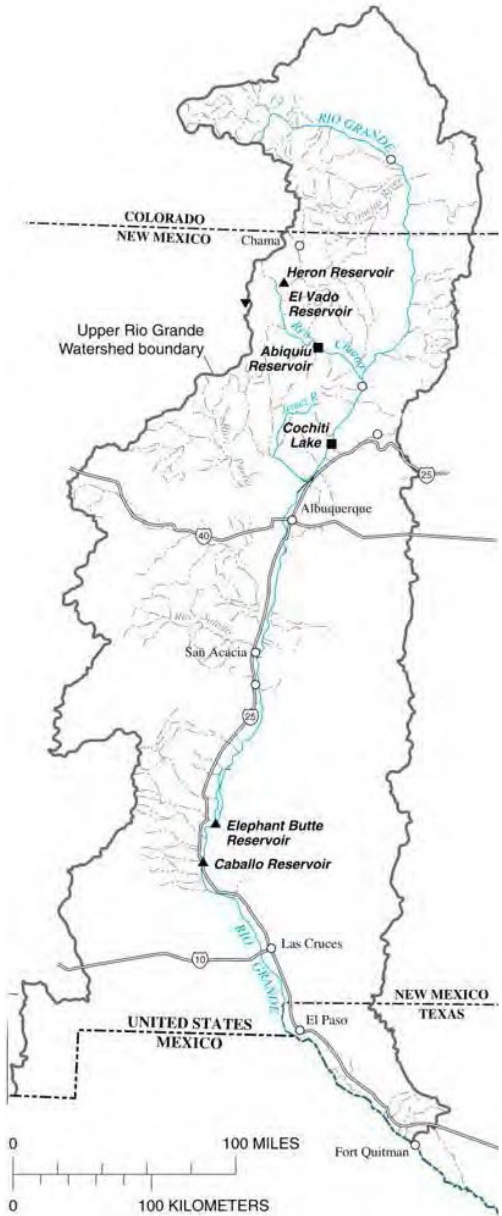
UPPER RIO GRANDE WATER OPERATIONS MODEL (URGWOM) DOCUMENTATION
VOLUME 1
PHYSICAL DOCUMENTATION



URGWOM Technical Team

June 30, 2020

UPPER RIO GRANDE WATER OPERATIONS MODEL (URGWOM) DOCUMENTATION
VOLUME 1
PHYSICAL DOCUMENTATION

Table of Contents

List of Figures

List of Tables

1 Introduction

The Upper Rio Grande Water Operations Model (URGWOM) was developed using the RiverWare software application developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado at Boulder. URGWOM is a computational model developed through an interagency effort and is used to complete simulations with actual data or rule based simulations using the URGWOM ruleset which is based on policy for operations of all the facilities in the Rio Grande Basin from its headwaters in Colorado to Hudspeth County, TX and involves the use of complex accounting to track water specifically allocated for different water users. Various methods are included to represent processes such as hydrologic travel times, reservoir evaporation and seepage, conveyance losses to deep percolation, river channel evaporation, evapotranspiration by riparian and agricultural vegetation, surface water-groundwater interaction, and municipal waste water and irrigation return flows. Note that URGWOM is not a water supply model, a climate model, a water rights model, a rainfall/runoff model, a hydraulic model, or a groundwater model; although, such models may be used as pre-processors or post-processors with URGWOM to complete evaluations for a broader range of indicators.
URGWOM is used for multiple applications. An accounting model application is used to complete simulations with actual year-to-date data to track the status of accounts for individual water users. Rule based simulations are used to prepare annual operating plans (AOP) and for preparing other short-term forecasts of operations. The model has also been used extensively for completing long-term planning runs to evaluate impacts of proposed actions and scenarios during development of biological assessments (BA) for Rio Grande Water Operations and for National Environmental Policy Act (NEPA) processes to evaluate potential actions in the basin.

This Volume 1 of the documentation describes the physical processes incorporated into the URGWOM model. Other volumes:

Volume 2a: Policy Rules Documentation
Volume 2b: Initialization Rules Documentation
Volume 2c: Expression Slot Functions Documentation
Volume 3: Accounting Concepts and Methods
Volume 4: Database Documentation
Volume 5: Data Management Interface and System Control Table Documentation
Volume 6: Script Documentation (User's Manual)

1.1 Purpose of URGWOM

The primary purpose of URGWOM is to facilitate more efficient and effective accounting and management of water in the Upper Rio Grande Basin. Historically, water of the Rio Grande has been used primarily for crop irrigation; however, rapid population growth in the Basin and

urbanization in many areas has resulted in increasing and diversifying demands on the hydrologic system. Water management decisions must account for a broad range of issues including flood control, irrigation demands, transmountain diversions, the Rio Grande Compact, municipal and industrial demands, Native American water rights, Endangered Species Act compliance, and recreational uses. As the wide range of water demands grow in the face of an inherently variable and limited water supply, higher levels of precision and reliability in water accounting and forecasting are required.
URGWOM is a river and reservoir operation model that applies the principals of mass conservation to simulate the physical processes of the hydrologic system in a single RiverWare model file with a single (timestep generalized) operational rule set. In addition, the URGWOM policy rule set includes major legal constraints such as reservoir and project authorization and the Rio Grande Compact. URGWOM is designed to be used for a variety of applications including:

- Accounting Application - Daily timestep, data driven up to the current date accounting of native and trans-basin (San Juan – Chama Project) water in the system.
- Water Operations Application - Daily timestep rule based Annual Operating Plan (AOP) runs. Typically run 5-6 times per year.
- Planning Application - Daily or monthly timestep rule based planning runs for specific projects such as environmental or biological assessments, modified operations of specific elements (reservoir or project) of the system and impact statements.

AOP and planning runs can be started from where the latest daily timestep, data driven accounting model ends in order to utilize the latest observed data as a starting point for rule based runs into the future.

Rule based simulations are completed in URGWOM using a RiverWare ruleset that represents policy for operating the facilities in the basin. The ruleset includes code in the RiverWare rule policy language for computing key demands, diversions, and releases from dams based on all the policy factors and is referred to as the Operations ruleset. The releases from the dams along the Rio Grande and its tributaries are set for each day in the daily timestep model based on the policy coded in the ruleset. The ruleset has been under development for several years with involvement from an interagency Technical Team and contractors. The URGWOM ruleset is described in a separate document, which is currently under development.

1.2 Description of physical features of Rio Grande Basin above Ft. Quitman, TX (man-made and natural) that are modeled in URGWOM

The Rio Grande rises in the San Juan and Sangre de Cristo Mountains in Southern Colorado, and flows through New Mexico before becoming the border between Mexico and Texas and then between Mexico and Texas. The waters of the Rio Grande are largely consumed by the time it reaches Fort Quitman in Hudspeth County, Texas. Although the river channel continues, it is eventually rewetted by the Rio Conchos entering from Mexico upstream of Big Bend, TX. The Upper Rio Grande, defined here as that portion of the river upstream of Fort Quitman is, for the purposes of water resource operations, hydrologically separate from the rest of the Rio Grande Basin. Figure 1-1 shows the spatial extent of the Upper Rio Grande Basin.

Within the U.S. portion of the Upper Rio Grande, there are three separate management regions that coincide geographically with the division of the river between the states of Colorado, New Mexico, and Texas, as codified in the interstate Rio Grande Compact (Compact). These are referred to in URGWOM as the Colorado portion (headwaters of the Rio Grande to CO-NM state line), the New Mexico portion (CO-NM state line to Elephant Butte Dam), and the Lower Rio Grande (LRG) portion (from Elephant Butte Dam to Fort Quitman, TX). The LRG covers the Rio Grande Project which provides water to lands in New Mexico, Texas, and Mexico. The salient characteristics of each portion of the model are discussed briefly below, with more detail in later sections of this document.

The Colorado portion of URGWOM includes operations to serve approximately 500,000 acres of irrigated agriculture. In 2013 there was a population of approximately 50,000 people in the San Luis Valley (San Luis Valley Development Resources Group and San Luis Valley Council of Governments 2015), with population centers in Alamosa and Monte Vista. Platoro reservoir has a capacity of approximately 53,500 acre-feet, and Rio Grande, Santa Maria, and Continental reservoirs (which are not represented in URGWOM) have a combined capacity of approximately 122,500 acre-feet. Water use in the Colorado portion of the Upper Rio Grande is administered according to strict priority of appropriation after accounting for downstream delivery obligations as set forth in the Compact. Colorado delivery obligations to New Mexico are based on flow at four “index” gages in Colorado, and deliveries are measured at the Rio Grande near Lobatos gage near the Colorado-New Mexico border.

The New Mexico portion of URGWOM (from the Colorado-New Mexico state line to Elephant Butte Dam) includes agricultural use of waters from the main stem Rio Grande (approximately 70,000 irrigated acres, does not include irrigated acres on Rio Grande tributaries) and the Rio Chama and its tributaries (approximately 25,400 irrigated acres). As of 2010, there was a population of approximately 1.2 million people (New Mexico Water Resources Research Institute 2017) in New Mexico’s Rio Grande Basin upstream of Elephant Butte, with population centers in Albuquerque, Rio Rancho, Santa Fe, and Socorro. There is approximately 2,700,000 acre-feet of storage capacity in Heron, El Vado, Abiquiu, and Cochiti reservoirs, though only approximately 200,000 acre-feet of that are conservation storage of Rio Grande native water and 600,000 acre-feet are for storage of San Juan-Chama Project water, the storage balance being for flood and sediment control capacity in Abiquiu Reservoir and Cochiti Lake. Virtually all conservation storage in the Rio Chama system is in Heron, El Vado, and Abiquiu.

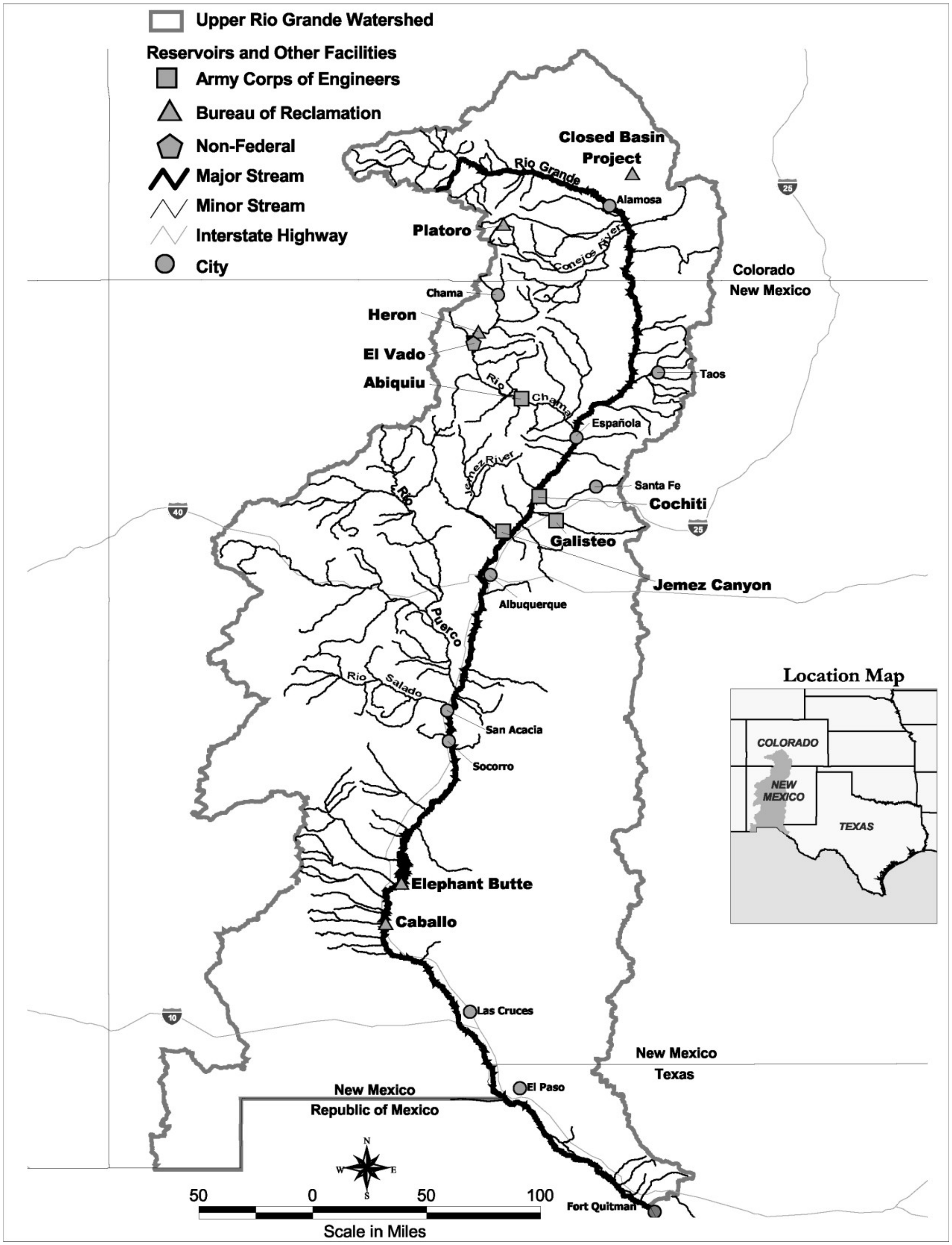


Figure 1-1. Rio Grande Basin from headwaters to Fort Quitman, Texas.

Approximately 92,000 acre-feet per year is imported from the Colorado River Basin via the San Juan-Chama project. New Mexico delivery requirement to Elephant Butte (at Elephant Butte Dam) is based on native flow at the Otowi gage upstream of Cochiti Lake.

The Lower Rio Grande portion of URGWOM (Elephant Butte Dam to Fort Quitman, TX) includes approximately 200,000 acres of irrigated agriculture, and a human population of approximately one million people located mostly in the cities of Las Cruces and El Paso. There is about 2,400,000 acre-feet of storage capacity in Elephant Butte and Caballo Reservoirs.

1.3 Physical processes represented in URGWOM

The physical processes represented in URGWOM include mass balance constrained reservoir, reach, shallow groundwater, and agricultural use dynamics. Figure 1-2 shows a simulation view of part of the URGWOM workspace which includes a visual representation of many of the modeled dynamics. Reservoir mass balance dynamics modeled include inflows, evaporation losses, seepage, precipitation gains, controlled reservoir releases, and spills. Reach mass balance dynamics modeled include tributary and wastewater inflows, agricultural diversions and return flows, municipal diversions, routing, open water evaporation, and surface water groundwater interactions. Shallow groundwater mass balance dynamics modeled include river seepage or gain, canal seepage, drain capture, crop irrigation deep percolation, riparian evapotranspiration, and groundwater movement within the shallow aquifer and to and from the surrounding regional aquifer. Agricultural mass balance dynamics include diversions, evapotranspiration, soil moisture, supplemental groundwater pumping, and return flows to surface water system and shallow groundwater aquifer. Total dissolved solids (TDS) is being modeled between Cochiti Dam and Elephant Butte Dam.

