H.Z. Weintraub, M.E. Ewers, T.L. Riggs, and C.J. Wilson. 2005. Decision support for water planning: the ZeroNet water-energy initiative. Proceedings of the American Society of Civil Engineers - Environmental & Water Resources Institute (ASCE-EWRI) "World Water and Environmental Resources Congress 2005: Impacts of Global Climate Change", May 15-19, Anchorage, AK. LA-UR-05-1068.

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Williams, S. 2003. Personal communication with Federal Water Master, Sean Williams, October 26, 2004.

Appendix A: WARMF Data Sources

Table A.1. Meteorology Stations in the San Juan River Basin

Station	Latitude	Longitude	Source	Station ID	Period of Record
Arboles 1 W	37.017	-107.433	NCDC	50310	11/1/2002-9/30/2004
Aztec Ruins National Monument	36.833	-108.000	NCDC	290692	9/1/1976 - 9/30/2004
Bloomfield 3 SE	36.667	-107.967	NCDC	291063	9/1/1976 - 9/30/2004
Chaco Canyon National Monument	36.033	-107.917	NCDC	291647	9/1/1976 - 9/30/2004
Chama	36.917	-106.583	NCDC	291664	9/1/1976 - 9/30/2004
Cortez	37.350	-108.600	NCDC	51886	11/1/1977-9/30/2004
Dulce	36.933	-107.000	NCDC	292608	9/1/1976 - 9/30/2004
Durango	37.283	-107.883	NCDC	52432	9/1/1976 - 2/28/1991
Farmington 4 NE	36.750	-108.167	NCDC	293134	9/1/1976 - 3/31/1978
Farmington AG Science Center	36.683	-108.317	NCDC	293142	5/1/1978 - 8/31/2004
Fort Lewis	37.233	-108.050	NCDC	53016	9/1/1976 - 9/30/2004
Fruitland 3 E	36.733	-108.350	NCDC	293340	9/1/1976 - 8/31/2003
Gallup Municipal Airport	35.517	-108.800	NCDC	293422	9/1/1976 - 9/30/2004
Hovenweep National Monument	37.383	-109.083	NCDC	424100	9/1/1976 - 9/30/2004
Ignacio 1 N	37.133	-107.633	NCDC	54250	9/1/1976 - 11/30/1992
Ignacio 8 E	37.083	-107.533	NCDC	54254	1/1/2001-9/30/2004
Lemon Dam	37.383	-107.650	NCDC	54934	4/1/1986 - 9/30/2004
Lindrith 1 W SW	36.300	-107.050	NCDC	294960	9/1/1976 - 9/30/2004
Lybrook	36.233	-107.550	NCDC	295290	9/1/1976 - 9/30/2004
Mancos	37.333	-108.317	NCDC	55327	9/1/1976 - 9/30/2004
Mesa Verde	37.200	-108.483	NCDC	55531	9/1/1976 -

National Park					9/30/2004
Navajo Dam	36.800	-107.617	NCDC	296061	9/1/1976 - 8/31/2004
Otis	36.333	-107.833	NCDC	296465	9/1/1976 - 9/30/2004
Pagosa Springs	37.250	-107.017	NCDC	56258	9/1/1976 - 11/30/1998
Pagosa Springs 4 NW	37.283	-107.050	NCDC	56259	10/1/1999- 9/30/2004
Rico	37.717	-108.033	NCDC	57017	9/1/1976 - 8/31/2001
Shiprock	36.800	-108.700	NCDC	298284	9/1/1976 - 9/30/2004
Silverton	37.817	-107.667	NCDC	57656	9/1/1976 - 9/30/2004
Teec Nos Pos	36.917	-109.083	NCDC	28468	9/1/1976 - 9/30/2004
Vallecito Dam	37.383	-107.583	NCDC	58582	9/1/1976 - 9/30/2004
Wolf Creek Pass 1 E	37.467	-106.783	NCDC	59181	9/1/1976 - 11/30/2001
Camp Jackson	37.800	-109.480	SNOTEL	UT09M02S	10/1/1994- 9/30/2003
Cascade	37.630	-107.800	SNOTEL	CO07M05S	10/1/1994- 9/30/2003
Cascade 2	37.650	-107.800	SNOTEL	CO07M35S	10/1/1994- 9/30/2003
Chamita	36.960	-107.660	SNOTEL	NM06N03S	10/1/1994- 9/30/2003
Columbus Basin	37.440	-108.020	SNOTEL	CO08M10S	10/1/1994- 9/30/2003
Idarado	37.930	-107.680	SNOTEL	CO07M27S	10/1/1994- 9/30/2003
Mancos	37.430	-108.170	SNOTEL	CO08M02S	10/1/1994- 9/30/2003
Middle Creek	37.620	-107.030	SNOTEL	CO07M21S	10/1/1994- 9/30/2003
Mineral Creek	37.850	-107.730	SNOTEL	CO07M14S	10/1/1994- 9/30/2003
Molas Lake	37.750	-107.690	SNOTEL	CO07M12S	10/1/1994- 9/30/2003
Stump Lakes	37.480	-107.630	SNOTEL	CO07M34S	10/1/1994- 9/30/2003
Upper San Juan	37.490	-106.840	SNOTEL	CO06M03S	10/1/1994- 9/30/2003
Vacas Locas	36.030	-107.810	SNOTE	NM06N16S	10/1/2000-

			L		9/30/2003
Vallecito	37.490	-107.510	SNOTE L	CO07M31S	10/1/1994-9/30/2003

Table A.2. Observed Stream Flow and Lake Elevation Data.

Warmf File Name	**Station Name**	**Data Source**	**Period Of Record**
Animas1.Orh	Animas River At Silverton, Co.	USGS 09358000	10/1/1991-9/30/2003
Animas2.Orh	Animas River Below Silverton, Co	USGS 09359020	10/1/1991-9/30/2003
Animas3.Orh	Animas River At Durango, Co.	USGS 09361500	10/1/1897-9/30/2003
Animas4.Orh	Animas River Near Cedar Hill, Nm	USGS 09363500	11/1/1933-1/23/2005
Animas5.Orh	Animas River At Farmington, Nm	USGS 09364500	10/1/1913-1/24/2005
Cement.Orh	Cement Creek At Silverton, Co	USGS 09358550	10/1/1991-9/30/2003
Chaco.Orh	Chaco River Near Waterflow , Nm	USGS 09367950	11/1/1975-10/11/1994
Efsanjuan.Orh	Ef San Juan R Ab Sand Creek, Nr Pagosa Spgs, Co.	USGS 09339900	10/1/1956-9/30/2003
Gallegos1.Orh	Gallegos Canyon At Niip Nr Carson Trading Post, Nm	USGS 09357245	9/1/1993-9/30/1994
Gallegos2.Orh	Gallegos Canyon At Niip Near Farmington, Nm	USGS 09357255	9/3/1993-10/27/1994
Highwayspring. Orh	Highway Spring Near Loma Linda, Co	USGS 09363070	7/26/1995-9/30/1997
Laplata1.Orh	La Plata River At Hesperus, Co.	USGS 09365500	10/1/1917-9/30/2003
Laplata2.Orh	La Plata River At Colorado-New Mexico State Line	USGS 09366500	10/1/1920-9/30/2003
Laplata3.Orh	La Plata River Near Farmington, Nm	USGS 09367500	3/1/1938-9/30/2002
Littlenavajo.Orh	Little Navajo R Bl L Oso Div Dam, Nr Chromo, Co.	USGS 09345200	5/26/1971-9/30/1996
Lospinos1.Orh	Los Pinos River Near Ignacio, Co	USGS 09353800	10/1/1999-9/30/2003
Lospinos2.Orh	Los Pinos River At La Boca, Co.	USGS 09354500	1/1/1951-1/24/2005
Mancos.Orh	Mancos River Near Towaoc, Co.	USGS 09371000	4/1/1921-9/30/2003
Mineral.Orh	Mineral Creek At Silverton, Co	USGS 09359010	10/1/1991-

			9/30/2003
Navajo1.Orh	Navajo R At Banded Peak Ranch, Near Chromo, Co.	USGS 09344000	10/1/1936-9/30/1995
Navajo2.Orh	Navajo River Bl Oso Diversion Dam Nr Chromo, Co.	USGS 09344400	3/1/1971-9/30/1998
Navajo3.Orh	Navajo River At Edith, Co.	USGS 09346000	10/1/1912-5/9/1996
Piedra.Orh	Piedra River Near Arboles, Co.	USGS 09349800	9/1/1962-1/24/2005
Rainbowsprings. Orh	Rainbow Springs Trout Ranch Near Bondad, Co	USGS 09362600	7/26/1995-9/30/1997
Recapture1.Orh	Recapture Creek Near Blanding, Ut	USGS 09378630	10/1/1965-9/30/2003
Recapture2.Orh	Recapture Cr Bl Johnson Cr Nr Blanding,Ut.	USGS 09378650	10/1/1975-10/12/1993
Rioblanco.Orh	Rio Blanco Bl Blanco Div Dam, Nr Pagosa Sps, Co.	USGS 09343300	3/1/1971-9/30/1998
Sanjuan1.Orh	San Juan River At Pagosa Springs, Co.	USGS 09342500	10/1/1935-9/30/2003
Sanjuan2.Orh	San Juan River Near Carracas, Co.	USGS 09346400	11/1/1961-1/24/2005
Sanjuan3.Orh	San Juan River Near Archuleta, Nm	USGS 09355500	12/1/1954-1/24/2005
Sanjuan4.Orh	San Juan River At Farmington, Nm	USGS 09365000	10/1/1930-1/27/2005
Sanjuan5.Orh	San Juan River At Shiprock, Nm	USGS 09368000	10/1/1934-1/27/2005
Sanjuan6.Orh	San Juan River At Four Corners, Co	USGS 09371010	10/01/1977-9/30/2002
Spring-A.Orh	Spring Creek At La Boca, Co.	USGS 09355000	1/1/1951-9/30/2003
Vallecito.Orh	Vallecito Creek Near Bayfield, Co.	USGS 09352900	10/1/1962-9/30/2003
Wfsanjuan1.Orh	W Fk San Juan R At W Fk Campgr Nr Pagosa Spr, Co	USGS 09340800	10/1/1984-9/30/1987, 5/1/1997-9/30/1999
Wfsanjuan2.Orh	West Fork San Juan River Nr Pagosa Springs, Co.	USGS 09341500	10/1/1935-9/30/1998
Wilson.Orh	Wilson Gulch Near Durango, Co	USGS 09362550	6/07/1995-9/30/2002
Wolf.Orh	Wolf Cr At Wolf Cr Campgr Nr Pagosa Spr, Co.	USGS 09341300	10/1/1984-9/30/1999
Farmlak.Olh	Farm Lake Elevation Data	SJ Water Master	1/4/2000-9/30/2003

Lemon.Olh	Lemon Reservoir	USBR	1/2/1990-9/19/2004
Navajores.Olh	Navajo Reservoir Elevation	USBR	1/2/1976-10/27/2004
Vallecito.Olh	Vallecito Reservoir	USBR	1/2/1990-9/19/2004

Table A.3. Diversions in San Juan River Basin.

