APPENDIX J
FLO-2D AND SURFACE WATER/GROUNDWATER MODEL

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FLO-2D Flood Routing Supporting URGWOPS

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June 2004

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1.0 FLO-2D Flood Routing for URGWOPS

1.1 Introduction

FLO-2D flood routing models for the Middle Rio Grande have been evolving since the first application of the model to the Isleta reach in 1997. The model development has involved the cooperation, support and funding from a number of agencies including the U.S. Fish and Wildlife Service, the Albuquerque District of the Corps of Engineers, the Bureau of Reclamation and the New Mexico Interstate Stream Commission (ISC). Initial applications of the model focused on specific reaches of the Rio Grande including the San Acacia to San Marcial reach, the Isleta Reach from the Isleta diversion to Belen, and the Corps' application to the Rio Bravo bridge reach. As these applications were reviewed and the Upper Rio Grande Water Operations Review (Review) began in earnest, the benefits of having complete, reach based, flood routing models became more apparent.

In support of the Review, three FLO-2D models have been developed. The first of the three, known as the Middle Rio Grande (MRG) FLO-2D Model, extends from Cochiti Dam to the San Marcial Railroad Bridge. The next model developed, also on the Rio Grande, extends from the Highway 285 Bridge, just north of the Rio Grande / Rio Chama confluence, to the Headwaters of Cochiti Reservoir. Both of these models predict discharge hydrographs for approximately every 500-ft of channel and compute overbank flood inundation. The third, and most recently developed FLO-2D model, is on the Rio Chama extending from below Abiquiu Dam to the confluence with the Rio Grande. This model computes overbank flood inundation and predicts discharge hydrographs for approximately every 200 ft of channel.

From Cochiti Dam to Elephant Butte Reservoir, the Middle Rio Grande (MRG) is about 173 miles in length. In establishing the grid system for this reach, as well as the other two reaches, it was necessary to balance spatial resolution with model run time. The factors in choosing a grid element size include the number of grid elements, discharge flux, floodplain surface area, digital terrain model (DTM) resolution, cross section spacing and desired flood area resolution. For the two Rio Grande models a 500-ft grid system was selected. The MRG model consists of 29,998 elements with 1,637 channel elements and the Above Cochiti model has 3,685 elements with 312 channel elements. For the Rio Chama model a 200-ft grid system consisting of 16,284 elements with 721 channel elements was selected. The smaller grid element size for the Chama model was implemented largely due to recent improvements in computer processor speeds as well as, recent efficiencies implemented in FLO-2D pre- and post-processor programs.

The FLO-2D program enhancements include processor programs to facilitate modifying the grid element attributes. These are a graphical working environment (FLOENVIR), grid developer system (GDS) and an inundation map display program (MAPPER). The GDS was created to generate grid systems from DTM points and assign elevations to the grid elements based on a user prescribed numerical filters. The FLOENVIR was designed to graphically edit the large data bases involving the floodplain roughness, infiltration and levees. To display the maximum flood depths and velocities, the water surface elevations and maximum area of inundation, the MAPPER program was developed to plot line contours and shaded contours. The Mapper contour plots are saved as shape files that can be imported into ArcView.

Spatial variable data for the Middle Rio Grande and its floodplain include a wide array of topographical, geomorphological, biological and hydrographical data sets. The available data includes detailed digital terrain models, topographic mapping, controlled aerial photography, field survey data such as river cross sections, geologic data such as floodplain alluvium and processed/interpreted data such as vegetation mapping. These data bases have been incorporated into the FLO-2D data input files.

While the Rio Grande FLO-2D models have relatively large grid elements, they are sufficiently detailed and accurate to conduct hydrograph flood routing and flood inundation analysis in support of the Review. The model will provide accurate estimates of in-channel discharge, area of inundation and water surface elevations. Estimated water losses include free surface water evaporation and infiltration seepage from the channel and floodplain. This report discusses model development, calibration and assumptions used in the application of the models supporting the Review.

1.2 FLO-2D Model Description

FLO-2D is a simple volume conservation, two-dimensional flood routing model that distributes a flood hydrograph over a system of square grid element (tiles). It can be a valuable tool for delineating flood hazards, regulating floodplain zoning or designing flood mitigation. FLO-2D numerically routes a flood hydrograph while predicting the area of inundation and simulating floodwave attenuation. The model is effective for analyzing river overbank flows, but it can also be used to analyze unconventional flooding problems such as unconfined flows over complex alluvial fan topography and roughness, split channel flows, mud/debris flows and urban flooding.

Starting with a basic overland flood scenario, details can be added to the simulation by turning on or off switches for various components. Multiple flood hydrographs can be introduced to the system at any number of inflow points either as a floodplain or channel flow. As the floodwave moves over the floodplain or down channels, flow over adverse slopes, floodwave attenuation, ponding and backwater effects can be simulated.

Channel flow is simulated one-dimensionally with the channel geometry represented by either by natural shaped, rectangular or trapezoidal cross sections. For the three models used to support the Review natural shaped cross sections have been used. Secondary currents, superevelation in bends and vertical velocity distribution are not computed by the channel component. Local flow hydraulics such as hydraulic jumps and flow around bridge piers are also not simulated with the model. FLO-2D does not distinguish between subcritical and supercritical flow because the momentum equation is used in the flood routing and it has no restrictions when computing the transition between the flow regimes. Overland flow is modeled two-dimensionally as sheet flow. Channel overbank flow is computed when the channel capacity is exceeded. An interface routine calculates the channel to floodplain discharge exchange including return flow to the channel. Once the flow overtops the channel, it will disperse to other overland grid elements based on topography, roughness and obstructions.

The two-dimensional representation of the equations of motion in FLO-2D is better defined as a quasi two-dimensional model using a square finite difference grid system. The equation of motion is solved by computing the average flow velocity across a grid element boundary one direction at a time. There are eight potential flow directions, the four compass directions (north, east, south and west) and the four diagonal directions (northeast, southeast, southwest and northwest). Each velocity computation is essentially one-dimensional in nature and is solved independently of the other seven directions. The individual pressure, friction, convective and local acceleration components in the momentum equation are retained. More discussion of model solution and constitutive equations is presented in the FLO-2D Manual which can be downloaded at the FLO-2D website.

The differential form of the continuity and momentum equations in the FLO-2D model is solved with a central, finite difference scheme. This explicit algorithm solves the momentum equation for the flow velocity across the grid element boundary one element at a time. Explicit numerical schemes are simple to formulate but usually are limited to small timesteps by strict numerical stability criteria. Finite difference explicit numerical schemes require significant computational time when simulating complex flow hydraulics such as fast rising flood waves, channels with non-prismatic features, abrupt changes in slope, tributaries or split flow and ponded flow areas.

The solution domain is discretized into uniform, square grid elements. The computational procedure for overland flows involves calculating the discharge across each of the boundaries in the eight potential flow directions. Each grid element hydraulic computation begins with an estimate of the linear flow depth at the grid element boundary. The estimated boundary flow depth is an average of the flow depths in the two grid elements that will be sharing discharge in one of the eight directions. Although a number of non-linear estimates of the boundary depth were attempted in earlier versions of the model, they did not significantly enhance or improve the results. The other hydraulic parameters are also averaged to compute the flow velocity including flow resistance (Manning's n-value), flow area, slope, water surface elevation and wetted perimeter.

The floodplain flow velocity at the boundary is the dependent variable. FLO-2D will solve either the diffusive wave momentum equation or the full dynamic wave momentum equation to compute the velocity. Manning's equation is then applied in one direction using the average difference in the water surface slope to compute the velocity. If the diffusive wave equation is selected, the velocity is then computed for all eight potential flow directions for each grid element. If the full dynamic wave momentum equation option is applied, the computed diffusive wave velocity is used as the first approximation (the seed velocity) in the Newton-Raphson second order method of tangents for determining the roots of the full dynamic wave equation which is a second order, non-linear, partial differential equation. The local acceleration term is the difference in the velocity for the given flow direction over the previous timestep. The convective acceleration term is evaluated as the difference in the flow velocity across the grid element from the previous timestep. For the FLO2-D models used to support the Review the full dynamic wave momentum equation is applied for all simulations.

FLO-2D is on FEMA's list of approved hydraulic models for riverine and unconfined alluvial fan flood studies. It has been used by a number of federal agencies including the Corps of Engineers, Bureau of Reclamation, USGS, NRCS, Fish and Wildlife Service and the National Park Service. It has been used on hundreds of projects by consultants worldwide. Current model and processor program updates and other modeling information can be found at the website: www.flo2d.com.

1.3 FLO-2D Model Development

1.3.1 FLO-2D Data Base

A partial listing of the agencies and institutions that have acquired or developed spatial data sets for the Middle Rio Grande corridor are listed in **Table J-1**. The Corps of Engineers (Corps), Bureau of Reclamation (BOR), U.S. Geological Survey (USGS) and the New Mexico Interstate Stream Commission (ISC) are the primary agencies responsible for compiling MRG water resource data. **Table J-2** lists the name and contact information for the three mapping consulting firms in Albuquerque that have acquired most of the source photography and topographic data used in the production of the various spatial mapping products. During the past 10 years, it is likely that one of these firms produced the detailed, digital terrain model data and/or digital topographic mapping from low level controlled aerial photography that the FLO-2D grids have been built from. The Bureau of Reclamation and its hydrographic data collection contractors have acquired most of the field-surveyed river cross sectional data used in the models. Tetra Tech, Inc., (formally FLO Engineering) has been the primary hydrographic data collection contractor for Reclamation for the past 12 years. In addition, the Earth Data Analysis Center (EDAC), affiliated with the University of New Mexico, provides services in geospatial technologies. The EDAC clearinghouse provides users with numerous spatial data sets and/or corresponding metadata.

Table J-1. Agencies and Institutions with Spatial Data Resources

Agency/Organization	Contact	Telephone No.	General Information
Corps of Engineers Albuquerque District	Clay Mathers	505-342-3255	GIS Coordinator
	Alvin Toya	505-342-3337	Mapping Coordinator
	Bruce Beach	505-342-3331	H & H Data
Bureau of Reclamation Albuquerque Office	Kristi Smith	505-465-3631	River Cross-Sections
	Robert Padilla	505-465-3626	H & H Data
Bureau of Reclamation Denver, TSC	Debra Callahan	303-445-3645	GIS Data
	Travis Bauer	303-445-3672	River Data
New Mexico State Engineers Office / Interstate Stream Commission	Gar Clark	505-827-6175	GIS Data
	Nabil Shafike	505-764-3868	H & H Data
Middle Rio Grande Conservancy District	Doug Stretch	505-247-0234	GIS Data
	David Ginsler		H & H Data
Fish and Wildlife Service Albuquerque Office	Mike Buntjer	505-346-2525	GIS / H & H Data
	Ric Riester		
University of New Mexico	Julie Coonrod	505-277-3233	H & H / GIS
	Mark Schmidt		
New Mexico Technological Institute	Rob Bowman	505-835-5992	H & H

Table J-2. Mapping Consulting Firms

Firm Name	Contact	Telephone No.
Bohannnan Huston, Inc	Dennis Sandin	505-823-1000
Thomas R. Mann & Associates	Tom Mann	505-266-7757
Pacific Western Technologies (formerly Koogle & Pouls Engineering)	Dick Coffey	505-294-5051
Tetra Tech, Inc	Doug Wolf Walt Kuhn	505-881-3188

On May 12, 1992, the BOR obtained aerial photography of the river and floodplain to document the area of inundation resulting from a “higher than normal” release from Cochiti Reservoir. The average daily discharge from this release was estimated to be approximately 7,000 cfs at the Albuquerque gage, about 5,700 cfs at San Acacia gage and 5,000 cfs at San Marcial gage. The visible area of inundation has been digitized from this photographic data set. This is one of the few data sets that are available for use in calibrating flood routing and hydraulic models in this reach of the Rio Grande. This data set was used in 1999 to calibrate the area of inundation predicted by the FLO-2D model between San Acacia and San Marcial, New Mexico. Calibration results indicated a high correlation between the FLO-2D predicted area of inundation and that estimated from the BOR aerial photography for equivalent predicted and measured discharges at San Acacia and San Marcial. This data set is now essentially obsolete because of channel narrowing, cross section changes, floodplain aggradation, and loss of channel conveyance capacity. Channel morphology changes since 1992 have been pronounced in this reach and are particularly significant south of the Highway 380 Bridge and specifically from Tiffany Junction to San Marcial.

1.3.2 DTM Data Base

To assemble the FLO-2D data files, voluminous topographic and cross section data were compiled. Initially the grid system was overlaid and assigned elevations based on digital topographic mapping that the Corps of Engineers and the Bureau of Reclamation had available. These digital terrain models (DTM) were developed, in some instances using photogrammetry (from aerial photography) and others using remotely sensed data (LIDAR) during the 1990's and early 2000's by the agencies. Through a combination of the various aerial surveys, contour maps with two-foot contours were developed and overlaid with a 500-ft grid system for the two Rio Grande FLO-2D models. Using Bently's SelectCADD InRoads software, each grid element was assigned a representative elevation and horizontal state-plane geometry (NM State Plane Central zone NAD 83 ft) coordinates. The Corps provided both ASCII data files and hard copies of the maps with the overlaid grid system. The same process was invoked for the Rio Chama Model, however a 200-ft grid system was used for this reach. **Table J-3** lists the DTM data sets that were used to create the FLO-2D grid systems for the three models supporting the Review.

Table J-3. DTM Data Sets used for FLO-2D Grid Development

Mapping Project	Extents	Brief Description
COE Mapping Reach6 (TRM for COE)	Rio Grande corridor - Cochiti Dam to North Bernalillo County Line	Digital mapping – 2' contour topography, CADD files, 2 ft natural color digital orthopotography – photogrammetry (2001)
Bernalillo County /AMAFCA Digital Mapping (BHI for COE)	Bernalillo County	Digital mapping – 2' contour topography, CADD files, 2 ft natural color digital orthopotography – LIDAR & photogrammetry (1999 –2000)
Belen Mapping (PWT for COE)	Rio Grande corridor & floodplain – Rio Bravo Bridge to Pipelines south of Belen	Digital mapping – 2' & 4' contour topography, CADD files, 2 ft B/W digital orthopotography – photogrammetry (1995)
COE Mapping Reach 7 (TRM for COE)	Rio Grande corridor & floodplain Railroad bridge south of Belen to Socorro Diversion Channel	LIDAR topography, 6 to 9 meter post spacing, No CADD files, 2 ft natural color digital orthopotography 1998-1999
Escondida to South Boundary BDA (PWT for COE, BOR,)	Rio Grande corridor – Escondida bridge to the South Boundary of Bosque del Apache NWR	1992 Agg/Deg Photography used to create digital mapping, No Cadd files, 2 ft B/W digital orthopotography - 1997
South Boundary BDA to EB 27 (PWT for BOR)	Rio Grande corridor and floodplain	Digital mapping – 2' contour topography, CADD files, 2 ft B/W digital orthopotography – photogrammetry (1997)
COE Mapping Reach 4 (TRM for COE)	Rio Grande corridor - Rio Chama confluence to Cochiti Reservoir headwaters	Digital mapping – 2' contour topography, No CADD files, 2 ft natural color digital orthopotography – photogrammetry (2000)
COE Mapping Reach 3 (TRM for COE)	Rio Chama corridor – Abiquiu Dam to Rio Grande confluence	Digital mapping – 2' contour topography, CADD files, 2 ft natural color digital

Table J-3. DTM Data Sets used for FLO-2D Grid Development

Mapping Project	Extents	Brief Description
		orthopotography – photogrammetry (2003)

When the FLO-2D Grid Development System (GDS) filters were developed in 2002 the DTM database was recompiled, re-projected, and parsed from the six different mapping efforts shown in **Table J-3**. Each DTM data set represented a specific reach of the Middle Rio Grande. The DTM data sets were originally compiled in various formats and had different reference elevation datums. The data sets were converted to a consistent datum (the New Mexico State Plane NAD 1983 horizontal and NAVD 1988 vertical reference). When necessary, the Corps of Engineers' software "Corpscon" was applied to rectify the data between different datums. The development of the GDS was an improvement over the use of an external CADD program to assign grid element elevations. CADD programs tended to overestimate the floodplain surface elevations by assigning the elevation of the surface directly over the center of grid element. The GDS DTM point filter scheme was designed to compute the average of DTM points after the high or low elevation DTM points within a prescribed radius of the grid element had been filtered out. The GDS was later used to re-assign grid element elevations to the entire MRG FLO-2D grid system. The Above Cochiti model and the Rio Chama model also have grid elevations derived using the GDS.

The resolution of the DTM data varies by reach. However, within the active floodplain for all three models the intent of the original mapping efforts was to have the aerial mapping contractors generate 2-ft contour interval digital mapping. This infers that, at worst, the points in the DTM data base files should be accurate within plus or minus one foot. Correspondingly, the FLO-2D water surface results should generally be considered to be accurate to plus or minus 1 foot. The reach from Belen to San Acacia diversion dam was collected using LIDAR techniques and did not have the same quality control as the photogrammetry methods used on the rest of the Middle Rio Grande floodplain.

For the MRG model the conglomeration of DTM data was imported into GDS and several filter scenarios were tested to determine the most appropriate filter scheme to use. The test objective was to apply the lowest representative floodplain elevation to the individual grid elements. One of the nine DTM files was imported to the GDS and the grid element elevations were assigned using the standard deviation as the maximum elevation limit filter, a two grid element radius and a minimum of 50 points. When the grid element elevations are assigned, statistics are computed for the number of DTM points within the prescribed filter radius. When applying a filter to the DTM data, the filter radius is expanded until the prescribed minimum number of DTM points is encountered. Based on the selected filter criteria, all the points greater the standard deviation or the prescribed maximum difference in elevation above the mean are discarded and the mean elevation is recomputed and assigned to the grid element. Various combinations of the maximum difference above the mean, the minimum number of points and the radius of influence were tested in an attempt to minimize the floodplain elevation. This was accomplished by comparing all the floodplain elevations in FPLAIN.DAT with the original standard deviation filter results. By summing all the differences in elevation between the grid elements in the two FPLAIN.DAT files, the lowest set of floodplain grid elevations could be determined. The best combination of filter criteria was the selection of maximum elevation difference of 1.0 ft above the mean elevation, a radius of 2 grid elements and 10 minimum points. This scheme provided the lowest floodplain elevation and was used to assign the remainder of the grid element elevations through the middle Rio Grande, Above Cochiti, and on the Rio Chama.

1.3.3 River Cross Section Data Base

Over 400 cross sections have been surveyed throughout the Middle Rio Grande from Cochiti Dam to Elephant Butte Reservoir. An additional 98 cross sections have been surveyed on the Rio Grande above Cochiti Reservoir. Finally, for the Rio Chama model 49 cross sections were established and surveyed in the spring of 2003. These new sections coupled with 18 sections that were surveyed in 2001 within the San Juan Pueblo comprise the cross section data base for the Chama model. Most of the Rio Grande cross sections were surveyed in conjunction with the Bureau of Reclamation's river maintenance program. For the past 10 years, the BOR and its hydrographic data collection contractors have surveyed the majority of these cross sections. Many of the cross sections are located in groups near specific project areas. When Cochiti Dam was under construction in the early 1970's, a series of cross sections were surveyed to monitor long term channel morphology changes. This set of cross sections is referred to as the Cochiti Lines and are labeled "CO" followed by a number. The first thirty-eight of these lines are numbered sequentially starting at 1 (which is actually within the pool at Cochiti). CO-38 is located upstream of the Interstate 25 Bridge over the Rio Grande just south of Albuquerque. From this location, the remainder of the CO-lines have increasing spacing and are numbered in accordance with Bureau's Aggradation – Degradation (Agg/Deg) Range Lines (e.g. CO-668). Most of the other cross sections within this reach have labels that refer to the nearby community such as Santa Domingo (SD), Isleta (IS), or Socorro (SO). For the most part, recently established lines follow the Agg/Deg numbering scheme. The sections above Cochiti reservoir have a similar naming scheme. The Rio Chama cross sections are named AB 1 through 48. The sections on the San Juan Pueblo are CH1 through CH-18. **Table J-4** provides a list of the cross section abbreviations.

The existing cross section end points have been monumented with rebar and cap and have an adjacent fence post, referred to as a 'tag-line post'. The location and elevation of the end points have been established with control surveys spatially referenced to the New Mexico State Plane Coordinate Grid System (NMSPCGS). All elevation data for the Rio Grande end points was initially referenced to the National Geodetic Vertical Datum (NGVD) of 1929. Subsequently this elevation data has been adjusted to the North American Vertical Datum (NAVD) of 1988 using the coordinate conversion software 'Corpscon'.

Table J-4. Cross Section Abbreviations

Line	Description
CO	Original Cochiti Lines, established in 1972, extend from Cochiti Dam to San Acacia
CI	Cochiti Lines (within and near Cochiti Pueblo (below dam))
SD	Santa Domingo Lines (within and near Santa Domingo Pueblo)
SFP	San Felipe Lines (within and near San Felipe Pueblo)
AR	Angostura Lines – near Angostura Diversion Dam
TA	Santa Ana Lines (within and near Santa Ana Pueblo)
BI	Bernalillo Island Lines – Near NM 44 bridge
BB	Below Bernalillo Lines – Below the village of Bernalillo
CR	Corrales Lines – Near Corrales
CA	Calabacillas Arroyo Lines - Near the confluence
A	Albuquerque Lines (between Bridge Blvd & Rio Bravo)
AQ	Proposed additional Albuquerque Lines (between Moñtano and Isleta diversion Dam)

Table J-4. Cross Section Abbreviations

Line	Description
IS	Isleta Lines (within and near Isleta Pueblo)
LL	Los Lunas Lines – Near Los Lunas restoration site
CC	Casa Colorado Lines
AH	Abeyta's Heading Lines
LJ	La Joya Lines – within and near La Joya Wildlife Refuge
RP	Rio Puerco Lines – Near the confluence
SA	San Acacia Lines – D/S of the diversion dam to ~ Socorro
SO	Socorro Lines – Socorro to the San Marcial RR bridge
FC	Fort Craig Lines – Below San Marcial RR bridge – near the old Fort Craig
EB	Elephant Butte Lines – Between the San Marcial RR bridge & the Reservoir
SI	San Idelfonso Lines
SC	Santa Clara Lines
AG	Arroyo Guachapange Lines
SR	Santa Cruz River Lines
VD	Vigil Ditch Lines
RC	Rio Chama Confluence Lines
EL	Espanola Lines
CH	Rio Chama Lines within San Juan Pueblo
AB	Rio Chama below Abiquiu Lines

All cross section point data within the three FLO-2D models are horizontally referenced to the NMSPCGS Central zone NAD 83 ft. All elevations are referenced to NAVD 88 ft.

Although the GDS now includes a low elevation filter, it did not initially have a filter for low floodplain elevations. Although DTM point elevations in canals and ditches can have an effect on the assigned floodplain elevations, these were generally ignored due to the relatively limited spatial extent of these features. More importantly, however, the river channel DTM point elevations in the data base collected at low river flow conditions could effect the river bank floodplain elevations. Along the river channel, floodplain grid elements may have been assigned low elevations. This may also occur where old channel features are located such as abandoned meander bends and oxbows. The grid element floodplain elevations along the river channel were reviewed. Elevations that appeared to be significantly lower (2 ft or more) than surrounding floodplain elevations (both inside and outside the levee system) were adjusted.

To further check the elevations along the river, a new output file CHANBANKEL.CHK was created that lists the difference between the grid element floodplain elevations and the cross section top of bank elevation when the difference is greater than 1 ft. A review of this file resulted in further adjustments in the grid element floodplain elevations. This file was also used to review cross section adjustments during model calibration. Changes to the grid element floodplain elevations were made with the FLOENVIR processor using the floodplain elevation editor.

High resolution flood routing and the prediction of overbank flood inundation require adequate cross section coverage. Ideally there would be a surveyed cross section for each of the channel elements within the FLO-2D models, but this would be cost prohibitive. There are 354 surveyed cross sections currently in the MRG FLO-2D model (**Table J-5**). These sections have been distributed to the 1,637 channel elements in the model. There is approximately one cross section for every four channel elements. In a few locations there are two or more surveyed cross sections within a 500 ft channel element. In this case, only one cross section can be assigned to the channel element. There are 9 LL-lines at the Los Lunas Restoration site (4/02) and 25 new Albuquerque (AQ) cross sections (9/03) that have been recently surveyed. The 25 new Albuquerque lines are listed in **Table J-6**. These cross sections, in the reach from Montano Bridge to the north boundary of the Isleta Pueblo, do not have surveyed endpoint coordinates as of this writing and are not incorporated into the MRG FLO-2D model. The ratio of surveyed cross sections to “channel” grid elements is about one to three for the Above Cochiti model and about one to ten for the 200 foot grid Rio Chama model.