RiverWare is an object oriented software environment where different types of objects are used to represent diversions, reaches, reservoirs, stream gages, etc. Each object in RiverWare has numerous methods available for modeling physical processes associated with that particular aspect of the system.

1.4 Previous Physical Documentation

This document is a synthesis of previous model documentation prepared by the URGWOM technical team describing the data, methods, and assumptions used in the development of URGWOM. Early model development (1997) focused in the reach from the Colorado-New Mexico state line to Caballo Reservoir. Eventually the model was extended to include the Rio Grande and Conejos River in Colorado and the Lower Rio Grande from Caballo Dam to near Tornillo, TX. Documentation of models in each individual section of the basin followed and they are listed below. Many technical memoranda were prepared by the URGWOM technical team during the course of physical model development that addressed specific or local hydrologic issues.

Additional information about model development history and the uses of URGWOM can be reviewed at the URGWOM web page, which is maintained by the US Army Corps of Engineers, Albuquerque District:
https://www.spa.usace.army.mil/Missions/Civil-Works/URGWOM/Basin/

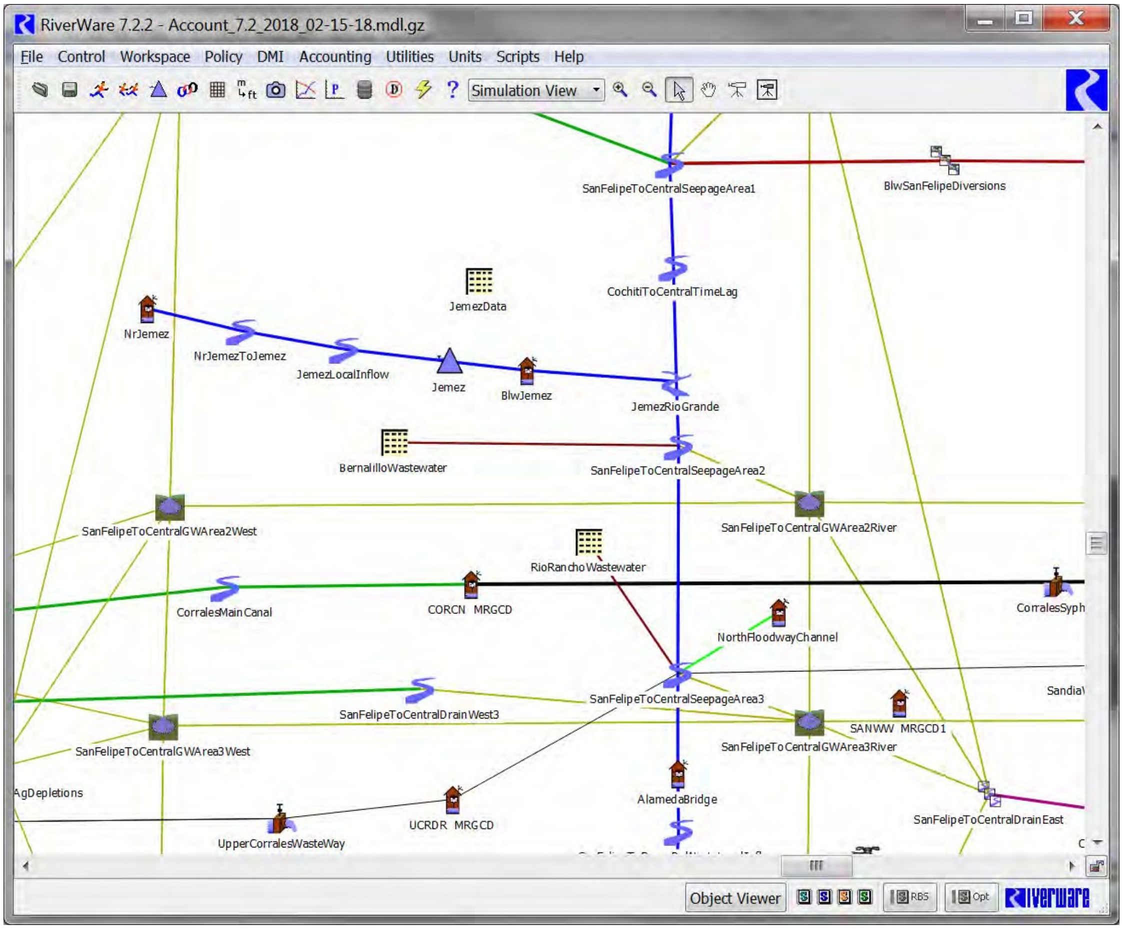


Figure 1-2. View of zoomed in portion of the URGWOM workspace with lines representing paths of water movement (links)

The following bullets list the previous documentation of the physical model development for the reach from the Colorado-New Mexico state line to Caballo Reservoir:

- Conceptualization of the Test Case Reach of the Upper Rio Grande Water Operations Model, Part I – Physical Model, December 11, 1997.
- Technical Review – Physical Model Calibration, April 22, 1999.
- Physical Model Documentation – First Technical Review Committee Draft, February 22, 2000.

- URGWOM Technical Team, Draft Upper Rio Grande Water Operations Model Physical Model Documentation: Third Technical Review Committee Draft, December, 2002, revised June, 2005.
- URGWOM Technical Team, Draft Upper Rio Grande Water Operations Model Physical Model GRAPHS: Third Technical Review Committee Draft, December, 2002.
- URGWOM Technical Team, Technical Review Committee Draft, Middle Rio Grande Valley Physical Model Upgrades, October 14, 2010.
- URGWOM Technical Team Middle Rio Grande Valley, Cochiti Dam to Elephant Butte Reservoir Physical Model Upgrades, Phase 3, October 1, 2014.

Previous documentation of the model development for the main stem Rio Grande and Conejos River in Colorado include:

- Boroughs, PhD., P.E., RiverWare Model for the Colorado Portion of the Rio Grande for Use in the Upper Rio Grande Water Operations Model (URGWOM). April, 2013.
- Tetra Tech Inc. 2015. "Enhancements to the Colorado Portion RiverWare Model of the Rio Grande Watershed, November 2015", Albuquerque, New Mexico.

Documentation of the development of the model in the lower Rio Grande reach includes:

- Sheng, Zhuping Ph.D., P.E., et al. Technical Completion Report on Development of RiverWare Model of the Rio Grande for Water Resources Management in the Paso del Norte Watershed. Project Number: W912HZ-10-2-0038. March, 2012.
- Hydros Consulting, Lower Rio Grande RiverWare Model, Draft Report prepared for the US Army Corps of Engineers and the URGWOM Technical Team. December 18, 2014.
- Hydros Consulting, Lower Rio Grande RiverWare Model, prepared for the US Army Corps of Engineers and the URGWOM Technical Team. July 11, 2016.

Other models or specific applications have been developed and are used in URGWOM. These applications are described in the following documents:

- Hydros Consulting, 2016. Soil Moisture Parameter Development in URGWOM. Technical Memorandum Prepared for the Corps of Engineers and the URGWOM Technical Team, March 16, 2016.
- Shafike, Nabil, 2005. Linked Surface Water and Groundwater Model for Socorro and San Marcial Basins between San Acacia and Elephant Butte Reservoir. Appendix J, Upper Rio Grande Water Operations Review DEIS. J-59 to J-94.
- Westfall, B. 2012, Draft EffPrecip Software Documentation and User Manual. EffPrecip Version 1.0.x. Keller-Bliesner Engineering, LLC. Logan, Utah.

Salinity model documentation includes:

Roark, M., Anderholm, S., Louise, A., Neumann, D., and Shafike, N., Testing of RiverWare Salinity Methods with Groundwater/Surface water Interaction Using the URGWOM Middle Valley Simulation. February 2, 2017.

This is the May, 2020 draft of the URGWOM Physical Documentation. This document describes the data, methods, and assumptions used by RiverWare to simulate streamflow, water accounting, and reservoir operation in the Rio Grande Basin above Fort Quitman, TX. Because this document represents the model's state of development as of the date of the document's release, it is considered a "working" document—that is, it will be updated further as the model changes.

1.5 Organization of this document

This document describes the hydrology of the Rio Grande and discusses how natural processes, human manipulation (operations) of the river, and laws related to human manipulation of the river is simulated using URGWOM. It is organized in an upstream to downstream direction with one section of the report devoted to each of the major basins within the Rio Grande drainage. These major basins are:

1) Colorado Portion: Rio Grande downstream of Thirty-Mile Bridge and Conejos River downstream of Platoro Reservoir and tributaries, in Colorado;
2) New Mexico Main Stem:
   a) Rio Grande from Lobatos Bridge to Cochiti Dam including the Rio Chama;
   b) Rio Grande from Cochiti Dam to Elephant Butte Reservoir including the Jemez River; and
3) Lower Rio Grande: Rio Grande downstream of Elephant Butte Dam to near Tornillo, TX.

This volume of the documentation includes a description of the physical features of streams, canals, drains, reservoirs and aquifers; physical constants (e.g., loss coefficients, travel times, irrigation efficiencies), calibration parameters (e.g., canal seepage %, conductivity), methods (e.g., reservoir mass-balance equations, crop ET, effective precipitation) and water quality (salinity in Middle Rio Grande Valley).

Each chapter has consistent subheadings so that each section presents similar information as found in each portion of the Rio Grande Basin modeled in URGWOM, to the extent practical.

1.6 Plan for Maintenance of Documentation

This document is intended to characterize the features of the model that do not change on a regular (e.g., annual) basis. Database files are updated as time progresses and rules files may change when errors are discovered and fixed. This Physical Documentation should be updated at the time when all or major portions of the model are recalibrated. At that time, the description of the changes to the physical model made for the calibration run would be included in an updated version of this document.

The URGWOM technical team will also conduct periodic reviews of the model documentation to ensure it is up to date and reflecting the current model in use at that time by state and federal agencies. The technical team may edit the document for clarity or to correct any errors or inconsistencies as required.

2 Colorado Portion

The main stem of the Rio Grande in Colorado flows west to east from the headwaters in the San Juan Mountains through the towns of Del Norte and Monte Vista and then south out of Alamosa into the state of New Mexico. The Conejos River, the principle tributary of the Rio Grande in Colorado, rises in the San Juan Mountains above Platoro Reservoir and enters the Rio Grande near Lasauces, CO. The Rio Grande basin is bounded to the east by the Sangre de Cristo Mountains and to the west by the San Juan Mountains with a basin area of approximately 7,500 square miles (CWCB, 2006).

Between the San Juan Mountains and the Sangre de Cristo Mountains lies the San Luis Valley, a principal feature of the Rio Grande Basin, with an average elevation of 7,500 feet and precipitation of less than eight inches per year. Basin wide, land is evenly divided between public and private ownership, however, most of the land in the San Luis Valley is privately owned. The primary use of more than 600,000 acres of irrigated land is for agricultural purposes in the central portion of the basin. Non-irrigated areas in the valley are mostly classified as shrub land (24%) and grassland (31%). The San Juan and the Sangre de Cristo Mountain ranges are largely forested. The northern one-third of the basin is considered a “closed basin” and does not contribute any surface-flows to the Rio Grande.

Refer to Figure 2-1 for a map of the Rio Grande Basin in Colorado with the location of several key components of the system depicted including reservoirs and tributaries that are discussed in subsequent sections.

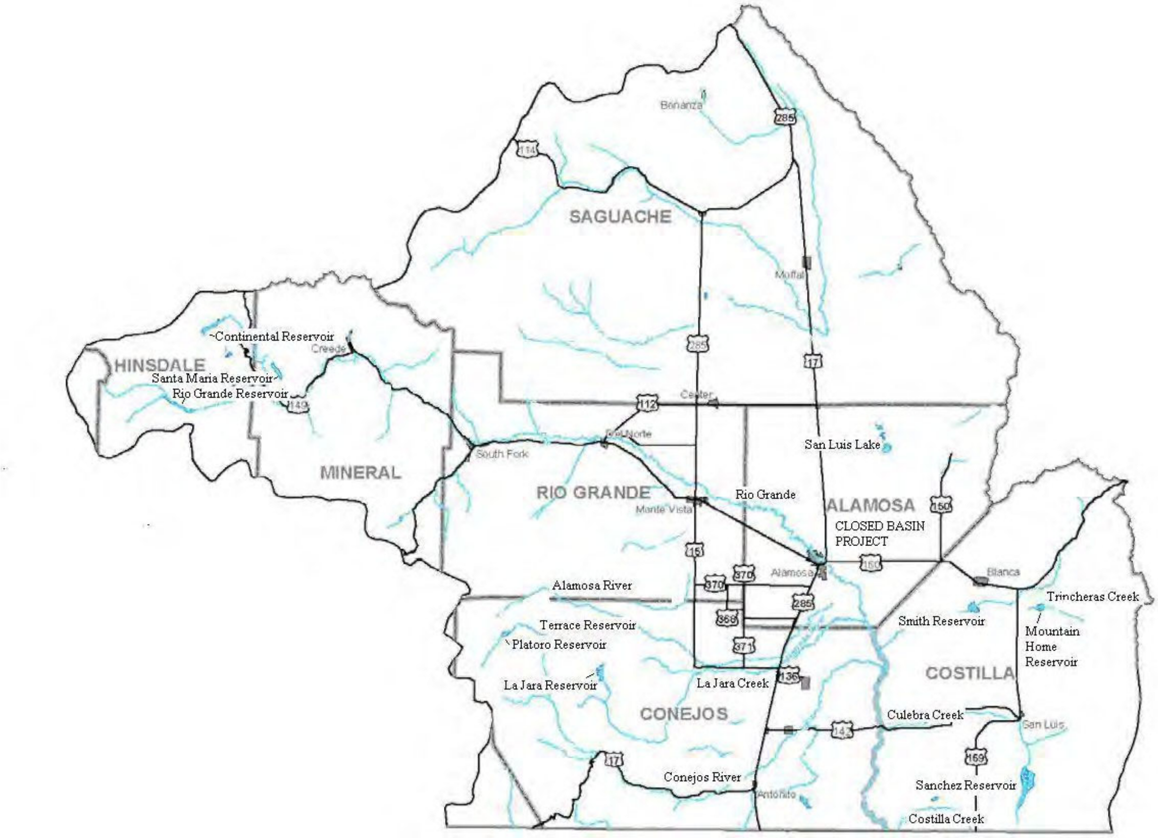


Figure 2-1. Map of Rio Grande Basin in Colorado (CWCB, 2006)

2.1 Nature of Water use and Depletion in Colorado

Separate delivery obligations under the Rio Grande Compact are computed for the main stem of the Rio Grande and the Conejos River Basin and are simulated in URGWOM. Water rights are administered separately for diversions from the Rio Grande (District 20 of Colorado Water Division 3, the Rio Grande Basin) and the Conejos (District 22). Water rights are also administered for other subbasins in Colorado Water Division 3, but are not included in URGWOM since operations in these other subbasins are not administered by Colorado for Compact deliveries, and were determined to have a negligible impact on the flows at Lobatos. The upstream index gages for the Conejos River Basin include gages on the San Antonio River and Los Pinos River, which are represented separately in the RiverWare model.