Diversion	**Diversion From**	**Data Source**	**Data Frequency[1]**	**FileName**
		M&I Diversions		
San Juan Generating Station	San Juan River	PNM	Monthly	SanJuanGen.flo
Four Corners Plant	San Juan River	PNM	Monthly	FourCorners.flo
City of Farmington Pump Station 1	Willet Ditch	Water Master	Monthly	Farmpump1.flo
City of Farmington Pump Station 2	Animas River	Water Master	Monthly	Farmpump2.flo
City of Farmington Farmers Ditch	Farmers Ditch	Water Master	Monthly	FarmfrFarmDitch.flo
City of Farmington Lake to WTP	Farmington Lake	Water Master	Monthly	FarmLakeWTP.flo
City of Farmington Lake to Raw Users	Farmington Lake	Water Master	Monthly	FarmLakeRaw.flo
City of Bloomington	Citizens Ditch	Water Master	Monthly	BloomDiv.flo
City of Aztec	Aztec Ditch	Water Master	Monthly	AztecFrAztec.flo
City of Aztec	Animas River	Water Master	Monthly	AztecFrAnimas.flo
City of Aztec	Lower Animas Ditch	Water Master	Monthly	AztecFrLowerAnimas.flo
		Navajo		
NIIP	Navajo Reservoir	USBR, Sanjuanflows .org	Monthly/dai ly	NIIPDiv.flo
Hogback	San Juan River	Sanjuanflows .org	Monthly	Hogback.flo
Fruitland	San Juan River	Sanjuanflows .org	Monthly	Fruitland.flo
		Agricultural		
Lower Animas Ditch	Animas River	Water Master	Adj Max	LowerAnimasDitch.flo
Eledge Mill Ditch	Animas River	Water Master	Daily	EledgeMillDitch.flo
Echo Ditch	Animas River	Water Master	Daily	EchoDitch.flo
Willett Ditch	Animas River	Water Master	Daily	WillettDitch.flo
Kello Blancett Ditch	Animas River	Water Master	Daily	KelloBlancettDitch.flo
Wright Leggett Ditch	North Farmington Ditch	Water Master	Adj Max	WrightLeggettDitch.flo
Ranchman's (Terrell) Ditch	Animas River	Water Master	Adj Max	RanchmansDitch.flo
Aztec Ditch	Animas River	Water Master	Adj Max	AztecDitch.flo

Cedar Hill Ditch	Animas River	Water Master	Adj Max	CedarHillDitch.flo
Ralston Ditch	Animas River	Water Master	Adj Max	RalstonDitch.flo
Stacey Ditch	Animas River	Water Master	Adj Max	StaceyDitch.flo
Twin Rocks Ditch	Animas River	Water Master	Daily	TwinrocksDitch.flo
Sargent Ditch	Animas River	Water Master	Daily	SargentDitch.flo
Independent Ditch	Halford Ditch	Water Master	Adj Max	IndependentDitch.flo
Halford Ditch	Animas River	Water Master	Adj Max	HalfordDitch.flo
Farmers Ditch	Animas River	Water Master	Adj Max	FarmersDitch.flo
North Farmington Ditch	Animas River	Water Master	Daily	NorthFarmingtonDitch.flo
Inca Ditch	Animas River	Water Master	Adj Max	Incaditch.flo
Farmers Mutual Ditch, Animas River	Animas River	Water Master	Adj Max	FarmersMutualDitch.flo
McDermott Ditch	La Plata River	Water Master	Daily	McDermottDitch.flo
La Plata Inidan Ditch	La Plata River	Water Master	Adj Max	LaplataIndianDitch.flo
Larkin Reynolds Ditch	La Plata River	Water Master	Daily	LarkinReynolds.flo
Hillside Thomas Ditch	La Plata River	Water Master	Adj Max	HillsideThomasDitch.flo
Left Hand Ditch	La Plata River	Water Master	Adj Max	LefthandDitch.flo
Cunningham Ditch	La Plata River	Water Master	Adj Max	CunninghamDitch.flo
Helton Ditch	La Plata River	Water Master	Adj Max	HeltonDitch.flo
Highland Park Ditch	La Plata River	Water Master	Adj Max	HighlandParkDitch.flo
Jackson Ditch	La Plata River	Water Master	Adj Max	JacksonDitch.flo
Greenhorn Ditch	La Plata River	Water Master	Adj Max	GreenhornDitch.flo
Pickering Ditch	La Plata River	Water Master	Adj Max	PickeringDitch.flo
Citizens Ditch	San Juan River	Water Master	Daily	CitizensDitch.flo
Farmers Mutual Ditch, San Juan River	San Juan River	Water Master	Adj Max	FarmersMutualDitchSanJuan.flo
Hammond Canal	San Juan River	Water Master	Monthly	Hammond.flo
Jewett Valley Ditch	San Juan River	Water Master	Adj Max	JewettValleyDitch.flo
Turley Ditch	San Juan River	Water Master	Adj Max	TurleyDitch.flo
Jaquez Ditch	Citizens Ditch	Water Master	Adj Max	JaquezDitch.flo
La Pumpa Ditch	Citizens Ditch	Water Master	Adj Max	LapumpaDitch.flo

[1] Adj Max = Adjudicated Maximum flow obtained from the Federal Water Master.

Table A.4. Point source data for the San Juan River basin

Name	**NPDES ID**	**Latitude**	**Longitude**	**Permitted Flow (MGD)**	**Data Source**
Aps Four Corners Power Plant	NM0000019	36.71	-108.47	1712	PNM
City Of Aztec	NM0020168	36.82	-108.02	1	SanJuan Water Master

City Of Farmington	NM0020583	36.72	-108.22	5.8	SanJuan Water Master
Shiprock Plant	NM0020621	36.79	-108.71	1	EPA PCS
City Of Bloomfield	NM0020770	36.71	-107.95	0.9	SanJuan Water Master
Central Consolidated School District	NM0029319	36.71	-107.83	0.075	EPA PCS
Mcgee Park Wastewater Facility	NM0030473	36.69	-108.10	0.05	EPA PCS

Appendix B: WARMF Calibration

Animas River above Farmington Glade

The calibration at Animas River above Farmington Glade yielded a very good match between simulated and observed flows. The model was able to simulate well under different flow conditions (e.g. high flow during 1993 and low flow during 1991; Figure B.1). The correlation between simulated and observed flows is high (0.977; Figure B.2). The simulated frequency and cumulative flow distributions also matched well with the observed distributions (Figure B.3, B.4).

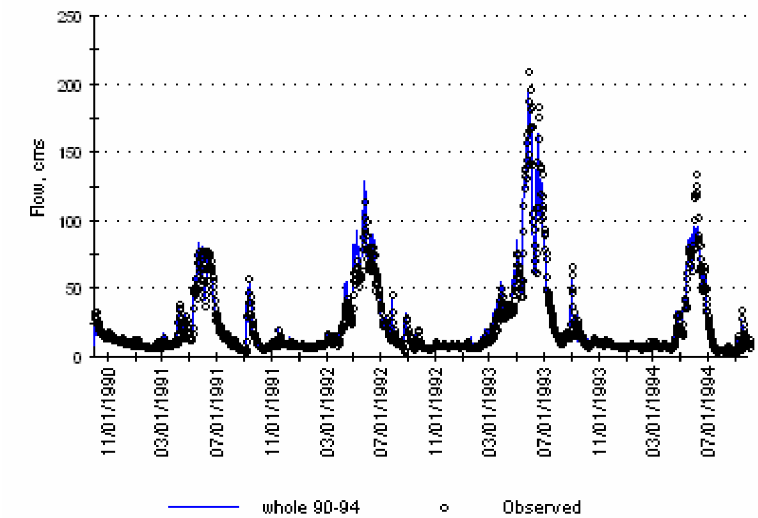

Figure B.1. Time Series of Simulated and Observed flows of Animas River above Farmington Glade

	whole 90-94	Observed
Mean	24.15	24.2
Minimum	1.999	3.115
Maximum	194.6	209.3
# Compare Pts	1461	1461
Relative Error	-0.0461	0
Absolute Error	2.399	0
RMS Error	4.47	0
r squared	0.977	1

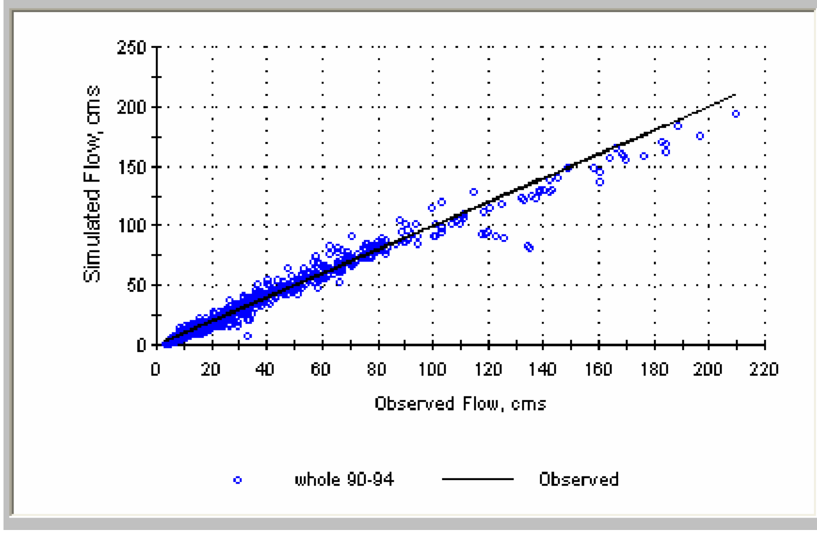

Figure B.2. Correlation Statistics of Simulated and Observed flows of Animas River above Farmington Glade