Table J-5. Middle Rio Grande Cross Sections

Cross Section		Date[1]	Cross Section		Date[1]	Cross Section		Date[1]
CI	27.1	8/24/98	SFP	194	10/20/89	CO	28	8/13/99
CI	29.1	8/24/98	CO	19	9/17/98	BI	284	5/31/00
CI	36.1	8/23/98	SFP	197	10/20/89	BI	286	5/31/00
CI	37.2	8/24/98	SFP	198	10/20/89	BI	289	5/31/00
CI	40	8/26/98	SFP	199	10/20/89	BI	291	8/14/99
CI	41	8/26/98	SFP	200	10/20/89	BI	292	8/15/99
CI	M1	9/13/99	AR	203	1/18/00	BI	293	8/15/99
CI	M4	9/13/99	AR	204	1/18/00	BI	294	8/18/99
CI	M7	9/14/99	AR	205	1/18/00	CO	29	8/15/99
CI	M10	9/14/99	AR	206	1/18/00	BI	296	8/18/99
CO	5	9/18/98	AR	207	1/18/00	CO	30	9/15/98
CO	6	9/18/98	AR	209	1/18/00	CO	31	9/24/98
CO	7	9/18/98	AR	211	1/18/00	CO	32	9/24/98
CO	8	9/18/98	AR	214.5	1/18/00	CO	33	9/24/98
SD	M1	8/10/99	AR	215	1/19/00	CO	34	9/29/98
SD	M3	8/10/99	AR	216	1/19/00	CA	1	6/2/96
SD	M6	8/10/99	AR	216.5	1/19/00	CA	2	6/2/96
SD	M10	9/2/99	AR	217.5	1/19/00	CA	3	6/2/96
CO	9	9/17/98	AR	219.5	1/19/00	CA	4	6/2/96
CO	10	9/17/98	AR	220.5	1/19/00	CA	5	6/3/96
SD	1	6/25/92	AR	222	1/19/00	CA	6	6/3/96
SD	3	6/25/92	AR	224	1/20/00	CA	9	6/3/96
SD	5	6/25/92	CO	22	9/17/98	CA	10	6/4/96
SD	7	2/28/93	AR	227.5	1/20/00	CA	11	6/4/96
SD	8	2/28/93	AR	229	1/20/00	CA	12	6/1/00
SD	10	6/26/92	AR	230	1/20/00	CA	13	6/4/96
SD	12	6/26/92	AR	232	1/21/00	CO	35	6/1/00
SD	14	6/26/92	AR	233	1/21/00	CA	36	6/2/00
SD	16	6/26/92	AR	234	1/21/00	A	1	5/19/99
SD	17	3/1/93	AR	235	1/21/00	A	4	5/20/99
SD	19	3/1/93	CO	23	9/18/98	A	6	5/20/99
SD	20	6/27/92	CO	24	8/18/99	CO	37	6/2/00
SD	22	6/27/92	TA	249	8/18/99	IS	658	6/22/98

Table J-5. Middle Rio Grande Cross Sections

Cross Section		Date[1]	Cross Section		Date[1]	Cross Section		Date[1]
SD	25	6/27/92	TA	250	8/18/99	CO	668	6/22/98
SD	27	6/27/92	TA	252	8/4/99	IS	675	6/22/98
SD	30	3/1/93	TA	253	8/4/99	IS	678	6/22/98
SD	32	3/1/93	TA	253.9	8/19/99	IS	688	6/22/98
SD	33	3/1/93	TA	255	8/5/99	IS	689	6/22/98
SD	34	3/2/93	CO	25	8/5/99	IS	691	6/22/98
SD	35	3/2/93	TA	258.2	8/12/99	IS	705	6/22/98
SD	36	3/2/93	TA	259	8/11/99	CO	713	6/22/98
SD	37	3/2/93	TA	259.4	8/19/99	CO	724	6/22/98
SD	39	3/2/93	CO	26	5/30/00	CO	738.1	6/21/98
SD	43	3/3/93	TA	262	8/19/99	IS	741	6/21/98
SD	44	3/3/93	TA	263	5/30/00	IS	748	6/21/98
SD	45	6/28/92	TA	264	8/19/99	IS	752	6/21/98
SD	47	6/28/92	TA	265	5/30/00	IS	765	4/02
CO	14	9/16/98	TA	267	5/30/00	IS	772	4/02
CO	15	9/16/98	CO	27	5/30/00	IS	782	4/02
CO	16	9/16/98	TA	269	5/30/00	IS	787	4/02
SFP	170	6/29/92	TA	270	5/30/00	IS	797	4/02
SFP	172	8/25/98	TA	273	6/2/00	IS	801	6/20/98
SFP	173	6/29/92	TA	274	6/2/00	IS	806	6/20/98
SFP	178	10/18/89	TA	276	6/2/00	IS	815	6/19/98
SFP	179	10/19/89	TA	278	5/31/00	IS	833	6/19/98
SFP	180	10/19/89	TA	279	8/13/99	IS	841	6/19/98
SFP	181	10/20/89	TA	280	5/31/00	IS	849	6/18/98
CO	18	9/17/98	TA	281	8/13/99	IS	849	6/18/98
SFP	193	10/20/89	TA	282	5/31/00	CO	858.1	6/18/98
IS	860	6/19/98	SA	1215	01/02	SO	1491	5/02
IS	864	6/19/98	SA	1218	01/02	SO	1496	5/02
IS	872	6/19/98	SA	1221	01/02	SO	1499	5/02
CO	877	6/17/98	SA	1223	01/02	SO	1502	5/02
IS	880	6/17/98	SA	1224	01/02	SO	1508.9	5/02
IS	884	6/17/98	SA	1225	01/02	SO	1517.2	5/02
IS	885	6/17/98	SA	1226	01/02	SO	1524	5/02
IS	887	6/17/98	SA	1228	01/02	SO	1531	5/02

Table J-5. Middle Rio Grande Cross Sections

Cross Section		Date[1]	Cross Section		Date[1]	Cross Section		Date[1]
CO	895	6/18/98	SA	1229	01/02	SO	1536	5/02
IS	899	6/18/98	SA	1230	01/02	SO	1539	5/02
IS	908	6/18/98	SA	1231	01/02	SO	1550	5/02
CO	926	9/1/98	SA	1232	01/02	SO	1554	5/02
CC	924	3/25/96	SA	1236	01/02	SO	1557	5/02
CC	927	3/25/96	SA	1243	01/02	SO	1560.5	5/02
CC	930	3/25/96	SA	1246	01/02	SO	1566	5/02
CC	932	3/25/96	SA	1252	01/02	SO	1572.5	5/02
CC	934	3/25/96	SA	1256	01/02	SO	1576	5/02
CC	936	3/25/96	SA	1259	01/02	SO	1581	5/02
CC	939	3/26/96	SA	1262	01/02	SO	1583	5/02
CC	941	3/28/96	SA	1268	01/02	SO	1584	5/02
CC	943	3/25/96	SA	1274	01/02	SO	1585	5/02
CC	945	3/25/96	SA	1280	01/02	SO	1596.6	5/02
CO	966	9/13/98	SA	1292	01/02	SO	1603.7	5/02
CO	986	9/1/98	SO	1298	5/02	SO	1626	5/02
CO	1006	9/1/98	SO	1302	5/02	SO	1641	5/02
AH	1	2/11/94	SO	1306	5/02	SO	1645	5/02
AH	2	2/10/94	SO	1308	5/02	SO	1650	5/02
AH	3	2/10/94	SO	1310	5/02	SO	1652.7	5/02
AH	4	2/10/94	SO	1311	5/02	SO	1660	5/02
AH	5	2/11/94	SO	1312	5/02	SO	1662	5/02
AH	6	2/11/94	SO	1313	5/02	SO	1663	5/02
AH	7	2/11/94	SO	1314	5/02	SO	1664	5/02
CO	1026	9/1/98	SO	1316	5/02	SO	1666	5/02
CO	1044	9/1/98	SO	1320	5/02	SO	1667	5/02
CO	1064	9/3/98	SO	1327	5/02	SO	1668	5/02
CO	1091	9/2/98	SO	1339	5/02	SO	1670	5/02
RP	1100	10/5/00	SO	1342.5	5/02	SO	1673	5/02
CO	1104	9/2/98	SO	1346	5/02	SO	1683	5/02
RP	1108	10/5/00	SO	1349	5/02	SO	1692	5/02
LJ	5	9/26/00	SO	1352	5/02	SO	1701.3	5/02
LJ	9	9/26/00	SO	1360	5/02	EB	10	5/02
RP	1128	9/26/00	SO	1371	5/02	EB	12	5/02

Table J-5. Middle Rio Grande Cross Sections

Cross Section		Date[1]	Cross Section		Date[1]	Cross Section		Date[1]
LJ	15	10/5/00	SO	1380	5/02	EB	13	5/02
LJ	20	9/26/00	SO	1394	5/02	EB	14	5/02
RP	1144	12/19/00	SO	1396.5	5/02	EB	15	5/02
RP	1150	10/5/00	SO	1398	5/02	EB	16	6/02
RP	1160	9/29/00	SO	1401	5/02	EB	17	6/02
CO	1164	9/2/98	SO	1410	5/02	FC	1754	6/02
RP	1170	9/29/00	SO	1414	5/02	EB	18	6/02
CO	1179	9/3/98	SO	1420	5/02	EB	19	6/02
RP	1184	9/29/00	SO	1428	5/02	EB	20	6/02
RP	1190	10/5/00	SO	1437.9	5/02	EB	21	6/02
CO	1194	9/2/98	SO	1443	5/02	EB	34	6/02
RP	1201	9/29/00	SO	1450	5/02	EB	23	6/02
RP	1205	9/28/00	SO	1456	5/02	EB	24	6/02
SA	1207	7/13/98	SO	1462	5/02	EB	25	6/02
SA	1209	7/13/98	SO	1464.5	5/02	EB	26	6/02
SA	1210	‘01/02	SO	1470.5	5/02	EB	27	6/02
SA	1212	‘01/02	SO	1482.6	5/02			

[1]Date of Last Survey

Table J-6. Albuquerque Reach Cross Sections

Line	River Mile
AQ-467	187.6
AQ-472	187.1
AQ-476	186.7
AQ-480	186.3
AQ-487	185.6
AQ-492	185.2
AQ-496	184.2
AQ-503	184.0
AQ-507	183.6
AQ-515.5	182.8
AQ-520	182.3
AQ-526	181.7
AQ-531	181.2
AQ-535	180.8
AQ-567	177.8
AQ-572	177.3
AQ-577	176.9
AQ-582	176.4
AQ-589	175.7
AQ-595	175.2
AQ-600	174.7
AQ-606	174.1
AQ-610	173.7
AQ-621	172.7
AQ-625	172.4

1.3.4 Levee Data and Crest Elevations

The Middle Rio Grande levee data base is complete. Using the FLOENVIR program, levee locations and crest elevations were assigned to the grid element flow directions. For reaches where digital photography and DTM's were available, a levee crest elevation profile was generated using the Corridor design software InRoads. The levee crest profile was then linearly interpolated using a projection line from the centroid of each grid element to a perpendicular intersection with the levee alignment to assign levee crest elevations to individual grid elements. Due to the variability of the LIDAR points in the MRG Model - Belen to San Acacia reach, levee data for this reach was obtained from a BOR HEC-RAS hydraulic model. The levee data in this model was based on earlier photogrammetry surveys and the crest elevations were adjusted to the NAVD88 datum. The levee locations with respect to the FLO-2D grid elements were assigned by correlating HEC-RAS cross section locations. A levee crest elevation profile was again generated and linearly interpolated using projections to the levee alignment to assign crest elevations to FLO-2D levee elements. In the San Acacia to San Marcial reach most of surveyed cross sections extend to the levee and a crest profile was created using NAVD88 datum adjusted survey data. This profile was then linearly interpolated using projections to the levee alignment to assign the levee elevation. It should be noted that the DTM data base did not extend to the floodplain outside of the levee system in a portion of this reach. As a result, the boundary of the grid system constituted the levee and levee crest designations were not assigned. Recently, the DTM data base has been expanded and new grid elements have been assigned to the floodplain in the Socorro area.

After the entire levee system for the MRG model was coded into the LEVEE.DAT file, the FLOENVIR was used to check the assigned levee crest elevations with the grid element floodplain elevations on either side of the levee. If the floodplain elevation was higher that the levee crest elevation, the information was reported in the CHANNEL.CHK file. Either the floodplain elevation or the levee crest elevation was then adjusted to eliminate this condition. There is no levee coding in either the Above Cochiti Model or the Rio Chama model, as levees are not prominent in either reach.

1.4 FLO-2D Model Calibration

A number of years of USGS gage record were searched for hydrographs that would support model calibration for both in-channel and overbank flooding. There were a number of factors which limited the hydrographs that could be used in the calibration effort including:

- Lack of hourly gage discharge records prior to 1993 and limited diversion data;
- Limited instantaneous peak discharge data after 1989.
- Ungaged tributary inflow that makes it difficult to distinguish between ungaged inflow, return irrigation flow or gaging error;
- Rating curve shift and gaging record discrepancies;
- Poor spatial distribution and a limited number of gages;
- Significant variation in infiltration and roughness characteristics.

The hourly gaging record can create a distorted picture of the volume of water passing the various gages. In particular, the San Acacia and San Marcial gages appear to be subject to a number of variable conditions that affect the rating curve. For example, in 1997 Cochiti Dam released less than 3,000 cfs for 10 days. This hydrograph should be entirely contained within the channel. The gage issues were:

- The Albuquerque gage reports a discharge greater than either Cochiti Dam release or the San Felipe gage for most of the 10 day record.
- Both the Bernardo and San Acacia record discharge exceeds that of the any of the upstream gaging discharge for the recessional limb.
- The San Marcial hydrograph does not reflect the record at San Acacia in magnitude or shape.
- Some of these incongruities may be explained by ungaged inflows, but there is no way to distinguish between inflow contributions and gage problems. In 1998, there was no flow in the Rio Puerco during high flow season, so the Rio Salado would have had to been flowing over 1,000 cfs to account for the increase between the Bernardo and San Acacia gages during the same time that the Rio Puerco had zero flow. In addition, the calibration effort revealed the following gaging inconsistencies:
- The San Felipe gage is reporting several hundred cfs more discharge than the Cochiti gage for a large portion of the hydrograph.

- The Bernardo gage shows a substantial increase in the discharge that is not reflected in either the upstream or downstream gages.
- The San Acacia gage plus the LFCC discharge does not match the shape of the hydrograph at San Marcial and has a number of high flow instantaneous spikes.
- The San Marcial gage record does not have corresponding discharge spikes.

The MRG model was divided into reaches represented by the gaging stations for calibration of the hydrograph timing. Each channel grid element is represented by a hydraulic roughness coefficient (Manning's n-value). N-values represent both friction drag (grain size resistance and bedforms) and form drag (sandbar macroforms, variation in channel geometry, vegetation, etc.). The primary concern related to hydraulic resistance is the potential variation in the n-value over the rising and falling limb of the hydrograph. The change in bedforms from lower regime to upper regime sediment transport can result in a significant reduction in hydraulic resistance. During calibration, channel roughness values were initially adjusted using limiting Froude number criteria. The San Acacia to San Marcial reach was calibrated in a previous project and n-values in this reach were not significantly modified during this calibration effort. The new cross section routine that uses the actual cross section data greatly improved the correlation between the slope, flow area and roughness and reduced the need for significant changes in the n-values during calibration.

Calibration of channel roughness was based on hydrograph timing. Abrupt variations in discharge (either spike increases or a rapid decrease in discharge) can be tracked through the system and used to adjust the n-values. By varying the n-value, the model can improve the replication of the hydrograph spike timing in the observed data. The 'in-channel' flow hydrographs were calibrated first. Then overbank flow hydrographs were calibrated. The final modifications of n-values were accomplished by increasing or decreasing n-values by a percentage for an entire reach.

Overbank flow calibration requires knowledge of the area of inundation for a given hydrograph. The predicted area of inundation can be adjusted by changing the relationship between the slope, flow area and roughness of individual channel elements to adjust the area of inundation along the channel. This was accomplished in the San Acacia to San Marcial reach as presented in a September 16, 2000 BOR report. Unfortunately, none of the other reaches have the supporting aerial photography to calibrate overbank flow conditions.

In the reach from Cochiti Reservoir to Bernalillo Bridge, there should be little to no overbank flooding for discharges less than 7,000 cfs from Cochiti Dam. A new output file was created called OVERBANK.OUT which lists all the channel elements that have overbank flow (i.e. flow depth exceeds bankfull depth) and the first time of occurrence. By reviewing this file for a constant discharge of 7,000.

During this calibration effort, the channel hydraulic conductivity was the focus of infiltration calibration. After calibrating the hydrograph timing with Manning's n-values, accounting for all the tributary inflow, diversions and return flow and estimating the evaporation loss, the channel hydraulic conductivity was adjusted on a reach by reach basis to improve the replication of the hydrograph shape and volume. Channel hydraulic conductivity was calibrated for the in-channel flows first. Minor adjustments to the floodplain hydraulic conductivity were then made for overbank flows.

MRG model calibration was undertaken using the spring runoff hydrographs for 1997, 1998 and 2001. The first calibration was attempted with the 1997 in channel flow hydrograph for the period April 20-30, 1997. The calibration of the five hydrographs were presented in the April, 2002 ISC FLO-2D calibration report. The hydrograph plots were presented in that report appendix. A brief discussion of the calibration runs follow:

1997 Low Flow Hydrograph

For the period from April 20 – 30, 1997 the discharge was in-channel flow and did not exceed a 3,000 cfs release from Cochiti Dam. At San Felipe gage the model underpredicted rising and falling limbs and overpredicted the peak discharge but the timing was good. The model overpredicted the entire hydrograph at Albuquerque by about 300 cfs, but timing was pretty good. The spike was missing from Cochiti Release in measured data. The model underpredicted entire Bernardo hydrograph by 200 to 300 cfs (10%) At the San Acacia gage, either the Rio Salado was flowing (there is no flow in Rio Puerco) or gage is off. The San Marcial record confirmed that the San Acacia gage was poorly calibrated. The Marcial gage report discharges that were too low because there was 2,500 cfs at Bernardo and 3,500 cfs (unlikely) at San Acacia. In summary, the model does a reasonably good job for the reach from Cochiti Dam to Bernardo. It is probable that neither the San Acacia or San Marcial gages reflect the actual flow in the river.

1998 Low Flow Hydrograph

The same data base for 1997 low flow hydrograph was used to predict the discharge for the 1998 low flow hydrograph. The model did good job of replicating the entire MRG for the 1998 low flow hydrograph. This demonstrates that the model was reasonably calibrated for most of the gains and losses in the system. The predicted discharge at San Acacia was slightly overpredicted (**Figure J-1**).

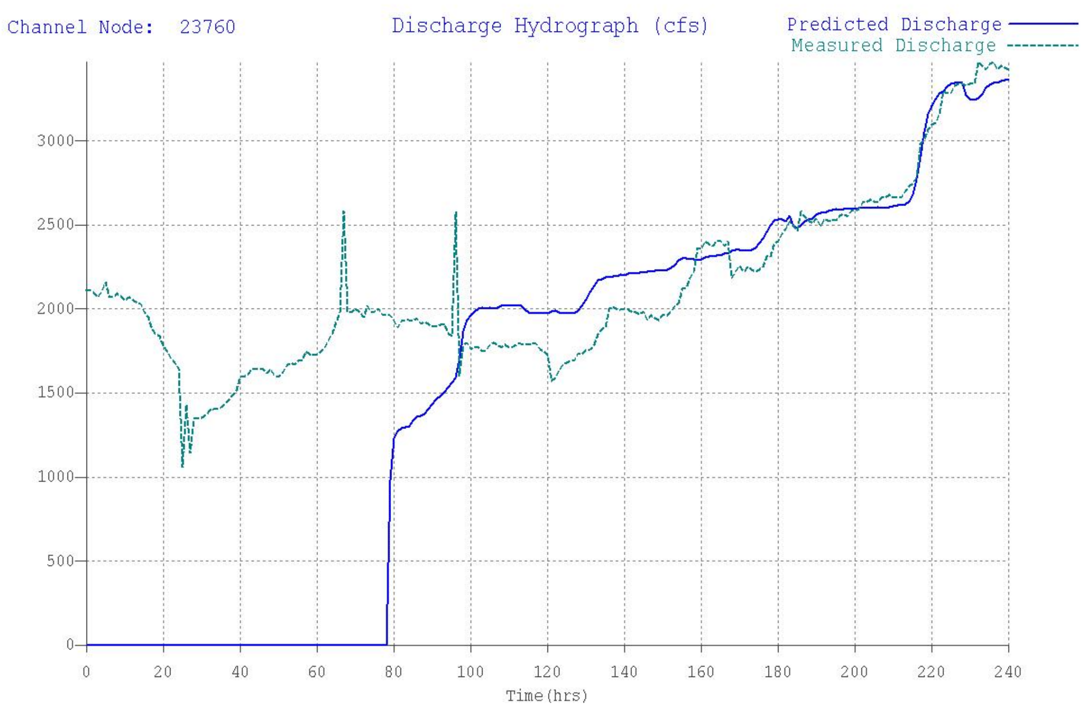

Figure J-1. San Acacia Gage 1998 Measured and Predicted Hydrographs

1997 High Flow Hydrograph

The 1997 high flow hydrograph for 31 days with a peak discharge exceeding 6,000 cfs was simulated. The model predicted the San Felipe and Bernardo measured hydrographs very well. The Albuquerque and

San Acacia gage record were poorly replicated. Overbank flow and the diversion at San Acacia dam may be part of the reason for the poor replication.

1998 High Flow Hydrograph

The 1998 High Flow Hydrograph also exceeded 6,000 cfs. In general, the model did a good job of predicting the shape of the measured hydrograph throughout the system of five gages. The model overpredicted the discharge at the Albuquerque and San Acacia gage and underpredicted the discharge at the Bernardo and San Marcial gages. Based on the previous calibration runs, it was considered inappropriate to increase or decrease the infiltration losses to create a better match.

2001 Hydrograph

The 2001 hydrograph represented a block release of about 4,000 cfs over a two day period. This block release would have been an excellent model test except for the additional Jemez Dam release whose hydrograph was not very well monitored. A one hour time lag was assumed for the Jemez release to arrive at the Rio Grande. The combined peak discharge exceeded 6,000 cfs. The 2001 flood pulse was accurately replicated for the San Felipe (**Figure J-2**) and reasonably reproduced the hydrograph shape at Bernardo and San Acacia. The replication was poor at the Albuquerque and San Marcial gages.

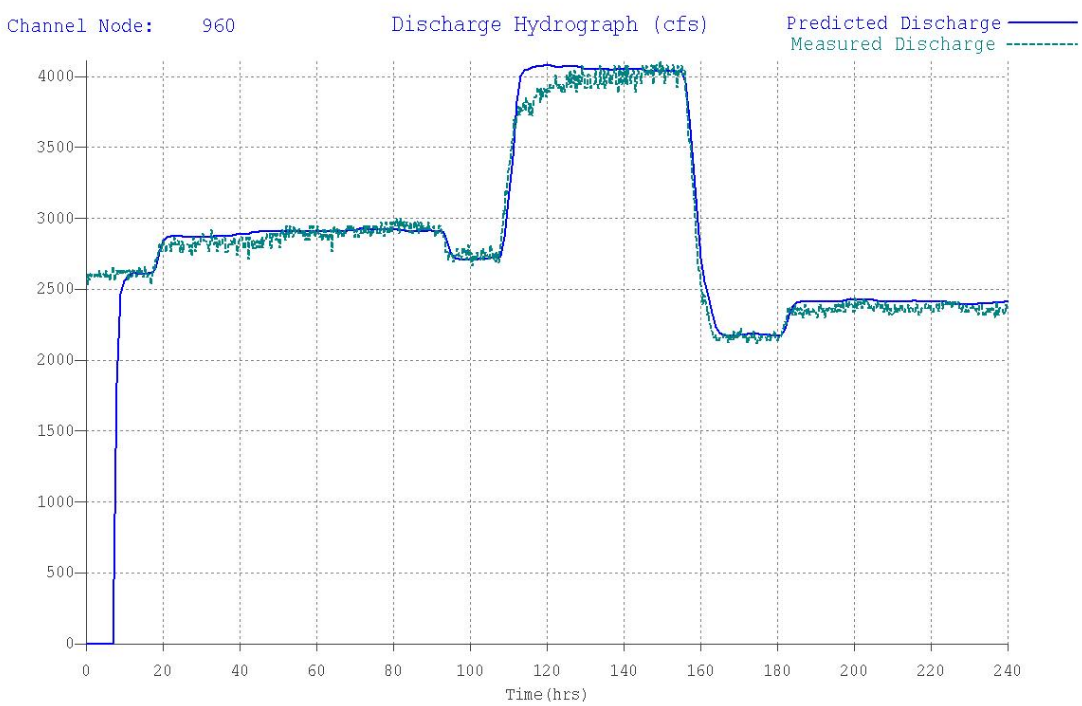

Figure J-2. San Felipe Gage 2001 Measured and Predicted Hydrographs

Overall the model did a reasonably good job of replicating the five calibration hydrographs. One or more gages are poorly replicated for each hydrograph. The San Acacia and San Marcial gages had the poorest replication followed by Albuquerque and Bernardo. The two gages at the lower end of the system are subject to vagaries of the sand bed channel and constant gage shifts.

1.4.1.1 URGWOM Flow Calibration

For the Review additional model calibration was done to verify that FLO-2D predicted discharges would reasonably match discharges from the URGWOM Planning Model. **Figure J-3** through **Figure J-8** show results from this work.