Reclamation's San Luis Valley Project, originally authorized in 1940, now includes the Conejos Division and the Closed Basin Division. The Conejos Division includes Platoro Reservoir which regulates water at the headwaters of the Conejos River and has a capacity of 59,570 acre-feet. The Closed Basin of the San Luis Valley is an area of approximately 2,900 square miles northeast of Alamosa, Colorado that has no surface water drainage to the Rio Grande due to a low ridge in an alluvial fan just to the north of the channel of the Rio Grande. Much of the water that flows into the Closed Basin from creeks and diversions from the Rio Grande is consumed by evapotranspiration or recharges the aquifers. The Closed Basin Project, completed in the early 1990s, consists of shallow wells and a conveyance system of canals and pipelines and allows for water in the Closed Basin to be pumped and delivered to the Rio Grande to help Colorado meet its delivery obligations to the state line under the Compact, among other purposes. Components of the Closed Basin are not modeled in the RiverWare model, but the inflow to the river from the Closed Basin Project is included. The flume at the outlet from the Closed Basin Project is shown in Figure 2-2, and the confluence at the Closed Basin Project outfall and the Rio Grande is shown in Figure 2-3.

No transmountain diversions are included in the Colorado portion of URGWOM. The bifurcations on the channels of the Conejos River and San Antonio River are not explicitly included but the diversions from both arms of the bifurcation are included separately in the model.

Figure 2-2. Flume at the end of the Closed Basin Project's Main Canal


Figure 2-3. Confluence of Outlet from Closed Basin Project (at right) and Rio Grande.

2.1.1 Water Rights Solver

Water rights in Colorado are adjudicated based upon the doctrine of prior appropriation, where users who started diverting water at an earlier date have priority over users who started diverting water later. Depending upon Compact curtailments and the total flow in the river, a certain number of water users will have priority and be able to divert water. Operational rules are used to:

1) Set the portion of allocatable flow (for use in Colorado) separate from the portion specifically designated for downstream Compact delivery;
2) Make two calls to the RiverWare water rights solver to set diversion accounts for the main stem of the Rio Grande and the Conejos River in accordance with the priority of the water right; and
3) Set physical diversions as a sum of all diversion for all accounts associated with each physical diversion.

2.2 URGWOM Storage Reservoirs in Colorado

2.2.1 Platoro Reservoir

Platoro Reservoir is operated for conservation storage and flood control. Platoro Dam was constructed in 1952 and has an allocation of 54,000 acre-feet for irrigation, as well as serving as a temporary control for spring flooding events from snowmelt and rainfall (joint-use-pool). An additional 6,000 acre-feet is allocated exclusively to provide flood control. Flood control operation is the responsibility of the Corps of Engineers. Conservation storage by the Conejos Water Conservancy District can occur when the reservoir's storage right goes into priority. Conservation storage within an irrigation season can also occur under specific circumstances for individual water rights holders who store their water in lieu of diversion when they are in priority to divert. Flood control rules maintain flood control space in the reservoir in order to reduce downstream flows when necessary on the Conejos at Mogote and Lasauces. Table 2-1 summarizes general information about Platoro Dam.

Table 2-1. General information about Platoro Dam

	Platoro
Type:	Earth fill
Year completed:	1951
Structural height (feet):	165
Top width (feet):	35
Width at base (feet):	1,110
Dam crest length (feet):	1,475
Dam crest elevation (feet NGVD 1929):	10,048
Outlet works discharge capacity (cfs):	935

Table 2-2 tabulates data on physical features of Platoro Reservoir.

Table 2-2. Elevation-related information about Platoro Reservoir

	Elevation (feet) NGVD 1929	**Area (acres)**	**Capacity (acre-feet)**
Top of dam:	10,048	1012	73,291
Maximum pool:	10,042	985	67,301
Total storage at spillway crest/Top Flood Control:	10,034	948	59,571
Top of Conservation:	10,027.57	917	53,571
Conduit Invert	9,911.39	0	0

2.2.1.1 Platoro Reservoir Evaporation and Precipitation

The accounting of the operation of Platoro Reservoir follows the general mass-balance equation for reservoirs. The mathematical calculation is:

$$S_t - S_{t\text{-}1} - I - P_t + E_t + O = 0 \qquad (1)$$

Where:

S_t = total storage today, in acre-feet;

S_{t-1} = total storage yesterday, in acre-feet;
I = inflow into the reservoir, in acre-feet/day;
P_t = physical model precipitation, in acre-feet/day;
E_t = physical model evaporation, in acre-feet/day; and
O = outflow from the reservoir, in acre-feet/day.

Physical model precipitation is determined by using the equation:

$$P_t = R_t (A_{res})/12 \tag{2}$$

Where:
R_t = rainfall, in inches/day; and
A_{res} = average reservoir area, in acres.

Physical model evaporation is determined by using one of two equations, depending on the time of year. The summer equation is:

$$E_t = Ep(coeff)(A_{res})/12 \tag{3}$$

Where:
Ep = pan evaporation, in inches/day; and
$coeff$ = pan evaporation coefficient (0.7 for reservoirs in the Rio Grande Basin).

The winter equation is:

$$E_t = [(T_{max} + T_{min})/2] * (k/days) * (1-cov) * A_{res} \tag{4}$$

Where:
T_{max} = maximum daily air temperature, in °F;
T_{min} = minimum daily air temperature, in °F;
k = factor for month, in inches per °F;
$days$ = days in the month; and
cov = reservoir ice cover, in percent.

Methods are included on the Platoro Reservoir Object in the model to represent evaporation losses and precipitation gains over the reservoir surface area. Constant monthly evaporation rates of 0.10, 0.25, 0.21, 0.17, 0.16, and 0.07 inches per day are specified for May through October respectively, with zero evaporation specified in the other half of the year. Daily precipitation data is not collected as a model input, and thus precipitation gains to the reservoir are assumed to be zero.

2.2.2 Rio Grande, Continental, and Santa Maria Reservoirs

The URGWOM Technical Team visited Rio Grande, Continental, and Santa Maria Reservoirs in Colorado in 2016. The Technical Team discussed the addition of these reservoirs to the Colorado portion of URGWOM and decided that it is not currently a priority to add these reservoirs. Members of the Tech Team felt that these reservoirs would add complexity with little to no marginal value to the Colorado portion of the model because:

1) It is difficult to predict or replicate the direct storage operations in each of these reservoirs;
2) These reservoirs are small, built prior to the signing of the Compact, and operate primarily to meet demands of farmers with junior priority water rights; and
3) The reach of river extending upstream of the Wagon Wheel Gap gage to these reservoirs is long and has many ungaged inflows and other gains and losses, making it difficult to accurately model gains and losses. Adding these reservoirs is likely a greater source of error than a benefit.

As the Colorado portion model is improved and more is known about direct reservoir storage operations, the Tech Team may reconsider adding these reservoirs to the model.

2.3 Simulation of Physical Processes in Colorado

The RiverWare model for the Colorado portion of the Rio Grande Basin includes methods for representing key physical processes. Methods are set up in the model for representing flood wave travel times; conveyances losses to open water evaporation, evapotranspiration, and seepage; precipitation and evaporation for a reservoir surface area; and inflows from gaged or ungaged local inflows.

URGWOM is set up with methods for computing physical losses using calibrated monthly loss coefficients. One-day lags are applied to represent travel times for the conveyed flows. Return flow fractions are set up on all the diversions. RiverWare rules are used to set the portion of allocatable flow separate from the portion specifically designated for Compact delivery, make two calls to the RiverWare water rights solver to set diversion accounts for the main stem of the Rio Grande and the Conejos River Basin, and set physical diversions as a sum of all diversion for all accounts associated with each physical diversion. Rules for Platoro Dam conservation storage and flood control operations are also included. Flood control operations simulated at Platoro include operations for Conejos River channel capacities at Mogote and Lasauces.

2.3.1 <u>Colorado Surface Water System</u>

2.3.1.1 Description of Reaches in Colorado

A schematic of the full system as represented in the RiverWare workspace for the Colorado portion of URGWOM is shown in Figure 2-4. The top line represents the main stem Rio Grande, the middle line the Conejos River, and the bottom line the Rio San Antonio, a tributary to the Conejos. An isolated segment of the workspace is shown in Figure 2-5. Separate objects are used in the RiverWare model for the Colorado portion of the Rio Grande Basin to represent key stream gages, reaches between gages, diversions/returns, and confluences at major tributaries.

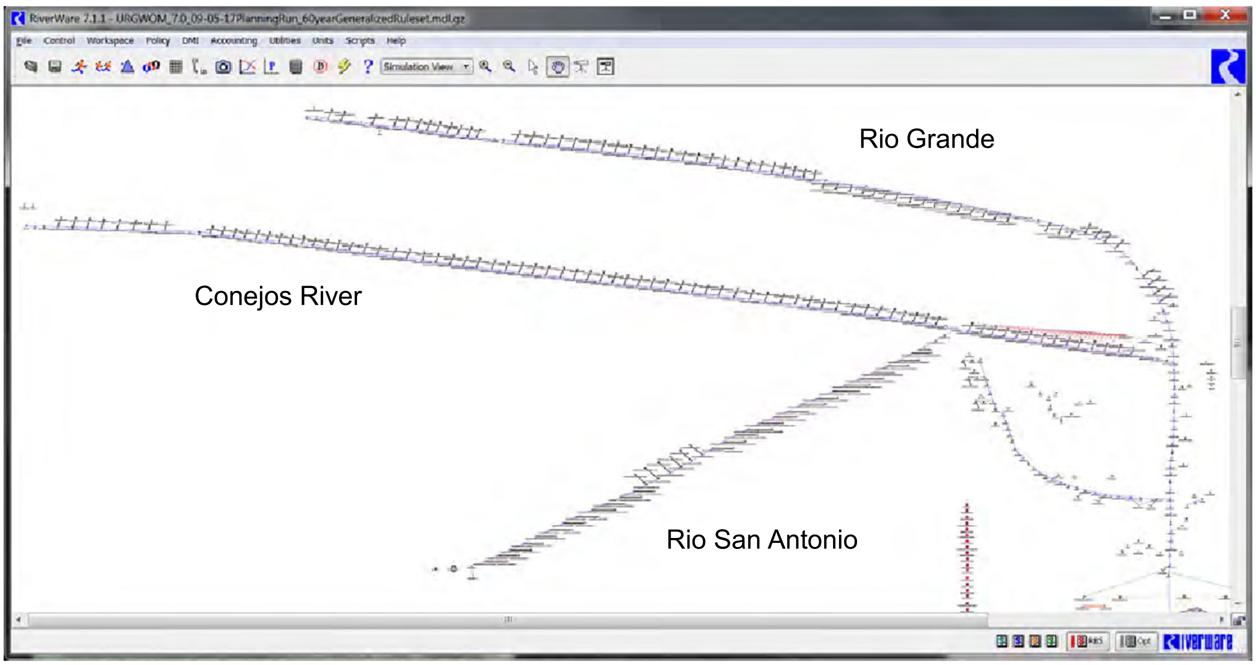


Figure 2-4. Schematic of System for Colorado Portion of Rio Grande in URGWOM

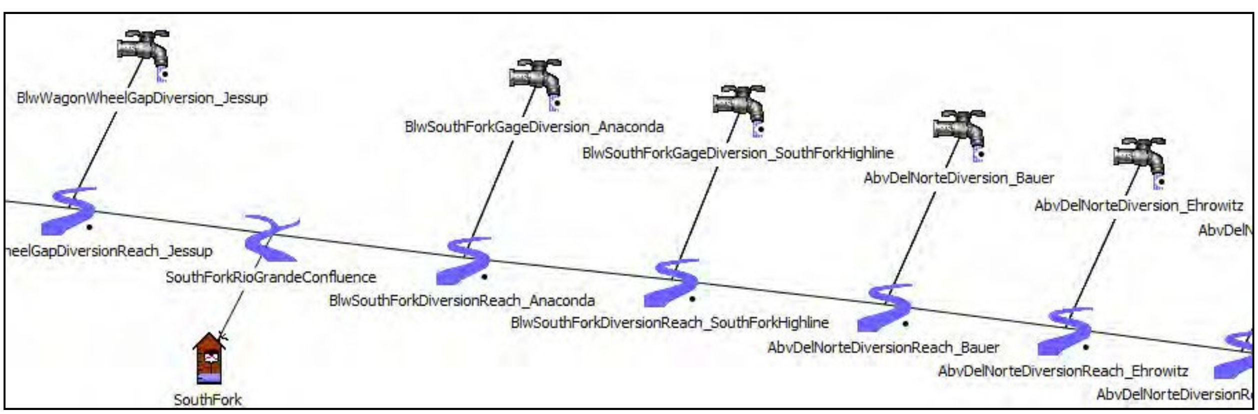


Figure 2-5. RiverWare Workspace in Colorado – Zoomed in to Isolated Segment

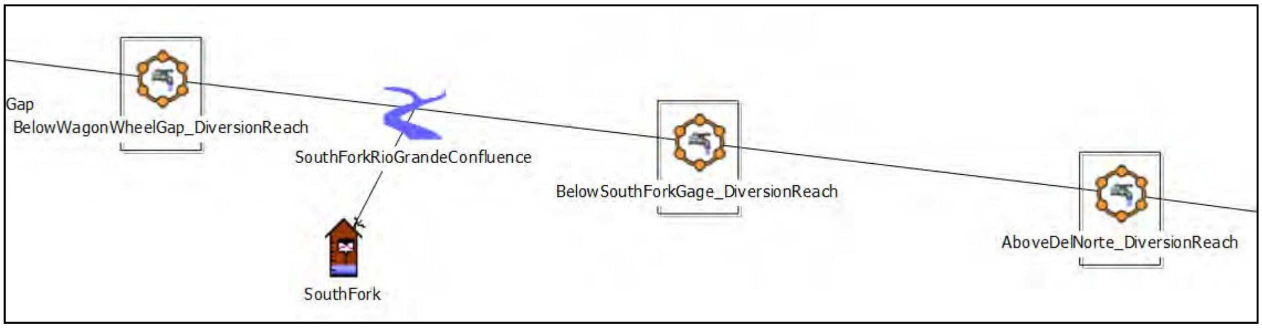


Figure 2-6. URGWOM Colorado Physical Layout with Collapsed Clusters

Each water user diversion is represented by a single Water User Object. The naming convention for water users is *ReachName*Diversion_*WaterUser* (Figure 2-5). This approach allows model flexibility because individual water users can have separate methodology (e.g., return flow percentage, lag times, etc.). To simplify the workspace, multiple water users are contained in clusters (Figure 2-6). These object clusters are marked with a black dot in RiverWare (Figure 2-5) and can be expanded and collapsed. Sixty-three individual diversions from the Rio Grande and 114 individual diversions from the Conejos and tributaries are included in the model.