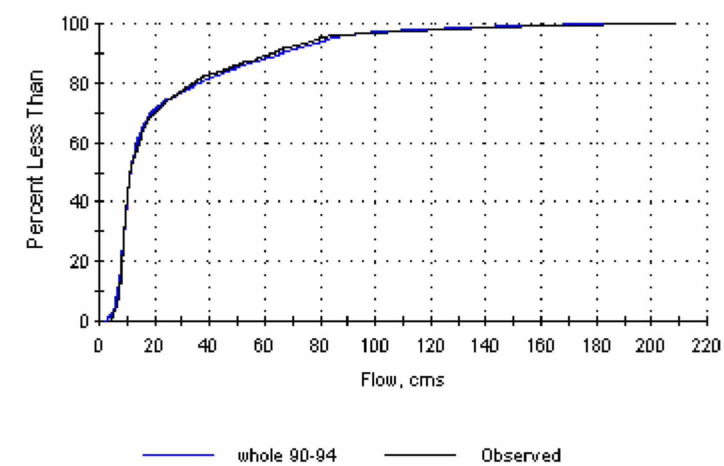

Figure B.3. Frequency Distribution of Simulated and Observed flows of Animas River above Farmington Glade

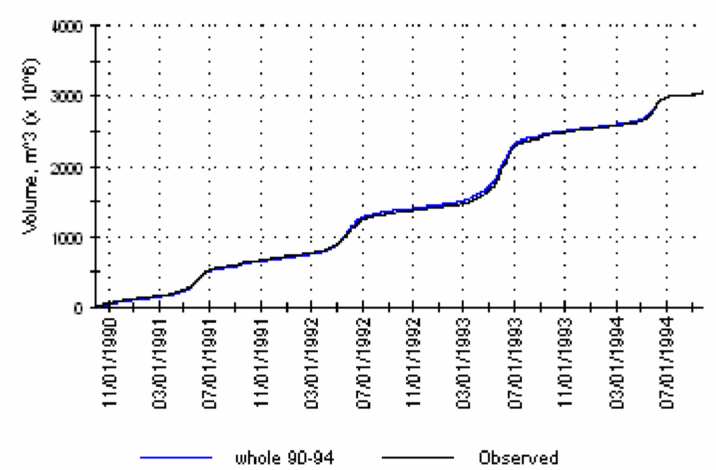

Figure B.4. Cumulative Curves of Simulated and Observed flows of Animas River above Farmington Glade

La Plata River at San Juan

The calibration at La Plata River showed the model generally captured the variation in flow condition (Figure B.5), simulating high flow during high flow period and low flow during low flow period. The model seemed to underpredict the peak flow and overpredict the low flow during several time periods. The discrepancy could be due to the uncertainty in meteorological data and diversion records. The correlation between simulated and observed flows is relatively high (0.776, Figure B.6). The frequency and cumulative distributions indicted overall the simulated flow is slightly larger than observed (Figure B.7, B.8).

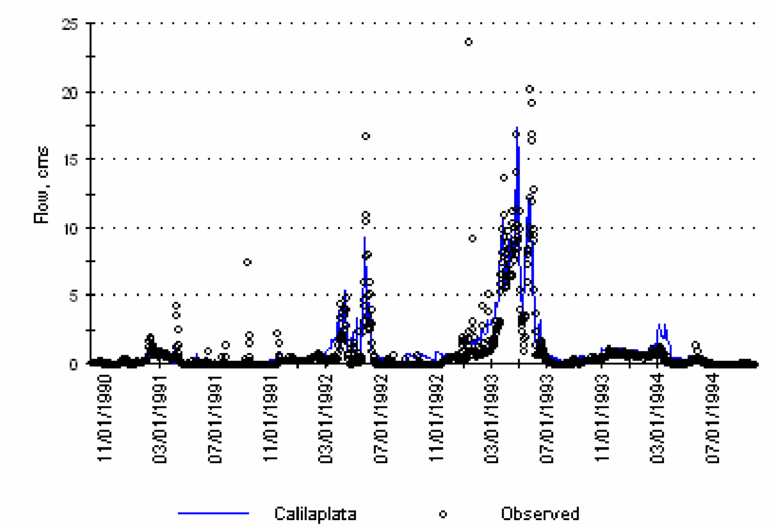

Figure B.5. Time Series of Simulated and Observed flows of La Plata River at San Juan.

	Calilaplata	Observed
Mean	1.057	0.918
Minimum	0	0
Maximum	17.39	23.76
# Compare Pts	1461	1461
Relative Error	0.139	0
Absolute Error	0.453	0
RMS Error	1.081	0
r squared	0.776	1

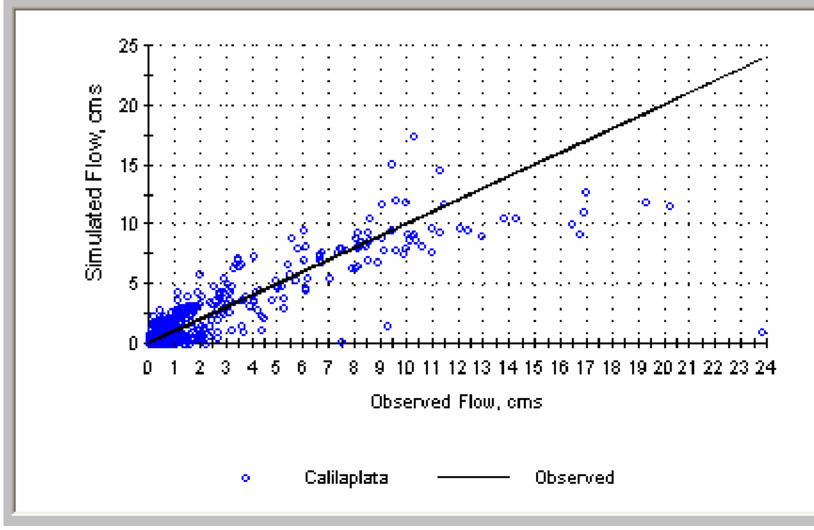

Figure B.6. Correlation Statistics of Simulated and Observed flows of La Plata River at San Juan.

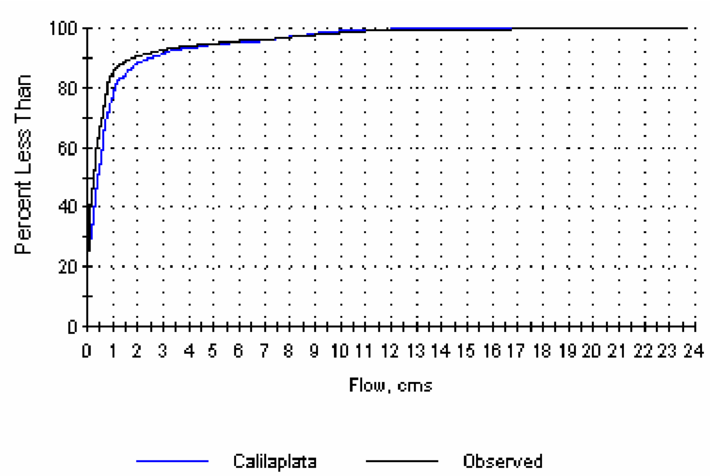

Figure B.7. Frequency Distribution of Simulated and Observed flows of La Plata River at San Juan.

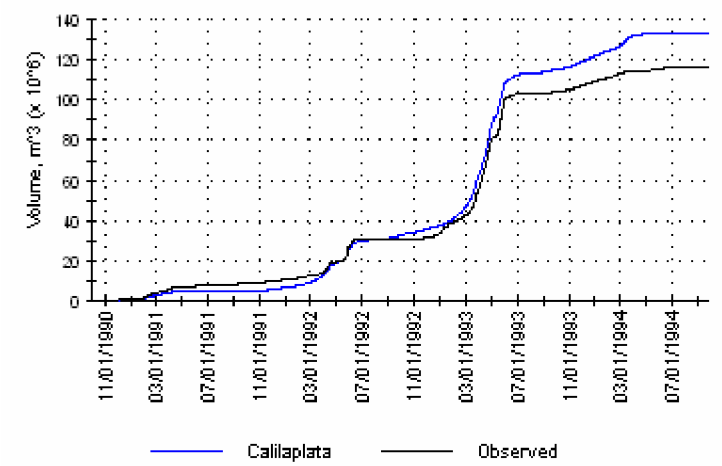

Figure B.8. Cumulative Curves of Simulated and Observed flows of La Plata River at San Juan.

San Juan River at Farmington

The flow in San Juan River downstream of Navajo Reservoir is highly regulated by Navajo Reservoir release, with additional modification from several tributaries (e.g. Animas River), ditches and point sources. Therefore the model is able to simulate flow in San Juan River well. The simulated time series of flow showed a very good match with the observed pattern (Figure B.9). High correlation is found between simulated and observed flow (0.98, Figure B.10). The frequency distributions of flow also showed the good match (Figure B.11), however the cumulative distributions indicated simulated flow is slightly larger than observed (Figure B.12).