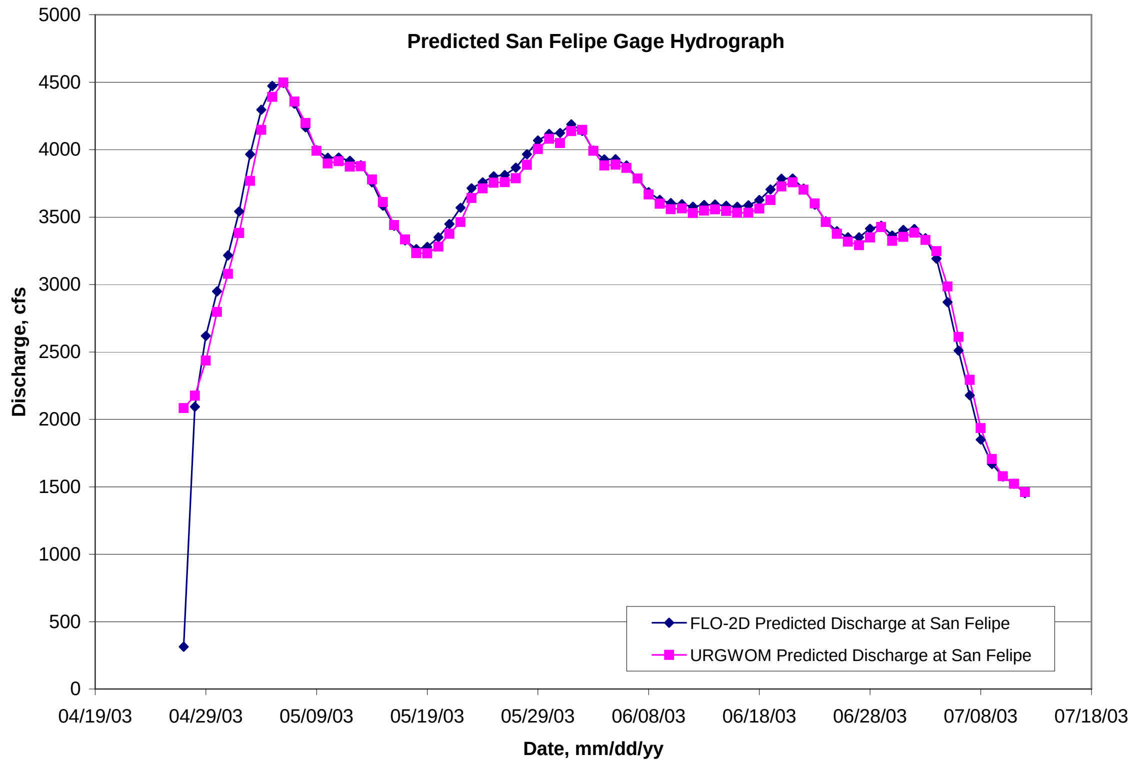

Figure J-3. MRG FLO-2D Hydrograph Replication

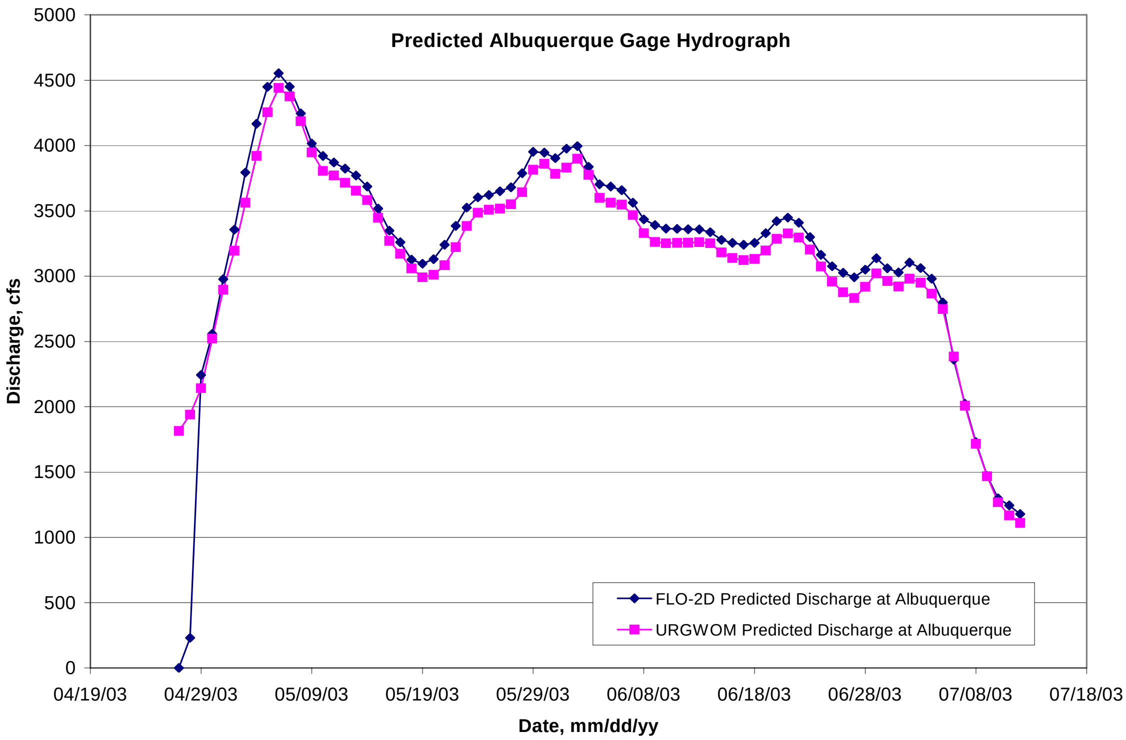

Figure J-4. MRG FLO-2D Hydrograph Replication

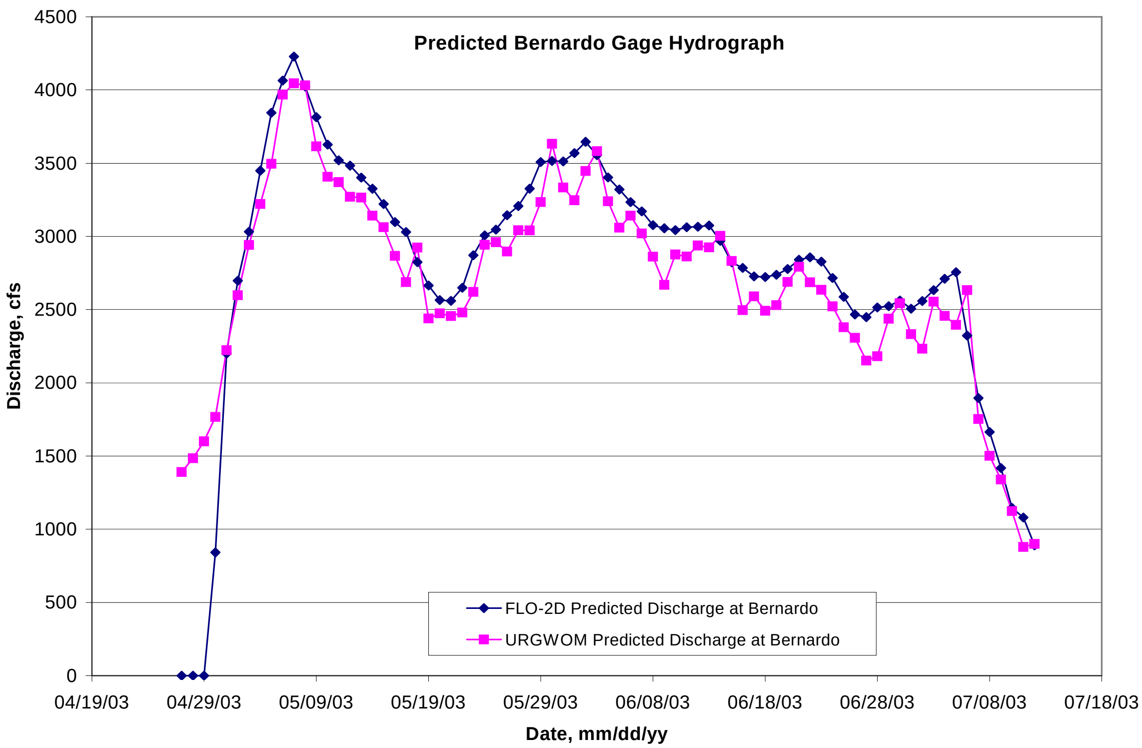

Figure J-5. MRG FLO-2D Hydrograph Replication

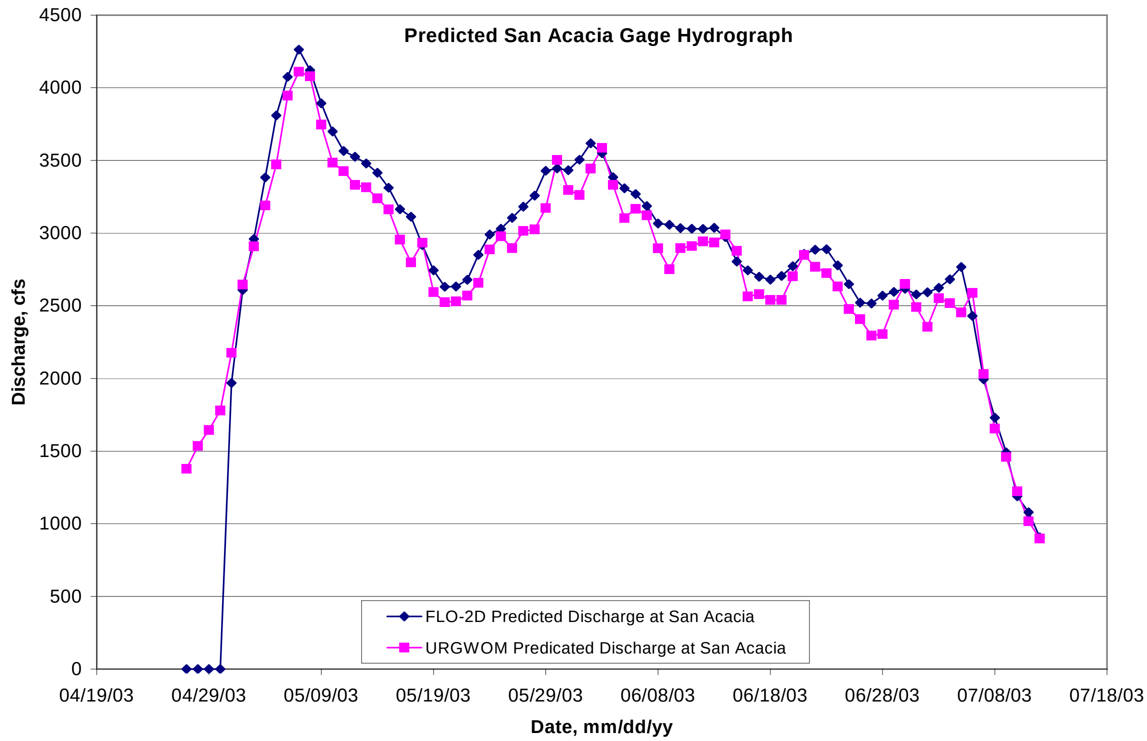

Figure J-6. MRG FLO-2D Hydrograph Replication

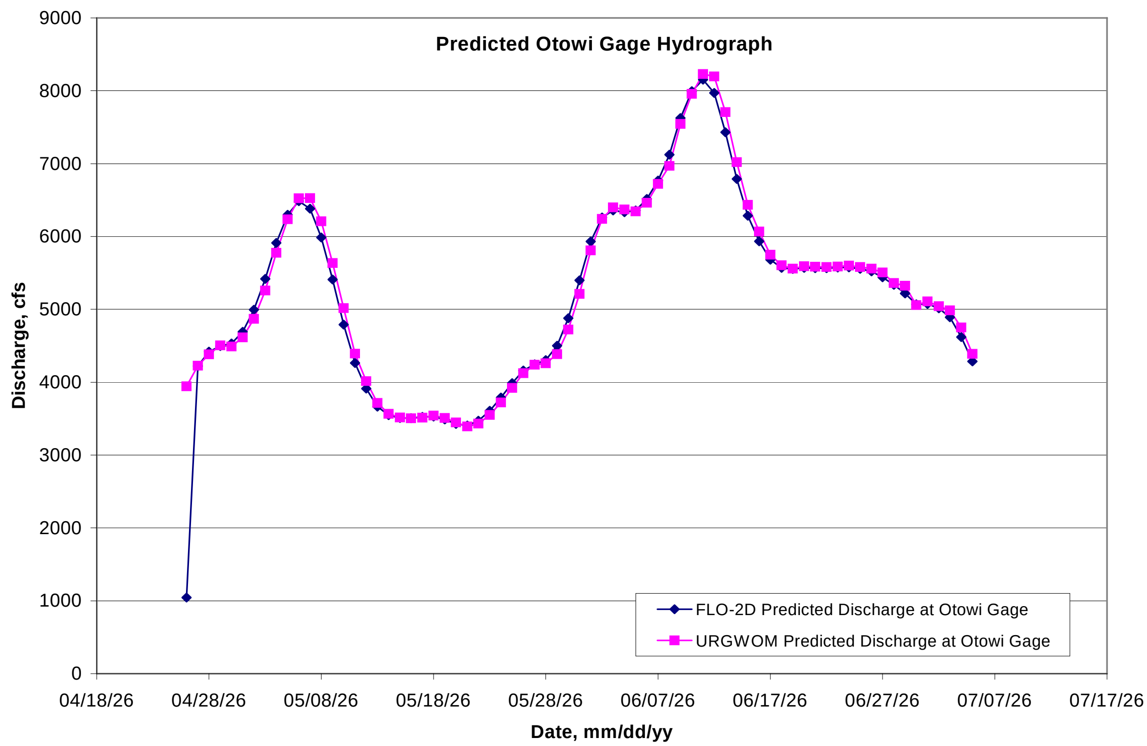

Figure J-7. Above Cochiti FLO-2D Hydrograph Replication

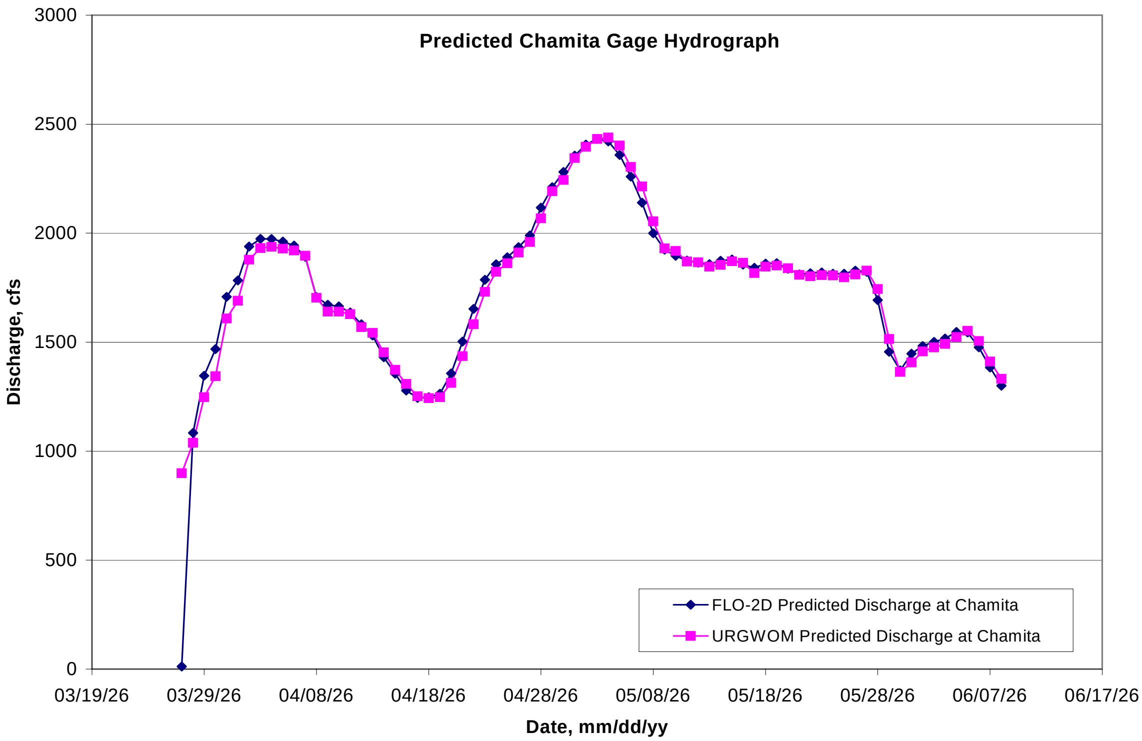

Figure J-8. Rio Chama FLO-2D Hydrograph Replication

2.0 MRG FLO-2D Model Components

2.1 Introduction

A number of FLO-2D model enhancements have been developed in conjunction with the FLO-2D modeling supporting the Review. These include recent improvements to the GDS and MAPPER. The improvements to these two processor programs are extensive and facilitate efficient FLO-2D input file and output file creation. Other enhancements to the FLO-2D model include an evaporation component, irrigation return flows, expanded spatially variable infiltration parameters, depth variable n-value adjustments, and output file details. A brief description of these components is discussed.

2.2 Evaporation

An estimate of free surface evaporation was coded into the MRG FLO-2D model. Previously, channel and floodplain infiltration were the only losses that were computed in the model. The objective of adding the evaporation component was to separate the evaporation from the infiltration loss when calibrating the model. The infiltration loss can then be assumed to be either an increase in groundwater storage or potential loss to plant evapotranspiration. The FLO-2D model tracks the water surface area for both the channel and the floodplain on a timestep basis. To calculate the evaporation loss, the user must specify a mean monthly evaporation (in inches/month or mm/month if using metric units) in the INFIL.DAT file. The only other data requirement is the clock time at the start of the simulation.

James Cleverly of the Department of Biology, University of New Mexico provided estimates of the percentage of daily evapotranspiration on an hourly basis for each month (**Table J-7**). The evaporation loss is assumed to be constant during the hour shown in the table. The evaporation loss is reported at the end of the BASE.OUT and SUMMARY.OUT files in terms of both total evaporation in inches and total volume loss in acre-ft or cubic meters. A mean monthly evaporation for each month was derived from various sources such as the Rio Grande Joint Investigation General Report. For example:

The mean monthly evaporation for Elephant Butte 1917-1936 for May: 12.77 inches.

The mean monthly evaporation for Albuquerque 1926-1932 for May: 10.73 inches.

The average for the two records was approximately 11.75 inches. A mean monthly evaporation of 8.22 inches was used in the FLO-2D model for May using a pan evaporation coefficient of 0.7. The mean monthly evaporation for the rest of the months were derived in a similar manner.

The Above Cochiti and the Rio Chama FLO-2D models do not use the evaporation component.

Table J-7. Average Hourly Evaporation/ET for 4 MRG ET Towers for May

Hour	Percent of Daily ET
12 – 1 am	1.0
1 – 2 am	0.0
2 – 3 am	0.0
3 – 4 am	0.0
4 – 5 am	0.0
5 – 6 am	0.0
6 – 7 am	0.0
7 – 8 am	2.0
8 – 9 am	5.0
10 – 11 am	6.0
11 – 12 pm	8.0
12 – 1 pm	10.0
1 – 2 pm	11.0
2 – 3 pm	11.0
3 – 4 pm	11.0
4 – 5 pm	10.0
5 – 6 pm	8.0
6 – 7 pm	7.0
7 – 8 pm	5.0
8 – 9 pm	2.0
9 – 10 pm	1.0
10 – 11 pm	1.0
11 – 12 am	1.0

2.3 Irrigation Diversion Return Flows

A modification to the FLO-2D model was made to simplify the simulation of diversions and return flows to the model. Previously, diversions were made by creating a tributary or diversion channel and assigning a hydraulic structure to the diversion channel to control the flow. The diversion channel also had to have an outflow node to discharge flow from the grid system. The model was modified such that inflow hydrographs to the channel could be assigned as either inflow or outflow hydrographs. A new variable was created to identify whether the hydrograph is an inflow to or outflow from the channel. In this way, simple diversions can be structured anywhere in the channel. No diversion structure or tributary channel is necessary. An outflow hydrograph can be created with as few as two or three hydrograph pairs if a constant flow is required. The diversion outflow hydrograph is limited to the flow in the channel such that if a diversion of 500 cfs is specified and there is only 300 cfs in the river channel, the diversion will be 300 cfs and the flow in the river channel will be set to zero.

In the existing model, irrigation diversions are specified for Angostura, Isleta and San Acacia diversion dams. There is also a diversion from Cochiti Dam that is not included in the Cochiti gage data. Based on collaboration with the Middle Rio Grande Conservancy District (MRGCD), return flow locations were identified. For the replication of historic flow events, the Angostura and Isleta Diversion return flows can be estimated as follows (**Table J-8)**:

Table J-8. MRG FLO-2D Model Diversions and Return Flows

Diversion or Return Flow	Diversion or Return	Approximate Discharge (cfs)	Approximate Location (grid element)
Cochiti Diversion	Diversion	200[1]	60
UCRDR	Return	50	2290
ATRDR	Return	50	8972
SANWW	Return	30	1837
ARSDR	Return	70	9000
CENWW	Return	75% of Angostura Diversion[2]	4883
LPIDR	Return	50	16447
PERWW	Return	25	15785
UN7DR	Return	50% of Isleta Diversion	23209
LSJDR	Return	40% Isleta Diversion	22227
Angostura Diversion	Diversion	Variable	1198
Isleta Diversion	Diversion	Variable	9334
LFCC Diversion	Diversion	Variable	23762
Albuquerque Diversion	Diversion	Variable	2349

[1]Cochiti Diversion was assumed to be a constant 200 cfs with an 80% return flow. This 160 cfs is added to the Angostura Diversion for computing the return flow in the Central Avenue Waste Way.
[2]CENWW is assumed to be 75% of the total Angostura Diversion plus the 160 cfs by-pass from Cochiti Diversion.

There are a number of small irrigation return flows that combined may total additional 50 to 100 cfs that are not accounted for in the model. In the FLO-2D simulations supporting the Review (for the 40-year URGWOM planning model data), these returns are consolidated within reaches. The diversion and return flow discharge data is provided by the URGWOM planning team for the various 40-year operation model alternatives. In addition, a diversion for the Albuquerque drinking water project has been added to the model. **Table J-9** through **Table J-11** shows diversions and returns used in the FLO-2D simulations supporting the Review.

Table J-9. MRG FLO-2D Model Diversions and Return Flows

Type	Name	FLO-2D SIM. Lag Time (days)	FLO2D Grid Element #
Inflows:	Cochiti	0	60
	Galisteo	1	538
	Below Cochiti	1	524
	Below Angostura Diversion	2	1180
	Jemez	3	1265
	North Floodway Channel	3	2016
	Albuquerque Wastewater	3	6953
	South Diversion/Tijeras Arroyo	3	7164
	64% bifurcation return below Isleta	4	15692
	36% bifurcation return below Isleta	4	16447
	Rio Puerco	4	22227
	Unit 7 drain below Bernardo	4	23209
	LFCC below San Acacia Diversion	4	24923
Diversions:	Angostura	2	1198
	City of Albuquerque	3	2349
	Isleta	4	9334
	San Acacia and LFCC	4	23762

Table J-10. Above Cochiti FLO-2D Model InFLOWS

Type	Name	FLO-2D SIM. Lag Time (days)	FLO2D Grid Element #
Inflows:	Confluence to Otowi	0	3
	Embudo to Otowi Local Inflow	0	1128
	Otowi to Cochiti Local Inflow	0	3149

Table J-11. Rio Chama FLO-2D Model InFLOWS & Diversions

Type	Name	FLO-2D SIM. Lag Time (days)	Grid Element #
Inflows:	Abiquiu	0	239
	Abiquiu to Chamita Local Inflow	0	11864
Diversions:	Blw Abiquiu Diversions	0	2568
	Abv Confluence Diversions	0	11076

Table J-11. Rio Chama FLO-2D Model InFLOWS & Diversions

Type	Name	FLO-2D SIM. Lag Time (days)	Grid Element #
	Blw Confluence Diversions	0	13026
	Blw Chamita Diversions	0	14407

2.3.1 Depth Variable Roughness

The Middle Rio Grande has significant variability in bed form roughness from lower regime to upper regime sediment transport as the flow approaches bankfull discharge. Upper regime plane bed can occur at a location for one discharge and not occur at a later time at the same location and same discharge. If the flow regime transitions from dunes to upper regime plane bed, the hydraulic roughness can decrease by as much as 50%. To simulate this effect and improve the timing of floodwave progression through the system, a depth variable roughness component was added to the model. It can be assigned on a reach basis. The basic equation is for the channel element roughness n_d as function of flow depth is:

$$n_d = n_b \, r_c \, e^{-(r2 \; depth/dmax)}$$

where:

n_b = bankfull discharge roughness
depth = flow depth
dmax = bankfull flow depth
r2 = roughness adjustment coefficient prescribe by the user (0. to 1.2)
$r_c = 1./e^{-r2}$

This equation provides that the variable depth channel roughness is equal to the bankfull roughness at bankfull discharge. If the user assigns a roughness adjustment coefficient value (r2 = 0 to 1.2) for a given reach, the roughness will increase with a decrease in flow depth; the higher the coefficient, the greater that the increase in roughness.

This roughness adjustment will slow the progression of the floodwave advancing down the channel by increasing the roughness for less than bankfull discharge. The roughness set for bankfull discharge will not be affected. For example, if the depth is 20% of the bankfull discharge and the roughness adjustment coefficient is set to 0.444, the hydraulic roughness of Manning’s n-value will be 1.4 times the roughness prescribed for bankfull flow.

2.3.2 Depth Duration

To address issues associated with the Review regarding overbank flooding, a depth duration analysis was coded into the model. An input data parameter is assigned a depth value (typically 0.5 ft.) and the FLO-2D model then computes the duration in hours that this depth is exceeded by the floodplain inundation. This computation is made on a grid element basis and can be plotted graphically with the MAXPLOT processor program. For a given spring runoff hydrograph, the depth duration in hours can be displayed to identify areas of the floodplain where the flood inundation is sufficient to support the riparian ecology in terms of flushing forest litter, nutrient recycling, and cottonwood/willow Bosque regeneration. The depth duration delineation can also support the prediction of slow floodplain velocity habitat for the silvery minnow.

2.3.3 Channel Hydraulics

The analysis of average channel hydraulics was expanded to include thalweg depth, flow velocity, discharge, water surface slope, bed slope, energy slope, bed shear stress, wetted perimeter, top width, hydraulic radius, width-to-depth ratio, and water surface elevation. This output data was written to file for a range of discharges. It can then be analyzed on a grid element basis or over several grid elements in the HYDROG post-processor program. The FLO-2D model was used to simulate steady flow, discharge increments of three to five days to generate the output data files that can be interpolated with the HYDROG program. HYDROG provides the opportunity to select a reach of river and a given discharge to compute the average flow hydraulics in the reach. The average flow hydraulics for a selected discharge are computed by interpolating discharge weighted and reach length weighted average hydraulic conditions. The reach average hydraulics can be computed for any selected discharge ranging from 25 cfs to 10,000 cfs assuming that the selected discharge can be conveyed by the channel at the reach location. This channel hydraulic data can be useful in accessing silvery minnow and other aquatic habitat as function of discharge.