A Reservoir Object is used for Platoro Reservoir, and twenty Stream Gage Objects are used in the model for all the key stream gages (Refer to Table 2-3 for a list of all the Colorado stream gages specifically included in the RiverWare model layout). Separate Reach Objects are included for adding ungaged local inflows and for the locations of diversions. Aggregate Reach Objects are used which effectively contain multiple Reach Objects. Different methods are set up on the individual reaches in the aggregate Reach Objects for representing physical lags for the conveyed flows and conveyance losses, computed with calibrated monthly loss coefficients. Several Data Objects are also included in the RiverWare workspace that contains information for Compact calculations, water rights amounts, Platoro flood control operations parameters and forecasting.

2.3.1.2 Colorado Inflows

Eighteen Stream Gage Objects are used in the Colorado portion of the model for all the key stream gages, see Table 2-3. Separate Reach Objects are included for adding ungaged local inflows and for the locations of diversions.

Table 2-3. Gages in the RiverWare Model for the Colorado Portion of the Rio Grande Basin

	Gage Name	URGWOM Name	ID	Period of Record
	Rio Grande			
1	Rio Grande at Thirtymile Bridge nr. Creede	ThirtyMileBridge	RIOMILCO	1909 to present
2	North Clear Creek below	NorthClearCreekBelowCo	NCLCONCO	1929 to present

	Gage Name	URGWOM Name	ID	Period of Record
	Continental Res	ntinentalReservoir		
3	Rio Grande at Wagon Wheel Gap	WagonWheelGap	RIOWAGCO	1951 to present
4	South Fork of Rio Grande below Columbine Creek nr. South Fork,	SouthFork	SOUCOLCO	1910 to present
5	Rio Grande near Del Norte, CO	DelNorte	RIODELCO	1890 to present
6	Rio Grande River at Monte Vista	MonteVista	RIOMONCO	1926 to present
7	Rio Grande River at Alamosa	Alamosa	RIOALACO	1912 to present
8	Closed Basin Project Canal near Alamosa	ClosedBasinProjectCanal	CBPALACO	1987 to present
9	Rio Grande above Trinchera Creek near Lasauces	RioGrandeLaSauces	RIOTRICO	1936 to present
10	Norton Drain near Lasauces	NorthChannelNortonDrain	NORDLSCO	1970 to present
11	Rio Grande near Lobatos, CO	Lobatos	RIOLOBCO	1899 to present
	Conejos River			
12	Conejos River below Platoro Reservoir	ConejosRiverBelowPlatoro	CONPLACO	1952 to present
13	Conejos River near Mogote, CO	Mogote	CONMOGO	1903 to present
14	Rio San Antonio near Ortiz	RioSanAntonioAtOrtiz	SANORTCO	1919 to present
15	Rio de Los Pinos near Ortiz	RioLosPinosAtOrtiz	LOSORTCO	1915 to present
16	San Antonio River at Mouth nr. Manassa	RioSanAntonioAtManassa	SANMANCO	1923 to present
17	South Channel Norton Drain nr. Las Sauces	SouthChannelNortonDrain	NORDSCCO	1989 to present
18	Conejos River near Manassa	ConejosLaSauces	CONMANCO	1921 to present

2.3.1.2.1 Gaged Inflows

Gage based inflows to the model along the Rio Grande include inflows from the main stem Rio Grande (at Thirtymile Bridge), North Clear Creek, the South Fork of the Rio Grande, the North Channel of the Norton Drain, and from the Closed Basin Project. Gage based inflows to the model along the Conejos and tributaries of the Conejos include main stem inflows above Platoro (calculated based on gaged flows below the reservoir and mass balance calculations in the reservoir), Rio San Antonio, Rio Los Pinos, and the South Channel of the Norton Drain.

2.3.1.2.2 Ungaged Local Inflows

Ungaged inflows are included in the model as local inflows added above each key river gage along the Rio Grande, Conejos River, or San Antonio River within the model domain. Historical local inflows along reaches defined by river gages were determined for the database by comparing historical gaged data at each key river gage to modeled flows starting with historical gaged flows at the upstream end of a reach. The following steps are necessary to develop monthly loss rates and local inflow (gains) in the Rio Grande, Conejos River, or San Antonio River:

a. Select an overall dataset of daily flow. Datasets used to determine travel times are based on discharge data for gages at the upstream and downstream ends of each URGWOM reach.

b. Model all significant human effects in the reach, including diversions and measured tributary inflows.

c. Determine and apply the appropriate time lag routing method for each reach.

d. Create a routed hydrograph by routing the upstream-observed hydrograph to the downstream location while accounting for diversions and measured inflows in the reach using the overall dataset.

e. Create a filtered dataset to determine only loss relations; keep data for the days when routed flow is greater than downstream-observed flow in groups of three or more consecutive days.

f. Plot the (filtered) downstream-observed hydrograph versus the (filtered) routed hydrograph for each month and perform a regression analysis on the data.

g. Create a monthly loss rate for each calendar month by using daily data in the regression analyses of the filtered dataset. The slope of the linear regression line of best fit represents the loss coefficient. Regression lines of best fit are computed with the line forced through the zero y-intercept.

h. Create a "routed with losses" hydrograph using the monthly regression coefficient minus one on the daily numbers (of the corresponding months), for the overall routed hydrograph.

i. Create a local inflow hydrograph that represents gains or losses (raw residuals) within the reach by subtracting the routed with losses hydrograph from the downstream-observed flow hydrograph, both for the overall dataset.

j. Calculate the total volume associated with all residuals for the year.

k. Calculate the volume associated with the positive residuals only for the year.

l. For each day with positive residual, divide the flow (volume) that day by the total positive volume for the year to get the percentage of total positive volume for the year represented by that flow.

m. Multiply the percentage of total positive volume on a given day by the total net volume for the year to get the smoothed positive flows.

n. Set all days with negative residuals to zero.

Ungaged local inflows were computed for nine reaches with the local inflows added just above the following gage locations: Wagon Wheel Gap, Del Norte, Monte Vista, Alamosa, Rio Grande at Lasauces, Lobatos, Mogote, Conejos at Lasauces, and San Antonio River at Manassa. Note that the local flows are more significant for Wagon Wheel Gap, Del Norte, and Mogote with the more significant snowmelt runoff that contributes to the reaches upstream of these locations.

2.3.1.3 Routing Travel Time in Colorado

Conveyance travel times are represented with one-day lags at five locations along the main stem (i.e. a 5-day lag from Thirtymile Bridge to Lobatos is represented) and at three locations along the Conejos River (i.e. a 3-day lag from Platoro Dam to Lobatos is represented). A separate single one-day lag is included on the San Antonio River. See Table 2-4 for a list of these reaches and lags. At all lag locations, matching one-day lags are set up separately on the pass-through accounts. For more specific information on accounting in the model, refer to the URGWOM Accounting Documentation Appendix (Under Development).

Table 2-4. Travel time lags for Colorado Portion of Model

Reach	URGWOM Reach Object Name	Time lag (days) for all flow rates
Thirtymile Bridge to Del Norte	AboveDelNorteLossesAndLag	1
Del Norte to Monte Vista	AboveMonteVistaLossesAndLag	1
Monte Vista to Alamosa	AboveAlamosaLossesAndlag	1
Alamosa to Rio Grande at La Sauces	AboveLaSaucesLossesAndLag	1
Below Platoro to Mogote	PlatoroToMogoteLossesAndLag	1
San Antonio River	SanAntonioRiverLossesAndLag	1
Mogote to Conejos at La Sauces	MogoteToLaSaucesLossesAndLag	1
Rio Grande at La Sauces to Lobatos	AboveLobatosLossesAndLag	1

2.3.1.4 Water Surface Evaporation / Channel Losses in Colorado

Conveyance losses of river flow to open water evaporation, evapotranspiration, and seepage are represented in the RiverWare model with monthly loss coefficients. Loss coefficients were developed for five separate major reaches of the main stem Rio Grande in Colorado, and three major reaches for the Conejos River Basin portion of the model. Loss coefficients were developed using the procedure described in Section 2.3.1.2.2, above, where monthly loss coefficients are computed based on a regression between historical downstream gaged flows and upstream flows routed to the downstream gage location with any lags or diversions included. Loss rates by month and reach are shown in Table 2-5.

The total conveyance loss is distributed between the Compact delivery water account and Rio Grande allocable water account on a proportional basis.

Table 2-5. Losses in the Colorado Portion of URGWOM

Adopted Loss Coefficients								
Month	**Thirtymile Bridge to Del Norte (Above DelNorte)***	**Del Norte to Monte Vista (Above Monte Vista)***	**Monte Vista to Alamosa (Above Alamosa)***	**Alamosa to Rio Grande at La Sauces (Above LaSauces)***	**Below Platoro to Mogote (PlatoroTo Mogote)***	**San Antonio River (San Antonio River)***	**Mogote to Conejos at La Sauces (MogoteTo LaSauces)***	**Rio Grande at La Sauces to Lobatos (Above Lobatos)**
Jan	-0.04	-0.04	-0.06	-0.06	-0.07	-0.56	-0.13	-0.01
Feb	-0.04	-0.04	-0.03	-0.06	-0.07	-0.48	-0.12	-0.02
Mar	-0.04	-0.10	-0.03	-0.07	-0.07	-0.27	-0.09	-0.03
Apr	-0.04	-0.11	-0.13	-0.07	-0.07	-0.16	-0.11	-0.06
May	-0.04	-0.12	-0.14	-0.07	-0.07	-0.12	-0.16	-0.06
Jun	-0.04	-0.14	-0.14	-0.07	-0.07	-0.10	-0.18	-0.06
Jul	-0.05	-0.17	-0.14	-0.07	-0.07	-0.27	-0.18	-0.06
Aug	-0.07	-0.16	-0.14	-0.07	-0.07	-0.59	-0.30	-0.06
Sep	-0.04	-0.16	-0.14	-0.07	-0.07	-0.48	-0.25	-0.10
Oct	-0.03	-0.15	-0.14	-0.05	-0.07	-0.44	-0.24	-0.06
Nov	-0.03	-0.14	-0.08	-0.05	-0.07	-0.53	-0.15	-0.06
Dec	-0.03	-0.08	-0.08	-0.05	-0.07	-0.58	-0.15	-0.06

* URGWOM reach name

A sample regression is presented in Figure 2-7 completed with historical June data for the Monte Vista and Alamosa gages. At all locations where monthly loss coefficients are applied, matching monthly loss coefficients are also set up on pass-through accounts.

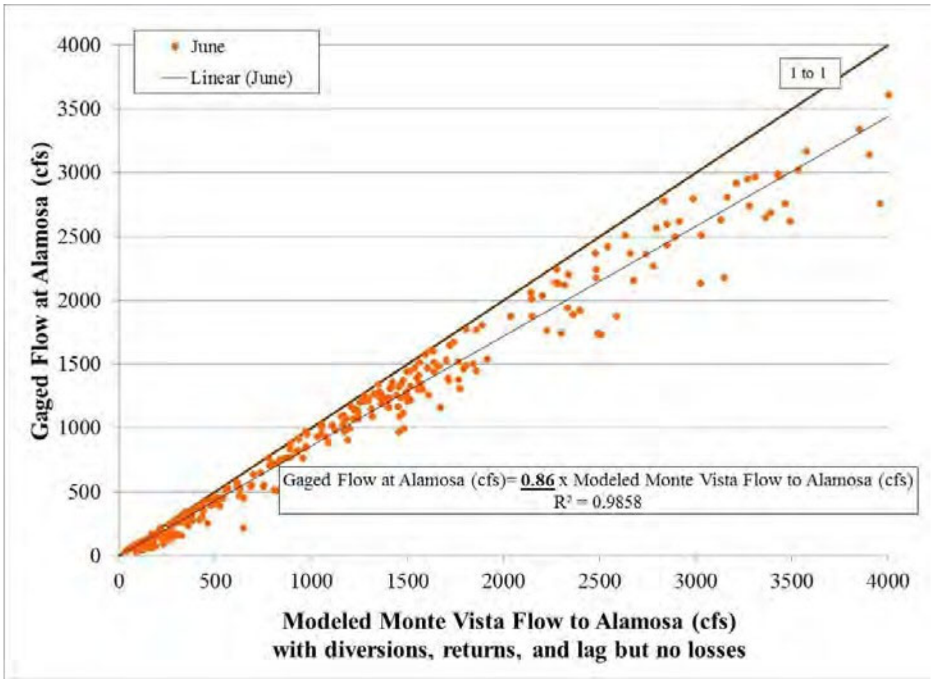


Figure 2-7. Sample Regression for Computing a Monthly Loss Coefficient

2.3.1.5 Colorado Compact Calculations

The Compact stipulates that the state of Colorado is obligated to deliver water to the Colorado-New Mexico state line as measured at the Lobatos gage based on separate delivery requirements from the Conejos River and the Rio Grande. The delivery obligation for the Conejos River is computed as a function of the Conejos Index Supply, which is defined as the natural flow of the Conejos River gaged near Mogote for the calendar year plus the gaged flows in the Los Pinos River near Ortiz and the San Antonio River at Ortiz from April through October. The actual Conejos delivery to the Rio Grande is gaged at the Las Sauces gage near the confluence with the Rio Grande over the calendar year. All of these Conejos gages are included in the model for the Colorado portion of the Rio Grande. The delivery for the Rio Grande is computed as a function of the Rio Grande flow at Del Norte corrected for the impact of reservoirs constructed after 1937. The Rio Grande delivery is based on the gaged river flow at Lobatos minus the flow from the Conejos River (states of Colorado, New Mexico, and Texas, 1939).