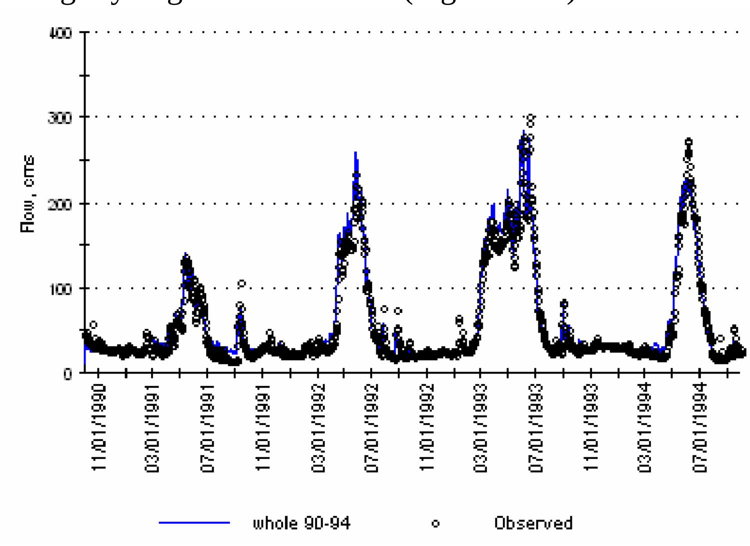

Figure B.9. Time Series of Simulated and Observed flows of San Juan River at Farmington.

	whole 90-94	whole 84-04	Observed
Mean	59.94		57.52
Minimum	11.76		13.39
Maximum	284		300.2
# Compare Pts	1461		1461
Relative Error	2.419		0
Absolute Error	5.91		0
RMS Error	8.829		0
r squared	0.98		1

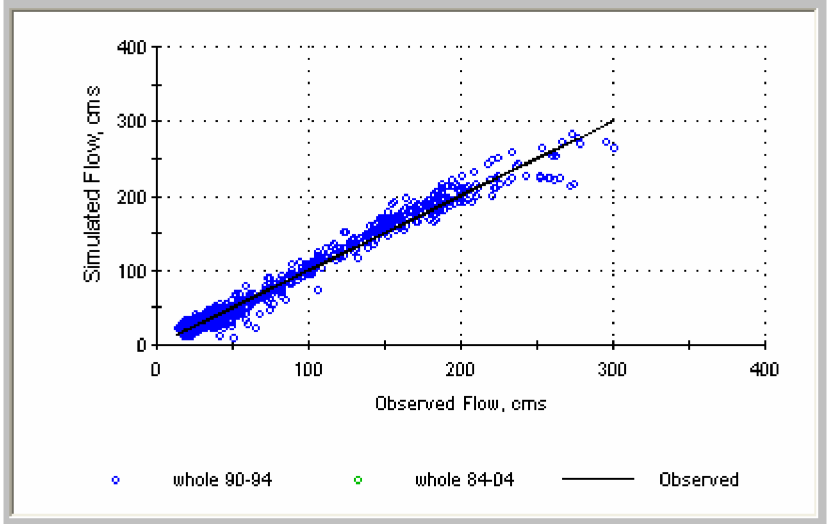

Figure B.10. Correlation Statistics of Simulated and Observed Flows of San Juan River at Farmington.

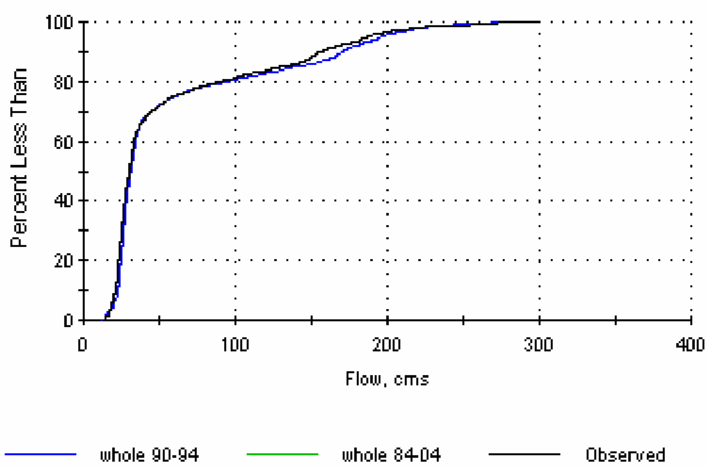

Figure B.11. Frequency Distribution of Simulated and Observed Flows of San Juan River at Farmington.

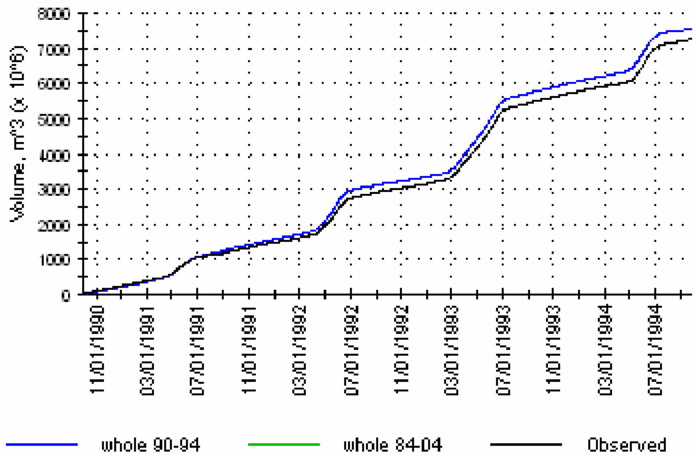

Figure B.12. Cumulative Curves of Simulated and Observed Flows of San Juan River at Farmington.

San Juan River at Shiprock

Similarly the flow in San Juan River at Shiprock is influenced by Navajo Reservoir release with additional influence from several tributaries, ditches and point sources. Therefore the simulated flow in San Juan River at Shiprock also compared very well with the observed values (Figure B.13-B.16).

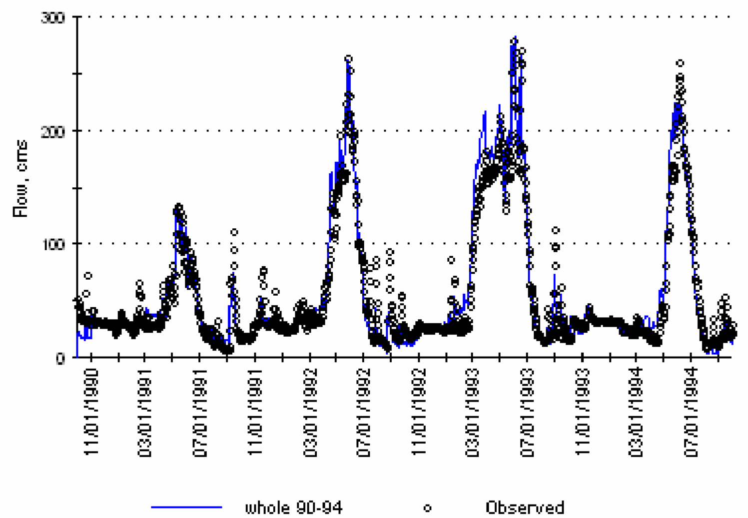

Figure B.13. Time Series of Simulated and Observed Flows of San Juan River at Shiprock.

	whole 90-94	whole 84-04	Observed
Mean	58.01		57.06
Minimum	0.744		7.306
Maximum	282.1		278.4
# Compare Pts	1461		1461
Relative Error	0.954		0
Absolute Error	8.423		0
RMS Error	12.42		0
r squared	0.962		1

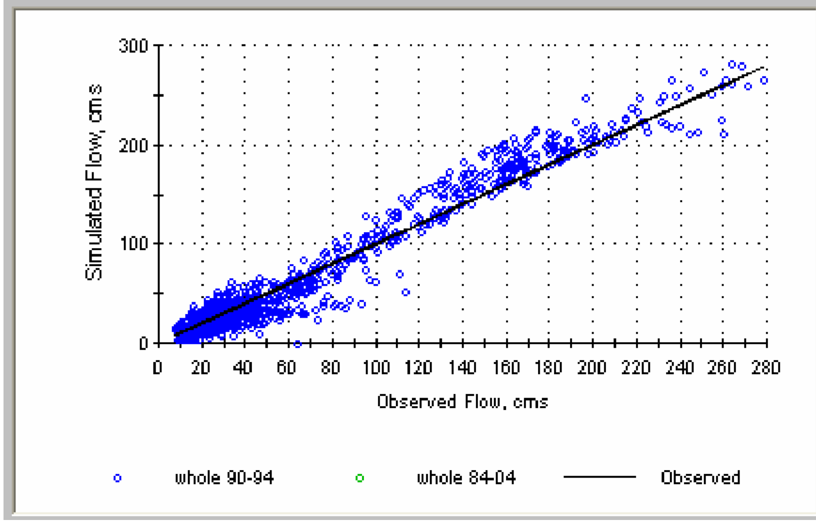

Figure B.14. Correlation Statistics of Simulated and Observed Flows of San Juan River at Shiprock.

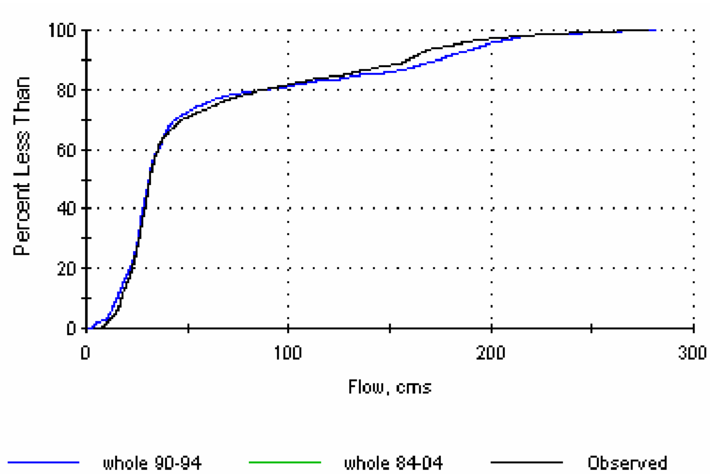

Figure B.15. Frequency Distribution of Simulated and Observed Flows of San Juan River at Shiprock.

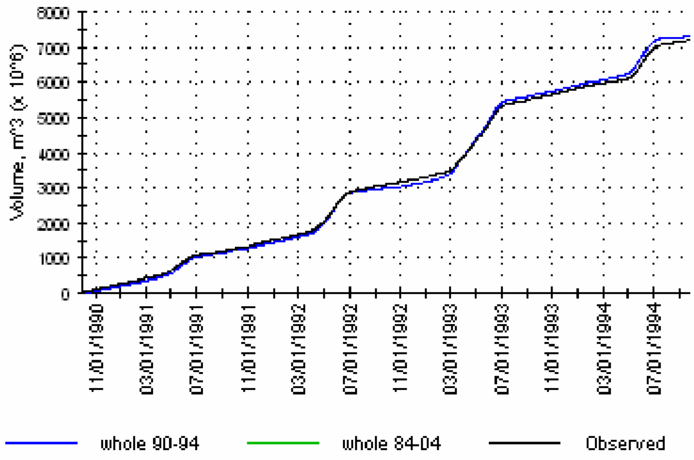

Figure B.16. Cumulative Curves of Simulated and Observed Flows of San Juan River at Shiprock.