2.3.4 Overbank Flooding

When overbank flooding is initiated in a given grid element, the simulation time (in hours) is written to an output file along with the grid element number, the channel cross section, the thalweg flow depth, velocity, discharge and water surface elevation. The volume of water (in acre-ft) on the floodplain for the whole river system is also reported in the same file. The 40-year URGWOM planning model alternative scenarios provide a wide range of spring flood hydrographs with variable peak discharge magnitude, duration and timing. With floodwave attenuation associated with both channel and overbank storage, the movement of the peak discharge and the corresponding time of initial overbank discharge through the system is highly variable. Overbank discharges can be initiated at different times in different locations for the same Cochiti Dam peak discharge release. The location of initial overbank flooding can be correlated with flood frequency, habitat value and other parameters. This overbank flood information is also provided on a reach basis corresponding with the reaches defined for the Review.

2.3.4.1 Overbank Flow Areal Representation

It is important to clarify the depiction of the predicted overbank flow areas using the FLO-2D model application for the URGWOM hydrographs.

1. The Rio Grande FLO-2D model(s) predict floodplain inundation using a 500 ft grid system. The 500 ft grid element is represented by one elevation and roughness. Topographic variation within the grid element varies, either as mounds or depressions or as a gradual slope of a hillside or bluff. This means that flooding could occur either sooner than predicted by the FLO-2D model or perhaps not at all when predicted by the FLO-2D model for a given grid element if the discharge is approximately bankfull. As was illustrated at the meeting, cattle trampled range lines provide a gully running from the river bank to the levee that could initiate flooding along the levee at an elevation of perhaps 2 ft lower than that predicted by the model.
2. The predicted maximum areas of inundation are summed during model simulation and reported in the SUMMARY.OUT files. These areas are based on the 500 ft grid element representation for the Rio Grande models and 200 ft for the Rio Chama model. Some portion of a flooded grid element can appear on both sides of a levee, or perhaps on the side of a bluff. These grid elements could be assigned area reduction (ARF) values to account for the area outside of the active floodplain. They were not because:

- o An effort was made to balance the number of grid elements with portions inside and outside the levee.
- o This detailed task was not a priority or deemed necessary for the magnitude of the system being modeled.

3. The overall accuracy of the entire area of inundation for a given URGWOM hydrograph is not compromised by this lack of detail.
4. In post processing of FLO-2D results the creation of contours to depict overbank flooding can be based on either grid element flow depths or flow depths that are assigned to every DTM point. The flow depth contours that have been created are based on the grid element resolution.
   - o Any contour generating program (e.g. surface modeling program) has a certain level of resolution in creating contour plots. Based on parameters such as line weight, smoothing, number of vertices, algorithm, etc., the contour lines can vary their representation of the flood area or topography. Common hurdles associated with contour line representation are crossing features, crossing contours lines, and extending outside the represented area. In some of the more advanced surface modeling programs breaklines are often used to control contour line creation. MAPPER has a simple contour routine that has to work within the constraints imposed by MapObjects. Mapper does not have breakline capabilities thus; the generated contours lines of flooding that are created as shape files will misrepresent some of the flooded areas. These contour lines will cross the levee in places and perhaps overlay areas with steep slopes.

It is important to recognize that the depiction of the flooded areas with shaded contours and shape files deviates from the FLO-2D computed flood areas. The individual shape polygons are only a general representation of the computed flood areas predicted by the model. The shape polygon areas will not add up to the computed FLO-2D maximum areas of inundation. Any adjustment of the contours or shape polygon could result in a further deviation from computed maximum flooded areas that are predicted as function of the discharge magnitude and duration and the channel geometry and flow hydraulics.

It is also important to realize that the application of the FLO-2D model and MAPPER programs have been consistent for all the URGWOM hydrographs. The same data base was used for every FLO-2D simulation. The contour plotting was automated in MAPPER and the same contour smoothing and resolution parameters were applied for the generation of every shape file. Although the shape polygon images may not “neatly overlay” other spatial data layers and images available in the study reach, the size and shape of the polygons have been created uniformly without additional adjustment and therefore can be used in a comparative study of URGWOM alternative hydrographs.

2.4 Summary Results – FLO-2D Simulations Supporting the Review

The results of the FLO-2D modeling supporting the Review are summarized in spreadsheets. Qualitative depictions of potential overbank inundation for a given FLO-2D simulation is also provided for in graphic shapefiles. The attributes that are included in the shapefiles are discussed in the following paragraph.

The original flood depth shapefile for a specific FLO-2D simulation is created using the MAPPER post-processing program internal to FLO-2D. In Mapper, a representative contouring interval has been selected and consistently used for all post processing of URGWOM simulations. The resulting shapefile from Mapper is then opened in ArcGIS (ArcMap Ver 8.1) an area field is generated and additional X,Y data is joined to the basic flood depth polygons. The X,Y data that is joined includes the following information; the grid cells which experience flood depth of 0.5 ft and higher for a minimum of 1 hour duration

(duration reported as hours), and the maximum floodplain velocity experienced at the grid cell during the simulation (reported as feet per second). There are additional fields included in the attribute tables that count occurrences of, average, and report maximum and minimum grid cell data that falls within a specific flood depth polygon.

Table J-12 through **Table J-32** list the summary spreadsheet results of the FLO-2D simulations for all the reaches modeled with FLO-2D. Also in the tables are the duration of each simulation.

Table J-12. MRG FLO-2D Results

	Base Run Version 2 (BaseRun-11.13.03)						
	Timestamp: Nov 24, 2003 3:52PM MST (on urg3)			Max Wetted Floodplain Area			
Year	**Simulation Time**	**Period**	**Peak at Cochiti**	**Reach 10**	**Reach 12**	**Reach 13**	**Reach 14**
	(days)		**(cfs)**	**(acres)**	**(acres)**	**(acres)**	**(acres)**
2003	77	Apr 27 - Jul 12	4370	0.00	3.58	16.78	3919.88
2005	86	Mar 24 - Jun 17	5617	35.84	378.16	670.48	6402.28
2007	43	Mar 22 - May 3	4316	0.00	0.00	11.05	4519.88
2010	43	Mar 22 - May 3	4345	0.00	0.00	11.05	4521.11
2011	43	Mar 22 - May 3	4355	0.00	0.00	11.05	4518.46
2017	95	Apr 1 - Jul 4	7386	415.51	1393.32	2471.6	7266.70
2018	91	Apr 20 - Jul 19	5379	0.00	60.82	163.13	5146.74
2021	91	Apr 21 - Jul 20	5380	0.00	60.82	163.13	5138.89
2025	64	Apr 28 - Jun 30	5177	0.00	31.34	120.20	4850.37
2026	125	Mar 27 - Jul 29	6915	293.25	814.80	898.08	5327.11
2027	61	Apr 30 - Jun 29	5175	0.00	31.34	120.20	4844.51
2028	81	Apr 4 - Jun 23	5776	49.48	155.40	232.16	5275.31
2029	85	Apr 17 - Jul 10	7009	330.86	1315.11	2313.1	6737.43
2030	86	Mar 23 - Jun 16	5406	0.00	271.52	571.79	6085.23
2031	126	Mar 11 - Jul 14	7514	1473.94	2152.96	3904.0	5526.50
2036	81	Apr 4 - Jun 23	5776	49.48	155.40	232.16	5289.64
2037	46	Mar 14 - Apr 28	3569	0.00	0.00	0.00	2224.59
2038	81	Apr 10 - Jun 29	7370	411.29	1323.70	2364.2	7033.34
2039	85	Mar 24 - Jun 16	5761	128.80	486.98	725.18	6425.56
2041	84	Apr 15 - Jul 7	4365	0.00	0.00	11.05	3544.54
2042	81	Apr 4 - Jun 23	5776	41.58	141.47	223.24	5285.13

Table J-13. MRG FLO-2D Results

	Alternative B - Wet (B-Wet)						
	Timestamp: Dec 1, 2003 10:11AM MST (on urg3)			Max Wetted Floodplain Area			
Year	Simulation Time	Period	Peak at Cochiti	Reach 10	Reach 12	Reach 13	Reach 14
	(days)		Gage Outflow(cfs)	(acres)	(acres)	(acres)	(acres)
2003	83	Apr 15 - Jul 6	4164	0.00	0.00	7.21	23.58
2005	94	Mar 25 - Jun 26	6301	185.59	1186.96	2119.15	4281.86
2007	60	Mar 17- May 15	4291	0.00	0.00	11.05	34.52
2010	59	Mar 17- May 14	4291	0.00	0.00	11.05	34.52
2011	60	Mar 17- May 15	4291	0.00	0.00	11.05	45.75
2017	94	Apr 2 - Jul 4	8425	1319.61	2103.14	3947.52	5586.46
2018	70	May 11 - Jul 19	4210	0.00	0.00	5.29	14.14
2021	90	Apr 21 - Jul 19	5167	0.00	95.33	185.21	697.92
2025	62	Apr 29 - Jun 29	4950	0.00	9.55	27.38	56.14
2026	95	Apr 25 - Jul 28	7383	411.29	1217.78	1742.32	1678.10
2027	60	May 1 - Jun 29	3873	0.00	0.00	0.00	0.00
2028	45	May 10 - Jun 23	6287	185.59	522.45	642.39	1176.16
2029	80	Apr 21 - Jul 9	7224	337.75	1306.64	2228.48	3190.50
2030	86	Mar 23 - Jun 16	5346	0.00	422.66	814.89	2566.11
2031	120	Mar 10 - Jul 7	8448	1476.85	2156.63	3922.26	5520.03
2036	45	May 10 - Jun 23	6287	185.59	563.28	726.52	1492.94
2037	41	Mar 15 - Apr 24	3236	0.00	0.00	0.00	0.00
2038	64	Apr 10 - Jun 12	8414	1024.78	1657.87	3009.11	4574.33
2039	85	Mar 24 - Jun 16	5401	0.00	462.38	825.52	2540.31
2041	84	Apr 15- Jul 7	4156	0.00	0.00	5.29	17.68
2042	130	Apr 4 - Aug 11	6287	185.59	654.56	887.10	2094.51

Table J-14. MRG FLO-2D Results

	Alternative D - Normal-Wet						
	Timestamp: Nov 26, 2003 9:49AM MST (on urg3)			Max Wetted Floodplain Area			
Year	**Simulation Time**	**Period**	**Peak at Cochiti**	**Reach 10**	**Reach 12**	**Reach 13**	**Reach 14**
	(days)		**(cfs)**	**(acres)**	**(acres)**	**(acres)**	**(acres)**
2003	86	Apr 14 - Jul 8	4588	0.00	3.82	10.99	17.68
2005	86	Mar 24 - Jun 17	5987	134.54	779.41	1324.62	3854.02
2007	41	Mar 22 - May 1	4324	0.00	0.00	11.05	48.45
2010	43	Mar 21 - May 2	4369	0.00	0.00	11.05	48.45
2011	41	Mar 22 - May 1	4367	0.00	0.00	11.05	48.45
2017	96	Apr 1 - Jul 5	7287	396.11	1428.08	2557.22	5049.00
2018	70	May 11 - Jul 19	4236	0.00	0.00	5.29	14.14
2021	90	Apr 21 - Jul 19	5520	0.00	246.21	383.80	1208.54
2025	64	Apr 28 - Jun 30	5276	0.00	41.93	134.41	221.72
2026	96	Apr 25 - July 29	7262	385.78	1096.12	1528.52	1965.63
2027	51	May 10 - Jun 29	3873	0.00	0.00	0.00	0.00
2028	45	May 10 - Jun 23	5776	30.10	112.37	150.76	321.66
2029	84	Apr 21 - Jul 13	7036	331.94	1313.85	2195.77	3451.59
2030	52	Mar 24 - May 14	5299	0.00	193.39	628.98	2298.96
2031	101	Apr 3 - Jul 12	7525	472.53	1408.40	2644.71	5562.38
2036	45	May 10 - Jun 23	5776	30.10	115.82	226.42	380.70
2037	42	Mar 15 - Apr 25	3236	0.00	0.00	0.00	0.00
2038	70	Apr 9 - Jun 17	7375	411.29	1411.15	2442.83	4318.76
2039	52	Mar 24 - May 14	5299	0.00	193.39	630.61	2304.83
2041	71	Apr 27 - Jul 6	4579	0.00	3.82	22.26	49.14
2042	79	Apr 4 - Jun 1	5282	0.00	63.99	153.63	969.55

Table J-15. MRG FLO-2D Results

	Alternative E						
	Timestamp: Nov 26, 2003 9:49AM MST (on urg3)			Max Wetted Floodplain Area			
Year	**Simulation Time**	**Period**	**Peak at Cochiti**	**Reach 10**	**Reach 12**	**Reach 13**	**Reach 14**
	(days)		**(cfs)**	**(acres)**	**(acres)**	**(acres)**	**(acres)**
2003	85	Apr 14 - Jul 7	4418	0.00	7.19	16.78	45.75
2005	83	Mar 24 - Jun 14	6656	264.55	1408.43	2607.79	4920.22
2007	60	Mar 16 - May 14	4324	0.00	0.00	11.05	48.45
2010	60	Mar 16 - May 14	4369	0.00	0.00	11.05	48.45
2011	58	Mar 17 - May 13	4368	0.00	0.00	11.05	48.45
2017	114	Mar 14 - Jul 5	8755	1768.50	2391.96	4226.20	5669.78
2018	70	May 11 - Jul 19	4110	0.00	0.00	5.29	14.14
2021	92	Apr 20 - Jul 20	5422	0.00	39.91	110.93	370.21
2025	63	Apr 28 - Jun 29	5205	0.00	66.56	165.37	351.45
2026	123	Mar 27 - Jul 27	7590	569.02	1343.79	2122.85	2869.23
2027	112	Apr 30 - Aug 19	3874	0.00	0.00	0.00	7.06
2028	79	Apr 6 - Jun 23	6757	255.50	790.44	986.06	1695.82
2029	81	Apr 21 - Jul 10	7480	415.51	1269.43	1928.12	6482.44
2030	86	Mar 23 - Jun 16	5347	0.00	426.50	815.11	2562.24
2031	121	Mar 10 - Jul 8	9401	2497.39	2689.61	4588.54	6746.90
2036	79	Apr 6 to Jun 23	6756	255.50	786.58	983.92	1683.87
2037	41	Mar 15 - Apr 24	3236	0.00	0.00	0.00	0.00
2038	64	Apr 9 - Jun 11	8346	1071.35	1835.41	3345.26	5057.77
2039	86	Mar 23 - Jun 16	5403	0.00	459.53	823.92	2576.83
2041	85	Apr 14 - Jul 7	4410	0.00	3.58	11.05	36.42
2042	80	Apr 3 - Jun 21	7503	370.22	1134.54	1613.08	2369.61

Table J-16. MRG FLO-2D Results

	Alternative I dry						
	Timestamp: Dec 16, 2003 9:28AM MST (on urg3)			Max Wetted Floodplain Area			
Year	Simulation Time	Period	Peak at Cochiti	Reach 10	Reach 12	Reach 13	Reach 14
	(days)		(cfs)	(acres)	(acres)	(acres)	(acres)
2003	85	4/14-7/7	4418	0.00	3.58	16.78	2609.62
2005	90	3/24-6/21	5709	3.57	246.03	627.05	5121.74
2007	60	3/16-5/14	4323	0.00	0.00	11.05	3070.41
2010	60	3/16-5/14	4369	0.00	0.00	11.05	3469.01
2011	53	3/22-5/13	4368	0.00	0.00	11.05	3496.93
2017	113	3/14-7/4	7428	415.51	1374.12	2433.79	6826.22
2018	88	4/23-7/19	5421	0.00	115.58	153.37	4683.38
2021	92	4/20-7/20	5422	0.00	115.58	153.37	4687.87
2025	63	4/28-6/29	5178	0.00	27.14	102.90	3724.77
2026	123	3/27-7/27	6920	306.93	892.02	1142.85	5092.10
2027	61	4/30-6/29	5176	0.00	31.34	125.94	4096.04
2028	79	4/6-6/23	5777	47.31	155.40	351.36	4799.73
2029	82	4/20-7/10	7049	330.86	1270.97	2079.33	5462.82
2030	87	3/22-6/16	5566	0.00	143.92	500.69	5323.39
2031	125	3/10-7/12	7530	471.99	1461.06	2806.74	7794.44
2036	80	4/5-6/23	6273	172.35	277.36	467.93	4856.15
2037	47	3/14-4/29	3236	0.00	0.00	0.00	230.61
2038	82	4/9-6/29	7381	405.55	1273.82	2130.25	5855.14
2039	86	3/23-6/16	5997	128.80	504.92	739.88	6514.75
2041	85	4/14-7/7	4409	0.00	0.00	11.05	3702.22
2042	81	4/3-6/22	5777	49.48	152.94	232.16	5387.11

Table J-17. MRG FLO-2D Results

	Alternative I - Normal (I-Normal)						
	Timestamp: Dec 16, 2003 9:28AM MST (on urg3)			Max Wetted Floodplain Area			
Year	**Simulation Time**	**Period**	**Peak at Cochiti**	**Reach 10**	**Reach 12**	**Reach 13**	**Reach 14**
	(days)		**Gage Outflow(cfs)**	**(acres)**	**(acres)**	**(acres)**	**(acres)**
2003	73	April 26-July 7	4418.11	0.00	3.58	16.78	3904.55
2005	90	March 24-June 21	5709.44	35.84	383.62	672.46	6250.86
2007	43	March 22-May 3	4323.34	0.00	0.00	11.05	4452.92
2010	43	March 21-May 2	4368.73	0.00	0.00	11.05	4476.75
2011	42	March 22-May 2	4368.01	0.00	0.00	11.05	4515.41
2017	95	April 1-July 4	7270.07	390.37	1392.37	2469.88	7255.62
2018	70	May 11-July 19	5337.29	0.00	54.91	131.68	4979.60
2021	91	April 21-July 20	5421.94	0.00	60.82	163.13	5141.91
2025	63	April 28-June 29	5177.82	0.00	31.34	120.20	4852.31
2026	96	April 24-July 28	7179.50	352.85	962.32	1190.32	5611.17
2027	51	May 10-June 29	4613.06	0.00	3.58	11.05	3614.99
2028	51	May 4-June 23	5777.00	53.05	155.40	232.16	5142.47
2029	81	April 21-July 10	7048.42	325.12	1306.48	2325.98	6861.27
2030	86	March 23-June 16	5299.00	0.00	193.64	630.61	4910.27
2031	127	March 10-July 14	7527.12	483.47	1457.66	2776.65	7288.33
2036	50	May 5-June 23	6273.00	172.35	288.84	486.04	3890.83
2037	42	March 14-April 24	3236.25	0.00	0.00	0.00	0.00
2038	70	April 9-June 17	7381.34	411.29	1406.09	2447.10	5754.9
2039	86	March 23-June 16	5299.00	0.00	183.94	618.83	4876.03
2041	73	April 26-July 7	4409.51	0.00	3.58	11.05	920.77
2042	67	April 3-June 8	5370.33	0.00	86.49	212.20	3244.85

Table J-18. MRG FLO-2D Results

	Alternative I - Wet (I-Wet)						
	Timestamp: Dec 16, 2003 9:28AM MST (on urg3)			Max Wetted Floodplain Area			
Year	Simulation Time	Period	Peak at Cochiti	Reach 10	Reach 12	Reach 13	Reach 14
	(days)		(cfs)	(acres)	(acres)	(acres)	(acres)
2003	72	Apr 27 - Jul 7	4418.00	0.00	3.58	16.78	45.75
2005	82	Mar 25 - Jun 14	5709.00	35.84	702.41	1138.87	3190.11
2007	43	Mar 22 - May 3	4323.00	0.00	0.00	11.05	48.45
2010	44	Mar 21 - May 3	4368.00	0.00	0.00	11.05	48.45
2011	43	Mar 22 - May 3	4368.00	0.00	0.00	11.05	48.45
2017	94	Apr 2 - Jul 4	7274.00	390.37	1428.32	2557.74	4884.40
2018	70	May 11 - Jul 19	4110.00	0.00	0.00	5.29	14.14
2021	92	Apr 20 - Jul 20	5421.92	0.00	60.82	163.13	5140.88
2025	63	Apr 28 - Jun 29	5177.88	0.00	31.34	120.20	4851.25
2026	96	Apr 24 - Jul 28	7146.74	328.30	852.13	1006.77	5511.65
2027	51	May 10 - Jun 29	3873.88	0.00	0.00	0.00	1512.77
2028	46	May 9 - Jun 23	5776.00	30.10	106.85	150.98	4901.59
2029	81	Apr 21 - Jul 10	7032.54	313.64	1127.32	1577.76	6231.19
2030	53	Mar 23 - May 14	5299.00	0.00	106.97	384.80	5625.38
2031	122	Mar 10 - Jul 9	7472.99	468.44	1412.43	2655.37	5563.57
2036	46	May 9 - Jun 23	5776.00	30.10	115.90	220.68	374.96
2037	42	Mar 15 - Apr 25	3236.27	0.00	0.00	0.00	0.00
2038	68	Apr 9 - Jun 15	7381.3	405.55	1325.43	2357.77	5815.05
2039	86	Mar 23 - Jun16	5299.00	0.00	193.39	627.94	2305.24
2041	73	Apr 26 - Jul 7	4409.6	0.00	3.58	11.05	36.42
2042	80	Apr 3 - Jun 21	5282.00	0.00	58.25	137.39	911.75

Table J-19. Above Cochiti FLO-2D Results

	Base Run Version 2 (BaseRun-11.13.03)			Max Wetted Floodplain Area	Max Wetted Floodplain Area
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	14	5/2/03-5/14/03	4097	16.97	0.00
2005	28	4/10/05-5/7/05	5265	111.83	0.00
2007	17	4/8/07-4/24/07	4385	16.97	0.00
2010	17	4/8/10-4/24/10	4419	16.97	0.00
2017	74	4/14/17-6/26/17	9283	802.26	37.74
2018	43	5/11/18-6/22/18	5060	108.99	0.00
2019	6	5/4/19-5/9/19	3751	6.52	0.00
2021	43	5/11/21-6/22/21	5060	108.99	0.00
2024	6	5/4/19-5/9/19	3751	6.52	0.00
2025	23	5/14/25-6/5/25	4733	73.96	0.00
2026	71	4/26/26-7/5/26	6959	327.63	4.45
2027	17	5/14/27-5/30/27	4733	73.96	0.00
2028	57	4/7/28-6/2/28	6969	327.42	4.45
2029	65	4/22/29-6/25/29	6635	284.67	0.00
2030	28	4/10/30-5/7/30	5263	115.42	0.00
2031	91	4/6/31-7/5/31	8486	724.48	46.46
2032	4	5/5/32-5/8/32	3558	6.52	0.00
2034	6	5/4/34-5/9/34	3731	6.52	0.00
2036	55	4/7/36-5/31/36	6969	330.58	4.45
2037	6	4/10/37-4/15/37	3607	6.52	0.00
2038	54	4/17/38-6/9/38	7286	416.98	13.31
2039	27	4/10/39-5/6/39	5265	111.83	0.00
2041	14	5/2/41-5/15/41	4097	16.97	0.00
2042	54	4/7/42-5/30/42	6969	330.58	4.45

Table J-20. Above Cochiti FLO-2D Results

	Alternative B - Wet (B-Wet)			Max Wetted Floodplain Area	
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	7	5/3/03-5/9/03	3832	9.81	0.00
2005	26	4/10/05-5/5/05	4997	103.26	0.00
2007	11	4/8/07-4/18/07	4342	13.39	0.00
2010	11	4/8/10-4/18/10	4342	13.39	0.00
2011	11	4/8/11-4/18/11	4342	13.39	0.00
2017	74	4/14/17-6/26/17	8082	410.37	8.83
2018	6	5/16/18-5/21/18	3709	16.97	0.00
2021	15	5/12/21-5/26/21	4795	98.91	0.00
2024	3	5/6/24-5/8/24	3462	6.52	0.00
2025	18	5/18/25-6/4/25	4468	64.01	0.00
2026	64	5/3/26-7/5/26	7313	358.39	4.45
2028	12	5/20/28-5/31/28	5736	209.50	0.00
2029	51	5/4/29-6/23/29	6370	254.71	0.00
2030	7	4/13/30-4/19/30	3895	22.71	0.00
2031	87	4/9/31-7/4/31	8485	710.05	46.46
2036	12	5/20/36-5/31/36	6045	238.87	0.00
2038	50	4/17/38-6/5/38	7021	366.01	8.83
2039	7	4/13/39-4/19/39	3895	22.71	0.00
2041	7	5/3/41-5/9/41	3832	9.81	0.00
2042	50	4/7/42-5/26/42	6384	269.52	0.00

Table J-21. Above Cochiti FLO-2D Results

	Alternative D - Normal - Wet (D-Nml-Wet)			Max Wetted Floodplain Area	
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	40	5/2/03-6/10/03	4273	34.44	0.00
2005	29	4/10/05-5/8/05	5422	129.33	0.00
2007	19	4/8/07-4/26/07	4386	16.97	0.00
2010	19	4/8/10-4/26/10	4420	16.97	0.00
2011	19	4/8/11-4/26/11	4426	16.97	0.00
2017	74	4/14/17-6/24/17	8462	466.71	17.78
2018	30	5/16/18-6/14/18	4077	16.97	0.00
2021	44	5/11/21-6/23/21	5237	108.99	0.00
2022	3	5/17/22-5/19/22	3507	6.52	0.00
2023	3	5/17/23-5/19/23	3507	6.52	0.00
2024	9	5/3/24-5/11/24	3928	9.81	0.00
2025	23	5/13/25-6/4/25	4909	78.11	0.00
2026	64	5/3/26-7/5/64	6981	335.72	4.45
2028	13	5/20/28-6/1/28	6045	241.67	0.00
2029	57	5/4/29-6/29/29	6812	301.88	4.45
2030	7	4/13/30-4/19/30	3895	22.71	0.00
2031	88	4/9/31-7/5/31	8485	710.05	46.46
2036	13	5/20/36-6/1/36	6045	233.67	0.00
2038	51	4/17/38-6/6/38	7463	427.14	17.78
2039	7	4/13/39-4/19/39	3895	22.71	0.00
2041	40	5/2/41-6/10/41	4273	34.44	0.00
2042	50	4/7/42-5/26/42	5923	227.40	0.00