The split in contribution from the Conejos River versus the Rio Grande is inconsequential for New Mexico, but in 1981, the Rio Grande Water Users Association and Conejos Water Conservancy District agreed to split the allowable debit 60,000 acre-feet for the Rio Grande and 40,000 acre-feet for the Conejos River and deliveries from the Closed Basin Project are also split 60% to 40% as contributions to the delivery requirement for the Rio Grande and Conejos River. This 60%/40% split is a model input for the Colorado portion of URGWOM and can very easily be changed. The same split is used to set the amount of the 10,000 acre-feet Compact buffer that applies to each basin. Inflow from the South Channel Norton Drain count toward the delivery requirement for the Conejos River, and the contribution from the North Channel near Lasauces minus the gaged flow at the South Channel counts toward the Rio Grande delivery obligation.

To ensure methods used in the model to calculate deliveries to the Lobatos gage are sufficient, they have been reviewed by examining the Compact calculations extensively. The formulas and tables contained in the model have been examined to ensure they match the tables and language of the Compact. Historical simulations have been performed to verify that the model is accurately replicating historical flow observations at the Lobatos gage. Rule-based simulations have been performed to verify that the model uses curtailment where possible to maintain a compact balance near zero (Tetra Tech Inc., 2017).

2.3.1.6 Colorado Farm Operations

On-farm operations are not modeled in the Colorado portion of URGWOM. Water rights based diversions are set at each timestep with the Water Rights Solver (Section 2.3.1.6.1), and a return flow percentage associated with each diversion location is used to calculate return flows (Section 2.3.1.6.6). Beyond this there is no representation of on-farm operations.

2.3.1.6.1 Colorado Diversions

Diversions are set up for every physical diversion on the main stem of the Rio Grande and in the Conejos River Basin based on the daily call sheets used by the Water Commissioners for District 20 and District 22. Refer to Figure 2-8 for photos of a diversion from the Rio Grande (Rio Grande Canal) and Figure 2-9 for photos of a diversion from the Conejos River (Romero Ditch). Multiple individual diversions are lumped at single nodes in the model. Diversions are determined during rule based simulation using a water right solver.

Figure 2-8. Diversion Dam (left) and Head Gates (right) to Rio Grande Canal.

Figure 2-9. Diversion for Romero Ditch (left), and Parshall Flume in Romero Ditch (right).

2.3.1.6.2 Colorado Canal Loses

Canal losses are not modeled explicitly in the Colorado portion of URGWOM, but are contained implicitly in the return flow parameterization.

2.3.1.6.3 Colorado Irrigated Acreage

Agricultural diversions in the Colorado portion of URGWOM are based exclusively on water rights, and thus irrigated acreage is not explicitly considered. The amount of land actually under irrigation, and the type of crops being irrigated impact the return flow parameterization of each ditch.

2.3.1.6.4 Colorado Crop ET

Agricultural diversions in the Colorado portion of URGWOM are based exclusively on water rights, and thus crop consumption is not explicitly considered. The amount of crop consumption impacts the return flow parameterization of each ditch.

2.3.1.6.5 Colorado Soil Moisture

Soil moisture is not tracked in the Colorado portion of URGWOM.

2.3.1.6.6 Colorado Return Flows / Interior Drains

Fractional return flows are set up in the model for the portion of a diversion that returns to the river. This return flow would include returns from canals, irrigated lands, or municipal users. Fractional returns are set to 30% for all diversions from the main stem of the Rio Grande above Del Norte. No return flow method is selected for diversions to river left (looking downstream) between Del Norte and Monte Vista and including the San Luis Valley canal as it is assumed that these diversions feed to the Closed Basin and no returns would be realized in the river. Fractional returns for all other diversions below Del Norte are set to 10%. Fractional returns are set to 10% for all the diversions in the Conejos River Basin except for diversions from the North Branch of the Conejos River and the North Branch of the San Antonio River where no return flow method is selected. (This setup could be reviewed further and refined to more accurately reflect expected returns, though one advantage to the current approach is that returns from the north branch are unavailable for the diversions from the south branch as occurs in reality due to the split of the river not represented in the Colorado portion of URGWOM.) Returns from diversions below the confluence of the Conejos River and San Antonio River directly feed the South Norton Drain in the model. Fractional returns are set on all the individual diversion accounts to match the fractional returns for the physical diversion objects.

2.3.1.7 Colorado Municipal and Industrial Diversions

Some of the water rights based diversions are for municipal and industrial uses, for example, *RGCanalWaterUsersAssocDiversion_DelNorteTown*. This is the only manner in which municipal and industrial uses and associated returns (as discussed above) are considered in the Colorado portion of URGWOM.

This page intentionally left blank

3 New Mexico Main Stem (Rio Grande from Lobatos to Cochiti Dam)

3.1 Nature of Water use and Depletion on New Mexico Main Stem

There is relatively little consumptive use of water in the reach of the Rio Grande in New Mexico above Cochiti Dam. Most of the river upstream of Embudo is in deep, narrow canyons with no floodplain and little or no riparian vegetation. Groundwater discharge accrues to the flow of the Rio Grande in the reaches above Embudo. A short distance below Embudo the river enters the Espanola Valley, which is some 25 miles long and from 1 to 3 miles wide. Here the Rio Grande is joined by the Rio Chama and Santa Clara Creek from the west and the Santa Cruz River from the east. At the lower end of the Española Valley, the river enters White Rock Canyon, a narrow gorge about 20 miles long.

Surface water diversion from the main stem Rio Grande supplies water to approximately 5,900 acres of irrigated land in the Española Valley (Embudo to Otowi).

Water is lost through evaporation from the 1,200 acre water surface of the permanent recreation pool at Cochiti Lake and the wetted sands of sediment deposits and lagoons in the river channel upstream of the Lake.

The residents of the City of Española and other communities in the Espanola area obtain municipal and domestic water supplies from groundwater withdrawals. The City of Santa Fe derives a part of its water supply by direct diversion from the Rio Grande at the Buckman Diversion, located about 3.2 miles downstream of the Otowi gage.

3.2 URGWOM Storage Reservoirs in New Mexico Main Stem

Cochiti Lake is the only reservoir constructed on the main stem of the Rio Grande in New Mexico above Cochiti Dam. There are smaller structures on tributaries of the Rio Grande (Costilla Dam, Cabresto Dam, and Santa Cruz Dam); however none of these facilities are simulated in the physical model. Nambe Falls Reservoir stores San Juan-Chama Project Water, by exchange, for the water users of the Pojoaque Valley Irrigation District and this water is accounted for in the Accounting application of the model. The operation of Nambe Falls Reservoir is simulated in the physical model. Cochiti Lake is discussed in more detail in Section 5.2.1

3.3 Simulation of Physical Processes in New Mexico Main Stem

Inflow to the reaches in this section of the model is based on gaged inflow on the main stem at Lobatos or modeled output from the URGWOM simulation of the Rio Grande in Colorado. Gaged tributary inflow to the main stem in New Mexico above Cochiti Dam include the Red

River, the Rio Pueblo de Taos and Embudo Creek. The ungaged tributary inflow is indirectly computed from main stem gages as local inflow (see Section 2.3.1.2.2). The surface water-groundwater interaction in the shallow river alluvium in the Espanola Valley is not simulated. Gains and losses to the shallow groundwater are computed as a component of local inflow.

Channel losses and travel times on the main stem are based on a statistical analysis of streamflow data measured at main stem gages operated and maintained by the USGS. These methods are more fully described in Section 3.3.1.2 and Section 3.3.1.3.

Consumptive use from the irrigation of lands along the main stem in the Española Valley is not specifically simulated in the model but is included as a component of the local inflow.

3.3.1 New Mexico Main Stem Surface Water System

This section of the Rio Grande, from the Colorado-New Mexico state line to Cochiti Dam, is characterized by snowmelt runoff contribution from the Sangre de Cristo Mountains to the East of the Rio Grande and from the Brazos Mountains which are drained by the Rio Chama and its tributaries. There is also substantial groundwater accretion to the Rio Grande in the reaches in Taos County. The consumptive use of water from agricultural use along the main stem in this reach is not significant compared to the amount of water generated in runoff in these reaches.

3.3.1.1 Description of Reaches in New Mexico Main Stem

The 132-mile reach of the Rio Grande between the Colorado-New Mexico state line and Cochiti Dam is divided into six URGWOM reaches. The first reach begins at the gage Rio Grande near Lobatos, CO; the second at the gage near Cerro, NM; the third at the gage below Taos Junction Bridge; the fourth at the gage at Embudo; the fifth at the Rio Chama confluence; and the sixth at the gage at Otowi Bridge. The discontinued gages, Rio Grande above San Juan Pueblo and Rio Grande near Arroyo Hondo, were used to help estimate travel times and loss rates in the reaches in which the gages formerly operated.

3.3.1.1.1 Rio Grande from near Lobatos, CO to near Cerro, NM

The stream gage near Lobatos, Colorado, located 6 miles upstream of the Colorado-New Mexico state line, marks the location where the Rio Grande enters a canyon carved through basalt lava flows and gradually increases in depth to about 1,200 feet at Embudo, about 70 miles south of the state line (Figure 4-1). The river channel in this reach is rocky and has little riparian vegetation. Costilla Creek is a major east-side tributary to the Rio Grande in this reach. Costilla Creek contributes very little water to the Rio Grande because its waters are largely regulated and diverted for irrigation before they reach the Rio Grande. Costilla Creek discharges into the Rio Grande during years of very high runoff, but no stream gage is located near its mouth. The Costilla Creek inflow is incorporated with local inflows in the river routing of this reach.

Rio Grande flow from near Lobatos, Colorado, to near Cerro, New Mexico, shows an accretion which is discharge from the ground-water reservoir beneath the lava-capped plateau to the west, Colorado to the north, the Sunshine Valley to the east, and occasional surface water from Costilla Creek. The unmeasured gain in flow in this reach was great enough in most months to mask losses determined by routing the upstream flow down to the gage near Cerro and comparing this routed flow to the observed or recorded flow near Cerro. Therefore, loss rates developed for the reach of the Rio Grande between the gage Rio Grande near Arroyo Hondo and the gage Rio Grande below Taos Junction Bridge, near Taos were applied to this reach. Flow of the Rio Grande in the reach from near Arroyo Hondo to below Taos Junction Bridge, near Taos is not significantly augmented by unmeasured flow accretions; thus, reasonable monthly loss rates were developed and applied to the reach from near Lobatos to near Cerro.

3.3.1.1.2 Rio Grande from near Cerro to below Taos Junction Bridge, near Taos

Between Cerro and Taos, the Rio Grande continues its descent into the basalt canyon, with very steep gradients of as much as 75 feet/mile between the Cerro gage and the mouth of Red River. The river channel is rocky, with no alluvial material in the bed or banks and a lack of riparian vegetation. Three major tributaries draining the Sangre de Cristo Mountains to the east enter the Rio Grande in this reach: Red River, Rio Hondo, and Rio Pueblo de Taos. Only the gages Red River below Fish Hatchery near Questa and Rio Pueblo de Taos below Los Cordovas are used in the river routing in this reach. The only gage on the Rio Hondo is 9 miles above its mouth and above all irrigation diversions; therefore, this tributary is modeled as a local inflow component. Data from the stream gage Rio Grande near Arroyo Hondo, which was discontinued in 1996, is used to help define travel time lags for this reach.

Substantial accretions of flow to the Rio Grande continue in this reach, as visibly evidenced by Big Arsenic and Little Arsenic Springs discharging directly into the Rio Grande and springs discharging into the lower Red River below Questa, NM. The unmeasured gain in flow was great enough to mask any losses in the reach determined by routing the lagged upstream flow down to the Taos gage and comparing this flow with observed flow at the Taos gage. As a result, the filtered data generated for this reach were insufficient for developing reliable monthly loss relations. Therefore, as in the upstream reach, loss rates developed for the reach of the Rio Grande between the gages Rio Grande near Arroyo Hondo and Rio Grande below Taos Junction Bridge, near Taos were applied to this reach. The Arroyo Hondo to Taos reach, which is a sub-reach of the Cerro to Taos reach, does not have significant unmeasured flow accretion and reasonable monthly loss rates were developed and prorated based the difference in length between the two reaches.

3.3.1.1.3 Rio Grande from near Arroyo Hondo to below Taos Junction Bridge, near Taos

This reach, located within the Cerro to Taos reach, is not an URGWOM reach and is presented here only because it was used to develop river-channel loss rates for the reaches near Lobatos to near Cerro and near Cerro to below Taos Junction Bridge, near Taos. The flow recorded at the gage Rio Pueblo de Taos below Los Cordovas is used in the river routing in this reach.

3.3.1.1.4 Rio Grande from below Taos Junction Bridge, near Taos to Embudo

In this reach, the Rio Grande enters the deepest portion of the gorge, and the river channel begins to widen. Alluvial deposits compose the bed and banks of the river here with the first appearance of any significant riparian vegetation. About 200 acres of irrigable land are served by direct diversion from the Rio Grande in the vicinity of Pilar and Rinconada. Embudo Creek is the major tributary in this reach, entering the Rio Grande about 3 miles above the Rio Grande at Embudo gage. The Embudo Creek at Dixon gage measures the discharge of Embudo Creek into the Rio Grande and these data are included in the river routing for this reach.

3.3.1.1.5 Rio Grande from Embudo to Rio Chama Confluence

The 13-mile reach of the Rio Grande between the stream gage at Embudo and the site of the discontinued stream gage above San Juan Pueblo was used to determine time lags and loss relations for the 15-mile reach from Embudo to the Rio Chama confluence. Because the gage above San Juan Pueblo was discontinued in 1987, it is not used in the model to route flow or to compute local inflow. Approximately 5,000 acres of irrigable land are served by direct diversion from the Rio Grande in this reach.

3.3.1.1.6 Rio Chama / Rio Grande Confluence to Rio Grande at Otowi Bridge

The Rio Chama enters the Rio Grande about 14 miles above the Otowi gage. In this reach, the Rio Grande continues to flow through the alluvium of the Española Valley. Water is diverted from the Rio Grande to serve irrigable lands on the west side of the river (Los Vigiles Ditch, Santa Clara Pueblo Ditch). Santa Clara Creek, Santa Cruz River, and the Pojoaque River discharge to the Rio Grande in this reach, but are not represented in the model, except as a component of local inflow. Discharge from the Espanola wastewater treatment plant occurs in this reach and is represented as a component of local inflow.