Appendix C: WARMF Verification

Animas River above Farmington Glade

Figure C.1 shows the simulated time series of flow compared to the observed values during the simulation period of 10/1984-9/2004. The model generally captured the variations in flow conditions very well with only several departures from the observed values (e.g. the simulated peak in 1995 and 2003). These discrepancies could be due to the uncertainties in meteorological data. The three types of statistical measure for the simulated results also showed very good matches with the observed values for the whole simulation period (Figure C.2-C.4).

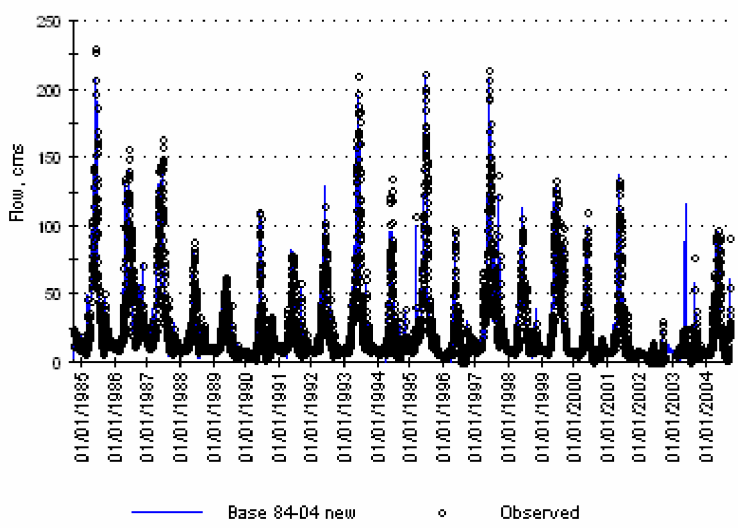

Figure C.1. Time Series of Simulated and Observed Flows of Animas River above Farmington Glade during 10/1984-9/2004.

	Base 84-04 new	Observed
Mean	23.74	24.11
Minimum	0	0
Maximum	209.1	229.7
# Compare Pts	7188	7188
Relative Error	-0.0972	0
Absolute Error	2.759	0
RMS Error	5.054	0
r squared	0.971	1

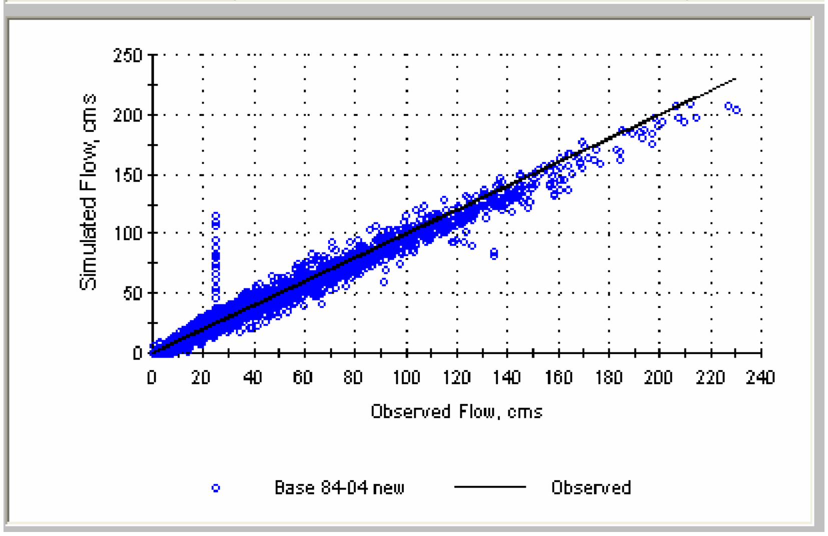

Figure C.2. Correlation Statistics of Simulated and Observed Flows of Animas River above Farmington Glade during 10/1984-9/2004.

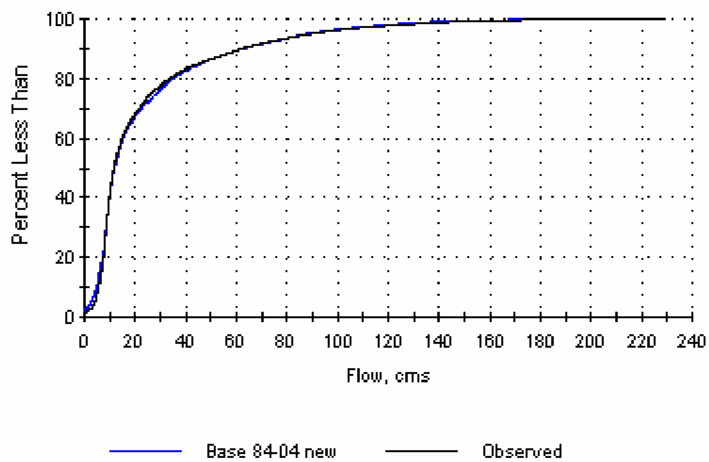

Figure C.3. Frequency Distribution of Simulated and Observed Flows of Animas River above Farmington Glade during 10/1984-9/2004.

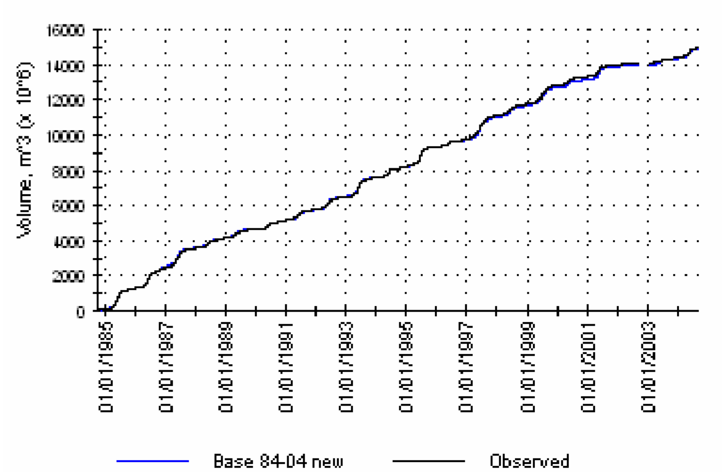

Figure C.4. Cumulative Curves of Simulated and Observed Flows of Animas River above Farmington Glade during 10/1984-9/2004.

The more detailed comparison of simulated versus observed flow for three representative wet, normal and dry years also suggested the model performed well simulating flow under all three climate conditions (Figure C.5–C.7).

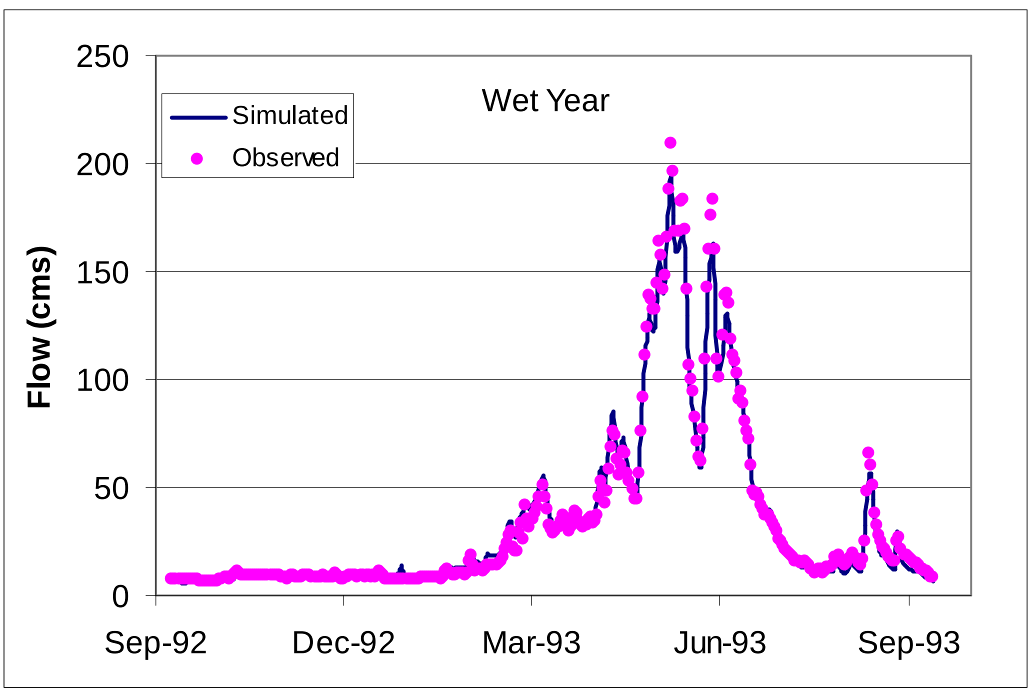

Figure C.5. Simulated and observed stream flow of Animas River at Farmington during a wet year (1993).

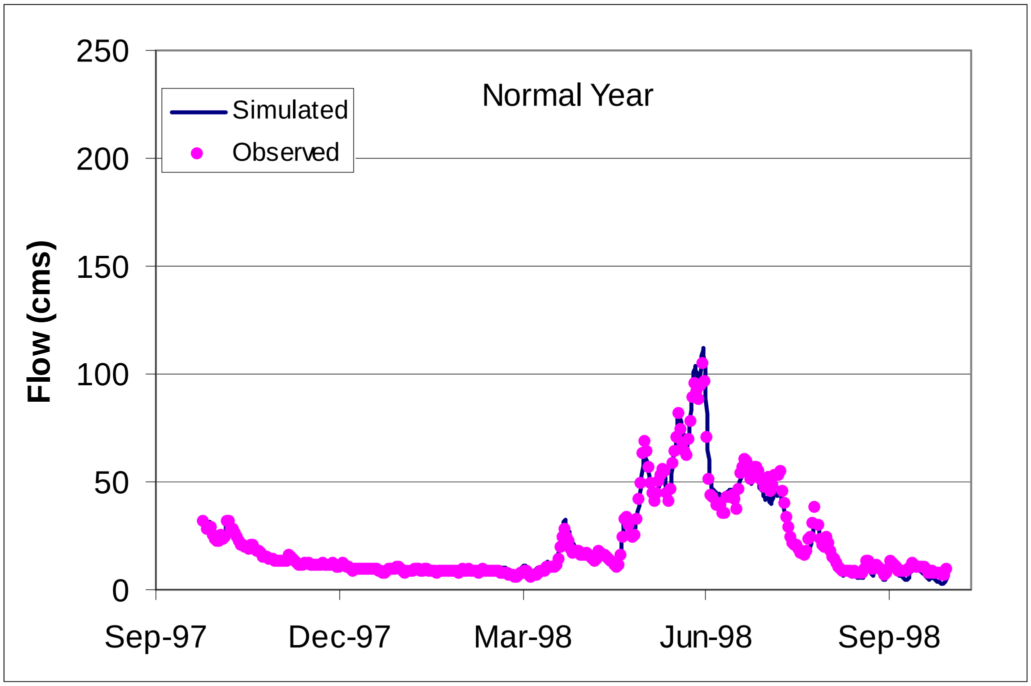

Figure C.6. Simulated and observed stream flow of Animas River at Farmington during a normal year (1998).