Table J-22. Above Cochiti FLO-2D Results

	Alternative E (E-All)			Max Wetted Floodplain Area	
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	13	May 2 - May 14	4097	16.97	0.00
2005	27	April 10 - May 6	5265	111.83	0.00
2007	16	April 8 - April 23	4386	16.97	0.00
2010	16	April 8 - April 23	4418	16.97	0.00
2011	16	April 8 - April 23	4427	16.97	0.00
2017	73	April 14 - June 25	8289	442.42	17.78
2018	5	May 16 - April 20	3703	16.97	0.00
2021	42	May 11 - June 21	5060	108.99	0.00
2024	5	May 4 - May 8	3751	6.52	0.00
2025	22	May 14 - June 4	4733	73.96	0.00
2026	63	May 3 - July 4	6968	331.62	4.45
2028	12	May 20 - May 31	6043	234.70	0.00
2029	52	May 4 - June 24	6635	283.63	0.00
2030	6	May 13 - May 18	3896	22.71	0.00
2031	87	April 9 - July 4	8485	712.42	46.46
2036	12	May 20 - May 31	6043	234.70	0.00
2038	49	April 17 - June 4	7286	421.40	13.31
2039	6	April 13 - April 18	3895	22.71	0.00
2041	13	May 2 - May 14	4097	16.97	0.00
2042	49	April 7 - May 25	6082	238.87	0.00

Table J-23. Above Cochiti FLO-2D Results

	Alternative 1 - Dry Ver. 2 (I-Dry)			Max Wetted Floodplain Area	
	Timestamp: Mar 1,2004 9:42AM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	14	5/2/03-5/15/03	4097	16.97	0.00
2005	28	4/10/05-5/7/05	5265	111.83	
2007	17	4/8/07-4/24/07	4385	16.97	0.00
2010	17	4/8/10-4/24/10	4419	16.97	0.00
2011	17	4/8/11-4/24/11	4427	16.97	0.00
2017	74	4/14/17-6/26/17	9283	810.17	37.74
2018	43	5/11/18-6/22/18	5060	108.99	0.00
2019	6	5/4/19-5/9/19	3751	6.52	0.00
2021	43	5/11/21-6/22/21	5060	108.99	0.00
2024	6	5/4/24-5/9/24	3751	6.52	0.00
2025	23	5/14/25-6/5/25	4733	73.96	0.00
2026	71	4/26/26-7/5/26	6960	330.58	4.45
2027	17	5/14/27-5/30/27	4733	73.96	0.00
2028	44	4/20/28-6/2/28	6969	328.51	4.45
2029	64	4/23/29-6/25/29	6635	286.42	0.00
2030	25	4/13/30-5/7/30	4603	73.96	0.00
2031	89	4/8/31-7/5/31	8486	724.48	46.46
2032	4	5/6/32-5/9/32	3690	6.52	0.00
2034	5	5/5/34-5/9/34	3725	6.52	0.00
2036	55	4/8/36-6/1/36	6969	328.51	4.45
2038	54	4/17/38-6/9/38	7286	417.76	13.31
2039	17	4/10/39-4/26/39	5265	115.42	0.00
2041	14	5/2/41-5/15/41	4097	16.97	0.00
2042	55	4/7/42-5/31/42	6969	330.58	4.45

Table J-24. Above Cochiti FLO-2D Results

	Alternative I - Normal (I-Normal)			Max Wetted Floodplain Area	
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	14	5/2/03-5/15/03	4097	16.97	0.00
2005	28	4/10/05-5/7/05	5265	111.83	0.00
2007	17	4/8/07-4/24/07	4385	16.97	0.00
2010	17	4/8/10-4/24/10	4419	16.97	0.00
2011	17	4/8/11-4/24/11	4427	16.97	0.00
2017	74	4/14/17-6/26/17	8289	442.42	17.78
2018	41	5/13/18-6/22/18	5023	108.99	0.00
2019	4	5/23/19-5/26/19	3618	6.52	0.00
2021	43	5/11/21-6/22/21	5060	108.99	0.00
2024	6	5/4/24-5/9/24	3751	6.52	0.00
2025	23	5/14/25-6/5/25	4733	73.96	0.00
2026	64	5/3/26-7/5/26	6969	336.32	4.45
2027	10	5/24/27-6/2/27	4086	22.71	0.00
2028	24	5/10/28-6/2/28	6969	324.84	4.45
2029	55	5/2/29-6/25/29	6635	286.42	0.00
2030	7	4/13/30-4/19/30	3896	22.71	0.00
2031	88	4/9/31-7/5/31	8486	724.01	46.46
2036	24	5/10/36-6/2/36	6969	324.84	4.45
2038	50	4/17/38-6/5/38	7286	421.40	13.31
2039	7	4/13/39-4/19/39	3896	22.71	0.00
2041	14	5/2/41-5/15/41	4097	16.97	0.00
2042	51	4/7/42-5/27/42	6649	291.95	4.45

Table J-25. Above Cochiti FLO-2D Results

	Alternative I - Wet (I-Wet)			Max Wetted Floodplain Area	
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)				
Year	Simulation Time	Period	~ Peak Inflow	Reach 8	Reach 9
	(days)		(cfs)	(acres)	(acres)
2003	14	5/2/03-5/15/03	4097	16.97	0.00
2005	28	4/10/05-5/7/05	5265	111.83	0.00
2007	17	4/8/07-4/24/07	4386	16.97	0.00
2010	17	4/8/10-4/24/10	4418	16.97	0.00
2011	17	4/8/11-4/24/11	4428	16.97	0.00
2017	74	4/14/17-6/26/17	4427	16.97	0.00
2018	6	5/16/18-5/21/18	8289	442.42	17.78
2021	43	5/11/21-6/22/21	3703	16.97	0.00
2024	6	5/4/24-5/9/24	5060	108.99	0.00
2025	23	5/14/25-6/5/25	3751	6.52	0.00
2026	64	5/3/26-7/5/26	4733	73.96	0.00
2028	13	5/20/28-6/1/28	6968	334.25	4.45
2029	53	5/4/29-6/25/29	6043	234.70	0.00
2030	7	4/13/30-4/19/30	6635	284.67	0.00
2031	88	4/9/31-7/5/31	3896	22.71	0.00
2036	13	5/20/36-6/1/36	8485	710.16	46.46
2038	50	4/17/38-6/5/38	7286	421.40	13.31
2039	7	4/13/39-4/19/39	3896	22.71	0.00
2041	14	5/2/41-5/15/41	4097	16.97	0.00
2042	50	4/7/42-5/26/42	5304	213.89	0.00

Table J-26. Rio Chama FLO-2D Results

	Base Run Version 2 (BaseRun-11.13.03)			Max Wetted Floodplain Area
	Timestamp: Nov 24, 2003 3:52PM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2003	86	April 12 - July 6	1800	226
2004	42	April 12 - May 23	1543	32
2005	87	April 8 - June 11	1800	240
2006	35	April 26 - May 30	1800	170
2007	41	March 31 - May 10	1800	210
2008	12	April 26 - May 7	1578	42
2010	41	March 31 - May 10	1800	211
2011	43	March 31 - May 12	1800	205
2012	6	April 29 - May 4	1407	11
2013	13	April 25 - May 7	1548	31
2014	12	April 26 - May 7	1586	42
2016	4	April 11 - May 24	1609	58
2017	52	April 13 - June 3	1800	241
2018	72	April 16 - June 26	1800	255
2019	38	April 23 - May 30	1800	205
2020	35	April 26 - May 30	1800	171
2021	96	April 19 - July 23	1800	255
2022	59	April 23 - June 20	1800	135
2023	61	April 23 - June 22	1800	204
2024	51	April 24 - June 13	1800	204
2025	48	April 24 - June 10	1800	184
2026	74	March 27 - June 8	1800	210
2027	31	April 29 - May 29	1800	185
2028	63	April 4 - June 5	1800	205
2029	86	April 14 - July 8	1800	291
2030	59	April 8 - June 5	1800	238
2031	121	March 9 - July 7	1800	290
2032	34	April 25 - May 28	1610	124
2033	38	April 25 - June 1	1800	200

Table J-26. Rio Chama FLO-2D Results

	Base Run Version 2 (BaseRun-11.13.03)			Max Wetted Floodplain Area
	Timestamp: Nov 24, 2003 3:52PM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2034	32	April 25 - May 26	1800	204
2035	6	May 12 - May 17	1132	1
2036	58	April 4 - May 31	1800	206
2037	13	April 4 - April 22	1027	1
2038	75	April 14 - June 27	1800	263
2039	45	April 7 - May 21	1800	239
2040	44	April 11 - May 24	1607	56
2041	86	April 12 - July 6	1800	226
2042	57	April 3 - May 29	1800	206

Table J-27. Rio Chama FLO-2D Results

	Alternative B - Wet (B-Wet)			Max Wetted Floodplain Area
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2003	85	April 12 - July 5	1500	126.25
2004	42	April 12 - May 23	1500	19.67
2005	80	April 8 - June 26	1500	132.64
2006	40	April 26 - June 4	1500	28.82
2007	44	March 31 - May 13	1500	131.82
2008	12	April 26 - May 7	1500	14.53
2010	44	March 31 - May 13	1500	130.01
2011	46	March 31 - May 15	1500	131.28
2012	6	April 29 - May 4	1407	11.69
2013	13	April 25 - May 7	1500	14.53
2014	12	April 26 - May 7	1500	14.01
2016	45	April 11 - May 25	1500	19.67
2017	25	April 13 - May 7	1500	137.91
2018	43	May 30 - July 11	1500	17.27
2019	61	November 1 - December 31	1495	24.82
2020	40	April 26 - June 4	1500	28.82
2021	90	April 19 - July 17	1500	143.05
2022	54	April 23 - June 15	1500	83.40
2023	54	April 23 - June 15	1500	82.56
2024	48	April 24 - June 10	1500	88.27
2025	55	April 24 - June 17	1500	77.47
2026	21	May 22 - June 11	1500	27.13
2028	11	May 24- June 3	1500	19.53
2029	65	May 4 - July 7	1500	140.17
2030	18	May 21 - June 7	1500	16.8
2031	67	May 1 - July 6	1500	172.68
2032	30	November 1 - November 30	1393	11.48
2033	7	December 16 - December 22	1120	0
2034	30	November 1 - November 30	1211	2.78

Table J-27. Rio Chama FLO-2D Results

	Alternative B - Wet (B-Wet)			Max Wetted Floodplain Area
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2036	12	May 23 - June 3	1500	22.17
2038	44	April 14 - May 27	1500	150.63
2039	12	May 22 - June 2	1500	16.8
2040	44	April 11 - May 24	1500	19.67
2041	85	April 12 - July 5	1500	124.08
2042	49	April 4 - May 22	1500	42.05

Table J-28. Rio Chama FLO-2D Results

	Alternative D - Normal-Wet (D-Nml-Wet)			Max Wetted Floodplain Area
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)			
Year	**Simulation Time**	**Period**	**~ Peak Inflow**	**Reach 7**
	(days)		**(cfs)**	**(acres)**
2003	86	April 12 - July 6	2000	305
2004	42	April 12 - May 23	1543	32
2005	50	April 8 - May 27	2000	315
2006	35	April 26 - June 30	2000	250
2007	41	March 31 - May 10	2000	270
2008	12	April 26 - May 7	1580	42
2010	41	March 31 - May 10	2000	271
2011	39	March 31 - May 8	2000	273
2012	6	April 29 - May 4	1408	12
2013	13	April 25 - May 7	1548	31
2014	12	April 26 - May 7	1580	42
2016	44	April 11 - May 24	1609	58
2017	30	April 13 - May 12	2000	320
2018	42	May 30 - July 10	2000	208
2019	61	November 1 - December 31	1425	15
2020	30	April 26 - May 25	1992	243
2021	83	April 19 - July 10	2000	343
2022	54	April 23 - June 15	2000	276
2023	54	April 23 - June 15	2000	276
2024	48	April 24 - June 10	2000	275
2025	43	April 24 - June 5	2000	268
2026	27	May 24 - June 19	2000	218
2028	12	May 23 - June 3	1902	182
2029	60	May 14 - July 12	2000	328
2030	14	May 23 - June 5	1902	174
2031	67	May 3 - July 8	2000	270
2032	30	November 1 - November 30	1243	4
2034	30	November 1 - November 30	1216	3
2036	11	May 23 - June 2	1902	188

Table J-28. Rio Chama FLO-2D Results

	Alternative D - Normal-Wet (D-Nml-Wet)			Max Wetted Floodplain Area
	Timestamp: Feb 26, 2004 1:38PM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2038	51	April 14 - June 3	2000	356
2039	7	May 26 - June 1	1517	19
2040	44	April 11 - May 24	1610	49
2041	85	April 12 - July 5	2000	306
2042	48	April 4 - May 21	2000	273

Table J-29. Rio Chama FLO-2D Results

	Alternative E - All (E-All)			Max Wetted Floodplain Area
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	**Simulation Time**	**Period**	**~ Peak Inflow**	**Reach 7**
	(days)		**(cfs)**	**(acres)**
2003	86	April 12 - July 6	1800	227
2004	42	April 12 - May 23	1543	32
2005	62	April 8 - June 8	1800	240
2006	35	April 26 - May 30	1800	171
2007	41	March 31 - May 10	1800	210
2008	12	April 26 - May 7	1578	41
2010	41	March 31 - May 10	1800	209
2011	43	March 31 - May 12	1800	206
2012	6	April 29 - May 4	1407	11
2013	13	April 25 - May 7	1548	31
2014	12	April 26 - May 7	1585	44
2016	44	April 11 - May 24	1609	57
2017	25	April 13 - May 7	1800	244
2018 Summer	22	May 29 - June 19	1800	112
2018 Fall	61	November 1 - December 31	1619	73
2019	61	November 1 - December 31	1418	15
2020	35	April 26 - May 30	1800	172
2021	96	April 19 - July 23	1800	256
2022	61	April 23 - June 22	1800	201
2023	61	April 23 - June 22	1800	201
2024	51	April 24 - June 13	1800	204
2025	48	April 24 - June 10	1800	184
2026 Summer	27	May 24 - June 19	1800	124
2026 Fall	61	November 1 - December 31	1800	114
2027	60	November 1 - December 30	1378	10
2028 Summer	12	May 23 - June 3	1800	111
2028 Fall	61	November 1 - December 31	1775	110
2029 Summer	56	May 14 - July 8	1800	246
2029 Fall	60	November 2 - December 31	1374	10

Table J-29. Rio Chama FLO-2D Results

	Alternative E - All (E-All)			Max Wetted Floodplain Area
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2030 Summer	15	May 22 - June 5	1800	108
2030 Fall	60	November 1 - December 30	1425	16
2031 Summer	66	May 3 - July 7	1800	197
2031 Fall	61	November 1 - December 31	1726	89
2032	60	November 1 - December 30	1255	5
2033	8	December 15 - December 22	1132	0
2034	30	November 1 - November 30	1227	4
2036 Summer	11	May 23 - June 2	1800	111
2036 Fall	60	November 1 - December 30	1762	108
2038	45	April 14 - May 28	1800	263
2039 Summer	13	May 21 - June 2	1800	106
2039 Fall	59	November 2 - December 30	1437	17
2040	44	April 11 - May 24	1607	55
2041	86	April 12 - July 6	1800	226
2042 Summer	48	April 4 - May 21	1800	199
2042 Fall	30	November 1 - November 30	1505	33

Table J-30. Rio Chama FLO-2D Results

	Alternative I-Dry Chama (I-Dry)			Max Wetted Floodplain Area
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2003	86	April 12 - July 6	1800	227
2004	42	April 12 - May 23	1543	32
2005	75	April 8 - June 21	1800	240
2006	35	April 26 - May 30	1800	170
2007	41	March 31 - May 10	1800	211
2008	12	April 26 - May 7	1578	42
2010	41	March 31 - May 10	1800	209
2011	43	March 31 - May 12	1800	206
2012	6	April 29 - May 4	1407	11
2013	13	April 25 - May 7	1548	31
2014	12	April 26 - May 7	1586	43
2016	44	April 11 - May 24	1609	57
2017	50	April 13 - June 1	1800	241
2018	78	April 23 - July 9	1800	256
2019	31	April 29 - May 29	1800	201
2020	35	April 26 - May 30	1800	170
2021	96	April 19 - July 23	1800	254
2022	59	April 23 - June 20	1800	200
2023	61	April 23 - June 22	1800	201
2024	51	April 24 - June 13	1800	204
2025	48	April 24 - June 10	1800	184
2026	72	March 28 - June 7	1800	211
2027	27	May 4 - May 30	1800	183
2028	54	April 13 - June 5	1800	207
2029	79	April 21 - July 8	1800	291
2030	52	April 15 - June 5	1800	203
2031	91	April 8 - July 7	1800	290
2032	27	May 2 - May 28	1800	182
2033	36	April 27 - June 1	1800	200

Table J-30. Rio Chama FLO-2D Results

	Alternative I-Dry Chama (I-Dry)			Max Wetted Floodplain Area
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2034	26	May 1 - May 26	1800	189
2035	9	May 12 - May 20	1144	1
2036	57	April 7 - June 2	1800	207
2037	5	April 20 - April 24	1380	32
2038	75	April 14 - June 27	1800	263
2039	45	April 7 - May 21	1800	240
2040	44	April 11 - May 24	1607	55
2041	86	April 12 - July 6	1800	227
2042	62	April 3 - June 3	1800	203

Table J-31. Rio Chama FLO-2D Results

	Alternative I – Normal (I-Normal)			
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	**Simulation Time**	**Period**	**~ Peak Inflow**	**Reach 7**
	(days)		**(cfs)**	**(acres)**
2003	86	April 12 - July 6	1800	227
2004	42	April 12 - May 23	1543	32
2005	75	April 8 - June 21	1800	240
2006	35	April 26 - May 30	1800	170
2007	41	March 31 - May 10	1800	211
2008	12	April 26 - May 7	1578	42
2010	41	March 31 - May 10	1800	209
2011	43	March 31 - May 12	1800	206
2012	6	April 29 - May 4	1407	11
2013	13	April 25 - May 7	1548	31
2014	12	April 26 - May 7	1586	43
2016	44	April 11 - May 24	1609	57
2017	31	April 13 - May 13	1800	241
2018	58	May 13 - July 9	1800	233
2019	15	May 19 - June 2	1800	106
2020	49	April 12 - May 30	1800	170
2021	96	April 19 - July 23	1800	253
2022	59	April 23 - June 20	1800	202
2023	61	April 23 - June 22	1800	202
2024	51	April 24 - June 13	1800	204
2025	48	April 24 - June 10	1800	183
2026 Summer	35	May 4 - June 7	1800	152
2026 Fall	30	November 1 - November 30	1381	11
2027	8	May 25 - June 1	1651	99
2028 Summer	33	May 4 - June 5	1800	206
2028 Fall	8	November 10 - November 17	1282	6
2029	67	May 3 - July 8	1800	275
2030	34	May 4 - June 6	1800	115
2031 Summer	80	April 19 - July 7	1800	292
2031 Fall	30	November 1 - November 30	1300	6

Table J-31. Rio Chama FLO-2D Results

	Alternative I – Normal (I-Normal)			
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	**Simulation Time**	**Period**	**~ Peak Inflow**	**Reach 7**
	(days)		**(cfs)**	**(acres)**
2032	7	May 22 - May 28	1500	16
2033	10	May 25 - June 3	1800	109
2034	9	May 21 - May 29	1800	104
2036 Summer	33	May 6 - June 7	1800	203
2036 Fall	8	November 10 - November 17	1282	6
2038	70	April 14 - June 22	1800	263
2039	29	May 4 - June 1	1800	115
2040	44	April 1 - May 14	1607	55
2041	86	April 12 - July 6	1800	226
2042 Summer	50	April 4 - May 23	1800	199
2042 Fall	8	November 10 - November 17	1292	7

Table J-32. Rio Chama FLO-2D Results

	Alternative I-3			Max Wetted Floodplain Area
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	Simulation Time	Period	~ Peak Inflow	Reach 7
	(days)		(cfs)	(acres)
2003	86	April 12 - July 6	1800	227
2004	42	April 12 - May 23	1543	32
2005	62	April 8 - June 8	1800	240
2006	35	April 26 - May 30	1800	171
2007	41	March 31 - May 10	1800	209
2008	12	April 26 - May 7	1578	42
2010	41	March 31 - May 10	1800	209
2011	43	March 31 - May 12	1800	205
2012	6	April 29 - May 4	1407	11
2013	13	April 25 - May 7	1548	31
2014	12	April 26 - May 7	1585	44
2016	54	April 1 - May 24	1609	57
2017	29	April 13 - May 11	1800	243
2018 Summer	22	May 29 0 June 19	1800	111
2018 Fall	61	November 1 - December 31	1690	74
2019	61	November 1 - December 31	1418	15
2020	35	April 26 - May 30	1800	171
2021	96	April 19 - July 23	1800	254
2022	61	April 23 - June 22	1800	201
2023	61	April 23 - June 22	1800	202
2024	51	April 24 - June 13	1800	204
2025	48	April 24 - June 10	1800	184
2026 Summer	27	May 24 - June 19	1800	124
2026 Fall	61	November 1 - December 31	1800	115
2027	61	November 1 - December 31	1378	10
2028 Summer	12	May 23 - June 3	1800	111
2028 Fall	61	November 1 - December 31	1775	108
2029 Summer	56	May 14 - July 8	1800	246
2029 Fall	60	November 2 - December 31	1374	10

Table J-32. Rio Chama FLO-2D Results

	Alternative I-3			Max Wetted Floodplain Area
	Timestamp: Mar 1, 2004 9:42AM MST (on urg3)			
Year	**Simulation Time**	**Period**	**~ Peak Inflow**	**Reach 7**
	(days)		**(cfs)**	**(acres)**
2030 Summer	15	May 22 - June 5	1800	108
2030 Fall	60	November 1 - December 30	1426	16
2031 Summer	66	May 3 - July 7	1800	197
2031 Fall	61	November 1 - December 31	1726	89
2032	60	November 1 - December 30	1255	5
2033	8	December 15 - December 22	1132	0
2034	60	November 1- December 30	1227	4
2036 Summer	11	May 23 - June 2	1800	111
2036 Fall	60	November 1 - December 30	1762	109
2038	50	April 14 - June 2	1800	263
2039 Summer	10	May 23 - June 1	1652	88
2039 Fall	59	November 2 - December 30	1419	15
2040	44	April 11 - May 24	1607	54
2041	86	April 12 - July 6	1800	227
2042 Summer	47	April 4 - May 20	1800	201
2042 Fall	30	November 1 - November 30	1531	40

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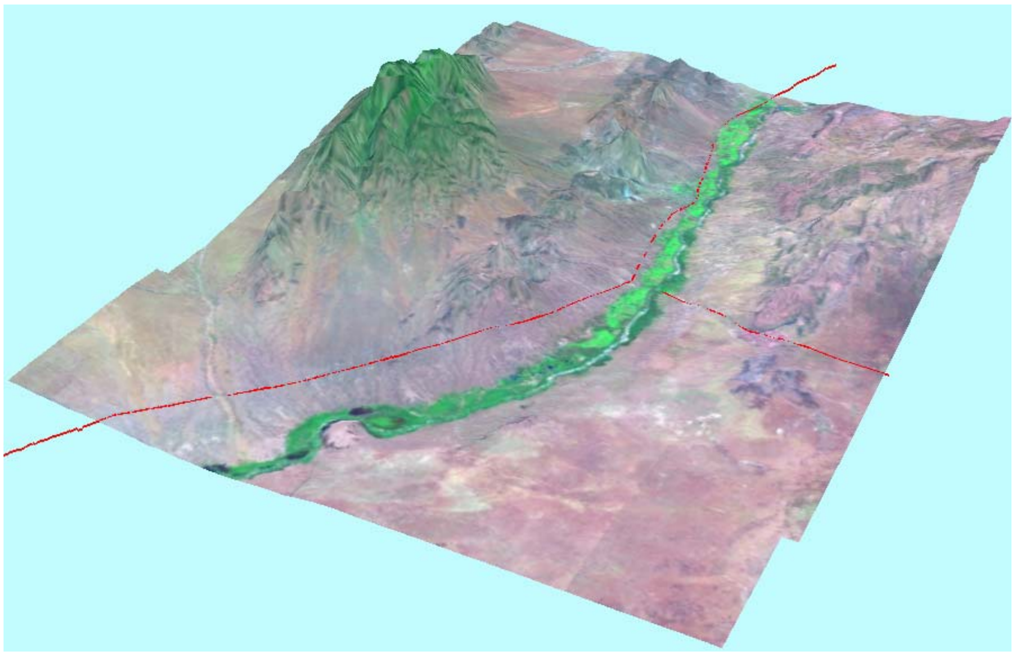
Linked Surface Water and Groundwater Model For Socorro and San Marcial Basins between San Acacia and Elephant Butte Reservoir



By

Nabil G. Shafike, Ph.D.
Interstate Stream Commission

December 2005

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Linked Surface Water and Groundwater Model for Socorro and San Marcial Basins Between San Acacia and Elephant Butte Reservoir

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ABSTRACT

Surface water and groundwater study of Socorro and San Marcial basins was conducted to develop an understanding of the interaction between surface and subsurface hydrologic systems. Socorro and San Marcial basins are located in central Socorro county, New Mexico. The sixty miles reach of the Rio Grande located between San Acacia and Elephant Butte reservoir experiences high seepage loss that impacts New Mexico's ability to deliver its obligation under the Rio Grande compact to Elephant Butte reservoir. Under Rio Grande compact, New Mexico is obligated to deliver a specified amount of water to Elephant Butte reservoir based on the flow at Otowi gage at northern New Mexico. This flow is required to satisfy portion of the demands above Ft. Quitman and below Elephant Butte Reservoir in New Mexico, Texas and Mexico.