The loss rate analysis of this reach was inconclusive because of a large variation in percentage of loss rates and a lack of sufficient data for some months. Because the data cannot be used to produce monthly loss rates that demonstrate a reasonable loss pattern, the losses developed for the reach from Embudo to above San Juan Pueblo were applied to this reach. Application of these loss rates is appropriate because of the similarities of the two reaches. This reach and the reach from Embudo to the confluence when combined constitute the Española Valley, a broad alluvial valley where land use comprises mainly riparian vegetation and irrigated agriculture.

3.3.1.1.7 Rio Grande from Otowi Bridge to Cochiti Dam

Although this reach is about 26 miles long, it is considered to be 21 miles for the purpose of computing losses because the reservoir above the dam is about 5 miles long at the permanent pool elevation of approximately 5,344 feet.

Table 3-1 summarizes physical data about the stream gages for the Rio Grande watershed between Lobatos and Cochiti Dam

Table 3-1. Summary of stream gage data for the Rio Grande from near Lobatos, Colorado, to Otowi Bridge, New Mexico

Gage Location	River mile (above mouth)		Elevation (feet, NGVD 1929)		Drainage area (square miles)	
	At gage	Δ	At gage	Δ	At gage	Δ
Lobatos	1,719		7,428		7,700	
		26		318		740
Cerro	1,693		7,110		8,440	
		35		1,060		1,290
Taos	1,658		6,050		9,730	
		15		261		670
Embudo	1,643		5,789		10,400	
		29		300		3,900
Otowi Bridge	1,614		5,489		14,300	
		26		145		300
Cochiti Dam	1,588		5,344[1]		14,600	

[1] Approximate elevation of Cochiti Lake permanent pool.

3.3.1.2 Routing Travel Time in New Mexico Reaches

Travel times for this reach of the Rio Grande in the URGWOM model is based on the variable time lag method which is computed based on wave velocity (Seddon's Law). The variable time lag method was chosen because of several considerations; first, the variable time lag method is fairly easy to develop if measurement data are available, second, it can be developed throughout the model for reaches with differing geomorphic and hydrologic conditions, and third, the variable time lag routing method takes advantage of the known direct relation between velocity and flow. The reader is referred to the previous URGWOM model documentation for additional information about the development of the variable time lag method (URGWOM Technical Team, 2005).

When this procedure is used to estimate travel time lags, the river cross sections at the site of the stream gages are assumed to be representative of the entire routing reach. If both upstream and downstream gage measurements are available, the results of wave velocity analysis are averaged to represent the entire reach. Analyzing the upstream and downstream hydrographs at various discharge rates verifies the results.

Table 3-2 tabulates river travel time lags in the reaches between Lobatos, CO and the confluence of the Rio Chama. There is no routing of flow between the Rio Chama confluence and Cochiti Lake.

Table 3-2. Travel time lags for the Rio Grande from near Lobatos, CO to Rio Chama Confluence

Reach	Time lag (days) for indicated flow rate (cfs)						
	50	200	500	750	1,000	3,000	6,000
LobatosToCerro	1.13	.75	.58	.54	.50	.38	.29
CerroToTaos	1.46	.88	.63	.54	.50	.33	.29
TaosToEmbudo	.54	.29	.21	.17	.17	.08	.08
EmbudoToConfluence	.54	.29	.21	.17	.17	.08	.08

3.3.1.3 Water Surface Evaporation /Channel Losses in New Mexico Main Stem

The procedures for computing monthly loss rates in the main stem reaches above Cochiti and the reaches on the Rio Chama are described in Section 2.3.1.2.2.

Table 3-3 is a tabulation of the adopted loss coefficients computed for the six reaches of the Rio Grande from Lobatos, CO to Cochiti Lake, NM.

Table 3-3. Adopted monthly loss coefficients for the reach of the Rio Grande from near Lobatos, Colorado, to Cochiti, NM

Month	Adopted Loss Coefficients					
	LobatosTo Cerro	CerroTo Taos	TaosTo Embudo	EmbudoTo Confluence	Confluence ToOtowi	OtowiTo Cochiti
Jan	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03
Feb	-0.03	-0.04	-0.02	-0.03	-0.03	-0.03
Mar	-0.03	-0.04	-0.02	-0.05	-0.05	-0.04
Apr	-0.05	-0.07	-0.03	-0.06	-0.06	-0.04
May	-0.05	-0.07	-0.04	-0.07	-0.07	-0.04
June	-0.04	-0.05	-0.04	-0.08	-0.08	-0.05
July	-0.04	-0.05	-0.04	-0.11	-0.11	-0.06
Aug	-0.04	-0.04	-0.04	-0.08	-0.08	-0.05
Sept	-0.03	-0.04	-0.03	-0.08	-0.08	-0.04
Oct	-0.03	-0.03	-0.03	-0.06	-0.06	-0.04
Nov	-0.02	-0.03	-0.03	-0.06	-0.06	-0.03
Dec	-0.03	-0.04	-0.03	-0.04	-0.04	-0.02

3.3.1.4 New Mexico Main Stem Gaged Inflows

The inflow from gaged tributaries in the reaches between Lobatos and Cochiti are included in the model simulation as stream gage objects. These measured tributaries include the Red River, the Rio Pueblo de Taos and Embudo Creek. See Table 3-4. Simulated flow in the Rio Chama is also included as an inflow to this reach.

3.3.1.5 New Mexico Main Stem Local Inflows

The inflow from unmeasured tributaries is indirectly determined as a part of the local inflow computation. Inflow from Costilla Creek, Rio Hondo, Santa Cruz River, Santa Clara Creek and Pojoaque Creek are computed as a component of local inflow, along with contributing drainage areas of many smaller tributaries and groundwater inflow. Computed local inflow for four reaches is added at Reach Objects located above the following locations: Cerro gage, Taos gage, Embudo gage, Otowi gage and Cochiti Lake. The method used to compute local inflow is described in Section 2.3.1.2.2.

Table 3-4. Stream gages in the RiverWare Model for the Main Stem Rio Grande above Cochiti Dam

Gage Name	URGWOM Name	Gage ID	Period of Record
Rio Grande nr. Lobatos, CO	Lobatos	08251500	1899 to present
Rio Grande nr. Cerro, NM	Cerro	08263500	1948 to present
Red River below Fish Hatchery	RedRiverblwFishHatchery	08266820	1969 to present
Rio Pueblo de Taos below Los Cordovas	RioPueblodeTaosAtLosCordovas	08276300	1957 to present
Rio Grande below Taos Junction Bridge, nr. Taos	Taos	08276500	1925 to present
Embudo Creek at Dixon	EmbudoCreekAtDixon	08279000	1923 to present
Rio Grande at Embudo	Embudo	08279500	1889 to present
Rio Grande at Otowi Bridge	Otowi	08313000	1895 to present
Rio Grande below Cochiti Dam	BlwCochiti	08317400	1970 to present

3.3.1.6 New Mexico Main Stem Farm Operations

The diversion, consumptive use and losses of water associated with irrigated agriculture in the reaches of the Rio Grande from Lobatos to Otowi are not specifically simulated. The consumptive use of water due to irrigated agriculture is indirectly computed in the local inflow computation as a component of the river loss in these reaches.

3.3.1.7 New Mexico Main Stem Municipal and Industrial Diversions

The single municipal and industrial diversion of water from the surface flow of the Rio Grande is at the Buckman Direct Diversion, which supplies water to the City of Santa Fe. This diversion is located in the Otowi to Cochiti reach.

4 Rio Chama

4.1 Nature of Water Use and Depletions in the Rio Chama

The Rio Chama heads at Cumbres Pass (El. 10,000 feet) in Conejos County, Colorado and it is the largest tributary to the Rio Grande in New Mexico in terms of water yield. The Rio Chama region is sparsely populated and the principal land uses are wildlife and livestock grazing, agriculture and forestry.

After debouching from the San Juan Mountains, the river enters the Chama Valley where irrigation water rights are served by diversions from the Rio Chama and its tributaries. Near Tierra Amarilla, NM, the river enters a series of canyons that extend to Abiquiu, NM. The crop yield is limited in areas above Abiquiu due the areas' high elevation and short growing season.

Heron, El Vado and Abiquiu Reservoirs are located in the canyon sections of the Rio Chama between Tierra Amarilla and Abiquiu. These facilities regulate snow-melt runoff to meet industrial, municipal and agricultural demands in the Middle Valley and provide flood and sediment control for the Rio Chama and Rio Grande. These structures also reregulate trans-basin water imported from the San Jun River Basin.

Nineteen Community Ditch Associations (Acequias) serve irrigated land by diversion from the Rio Chama between Abiquiu and Espanola and two Acequias serve irrigated land between El Vado Dam and Abiquiu Reservoir. There are about 4,500 acres of irrigated land along the Rio Chama below El Vado Reservoir.

There is no significant diversion of groundwater in the Rio Chama Basin except for domestic purposes.

4.2 URGWOM Storage Reservoirs in the Rio Chama

Three reservoirs–Heron, El Vado, and Abiquiu–were formed by dams constructed on the Rio Chama and its tributaries to store water for flood and sediment control and water supply. Hydroelectric power plants are located at El Vado Dam and Abiquiu Dam, which are operated as "run-of-the-river" plants–that is, the demand for release for hydroelectric power at these dams is subservient to other demands. Table 4-1 summarizes general information about these dams.

Table 4-1. General information about dams in the Rio Chama Basin

	Heron	El Vado	Abiquiu
Type:	Earth fill	Earth fill	Earth fill
Year completed:	1971	1935	1963
Structural height (feet):	269	230	341
Top width (feet):	40	20	30
Width at base (feet):	1500	642	2000
Dam crest length (feet):	1,220	1,326	1,800
Dam crest elevation (ft., NGVD, 1929):	7,199	6,914.5	6,381
Outlet works discharge capacity (cfs):	4,160	6,890	8,200

4.2.1 Heron Reservoir

Heron Reservoir stores and releases water imported from the San Juan River Basin and is the primary storage feature of the San Juan-Chama Project. Owned and operated by Reclamation, Heron Reservoir's entire capacity of about 401,300 acre-feet is dedicated to storing San Juan-Chama Project water. All native Rio Grande inflow to Heron Reservoir is bypassed. The water imported to the Rio Grande Basin from the San Juan River Basin provides supplemental water supplies for various communities and irrigation districts. The project also provides fish, wildlife, and recreational benefits from the storage and movement of this water. Table 4-2 tabulates data on physical features of Heron Reservoir.

Table 4-2. Elevation-related information about Heron Reservoir

	Elevation (feet, NGVD 1929)	Area (acres)	Capacity (acre-feet)
Top of dam:	7199.00	--	--
Maximum pool:	7190.80	6148	429,657
Total storage at spillway crest:	7186.10	5905	401,334
Top of dead pool:	7003.00	106	1218

4.2.2 El Vado Reservoir

El Vado Dam was constructed to provide conservation storage for irrigation purposes on Middle Rio Grande Conservancy District (MRGCD) lands along the Rio Grande between Cochiti Dam and Bosque del Apache National Wildlife Refuge. Operated by Reclamation, the reservoir is used to store San Juan-Chama and native water for use by the MRGCD and associated subcontractors. El Vado Reservoir also stores water for release to irrigate 8,847 acres of Prior and Paramount (P&P) Pueblo acreage in the Middle Rio Grande Valley. Table 4-3 tabulates data on physical features of El Vado Reservoir.

Los Alamos County operates and maintains a run of the river 8,000 kW hydroelectric power plant located at the toe of El Vado Dam.

Table 4-3. Elevation-related information about El Vado Reservoir

	Elevation (feet, NGVD 1929)	Area (acres)	Capacity (acre-feet)
Top of dam:	6914.50	--	--
Maximum pool:	6908.00	--	--
Total active conservation storage:	6902.00	3232	186,252
Total storage at spillway crest:	6879.00	2454	120,544
Top of dead pool:	6775.00	84	480

4.2.3 Abiquiu Reservoir

Abiquiu Dam and Reservoir is operated by the USACE for flood and sediment control in accordance with conditions and limitations stipulated in the Flood Control Act of 1960 (Public Law 86-645). Reservoir regulation for flood control is also coordinated with the operation of Jemez Canyon Reservoir, Cochiti Lake, and Galisteo Reservoir. Abiquiu Reservoir is operated to limit flow in the Rio Chama, to the extent possible, to downstream channel capacities of 1,800 cfs for the reach below Abiquiu Dam, 3,000 cfs for the reach below the confluence with the Rio Ojo Caliente, and 10,000 cfs through the Española Valley on the Rio Grande main stem. Irrigation releases from El Vado Reservoir pass through Abiquiu Reservoir.

Typically, Rio Grande water is stored in Abiquiu Reservoir in April and May, during the peak of snowmelt runoff, and released in June and early July. Any storage remaining in the reservoir after natural flow at the Otowi Bridge gage drops below 1,500 cfs is carried over or stored until after November 1, when it may then be released. In 1981, Congress authorized the use of Abiquiu Reservoir to store as much as 200,000 acre-feet of San Juan-Chama Project water. The San Juan-Chama Project water allocated to the City of Albuquerque and other entities is stored in the unused sediment space and a small portion of the flood-control space. Los Alamos County operates and maintains a run of the river hydroelectric power system at Abiquiu Dam. There are two 6.6 MW units at Abiquiu Dam for total generating capacity of 13.2 MW. Table 4-4 lists elevation information about Abiquiu Reservoir.

Table 4-4. Elevation-related information about Abiquiu Reservoir

	Elevation (feet, NGVD 1929)	Area (acres)	Capacity (acre-feet)
Top of dam:	6381.0	15,878	1,662,642
Maximum pool:	6374.7	15,497	1,563,693
Total storage at spillway crest:	6350.0	12,607	1,215,658
Top of flood-control pool:	6283.5	7,669	558,784
Top of San Juan-Chama storage:	6220.0	4,174	186,820
Conduit Invert:	6060.0	0	0

The accounting of the operation of Heron, El Vado and Abiquiu Reservoirs follows the general mass-balance equation for reservoirs. The mathematical calculation is:

$$S_t - S_{t\text{-}1} - I - P_t + E_t + O = 0 \tag{5}$$

Where:

S_t = total storage today, in acre-feet;
$S_{t\text{-}1}$ = total storage yesterday, in acre-feet;
I = inflow into the reservoir, in acre-feet/day;
P_t = physical model precipitation, in acre-feet/day;
E_t = physical model evaporation, in acre-feet/day; and
O = outflow from the reservoir, in acre-feet/day.

Physical model precipitation is determined by using the equation:

$$\mathrm{P_t = R_t\ (A_{res})/12} \tag{6}$$

Where:

R_t = rainfall, in inches/day; and
A_{res} = average reservoir area, in acres.