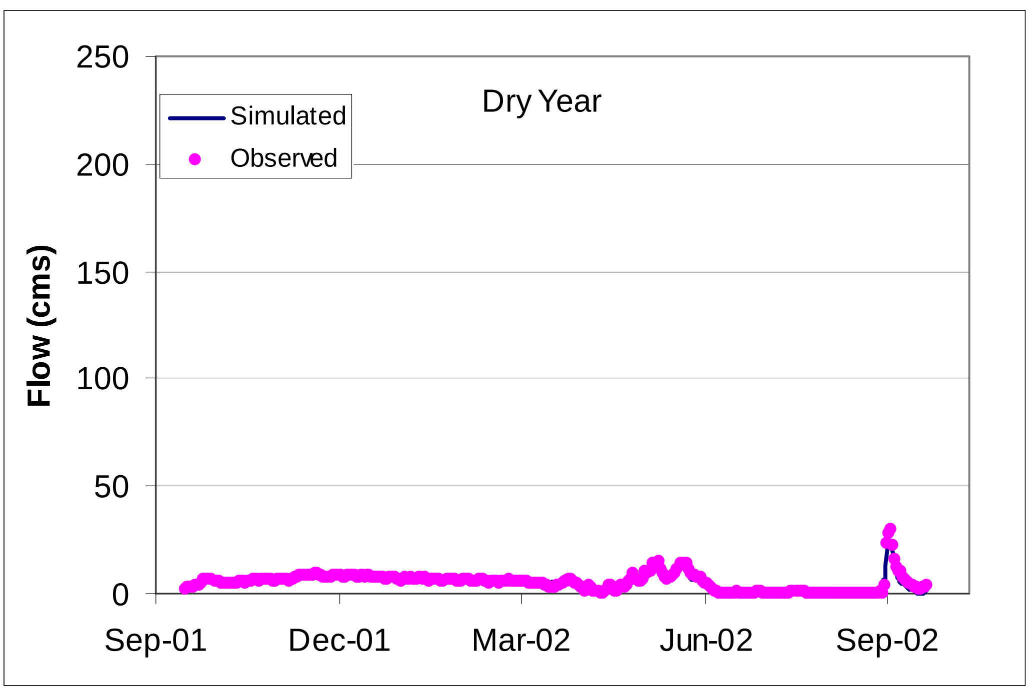

Figure C.7. Simulated and observed stream flow of Animas River at Farmington during a dry year (2002).

San Juan River at Farmington

Model simulated time series of flow of San Juan River at Farmington also compared well with observed values for the period of 10/1984-9/2004 (Figure C.8), capturing the flow both under high and low flow periods. The model however did over predict the peak in flow at several occasions (e.g. 1992, 2000 and 2001) and under predict at several occasions (e.g. 1999) as well. The three types of statistical measure for the simulated results again showed very good matches with the observed values for the whole simulation period (Figure C.9-C.11). The more detailed comparison of simulated versus observed flow under three climate conditions of wet, normal and dry condition also suggested the model generally performed well under all three climate conditions (Figure C.12-C.14). Note the model slightly under predicted the peakflow in 1999 (normal year, Figure C.13). The simulated flow in the Animas River (the biggest tributary for this segment of San Juan River) for 1999 agreed well with observed values. Therefore the discrepancy should be resulted from the underprediction from other smaller tributaries upstream.

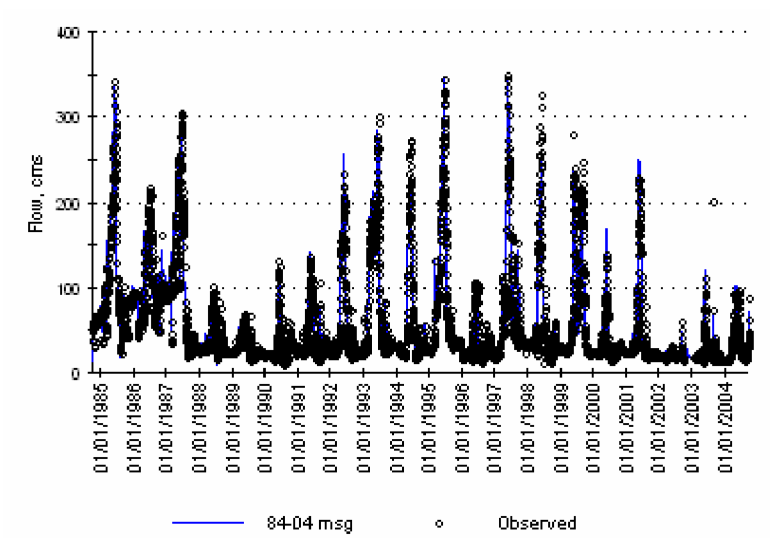

Figure C.8. Time Series of Simulated and Observed Flows of San Juan River at Farmington during 10/1984-9/2004.

	84-04	Observed
Mean	55.67	56.08
Minimum	8.245	9.288
Maximum	345	348.3
# Compare Pts	7172	7172
Relative Error	0.287	0
Absolute Error	5.774	0
RMS Error	9.567	0
r squared	0.972	1

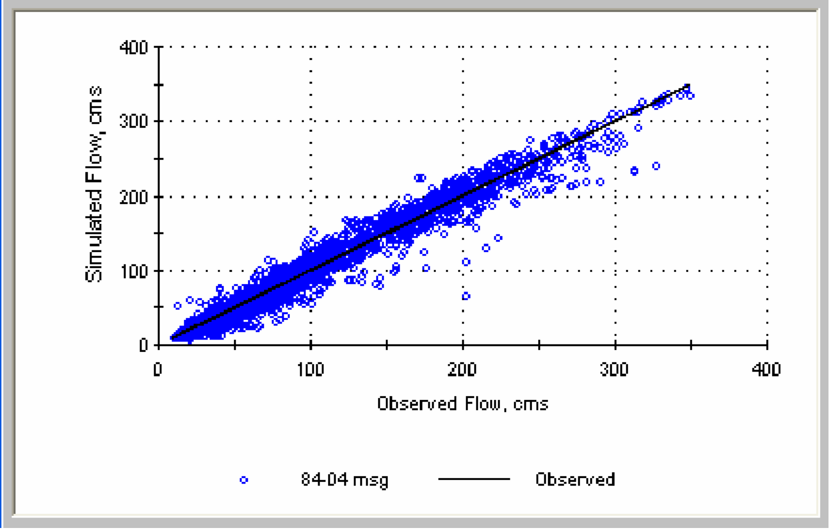

Figure C.9. Correlation Statistics of Simulated and Observed Flows of San Juan River at Farmington during 10/1984-9/2004.

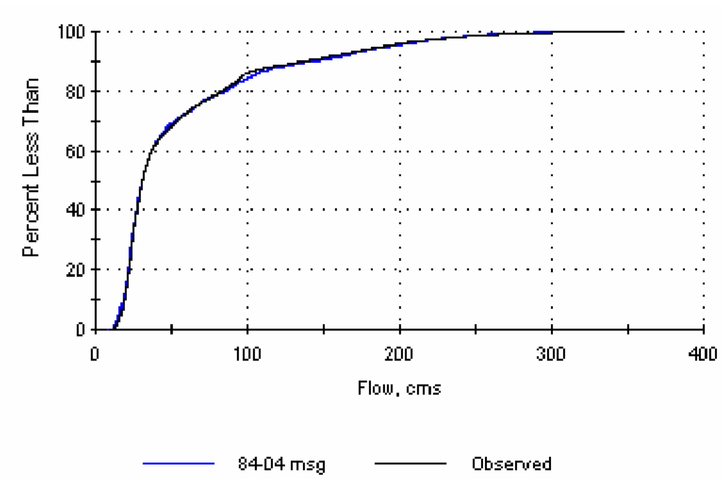

Figure C.10. Frequency Distribution of Simulated and Observed Flows of San Juan River at Farmington during 10/1984-9/2004.

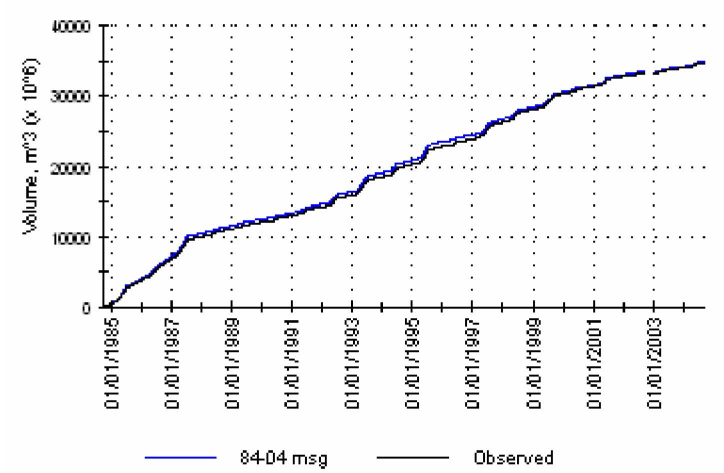

Figure C.11. Cumulative Curves of Simulated and Observed Flows of San Juan River at Farmington during 10/1984-9/2004.