Surface water system in the study area consists of Rio Grande floodway channel, low flow conveyance channel (LFCC) and irrigation and drainage system. The LFCC was constructed during the 1950's to provide an efficient conveyance of water to the reservoir. The LFCC was fully operational for the period from 1959 to 1986. Currently no flow is diverted to the channel and it functions passively as the main drain for the system from San Acacia to Elephant Butte reservoir. Most of the surface water enters the basin at San Acacia is delivered to Elephant Butte reservoir through the Rio Grande floodway and the LFCC. Surface water is consumed by evapotranspiration of crops and riparian vegetations and Evaporation from open waters and wet sand.

Groundwater system consists of the shallow alluvium and Santa Fe group aquifers. The shallow alluvium aquifer thickness varies from few feet along the margin of the basin to about 80 ft at the center of the basin. Thickness of the Santa Fe group aquifer varies from a few feet along the outcrop of the upper Santa Fe to more than 5000 ft at middle of the basin in San Antonio area. Observations of the shallow groundwater system indicated a direct link to the surface water system. Groundwater in the basin is consumed by evapotranspiration of crop and riparian vegetation and municipal and industrial uses. Groundwater levels in the shallow alluvial aquifer oscillate seasonally but do not show a declining tend.

A dynamically linked numerical surface water and groundwater model was developed to better characterize surface water and groundwater relations and to evaluate the use of the LFCC. The model simulates the Rio Grande channel, the LFCC, and the main irrigation canals and drains as well as the alluvial and the Santa Fe group aquifers. The USGS program MODBRANCH is used to represent the surface water/groundwater system. The surface water component is represented by solving the one-dimensional form of the continuity and momentum equations, known as Saint-Venant equation. The groundwater component is dynamically linked to the surface water

component. The physical processes represented in the model are surface water routing, surface water / groundwater interaction, discharge from springs, riparian and crop depletions, groundwater withdrawals and groundwater levels. The model provides groundwater elevation, surface water flow and riparian and crop depletion.

The model was calibrated to surface water flows and groundwater elevations. The model was calibrated against water level data and flow data. Water level data mostly represent measured water levels in the shallow alluvial aquifer. Flow data represent the seepage loss of the Rio Grande and the Gain of the LFCC. Steady state and transient simulations were conducted and the results indicate that the model is adequately represents the hydrologic system.

1.1 INTRODUCTION

During the past five years Interstate stream commission has lunched several data collection studies for the Rio Grande reach from San Acacia to Elephant Butte reservoir. The focus of these studies was to collect hydrologic data to assist in understanding the surface water and groundwater relations. Several seepage investigations were performed to characterize the conveyance efficiency of the surface water system. Improving conveyance efficiency of this reach of the Rio Grande is essential to New Mexico to meet its obligations under the Rio Grande compact. A comprehensive survey of all groundwater monitoring well was conducted to identify well characteristics and develop a water table map for the shallow alluvial aquifer.

Socorro and San Marcial basins are located in central Socorro County, New Mexico as shown in **Figure 1**. Socorro basin is downstream of Albuquerque basin and receives outflow from Albuquerque basin. The study area covers about 453 square miles from San Acacia to the headwaters of Elephant Butte reservoir. Along the Rio Grande valley in the study area altitude ranges from 4730 ft msl (feet mean sea level) at San Acacia to 4420 ft msl at the delta of Elephant Butte Reservoir. About 300 ft drop in altitude through 55 miles length of the Rio Grande. The climate within the basins area is semiarid with an average annual precipitation varies from 6 to 8 inches (NCRS publication).

Most of the study area lies in Socorro county which has a population of about 18,000 people in year 2003 (U. S. Census Bureau, Population Division, April 2004). Population centers in the area are Socorro, San Antonio, Lemitar, and Polvadera. City of Socorro is the largest community with a population of about 8,900 people (BBER, 2000). Groundwater is the principal source for domestic, municipal and industrial uses in the basin. Surface water from the Rio Grande is the main source for irrigated agriculture in the basin. However shallow groundwater is used frequently as a supplemental source for irrigation in the basin during times when there is a shortage of surface water supply.

Under Rio Grande Compact New Mexico is required to deliver its obligations at Elephant Butte reservoir. This reach of the Rio Grande lies just above the headwaters of Elephant Butte reservoir and understanding its hydrologic characteristics are essential for New Mexico to comply with Rio Grande Compact. Therefore, New Mexico Interstate Stream Commission (ISC) has begun a hydrologic and modeling investigations of the San Acacia reach. This report describes hydrologic modeling study of the surface water and groundwater of Socorro and San Marcial basins.

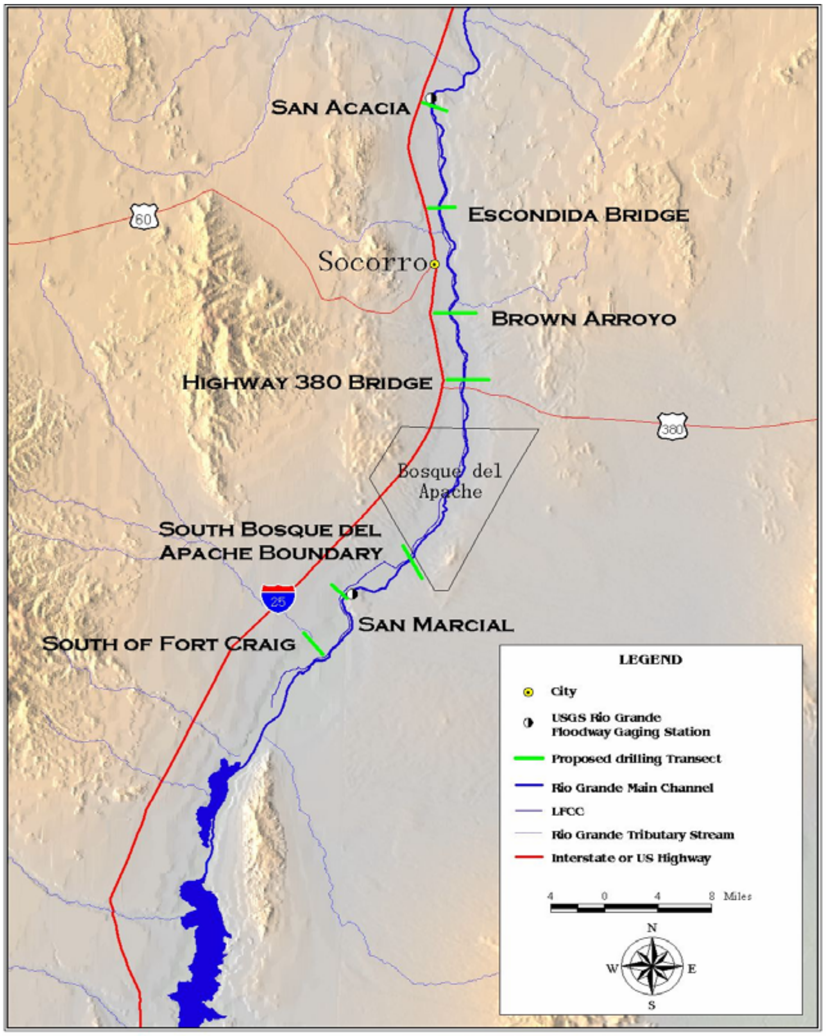

Figure 1. Location Map of Socorro and San Marcial Basins.

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2.0 Purpose and Scope

Understanding surface water and groundwater relations in the San Acacia reach of the Rio Grande is critical for New Mexico to comply with its compact obligations. The purpose of this study is to develop numerical model that describes the interaction between each components of the hydrologic system. The objectives of the surface water and groundwater model are to evaluate surface water conveyance efficiency, investigate different mode of operations of the LFCC, and evaluate impact of restoration projects on river flow.

2.1 Previous Investigations

Several previous studies focused on the geologic formation and structure of the study area. Denny (1940, 1941) described the Quaternary and Tertiary geology of the San Acacia area. Kelley (1952) presented a description of the structural features in Socorro and San Marcial basins. Chapin and Seager (1975) described the development of the Rio Grande rift and Chapin et al. (1978) described the hydrogeologic setting of the Socorro geothermal area.

Allan Sanford (1968) developed a detailed gravity survey map covering part of the Rio Grande depression and adjacent area in central Socorro County, New Mexico. A regional and residual Bouguer anomaly maps were presented and was utilized in the present study for interpretation of the total model thickness.

Anderholm (1983) provided a hydrogeologic description of Socorro and La Jencia basins. Anderholm's report presented a brief description of the surface water and groundwater systems and their interrelation. Anderholm estimated about 2000 acre-feet per year (afy) as mountain front recharge to Socorro basin. In addition, he provided an overall estimate of the water budget for Socorro basin.

Roybal (1989) studied the groundwater resources in Socorro County. The study presented water levels and water quality for most of groundwater wells in Socorro County. The report provided an estimate of mountain front recharge in all County including Socorro and San Marcial basins using a regression equation described in Hearne and Dewey (1988). About 14,000 afy were estimated as mountain front recharge to Socorro and San Marcial basins.

2.2 Acknowledgments

Several people have contributed to the development of this work. Specifically the author acknowledges the valuable discussion with John Hawley and Bruce Allan regarding basin geohydrologic concept. Rob Bowman and his students and Papa Dopulos and Associates were instrumental in data collection. The author thanks Estevan Lopez, Rolf Schmidt Petersen and Kevin Flanigan for their support and technical review of the document.

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3.0 GEOHYDROLOGY OF SOCORRO AND SAN MARCIAL BASINS

The study area extends about 55 miles along the Rio Grande from San Acacia to the headwaters of Elephant Butte reservoir with an average of 8 miles wide, as shown in **Figure 1**. The study area is about 453 square miles lie within the Rio Grande depression and surrounded by Lemitar, Socorro, Magdalena and San Mateo mountains from the west and Lomas De Las Canas upleft, Cerro Colorado and Little San Pascual Mountains from the east. The following sections describe the climatic and geo-hydrologic characteristics of the area.

3.1 Climate

The climate in the basin area is predominantly semi-arid. Precipitation records at selected weather stations indicated that long-term average annual precipitation is 8.0 inches in the valley and about 12 inches in mountainous areas. More than 40 percent of precipitation falls during monsoon months July through September. Average annual temperatures vary from 57 F in the valley to 52 F on the Magdalens.

3.2 Geologic Setting

Understanding the geologic settings in the basin is essential in determining conceptual framework of the system and its hydrologic properties. **Figure 2a** illustrates the surface geology of the Socorro and San Marcial basins. The basin is bounded on north by basin uplift (San Acacia constriction) which separate Socorro basin from the Middle Rio Grande basin. Lemitar, Magdalena, Chupadera Mountains and Socorro peak form the western boundary of the basin. Joyita and Los Pinos uplifts and San Pascual Plateform form most of the eastern boundary, and from the south by San Mateo uplift and San Pascual Plateform.

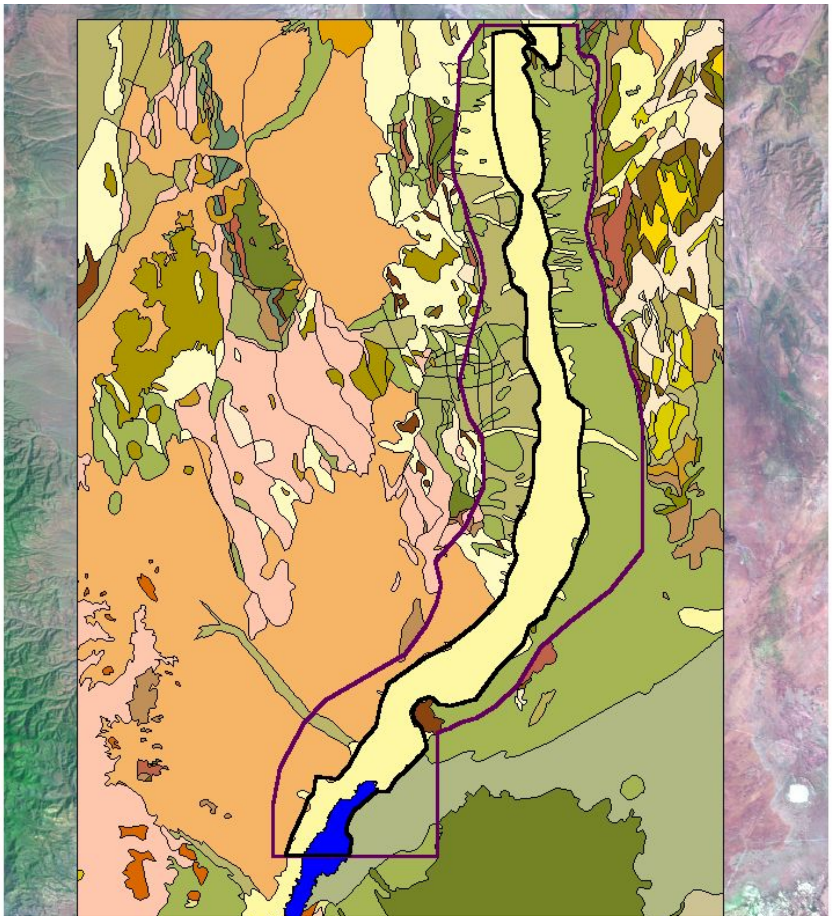


Figure 2a. Surface Geology and Model Outline.

In Socorro peak, Lemitar Mountains, Magdalena and Chupadera mountains volcanic rocks overlie the Precambrian and Pennsylvanian rocks. Alluvial deposits cover the valley of the basins which overlie the Santa Fe group of the Tertiary and Quaternary age. A geologic cross section in Socorro basin is illustrated in **Figure 2b** (Anderholm, 1987). Faults exist on the eastern and western boundaies of the basin that separate Socorro basin from La Jencia (west) and the Jornada Del Muerto (east) basins.

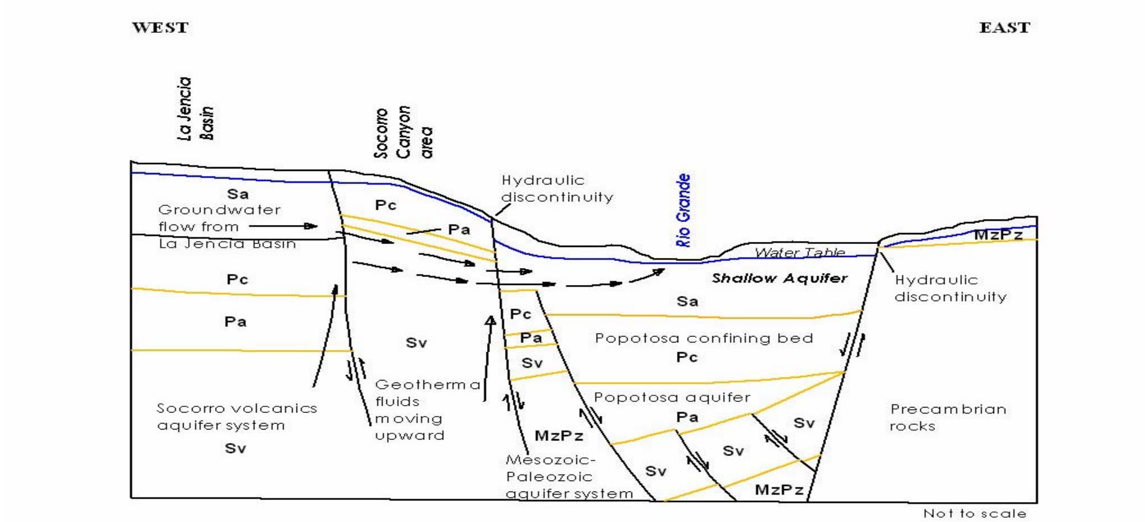


Figure 2b. Geologic X-Section (Anderholm 1987)

The sedimentary fill of the Socorro and San Marcial basins is composed of the Teriary and Quaternary Santa Fe Group and basin fill deposits. The Santa Fe Group thickness is as much as 5000 ft. The alluvium of the inner valley consists of post Santa Fe Group deposits from the most recent deposits. Recent geologic logs indicated that thickness of alluvial deposits varies from 80 to 100 ft.

3.2.1 Surface Water Hydrology

Surface waters enter the basin at San Acacia through the Rio Grande and drain unit 7 west of the Rio Grande (**Figure 3**). The Rio Grande represents the main natural river channel which flows through the basin from San Acacia to Elephant Butte reservoir. Depending on the hydrologic year this reach of the Rio Grande can dry during the summer months. Other ungaged tributaries east and west of the Rio Grande collect runoff during storm events mainly during monsoon season. The total surface water flow enters to the basin is highly variable (**Figure 4)** it can vary from 200,000 afy to more than 2,000,000 afy.

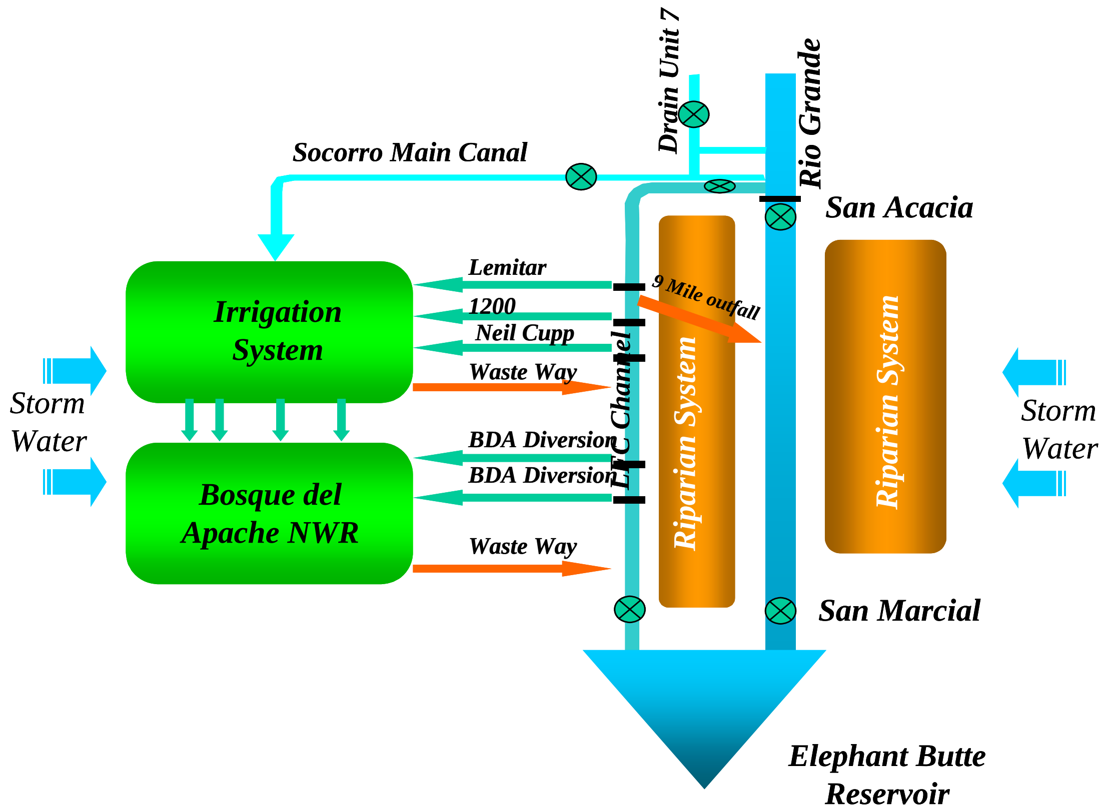


Figure 3: Schematic of the Surface Water System.

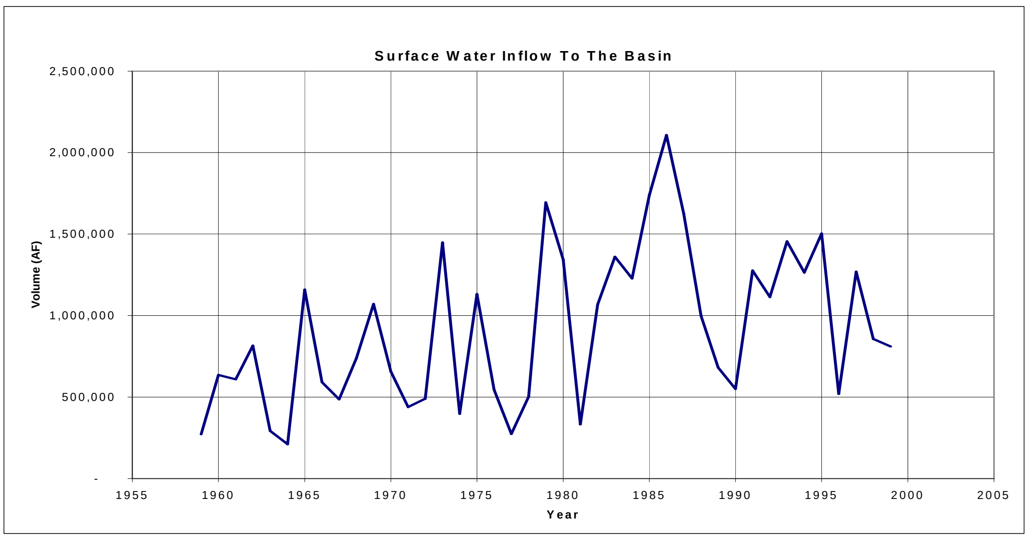


Figure 4. Total Surface Water Inflow.

Another surface water feature of the basin is the Low Flow Conveyance Channel (LFCC), which runs parallel to the river starting from San Acacia to Elephant Butte reservoir. LFCC was constructed during the 1950's as part of the Middle Rio Grande project to improve water conveyance through the basin. The LFCC was designed to be the lowest point in the valley (i.e. its bed elevation is below the river channel by about 10 to 15 ft) and carry a maximum capacity of 2000 cfs. From mid 1950's till 1986 the LFCC was used to convey the Rio Grande water up to its maximum capacity to Elephant Butte reservoir and the river channel was to carry only the additional flows above 2000 cfs. After the high flow years of early 1980's and the spill of the Elephant Butte reservoir the lower end of the LFCC was plugged by sediment and active diversions to the LFCC were discontinued till present. Currently the LFCC is serving as the main drain of the surface water system and at the same time supplies water for irrigated land and for Bosque del Apache National Wild Life Refuge. **Figure 5** shows the annual flow of the LFCC and the Rio Grande floodway at San Marcial, the sum of these two flows represent the total surface water outflow.

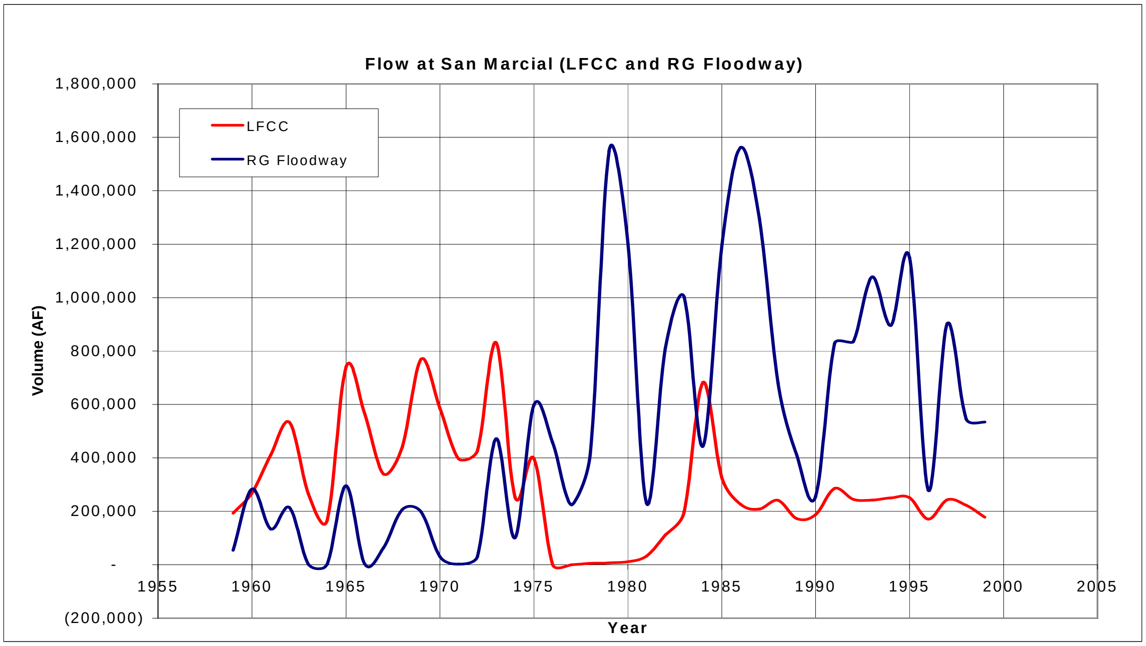


Figure 5. Flow at San Marcial LFCC and Rio Grande Floodway (SW outflow).

Surface water is diverted for irrigation from the Rio Grande at the San Acacia diversion dam. Socorro Main canal is the main irrigation channel (max capacity of about 280 cfs) that distributes water to farms in Socorro basin. Socorro main canal gets its water from direct diversion from the Rio Grande and from drain Unit 7 which collects drainage water of the west side of Bellen division. In addition to Socorro Main canal, the irrigation system consists of laterals, sub-laterals, ditches and drains. Elmondorf drain collects all drainage water from the basin and routed it to the LFCC above San Marcial. All irrigation in Socorro basin occurs west of the Rio Grande, it is reported by MRGCD that about 10,000 to 12,000 acres irrigated annually in Socorro division.