Physical model evaporation is determined by using one of two equations, depending on the time of year. The summer equation is:

$$\mathrm{E_t = Ep(coeff)(A_{res})/12} \tag{7}$$

Where:

Ep = pan evaporation, in inches/day; and
$coeff$ = pan evaporation coefficient (0.7 for reservoirs in the Rio Grande Basin).

The winter equation is:

$$E_t = [(T_{max} + T_{min})/2] * (k/days) * (1\text{-}cov) * A_{res} \tag{8}$$

Where:

T_{max} = maximum daily air temperature, in °F;
T_{min} = minimum daily air temperature, in °F;
k = factor for month, in inches per °F;
$days$ = days in the month; and
cov = reservoir ice cover, in percent.

Heron Reservoir is simulated as a Storage Reservoir Object in URGWOM. El Vado and Abiquiu are simulated as Level Power Reservoirs. Each reservoir solves a mass-balance equation and additional user-defined equations and methods related to specific physical and accounting attributes of the reservoirs. Methods for accounting of real-time sediment deposition in Abiquiu Reservoir have been developed using empirical data and assumptions unique to that reservoir. These methods provide an estimate of sediment accumulation in storage between reservoir sediment surveys, resulting in a more accurate accounting of water in storage in the reservoirs. For more specific information on reservoir accounting in the model, refer to the URGWOM Accounting Documentation Appendix (Under Development).

4.3 Simulation of Physical Processes in the Rio Chama

Inflows to the reach are based on gaged inflow on the main stem (ElVadoLocalInflow) and a tributary, Willow Creek. The ungaged tributary inflow is indirectly computed from main stem gages as local inflow (see Section 2.3.1.2.2). The movement of groundwater in the shallow river alluvium along the inner valleys of the Rio Chama is not simulated. Gains and losses to the shallow groundwater are computed as a component of local inflow computations.

Channel losses and travel times on the main stem are based on a statistical analysis of streamflow data measured at main stem gages operated and maintained by the USGS. These methods are more fully described in Section 3.3.1.2 and Section 3.3.1.3.

Depletion due to irrigation on the Rio Chama and its tributaries above El Vado Reservoir are not included in the model as these uses are upstream of the reaches of the Rio Chama that are included in URGWOM. Depletions due to diversion of water for irrigated agriculture on the main stem downstream of Abiquiu Dam are based on measured or authorized diversion rates and assumed return flows.

Table 4-5 summarizes stream-gage location and elevation data for the reach between El Vado Dam and Abiquiu Reservoir.

Table 4-5. Summary of stream-gage data for the reach of the Rio Chama from below El Vado Dam to above Abiquiu Reservoir

	Rio Chama below El Vado Dam (BlwElVado)*	Rio Chama above Abiquiu Reservoir (AbvAbiquiu)*	Total Δ
River mile (above mouth)	76.2	47.4	28.8
Elevation (NGVD 1929)	6,696	6,280	416
Drainage area (square miles)	877	1,600	723

* URGWOM gage name

Table 4-6 summarizes stream-gage location and elevation data for the reach between Abiquiu Dam and the Chamita gage.

Table 4-6. Summary of stream-gage data for the reach of the Rio Chama from below Abiquiu Dam to near Chamita

	Rio Chama below Abiquiu Dam (BlwAbiquiu)*	Rio Chama near Chamita (Chamita)*	Total Δ
River mile (above mouth)	31.3	2.8	28.5
Elevation (NGVD 1929)	6,040	5,654	386
Drainage area (square miles)	2,147	3,144	997

* URGWOM gage name

4.3.1 Rio Chama Main Stem Surface Water System

A 73.4-mile section of the Rio Chama is divided into two reaches. The first reach begins at the gage Rio Chama below El Vado Dam and extends to the next downstream gage Rio Chama above Abiquiu Reservoir. The second reach is from below Abiquiu Dam downstream to the Chamita gage, which is considered in the simulation to be the same as the confluence of the Rio Chama and the Rio Grande. San Juan-Chama Project water diversion and delivery into Heron Reservoir are included in the physical model. The transport of San Juan-Chama Project water from the Azotea Tunnel portal to Heron Reservoir is not based on physical gains/losses and lags, but on an approved (Rio Grande Compact Commission) loss rate of 0. 2% with no travel time lag.

4.3.1.1 Description of Reaches in the Rio Chama

Each individual reach of the Rio Chama that is modeled in URGWOM is described in the following sections.

4.3.1.1.1 Willow Creek above Heron Reservoir

Although the reach of Willow Creek between the Azotea Tunnel portal and Heron Reservoir is simulated in the physical model, neither natural flows nor San Juan-Chama Project water is routed through this reach. A fixed loss (0.20%) rate is applied to San Juan-Chama Project water between the Azotea Tunnel portal and Heron Reservoir.

This reach flows down a short reach of Azotea Creek and a portion of Willow Creek for about 12 miles at a slope of about 25 feet per mile (feet/mile). The channel varies from 30 to 65 feet in width.

4.3.1.1.2 Rio Chama above El Vado Reservoir

This reach of the Rio Chama and its tributaries are not included in the model. The NRCS/NWS runoff forecast point is the inflow to El Vado Reservoir, which means that computations of losses and river routing are not necessary for the reaches above El Vado Reservoir.

4.3.1.1.3 Rio Chama from below El Vado Dam to above Abiquiu Reservoir

Inflow to this reach is water released from El Vado Reservoir, which is measured at a gaging station 1.5 miles downstream from the dam (Rio Chama below El Vado Dam). The downstream end of the reach is the gage above Abiquiu Reservoir (Rio Chama above Abiquiu Reservoir). The reach is 28.8 miles long. The upper part of this reach is a canyon section with a rocky, narrow river channel and flood plain terrace. The lower 6 miles flows through a broad alluvial plain that supports a small amount of irrigable land and a riparian bosque.

The distance between the gage above Abiquiu Reservoir and Abiquiu Dam is about 15.3 miles. The distance from the gage to the headwaters of the reservoir at the top of the existing storage easement (elevation 6,220 feet) is about 4 miles and to the top of the flood control pool (elevation 6,283.5 feet) the distance is less than 2 miles. Because of the short length to the head of the reservoir during normal operations, the reach from the gage above Abiquiu Reservoir to Abiquiu Reservoir does not include any routing or losses.

4.3.1.1.4 Rio Chama from below Abiquiu Dam to near Chamita

This reach of the river is 28.5 miles long and seventeen Acequia diversions are located within this reach. Inflow to the reach is water released from Abiquiu Dam, as recorded by the gage Rio Chama below Abiquiu Dam. Outflow is measured at the gage Rio Chama near Chamita.

4.3.1.1.5 Rio Chama from near Chamita to Rio Grande Confluence

This reach of the Rio Chama does not include any routing or losses because it is very short (2.8 miles) and no gage is located at the confluence.

4.3.1.2 Routing Travel Time in the Rio Chama

The river travel time lag in the reach from below El Vado Dam to above Abiquiu Reservoir is one day (24 hours) that is applied to all flow levels. The river travel time lag in the reach from below Abiquiu Dam to the Chamita gage is also one day (24 hours) that is applied to all flow levels.

Figure 4-1. Rio Grande from near Lobatos, Colorado, to Cochiti, New Mexico.

4.3.1.3 Water Surface Evaporation/Channel Losses in the Rio Chama

The locations of reaches used in the Rio Chama Basin are shown in Figure 4-1. Table 4-7 is a tabulation of the adopted loss coefficients computed for the two reaches of the Rio Chama from below El Vado Dam to the gage near Chamita. These loss rates were computed using the method described in Section 2.3.1.2.2.

The Rio Grande Compact Commission has approved fixed loss rates for San Juan-Chama Project water in the Rio Chama. The difference between the total calculated physical loss and the loss from the San Juan-Chama Project water is accounted as Rio Grande loss. The fixed loss rate is applied to each of the San Juan-Chama Project water pass through account.

Table 4-7. Adopted monthly loss coefficients for the reaches of the Rio Chama

	Adopted monthly loss coefficient	
Month	**El Vado to Abiquiu (BlwElVadoToAbvAbiquiu)***	**Abiquiu to Chamita (BlwAbiquiuToChamita)***
Jan	-0.03	-0.04
Feb	-0.03	-0.04
Mar	-0.04	-0.05
Apr	-0.04	-0.05
May	-0.04	-0.05
June	-0.05	-0.06
July	-0.06	-0.07
Aug	-0.05	-0.06
Sept	-0.04	-0.05
Oct	-0.04	-0.05
Nov	-0.03	-0.04
Dec	-0.02	-0.03

*URGWOM reach name

Because of assumptions made for the distribution of monthly irrigation diversion data and return flow and the substantial unmeasured tributary inflow in the Abiquiu to Chamita reach, reliable loss rates could not be developed for all of the months. Therefore, the adopted monthly loss coefficients for the reach from below Abiquiu Dam to near Chamita are based on adding -0.01 to the values for the reach from below El Vado Dam to above Abiquiu Reservoir.

4.3.1.4 Rio Chama Inflows

There are no measured inflows to the Rio Chama and separate Reach Objects are included for adding ungaged local inflow to the mainstem. Reach Objects to add local inflow are located above Heron, El Vado and Abiquiu Reservoirs and above the Chamita gage. Local inflows for the reach between El Vado Dam and Abiquiu Reservoir and the reach between Abiquiu Dam and the Chamita gage are computed using the methods described in Section 2.3.1.2.2.

4.3.1.4.1 <u>Willow Creek Local Inflow (AzoteaWillow)</u>

AzoteaWillow.Inflow2 is the computed Rio Grande local inflow to Willow Creek between the Azotea Tunnel portal and the streamgage Willow Creek above Heron Reservoir near Los Ojos, NM (AbvHeron). AzoteaWillow.Inflow2 is the residual, or computed difference, between the Azotea Tunnel outlet (AzoteaTunnel) and the flow recorded at the AbvHeron gage and is the amount necessary to satisfy the mass balance in this reach. The AzoteaTunnel flow is reduced by a loss rate applied to San Juan-Chama Project water between the tunnel and the AbvHeron gage (AzoteaToHeronLoss) before the residual is computed. This loss rate is a fixed value of -.002.

4.3.1.4.2 El Vado Local Inflow

ElVadoLocalInflow.LocalInflow is the computed inflow to El Vado Reservoir less release from Heron Reservoir, less seepage from Heron Reservoir (HeronSeepage). This is essentially the computed flow of the Rio Chama above the confluence with Willow Creek. The inflow to El Vado Reservoir is computed using a mass balance equation according to the methods described in Section 4.2.3.

HeronSeepage.Inflow2 is leakage from Heron Reservoir that reaches the Rio Chama upstream of the mouth of Willow Creek. HeronSeepage.Inflow2 is computed using the following linear relationship:

$$y = .02134(x) + .76 \tag{9}$$

Where:

$y =$ Seepage from Heron Reservoir (cfs)
$x =$ Distance (ft.) between reservoir pool elevation and a base (bottom) elevation of the reservir (7,100 ft.)

4.3.1.4.3 El Vado to Abiquiu Local Inflow

Major tributaries to the Rio Chama between El Vado Dam and Abiquiu Reservoir include the Rio Nutria, the Rio Cebolla, the Rio Gallinas, the Rio Puerco and Cañones Creek. These tributaries are not gaged and the inflow from these tributaries is included in the local inflow computation.

4.3.1.4.4 Abiquiu to Chamita Local Inflow

The Rio Ojo Caliente, a major tributary to this reach, discharges into the Rio Chama about 6 miles above the confluence with the Rio Grande. This tributary inflow is not included in river routing for this reach because of a lack of data needed to reliably estimate time lags and losses between the gage Rio Ojo Caliente at La Madera (20 miles above mouth) and the Rio Chama confluence. About 500 acres of land can be irrigated from the Rio Ojo Caliente below the gage at La Madera. Discharge of water from the Rio Ojo Caliente to the Rio Chama during spring runoff can be substantial, and the lack of reliable estimates of this discharge to the Rio Chama complicates the reliability of loss estimates for the Abiquiu to Chamita reach. El Rito Creek, which discharges into the Rio Chama about 16 miles above the mouth of the Rio Chama, is not specifically represented in the model because of similar circumstances. These two tributaries, along with other tributary inflows, are included in the computation of local inflow originating between Abiquiu Dam and the Chamita gage.

Table 4-8 lists information about the Rio Chama stream gages used in the model.

Table 4-8. Stream gages in the RiverWare Model for the Rio Chama

Gage Name	URGWOM Gage Name	Gage ID	Period of Record
Rio Blanco below Blanco Diversion	RioBlancoBlwBlancoDiversion	RIOBLACO	1970 to present
Little Navajo River below Little Oso Diversion	LittleNavajoRiverBlwLittleOso Diversion	LITOSOCO	1970 to present
Navajo River below Oso Diversion	NavajoRiverBlwOsoDiversion	NAVOSOCO	1970 to present
Azotea Tunnel at Outlet nr. Chama, NM	AzoteaOutlet	08284160	1970 to present
Willow Creek above Heron Reservoir nr. Los Ojos	AbvHeron	08284200	1962 to present
Rio Chama below El Vado Dam	BlwElVado	08285500	1913 to present
Rio Chama above Abiquiu Reservoir	AbvAbiquiu	08286500	1961 to present
Rio Chama below Abiquiu Dam	BlwAbiquiu	08287000	1961 to present
Rio Chama near Chamita	Chamita	08290000	1912 to present

4.3.1.5 Rio Chama Farm Operations.

Depletions associated with irrigated lands served by two Acequias in the reach between the gage below El Vado Dam and the gage above Abiquiu Reservoir is simulated in the model. The diversion is based on the adjudicated water right or the record of historic diversion data for these lands, when these data are available. An assumed return flow of 50% is applied to these irrigation diversions.

The simulated diversion data for seventeen Acequias downstream of Abiquiu Dam are based on a record of historic diversion by the Acequias or the authorized diversion amount if historic data are not available. An assumed return flow of 33% of the diversion amount is applied to

Acequias in this reach. Two Acequias (Acequia de Chamita and the Acequia de Hernandez) divert from the Rio Chama immediately above the Chamita gage and the return flows from the Acequias and irrigated lands (33% of diversion) are applied to the reach below the Chamita gage. A single Acequia (Salazar) diverts from the Rio Chama below the Chamita gage and irrigation return flow is applied to the reach between the Chamita gage and the mouth of the Rio Chama.

4.3.1.6 Rio Chama Municipal and Industrial Diversions

The Village of Chama diverts surface water from the Rio Chama for municipal water supply purposes but this system is not simulated in the model. There are no other municipal water supply diversions of surface water in the Rio Chama Basin. There are no major industries in the Rio Chama Basin and there are no industrial water users.