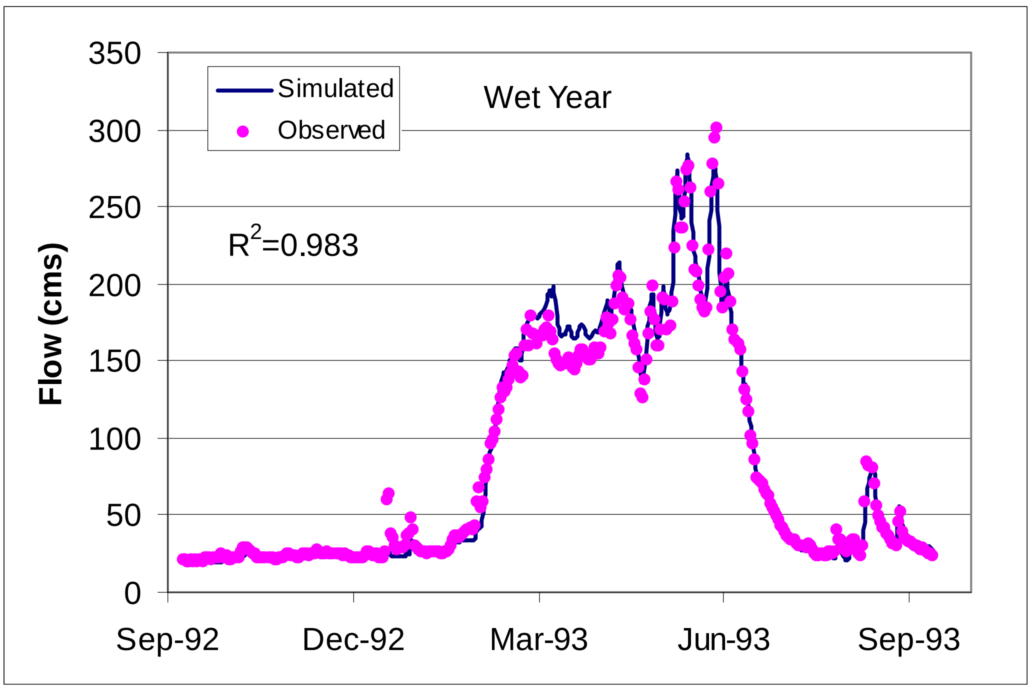

Figure C.12. Simulated and observed stream flow of San Juan River at Farmington during a wet year (1993).

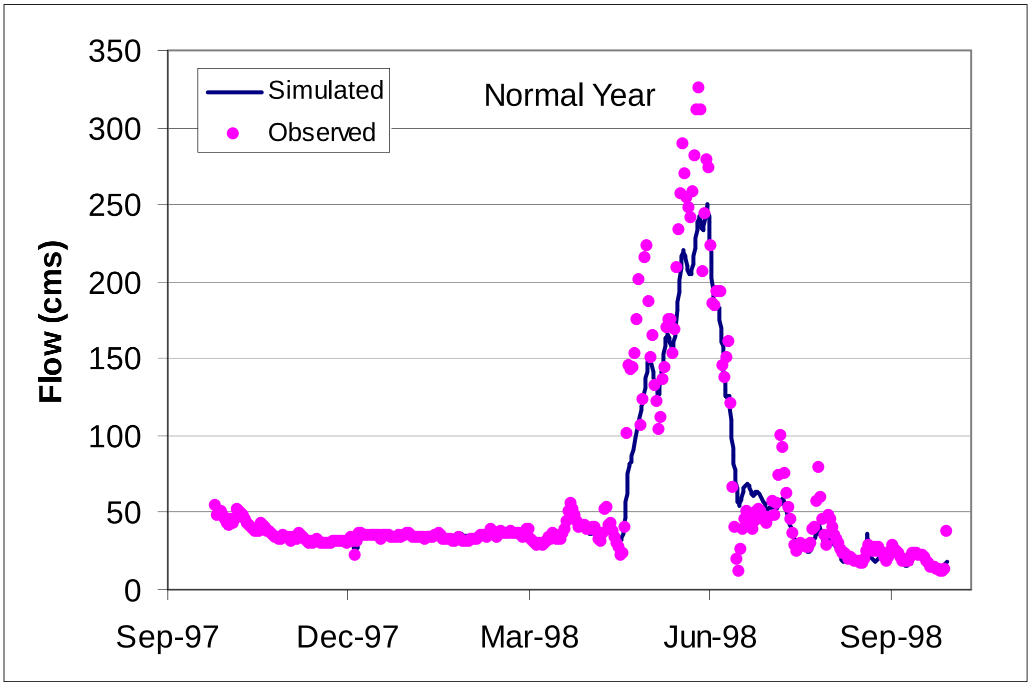

Figure C.13. Simulated and observed stream flow of San Juan River at Farmington during a normal year (1998).

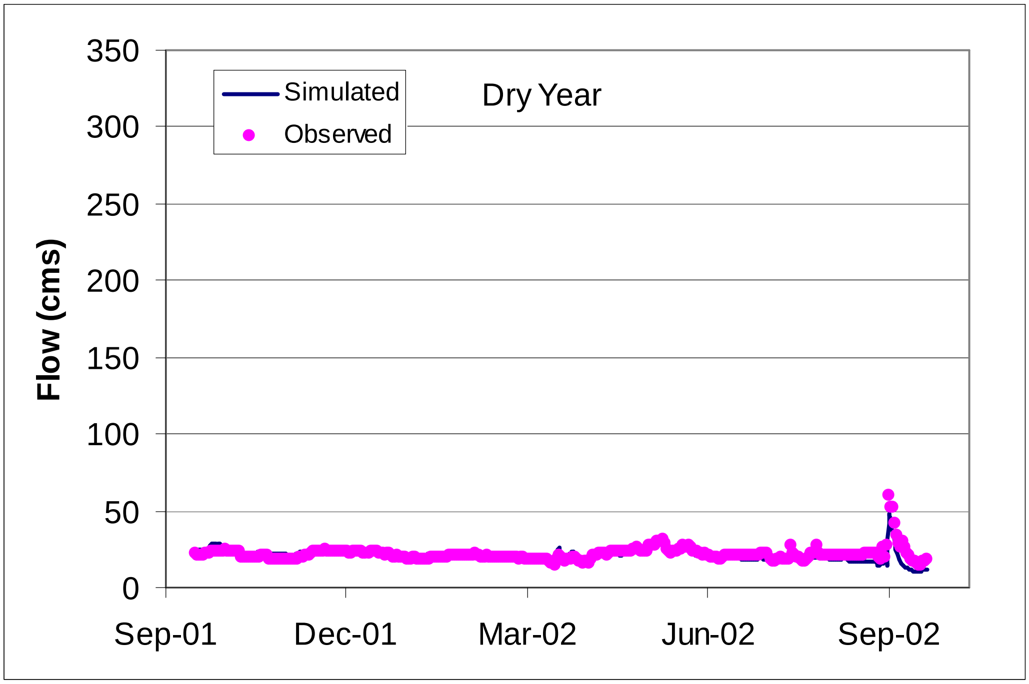

Figure C.14. Simulated and observed stream flow of San Juan River at Farmington during a dry year (2002).

San Juan River at Shiprock

Simulated time series of flow of San Juan River at Shiprock similarly compared well with observed values for the period of 10/1984-9/2004 (Figure C.15), although the model again over predicted the peak flow at several occasions (e.g. 1998, 1999 and 2000). The statistical measures also suggested good agreement between model simulation and observed values (Figure C.16-C.18). The model was able to reproduce flow under different climate conditions of wet, normal and dry conditions (Figure C.19-C.21). The model however underpredicted several flow peaks in September, which might be a result of uncertainties in the precipitation data.

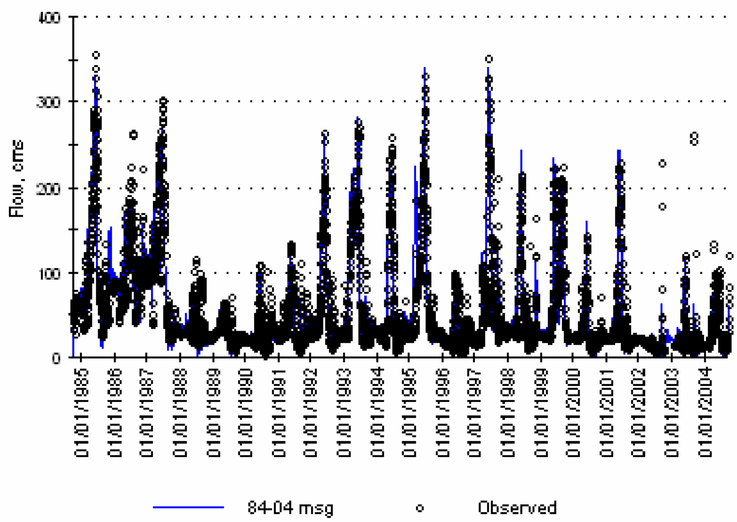

Figure C.15. Time Series of Simulated and Observed Flows of San Juan River at Shiprock during 10/1984-9/2004.

	84-04	Observed
Mean	53.96	54.15
Minimum	0.802	3.087
Maximum	340.8	356.8
# Compare Pts	7164	7164
Relative Error	0.501	0
Absolute Error	9.337	0
RMS Error	16.67	0
r squared	0.919	1

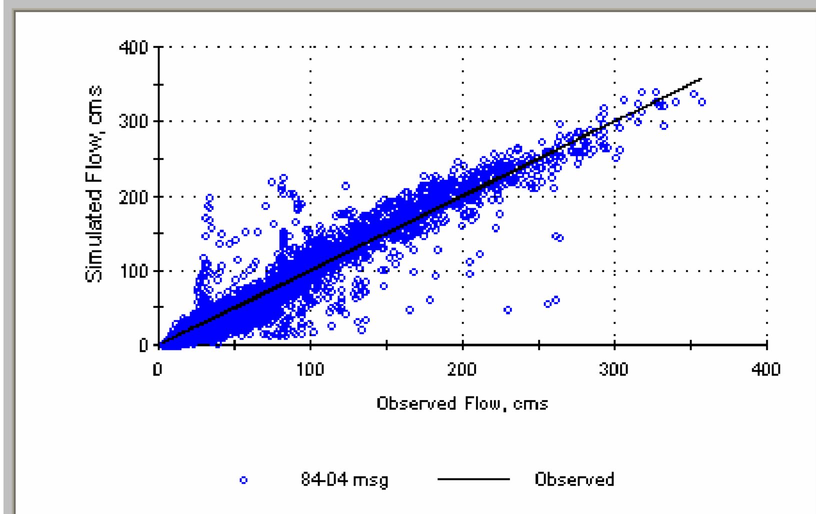

Figure C.16. Correlation Statistics of Simulated and Observed Flows of San Juan River at Shiprock during 10/1984-9/2004.