Surface water depletion in the basin is defined as the difference between total surface water inflow and total surface water outflow of the basin. Total surface water inflow is represented by the sum of the following gaging station at San Acacia: Rio Grande Floodway, LFCC, and Socorro Main canal. Total surface water outflow is represented by the sum of the Rio Grande Floodway and the LFCC at San Marcial. **Figure 6** illustrates the cumulative surface water depletion for the period from 1959 to 1999. Analysis indicated that changing LFCC operation resulted to more surface water depletion in the basin. When the LFCC was used to convey water regularly surface water depletion was about 70,000 afy. When using the river channel as the main conveyance and discontinuous the use of the LFCC surface water depletion increased to about 100,000 afy. This increase of depletion is mainly due to increase of evaporation loss from river channel and transpiration loss of riparian vegetation east of the river.

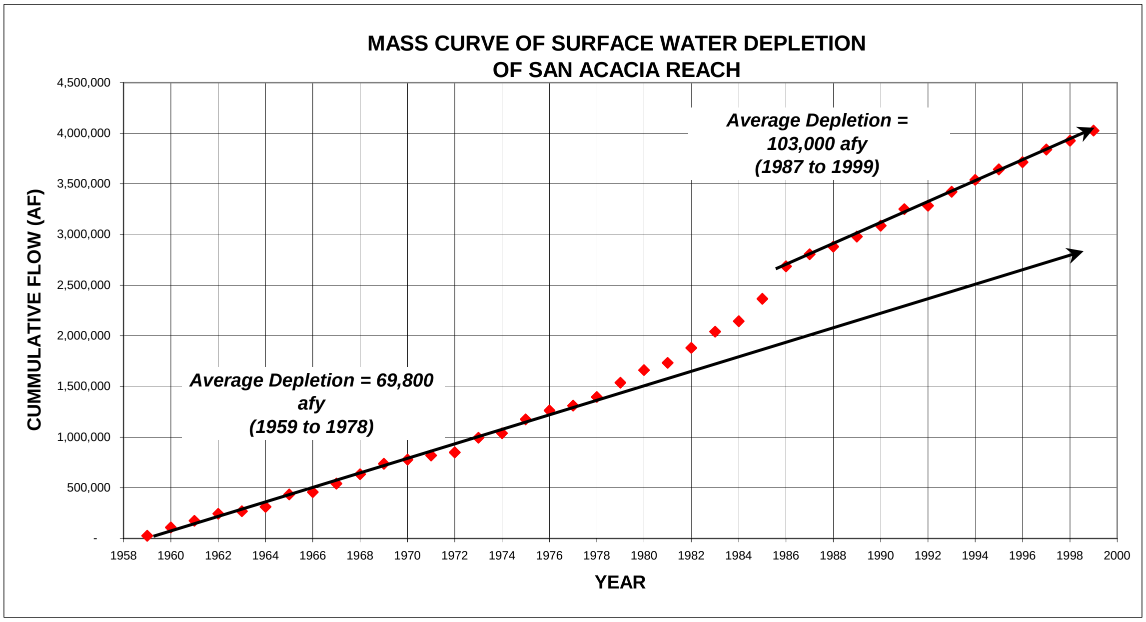


Figure 6. Mass Curve of Surface Water Depletion.

3.2.2 Groundwater Hydrology

The aquifer system in Socorro and San Marcial basins is composed of the Tertiary and Quaternary Santa Fe Group and basin fill alluvial deposits. The shallow alluvial aquifer along the Rio Grande channel represents the most permeable part of the aquifer system while the Santa Fe Group aquifer is orders of magnitude less permeable. Thickness of the alluvial aquifer varies from 10 ft along the edges to about 100 ft along the axis of the Rio Grande. Thickness of the Santa Fe group aquifer varies from couple hundred feet along the edges to about 5000 ft at the thickest part near San Antonio.

Recharge to groundwater occurs through shallow underflow originating from mountains adjacent to the basin (Mountain-Front recharge) and seepage through streambeds (ephemeral streams recharge) during rainfall events. Recharge on the east side of the basin is mostly due to infiltration of runoff derived from precipitation and was estimated at about 1,450 afy (Roybal, 1991) using Hearn and Dewey (1988) approach. Along the west recharge occur along Lemitar Mountains (724 afy), Socorro Peak (2900 afy) and Chupadera Mountains (724 afy) as shown in **Figure 7** (Roybal, 1991).

To understand the general water movement in the shallow aquifer monitoring wells in the study area with depths less than 100 feet was used to develop a water table map (**Figure 8**). In general groundwater moves from east and west to the center of the basin where it discharges to the surface water features. The water table map also indicates a strong north-south hydraulic gradient.

Groundwater is used in the basin for domestic, municipal and Industrial purposes as well as to supplement irrigation use. Most of wells in Socorro and San Marcial basins derive water from the shallow and the top of Santa Fe Group aquifers. Monitoring wells indicate that shallow groundwater levels experience seasonal fluctuations with almost steady water levels as shown in **Figure 9**.

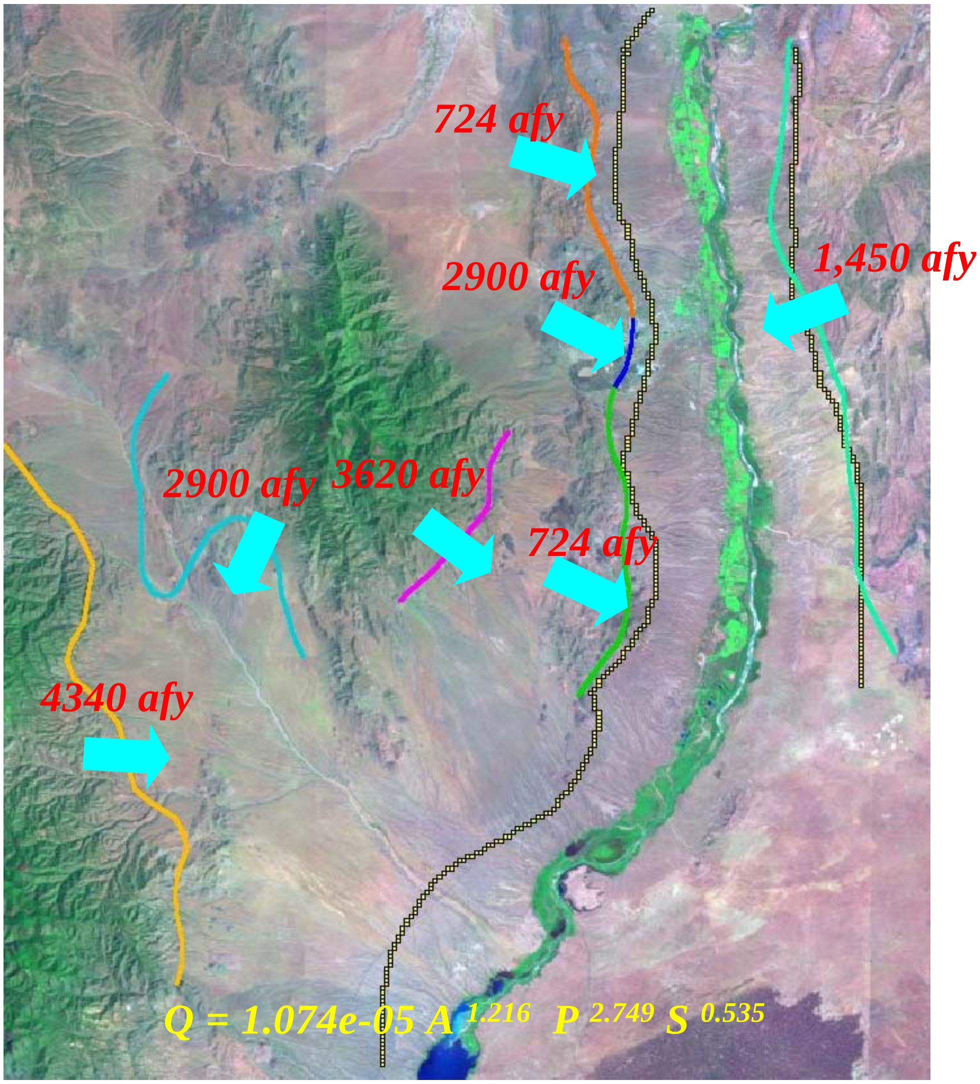


Figure 7. Estimated Mountain Front Recharge (Roybal 1991).

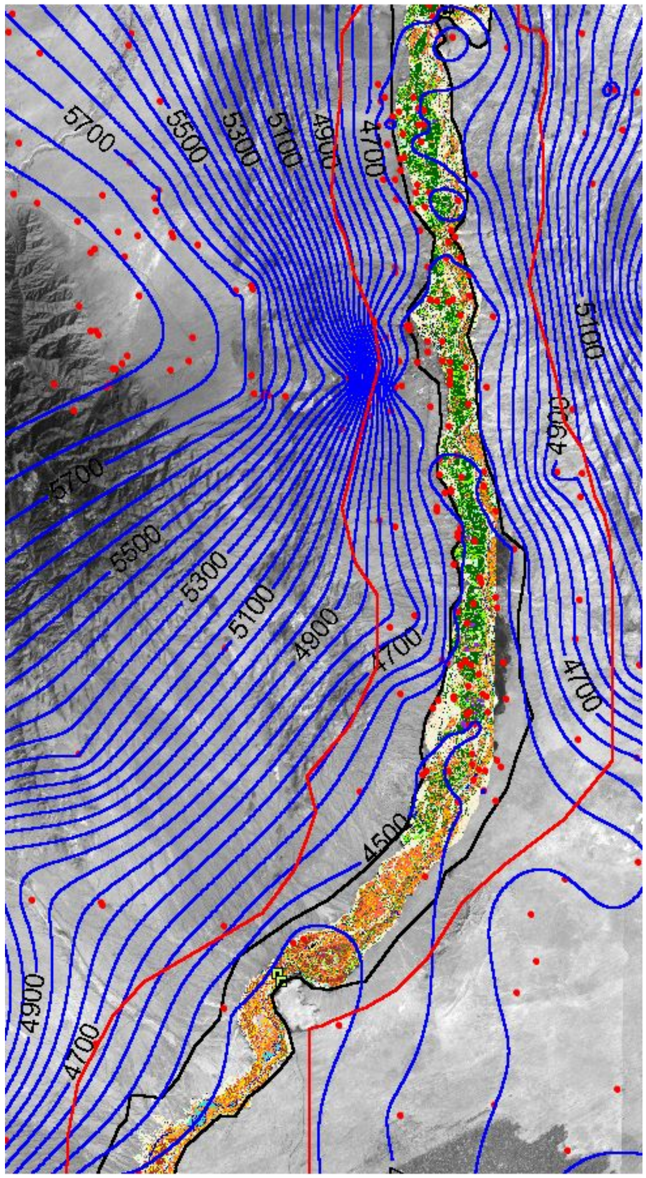


Figure 8. Map of Water Table Using Monitoring Wells.

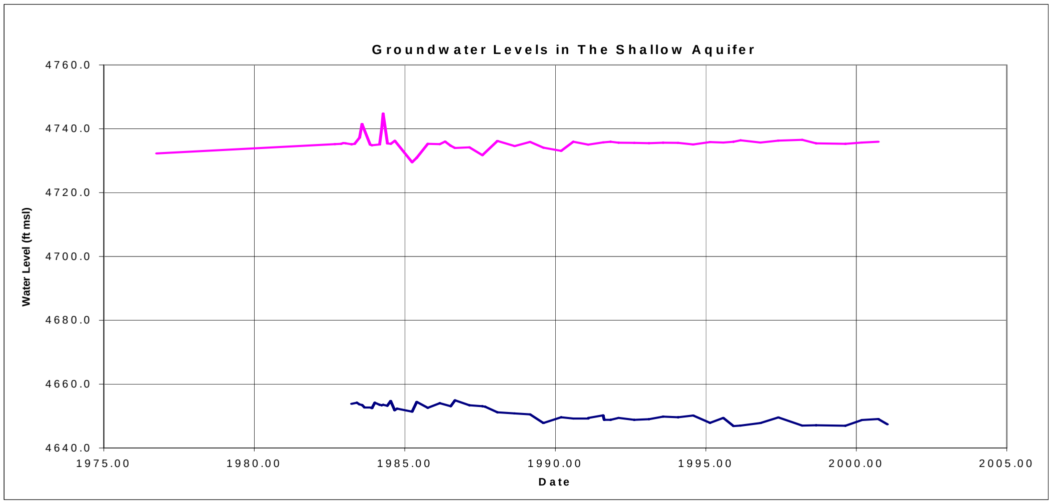


Figure 9. Measured Water Levels at Selected Locations

3.3 Hydrologic Properties

Several aquifer tests were conducted recently by Interstate Stream commission to characterize the hydrologic properties of the shallow aquifer. Two irrigation wells with total depth of about 100 ft were tested and yield a hydraulic conductivity of the shallow aquifer of 100 to 150 ft/day and specific yield of about 0.15. Another well-designed aquifer test was conducted along the HW-380 transect. The shallow aquifer was pumped at a rate of 76 gpm from depth 35 to 50 ft below ground surface. Aquifer response was monitories at depths of 5 to 10 ft bgs, and 75-85 ft bgs as well as the pumped zone (**Figure 10**). The test was analyzed by the ISC staff (Nabil Shafike) and the ISC consultant Papadopulos and Associates. Both analysis estimated aquifer hydraulic conductivity of 60 to 70 ft/day, specific yield of 0.15 and vertical anisotropy between 10:1 and 20:1.

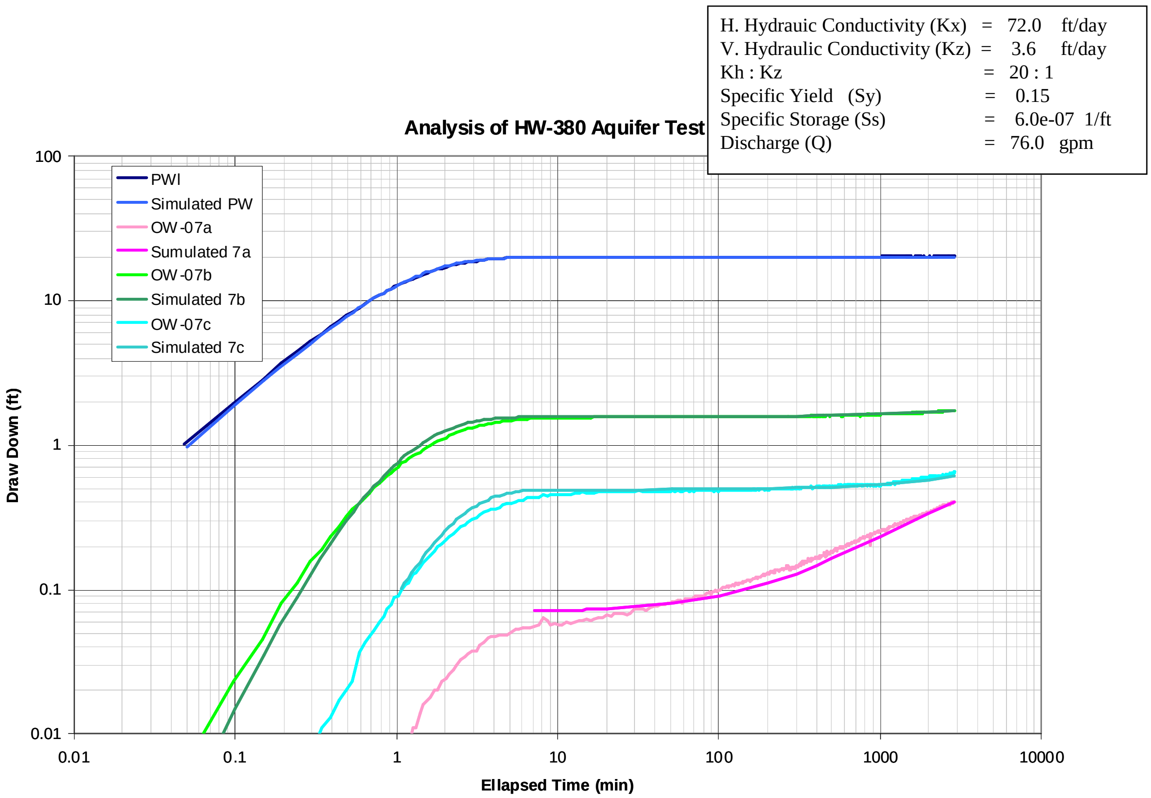


Figure 10. HW-380 Aquifer Test Analysis.

3.4 Basin Water Depletion

Depletion is defined as the amount of water that is lost from the system. Water is depleted in the basin by riparian and crop evapotranspiration, M&I and openwater evaporation. For riparian and crop evapotranspiration and open water evaporation estimates were developed using an average area multiplied by average consumptive use. Municipal and Industrial uses were estimated based on City of Socorro consumption. Average annual basin depletion of about 108,000 af. Riparian ET represents 59 percent of total depletion, crop consumption represents 31 percent, open water evaporation represents about 9 percent, M&I is about 1 percent.

4.0 MODEL DESCRIPTION

General groundwater movement through porous media can be described by combining the continuity and momentum equations of the flow system to yield the general partial differential equation as follow:

$$\frac{\partial}{\partial x}(K_x \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial h}{\partial y}) + \frac{\partial}{\partial z}(K_z \frac{\partial h}{\partial z}) - q = S_s \frac{\partial h}{\partial t} \qquad (1)$$

Where:

K_x, K_y, *and* K_z are the hydraulic conductivity along the principal axis x,y and z (LT^{-1});
h, is potentiometric head (L);
S_s is the specific storage (L^{-1}); and
T is time (T).

The surface water flow equation can also be described using the Saint Venant equation, which is the one-dimensional momentum and continuity equations in open channel, and can be written as follows:

$$\frac{1}{gA}\frac{\partial Q}{\partial t} + \frac{2\beta Q}{gA^2}\frac{\partial Q}{\partial x} - \frac{\beta Q^2}{gA^3}\frac{\partial A}{\partial x} + \frac{\partial Z}{\partial x} + \frac{k}{A^2 R^{4/3}} Q|Q| - \frac{\xi B}{gA} U_a^2 \cos\alpha = 0 \qquad (2)$$

$$B\frac{\partial Z}{\partial t} + \frac{\partial Q}{\partial x} + q = 0 \qquad (3)$$

Where,

Q is the flow in stream (L^3T^{-1});
A is the cross section area (L2);
Z is the depth of the flow in channel (L); and
B is the channel width (L)

The above system of equations is used to describe the flow movement in the surface water and groundwater systems and the link between the two systems can be described as follows:

$$q = \frac{K'}{b'} B \,(Z - h) \qquad (4)$$

Where,

q is the flow per unit length (L^2T^{-1});
K` is the vertical hydraulic conductivity of riverbed (LT^{-1}); and
b` is the thickness of the riverbed (L).

The USGS program developed a program that uses the above system of equation called MODBRANCH (USGS, 1997) which couples the groundwater program MODFLOW to the surface water model Branch. This program is used in this study because its ability to accurately represent the interaction between surface water and ground water which is an important aspect of this study.

4.1 Spatial and Temporal Discretization

The model covers an area of about 600 square miles and is discretized horizontally into a 1000 ft by 1000 ft grid as shown in **Figure 11a**. In the vertical dimension the model consists of five layers, layer one represent the shallow alluvial aquifer. Layers 2 through 5 represent the upper, middle and lower Santa Fe group aquifer (**Figure 11b**). Due to the fact that surface water travel faster than groundwater, and to be able to reach stable numerical solution the groundwater computations is done on a daily stress period and the surface water computation is done on a much smaller time step.

4.2 Boundary Conditions

In general model boundary conditions describe how water enters or leaves the aquifer system. These conditions can be specified flow or head-dependent flow boundaries.

4.2.1 Specified Flow Boundaries

Mountain front recharge, municipal pumping and crop deep percolation are represented in the model as specified flow. Most of irrigation canals and distribution system is above the water table therefore canal seepage is also represented as constant flow.

4.2.2 Head-Dependent Flow Boundaries

The Rio Grande, the LFCC and the drains are represented as head dependent boundaries. A prescribed head boundary is used to represent the link between the Middle Rio Grande basin and the Socorro basin; and the groundwater leaving the system at the southern boundary of the model (south of San Marcial). Riparian vegetation is represented by head-dependent flow boundary that allows water to discharge from the aquifer as a function of the depth to water table.

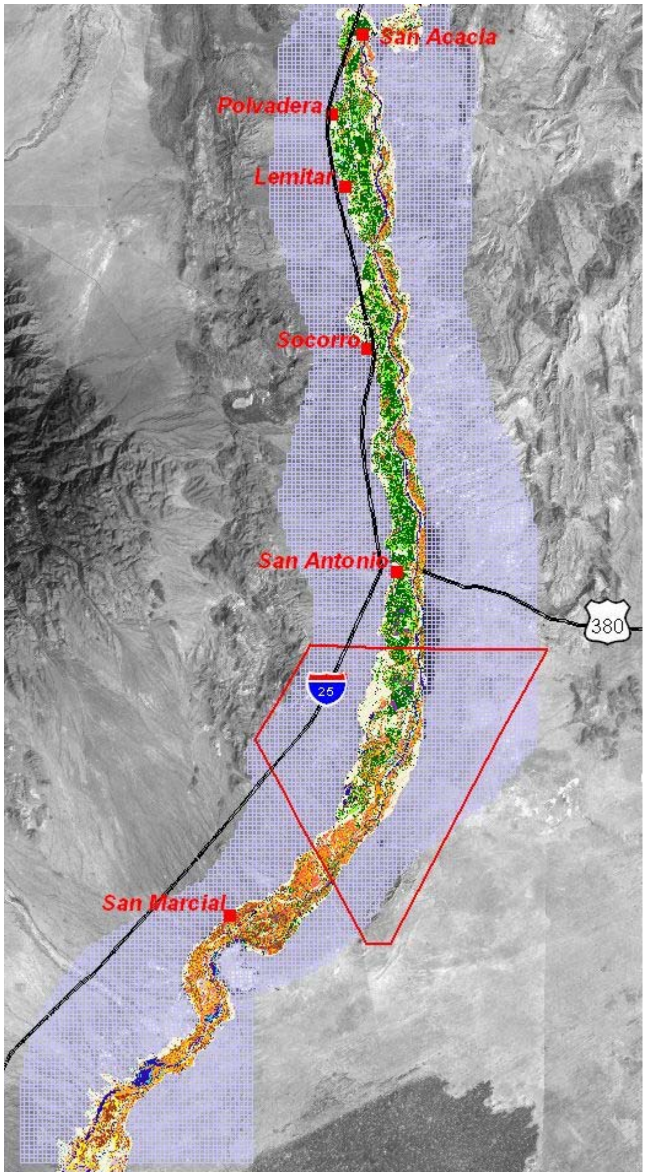
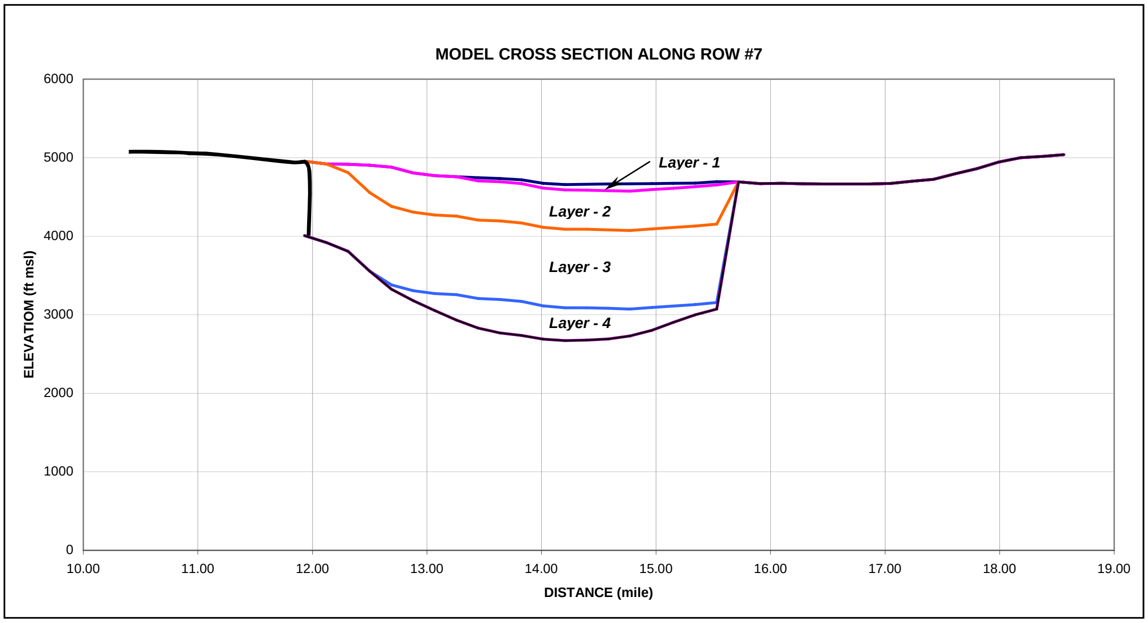
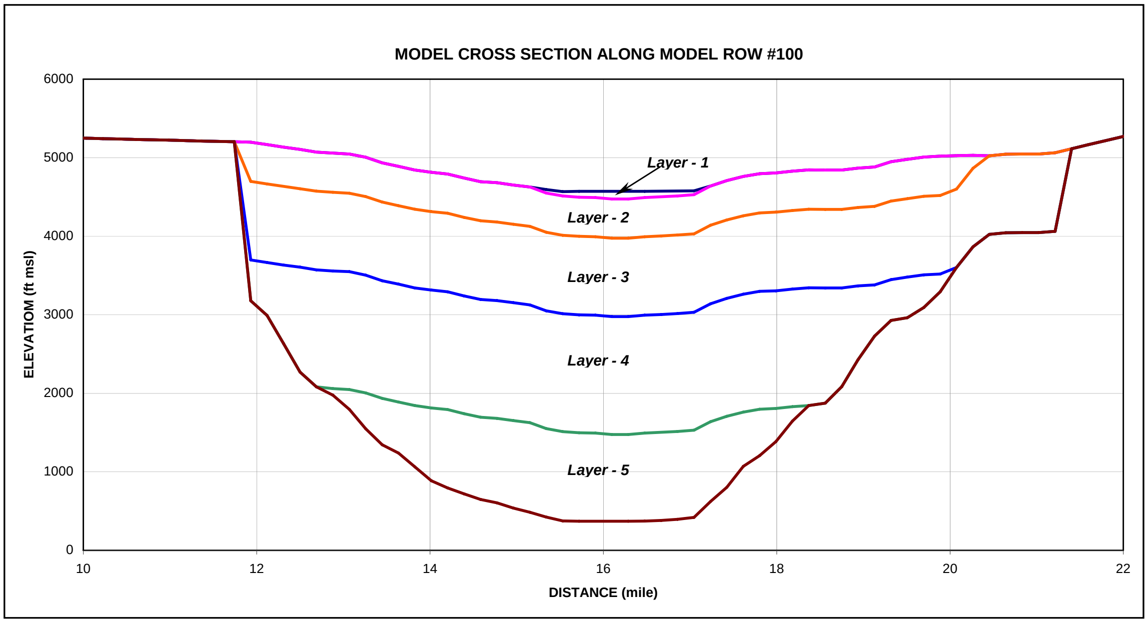


Figure 11a. Active Model Grid



Model X-Section Near San Acacia



Model X-Section Near Socorro

Figure 11b. Model X-Sections

5.0 MODEL CALIBRATION

The model was calibrated using trial and error approach by adjusting aquifer properties and conductance in an effort to minimize the difference between measured and simulated water level and flow data.

5.1 Calibration Targets

The primary calibration targets are water levels measured in wells and piezometers and estimated seepage or gain of surface water system. The calibration is said to be satisfactory if we achieved acceptable match within the reasonable range of aquifer properties.

5.2 Steady State

The calibration process was focused on the shallow aquifer within the valley since all measured water level data is in that area. The model was run for steady state and the horizontal hydraulic conductivity was adjusted. Final calibrated hydraulic conductivities are 100 ft/day for the shallow aquifer, 1 ft/day for the upper Santa Fe Group aquifer and 0.1 ft/day for the deeper Santa Fe aquifer. **Table 1** lists the calibrated aquifer properties. **Figure 12** illustrate the comparison between measured and simulated water levels at observation wells. Results indicated that the root mean square error is about 24 ft. **Figure 13** illustrate the simulated water table that indicates that the water table varies from 4700 ft msl at San Acacia to about 4500 ft msl at San Marcial. The Rio Grande seepage and the LFCC gain was computed and compared to the estimated amount using seepage runs analysis (**Figure 14**). Results indicated that under steady state conditions the river loses about 265 cfs between San Acacia and San Marcial and the LFCC gains about 200 cfs at the same reach (**Figure 15**). These results are consistent with the seepage run analysis conducted during 2000 and 2001.

Table 1. Calibrated Aquifer Properties.

Formation	K_h (Feet/day)	K_h/K_z	Sy
Alluvial Aquifer	100.00	2.00	0.050
Upper Santa Fe	1.00	100.00	0.001
Middle Santa Fe	0.50	100.00	0.001
Lower Santa Fe	0.10	100.00	0.001

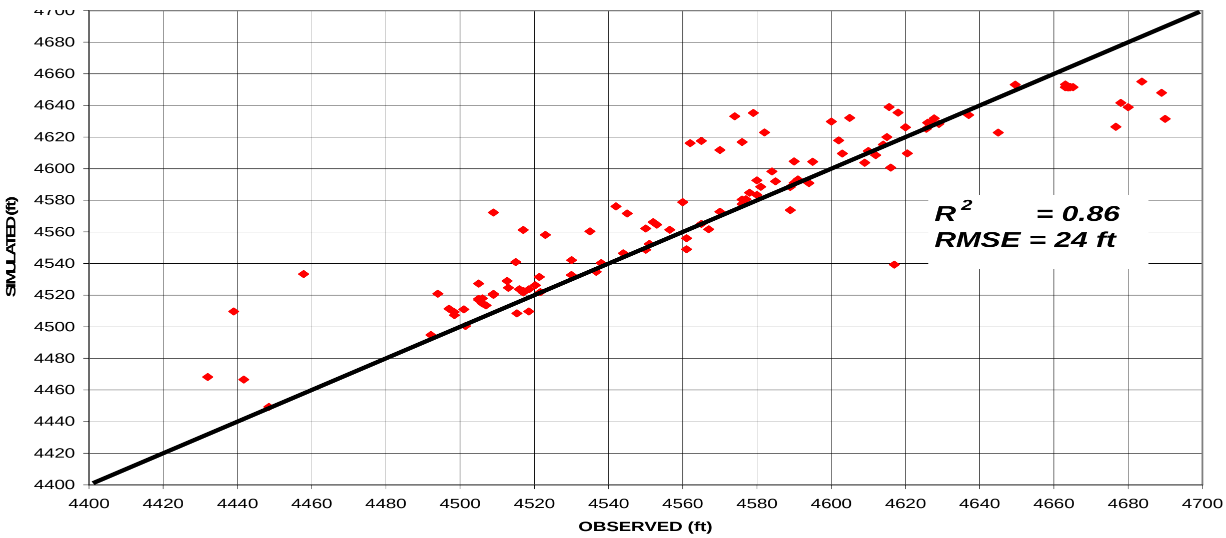


Figure 12. Measured vs Simulated Steady State Water Levels

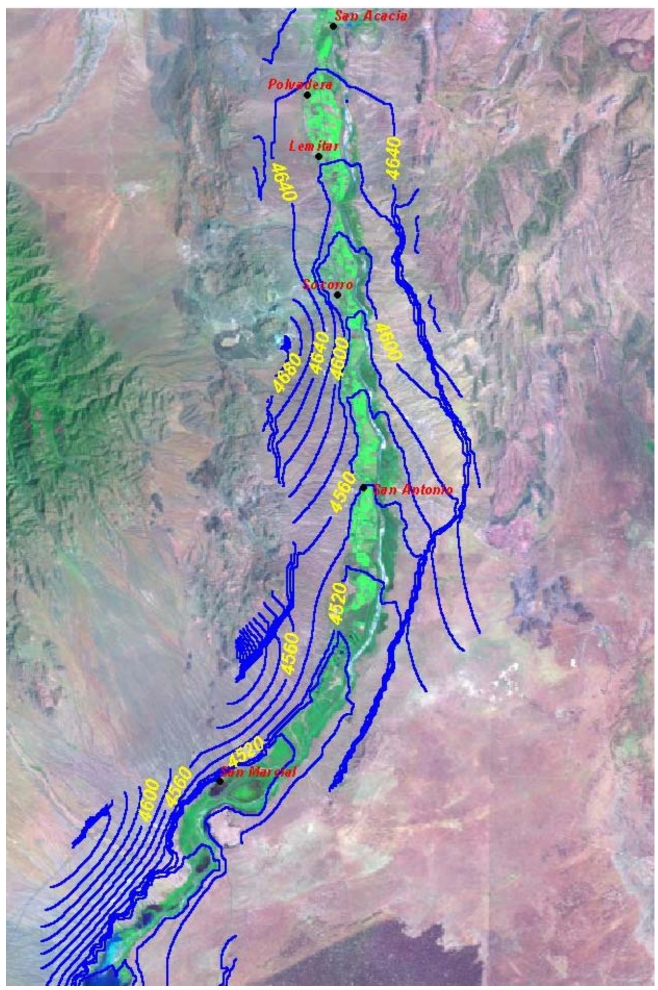


Figure 13. Simulated Steady State Water Levels

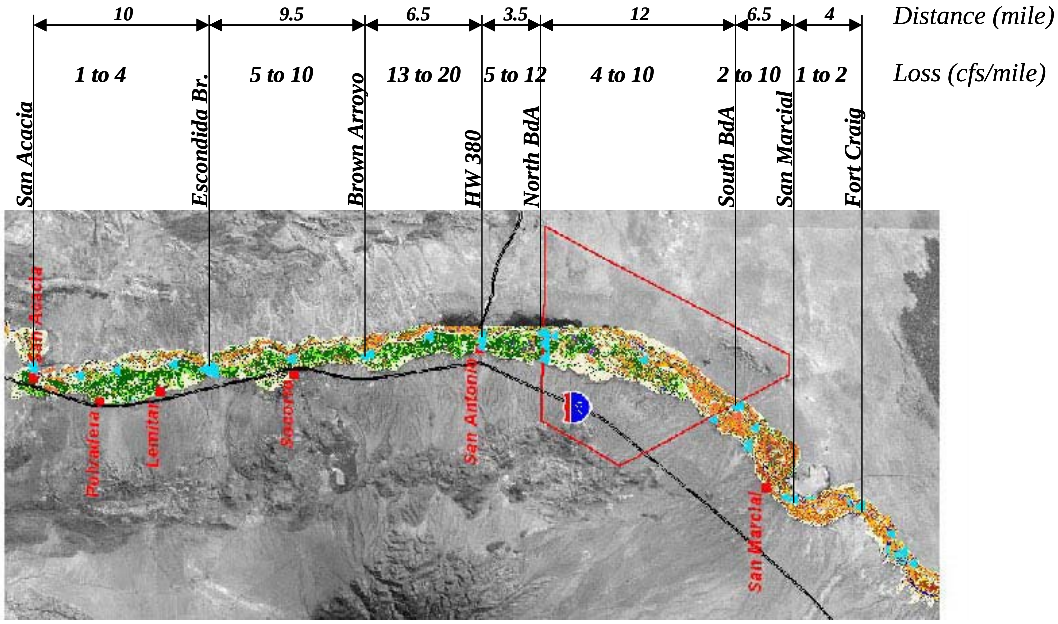


Figure 14. Summary of Rio Grande Seepage Runs

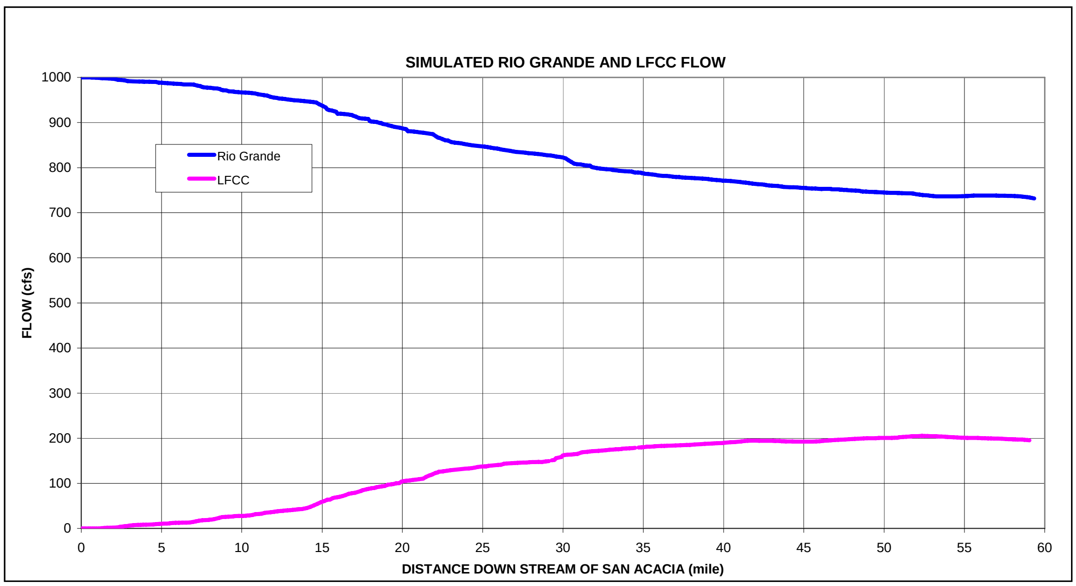


Figure 15. Steady State Rio Grande Seepage and LFCC Gain.

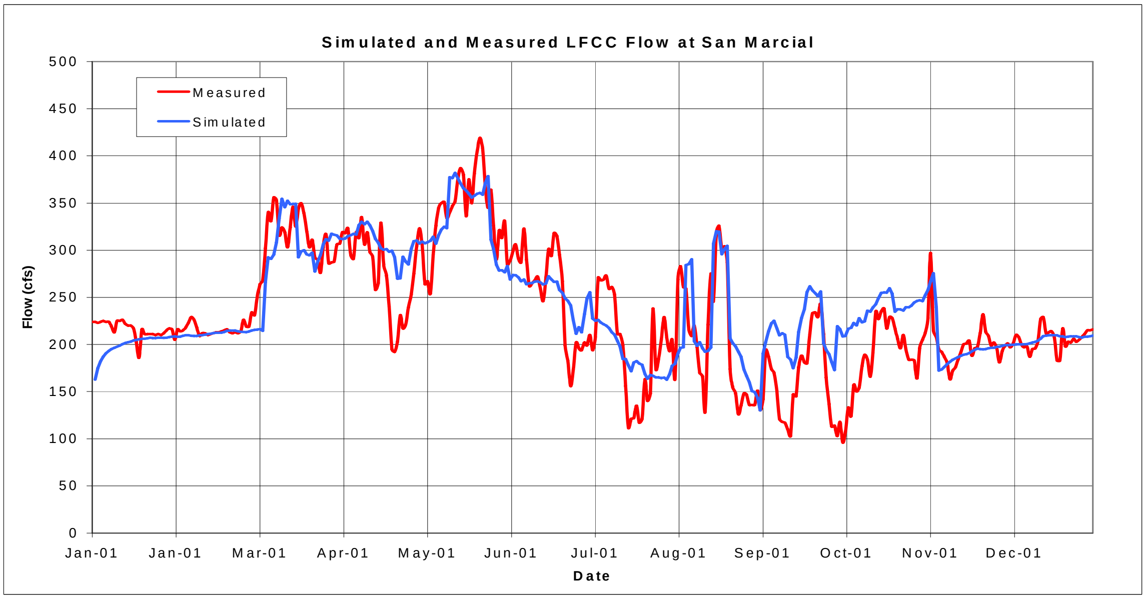
Table 2 illustrates the steady state budget for the basin. Results indicated that inflow to the basin from the Albuquerque basin is not significant. Total inflow to the system is about 220,000 afy with the Rio Grande as the major source to the system. Water discharges out of the system through the LFCC, riparian ET and the model southern boundary. The model estimates that about 65,000 afy are consumed by riparian vegetation in the basin. This is consistent with independent estimates using the BDA ET-tower data.

Table 2. Simulated Steady State Water Budget.

Inflow		Outflow	
Upper Basin	115 afy	GW Outflow	5430 afy
Mountain Front	15,210 afy	Riparian ET	63,030 afy
RG Loss	205,020 afy	LFCC Gain	152,140 afy
Total	220,345 afy	Total	220,600 afy

5.3 Transient Simulation

The model was run for one year on a daily stress period using the surface water inflow to the system of year 2001 using the steady state head as starting head. **Figure 16** illustrate the measured and simulated flow at San Marcial in the LFCC and the Rio Grande. Results indicate that the model is reasonably simulates the surface water routing through the system. **Figure 17-Figure 18** show the shallow water level at different location through the basin and areas with water table above land surface.



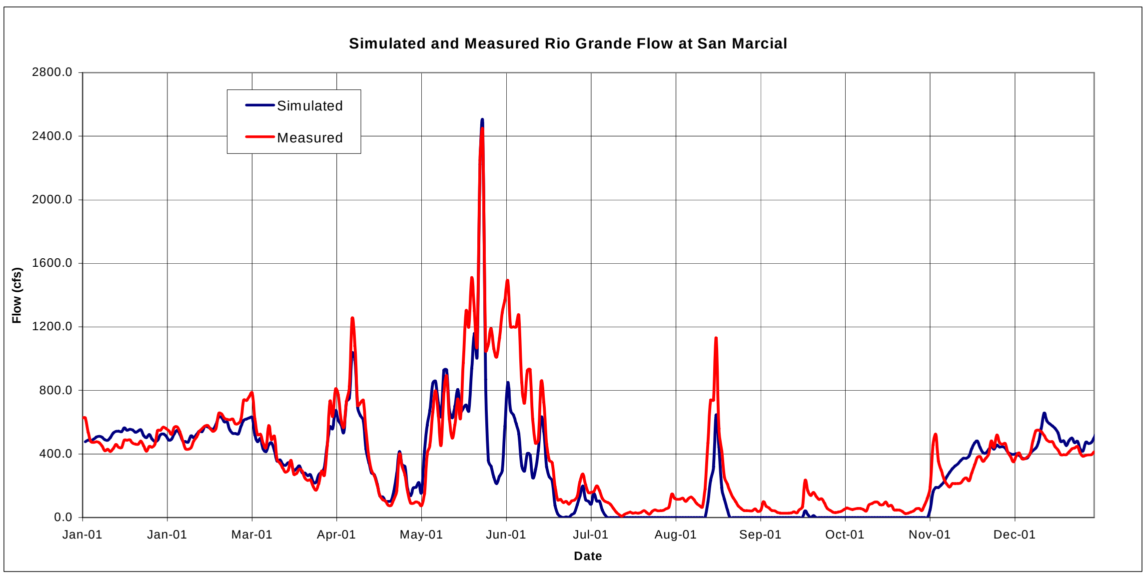


Figure 16. Simulated vs Measured flow at LFCC and Rio Grande at San Marcial

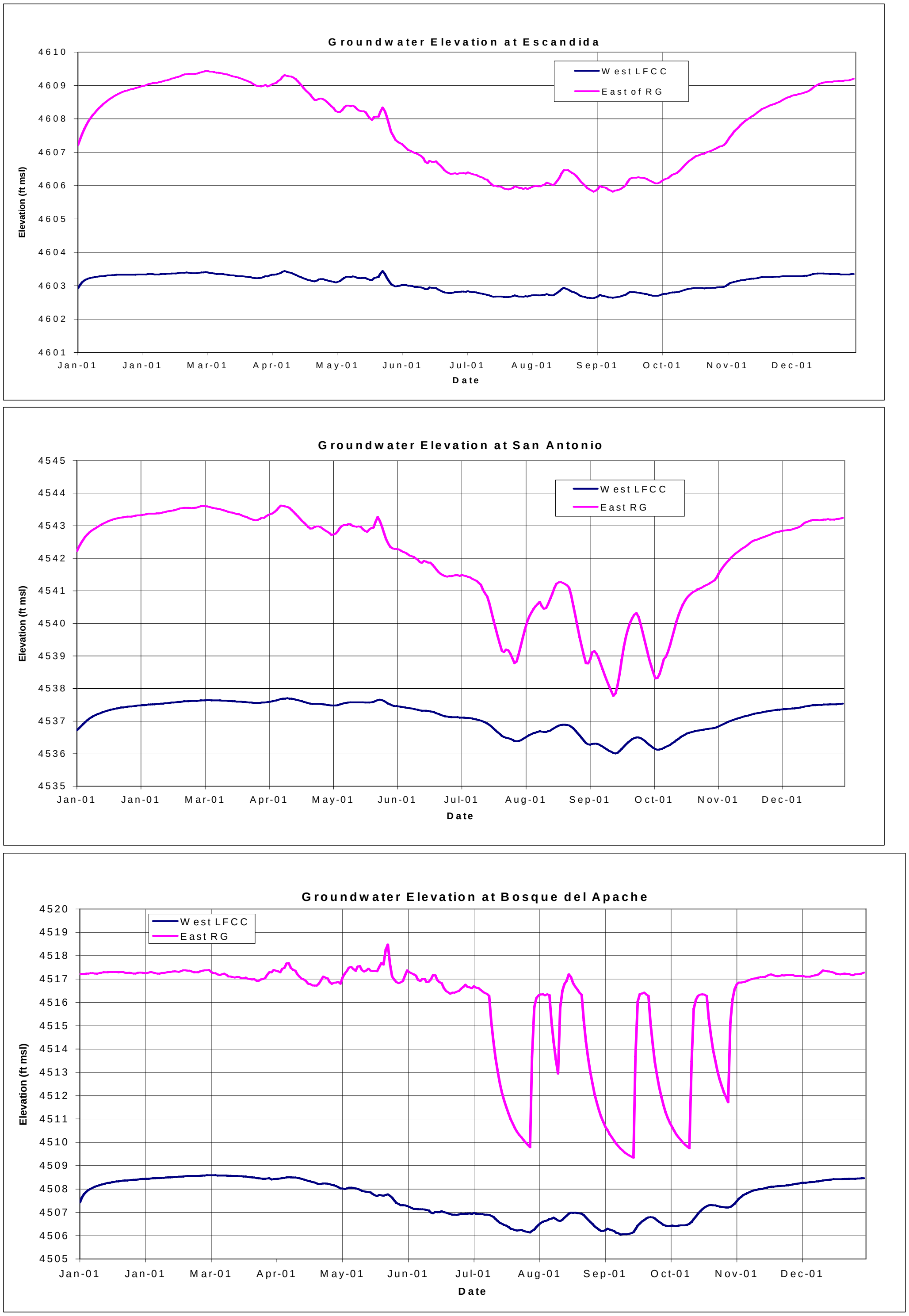


Figure 17. Simulated Water Levels at Selected Locations

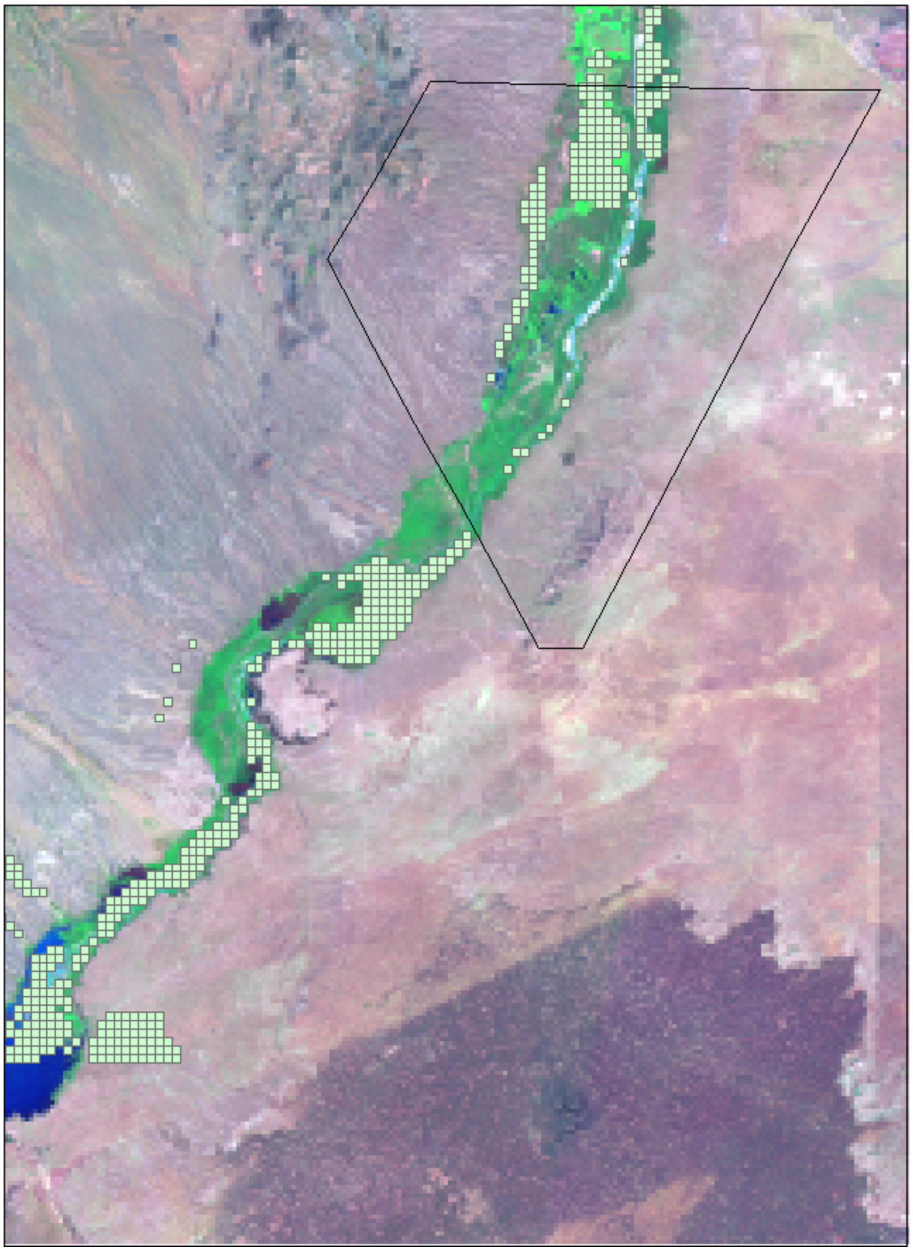


Figure 18. Map of Area with Water Table Above Land Surface (using 2001 hydrologic inflow).

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6.0 SUMMARY AND CONCLUSIONS

Linked surface water and groundwater model was developed for the Socorro and San Marcial basins. The model covers the area from San Acacia to the headwaters of the Elephant Butte reservoir. The model is designed to evaluate different operational alternatives of the LFCC. The model uses a unique surface water package to be able to rout surface water in the Rio Grande and the LFCC. The model simulates the shallow alluvial and the Santa Fe Group aquifers. Additional physical processes represented in the model are riparian and crop evapotranspiration.

The model was calibrated against water level data and flow data. Water level data mostly represent measured water levels in the shallow alluvial aquifer. Flow data represent the seepage loss of the Rio Grande and the Gain of the LFCC. Steady state and transient simulations were conducted and the results indicate that the model is adequately represents the hydrologic system.

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