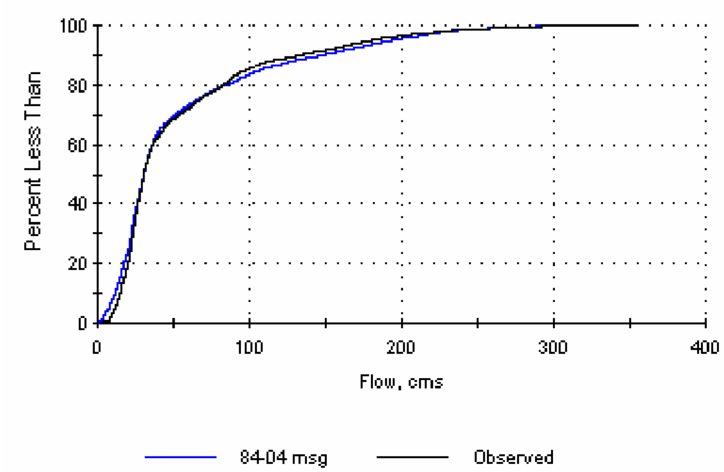

Figure C.17. Frequency Distribution of Simulated and Observed Flows of San Juan River at Shiprock during 10/1984-9/2004.

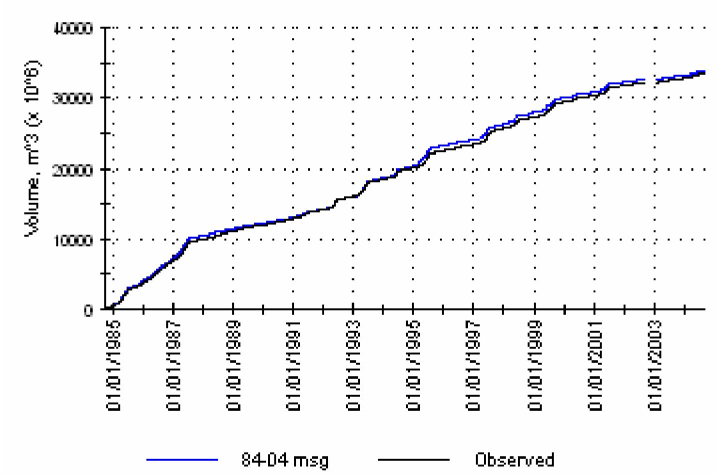

Figure C.18. Cumulative Curves of Simulated and Observed Flows of San Juan River at Shiprock during 10/1984-9/2004.

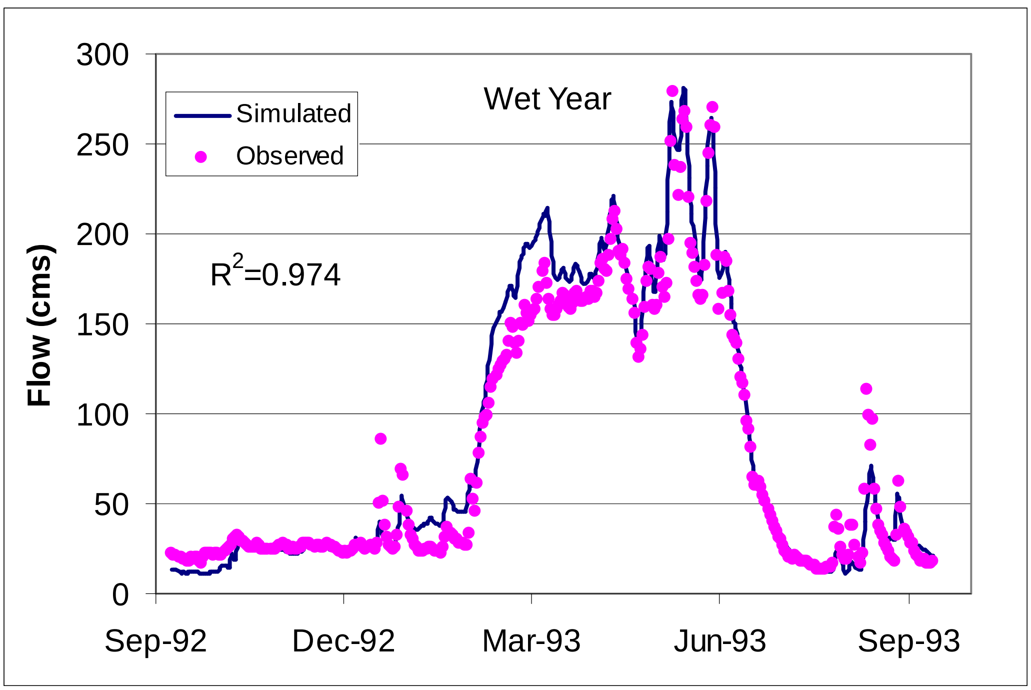

Figure C.19. Simulated and observed stream flow of San Juan River at Shiprock during a wet year (1993).

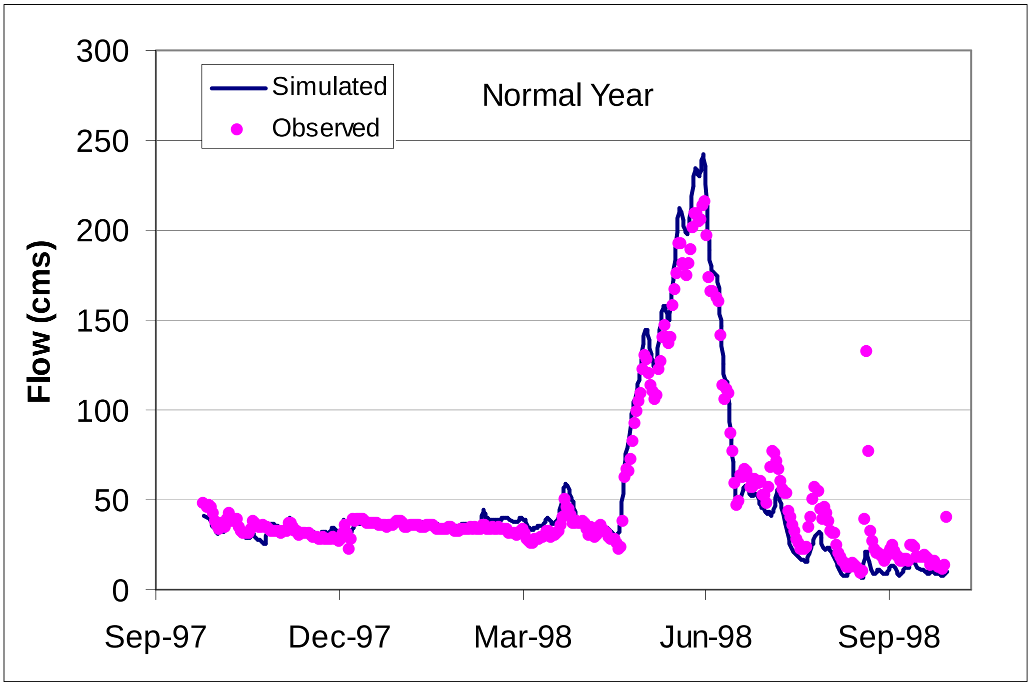

Figure C.20. Simulated and observed stream flow of San Juan River at Shiprock during a normal year (1998).

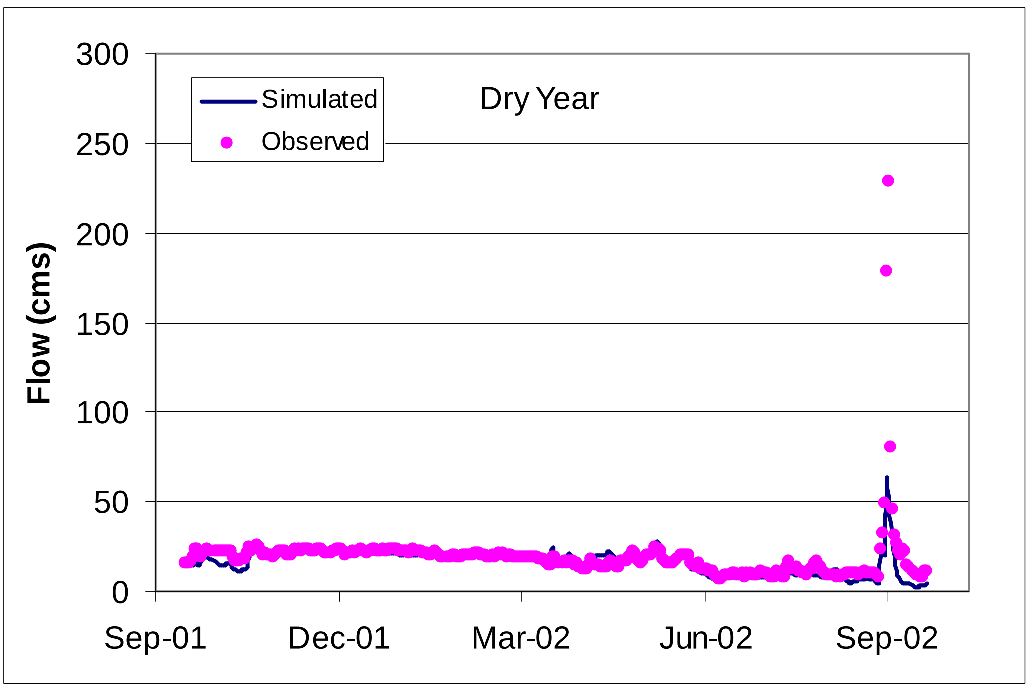

Figure C.21. Simulated and observed stream flow of San Juan River at Shiprock during a dry year (2002).