5 Middle Valley (Cochiti to Elephant Butte Dam)

The Middle Rio Grande Valley or Middle Rio Grande (MRG), is defined in this section as the river, adjacent crop lands, and groundwater system near the river from Cochiti Dam to the headwaters of Elephant Butte Reservoir. The Rio Grande in the Middle Valley is influenced to a great extent by surface water-groundwater interaction. URGWOM simulates the influence of the groundwater system on the Rio Grande through the MRG (and Lower Rio Grande as well) using a course discretization representation of the shallow groundwater system linked to the surface water system. The surface water system including agricultural conveyances and drains on the east and west sides of the river are simulated separately. The riverside and internal drains are simulated separately from the canals and ditches on each side of the river because of the short term interaction between the river and these drains.

5.1 Nature of Water Use and Depletion in the Middle Valley

The Middle Valley runs north to south through central New Mexico from Cochiti Reservoir to the headwaters of Elephant Butte Reservoir, a distance of 180 miles (Figure 5-1). The valley is narrow with a maximum width of about 5 miles in places. The bosque, or the riverside forest of cottonwood, willows, Russian olive and salt cedar, is supported by the shallow groundwater system that is connected to the Rio Grande. Surrounding the river forest, there is widespread irrigated agriculture supported by diversions of water directly from the Rio Grande, supplemented by groundwater pumping in some instances. The City of Albuquerque, Rio Rancho, and several smaller communities are located in and adjacent to the Middle Valley. The Rio Grande in the Middle Valley supports a rich and diverse ecosystem and is a common resource for communities in the region.

The systems in which water moves in the Middle Valley include the Rio Grande main stem (river), canals and laterals, riverside and interior drains, and the shallow groundwater system.

5.2 URGWOM Storage Reservoirs in the Middle Valley

Three reservoirs were constructed on the Rio Grande in the Middle Valley and its tributaries. Only two, Jemez Canyon Reservoir and Cochiti Lake, are simulated in URGWOM. Galisteo Dam is an unregulated flood control structure and is not included in the model. Gaged flows below the Dam are used as inflows to URGWOM from Galisteo Creek. Jemez Canyon Dam is operated for flood- and sediment-control purposes only, while in addition to these two primary purposes, Cochiti Dam is also operated for recreation. Table 5-1 summarizes general information about these facilities.

Table 5-1. General information about Middle Rio Grande Valley reservoirs

	Cochiti	Jemez Canyon
Type:	Earth fill	Earth fill
Year completed:	1973	1953
Structural height (feet):	251	149
Top width (feet):	30	23
Width at base (feet):	1760	835
Crest length (feet):	28,815	861
Crest elevation (feet, NGVD 1929):	5479	5271.6
Outlet works discharge capacity (cfs):	14,790	9,700

5.2.1 Cochiti Dam and Lake

Cochiti Lake is owned and operated by the USACE in coordination with other USACE projects in the basin. Cochiti Lake has maintained a permanent recreation pool of approximately 50,000 acre-feet since the dam was completed in 1973. The permanent pool, which includes an intermittent pond in the arm of the Santa Fe River, provides sediment-control benefits, trapping about 1,000 acre-feet of sediment per year. The permanent pool was established by and is maintained with San Juan-Chama Project water. The remaining capacity of the reservoir, totaling about 532,000 acre-feet, is reserved for flood and sediment control.

Cochiti Dam is operated to bypass all inflow to the lake except San Juan-Chama project water released to Cochiti to make up for losses to the recreation pool. Flows are bypassed to the extent that downstream channel conditions are capable of safely conveying that flow. Flood control operations are initiated when inflow to the lake is in excess of the downstream channel capacity. Stored floodwaters are released when downstream channel conditions permit, all in accordance with the provisions of Public Law 86-645 and the Compact. Table 5-2 contains elevation information about Cochiti Lake.

Table 5-2. Elevation-related information about Cochiti Lake

	Elevation (feet, NGVD 1929)	Area (acres)	Total capacity (acre-feet)
Top of dam:	5479.00	11,507	773,086
Maximum pool:	5474.10	10,994	717,931
Total storage at spillway crest:	5460.50	9,437	578,433
Permanent pool (varies):	5343.59	1,200	46,860
Conduit invert:	5255.00	0	0

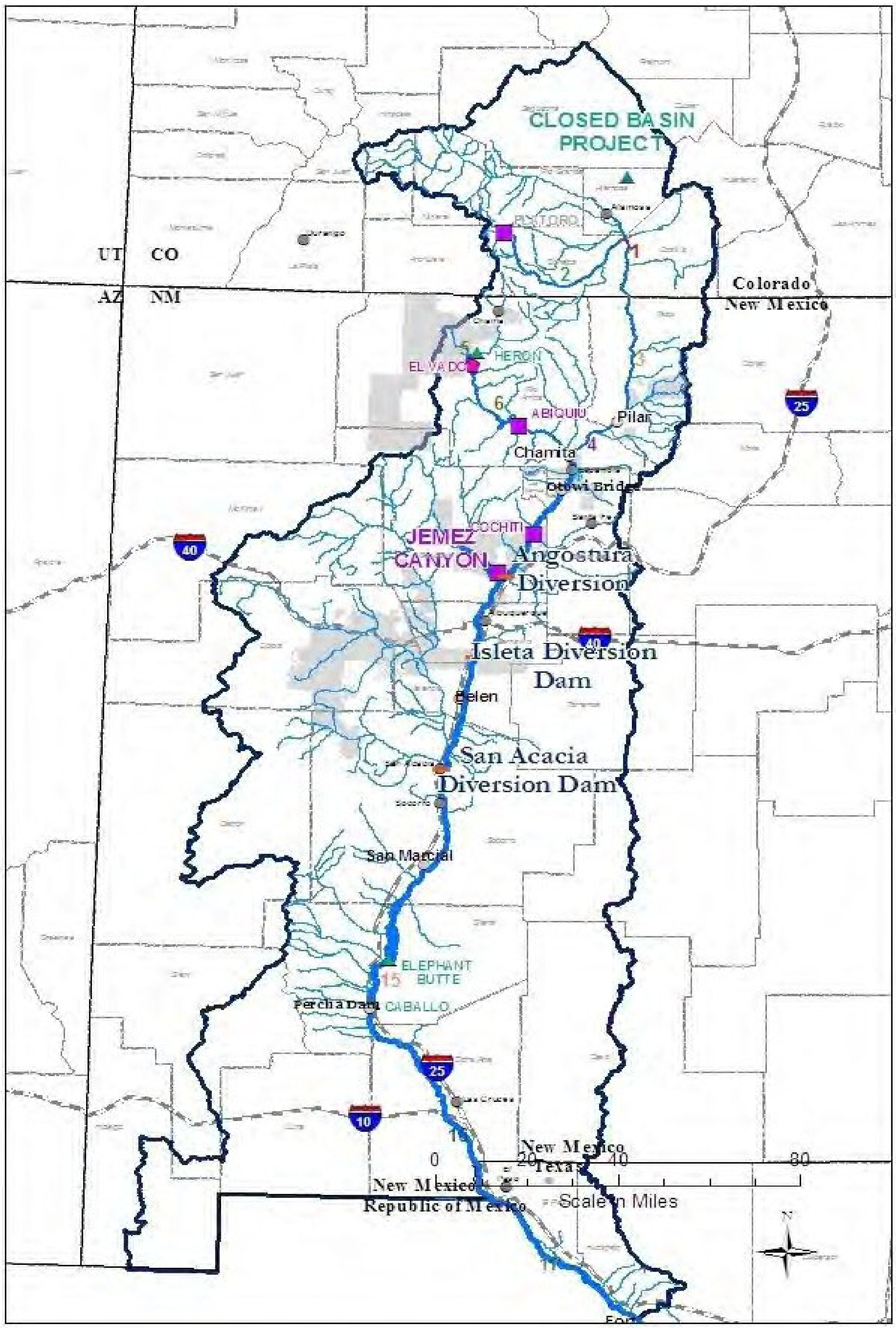


Figure 5-1. Map of the Upper Rio Grande

5.2.2 Jemez Canyon Dam

Jemez Canyon Dam is owned and operated by the USACE for flood and sediment control purposes. Establishment and maintenance of a permanent pool significantly enhanced the sediment-control function of Jemez Canyon Reservoir. A sediment retention pool of about 2,000 acre-feet was established in 1979, which ultimately grew to size of about 17,000 acre-feet before it was evacuated in 2001. Jemez Canyon Dam is operated in conjunction with Cochiti Dam to limit downstream flow to existing channel capacity. Table 5-3 contains elevation information about Jemez Canyon Dam.

Table 5-3. Elevation-related information about Jemez Canyon Dam

	Elevation (feet, NGVD 1929)	Area (acres)	Total capacity (acre-feet)
Top of embankment:	5271.6	5,320	260,723
Maximum pool:	5271.2	5,300	259,423
Total storage at spillway crest:	5232.0	2,943	97,425
Sediment retention pool:	5196.7	1,364	24,566
Zero storage:	5154.0	--	--

The accounting of the operation of Cochiti Lake and Jemez Canyon Reservoir follows the general mass-balance equation for reservoirs. The mathematical calculation is:

$$S_t - S_{t-1} - I - P_t + E_t + O = 0 \tag{10}$$

Where:

S_t = total storage today, in acre-feet;
S_{t-1} = total storage yesterday, in acre-feet;
I = inflow into the reservoir, in acre-feet/day;
P_t = physical model precipitation, in acre-feet/day;
E_t = physical model evaporation, in acre-feet/day; and
O = outflow from the reservoir, in acre-feet/day.

Physical model precipitation is determined by using the equation:

$$P_t = R_t\,(A_{res})/12 \tag{11}$$

Where:
R_t = rainfall, in inches/day; and
A_{res} = average reservoir area, in acres.

Physical model evaporation is determined by using one of two equations, depending on the time of year. The summer equation is (April – October):

$$E_t = Ep(coeff)(A_{res})/12 \tag{12}$$

Where:

Ep = pan evaporation, in inches/day; and
$coeff$ = pan evaporation coefficient (0.7 for reservoirs in the Rio Grande Basin).

The winter equation is:

$$E_t = [(T_{max} + T_{min})/2] * (k/days) * (1\text{-}cov) * A_{res} \tag{13}$$

Where:

T_{max} = maximum daily air temperature, in °F;
T_{min} = minimum daily air temperature, in °F;
k = factor for month, in inches per °F;
$days$ = days in the month; and
cov = reservoir ice cover, in percent.

Jemez Reservoir and Cochiti Lake are simulated as Storage Reservoir Objects in URGWOM. Each reservoir solves a mass-balance equation and additional user-defined equations and methods related to specific physical and accounting attributes of the reservoirs. Methods for accounting of real-time sediment deposition in Jemez Canyon Reservoir and Cochiti Lake have been developed using empirical data and assumptions unique to each reservoir. These methods provide an estimate of sediment accumulation in storage between sediment surveys, resulting in a more accurate accounting of water in storage in the reservoirs. For more specific information on reservoir accounting in the model, refer to the URGWOM Accounting Documentation Appendix (Under Development).

5.3 Simulation of Physical Processes in Middle valley

Early versions of URGWOM (prior to 2009) included a more simplified approach to simulation of surface water-groundwater interactions (URGWOM Technical Team, 2005) than is currently employed. The surface water system that was simulated in the model consisted of the river, simulated by several Reach Objects, and all drains, canals and ditches for both sides of the river as one set of lumped stream reaches. This setup was made possible because the seepage between the surface water system and the groundwater system was simulated using equations derived from statistical analysis of the seepage (URGWOM Tech Team, 2014). The seepage calculations were completed in the Reach Objects and the groundwater system was not simulated. This approach gave reasonable results when the flows in the river were near average but was less accurate under more extreme conditions.

Beginning in 2009, URGWOM's Middle Valley was redeveloped based on a more physically based approach to simulating the interaction between the groundwater and surface water systems (URGWOM Technical Team, 2010). The groundwater system is simulated using a course discretization and is linked to the surface water system so that head-dependent flux can be simulated between the two systems. The surface water system on the east and west side of the river are simulated separately. The drains are simulated separately from the canals on each side of the river because of the short term interaction between the river and these drains.

The 2013 Middle Valley model incorporated improvements to the 2009 model framework with respect to simulation of the riverside drains, return flows to the river from the drains, losses from open-water evaporation and wetted sand, and a simplified approach to calculations of crop and riparian evapotranspiration (URGWOM Technical Team, 2014). Most of the 2013 improvements were made possible due to the availability of new data. The change in the simulations of the crop and riparian evapotranspiration was driven by the desire to simplify the model and to limit the model size.

5.3.1 Middle Valley Surface Water System

In the 2005 URGWOM model configuration, the Middle Valley included six reaches that were delineated at points along the river where discharge readings were available across the entire river valley for the historical calibration period. These locations (below Cochiti Dam, San Felipe, Central Ave., Bernardo, San Acacia, San Marcial, and below Elephant Butte) are referred to as "full cross sections" and provide calibration points for each canal and drain as well as the river.

In the 2009 and 2013 Middle Valley models, the river reaches were broken up into sub-reaches associated with Groundwater Storage Objects in order to simulate more physically based surface water/groundwater interactions. Analysis of the slope of the Rio Grande in the Middle Valley indicated that a reach length of six to seven miles would be sufficient to adequately simulate the surface water-groundwater interaction (URGWOM Technical Team, 2014). The boundaries of some of the reaches were adjusted to the location of gages or other physical structures in the river. The river reach from San Felipe to Central was subdivided at the surface water diversion for the Albuquerque Bernalillo County Water Utility Authority (ABCWUA – also referred to as Albuquerque in URGWOM) to enable the simulation of the diversion. The river reach from Central to Bernardo was broken up at the Isleta diversion. The final location of the reach boundaries are shown in Figure 5-3 and Figure 5-4. There are nineteen simulated river sub-reaches in the current Middle Valley model.

5.3.1.1 *Description of Reaches in the Middle Valley*

The river channel in the Middle Valley is divided into seven main reaches for the simulation: Cochiti to San Felipe; San Felipe to Central; Central to Isleta; Isleta to Bernardo; Bernardo to San Acacia; San Acacia to San Marcial and San Marcial to Elephant Butte Reservoir. These main reaches can be described as follows:

1) The Cochiti to San Felipe reach is a single unconfined straight channel in a broad alluvial valley without extensive urban developments that extends from Cochiti Dam to the gage Rio Grande at San Felipe. The channel width is about 400 feet and is stabilized by jetty jacks and more recently riprap. The reach is considered mostly a gaining reach at low flow and losing reach at high flow (flow above 3000 cfs). Water is diverted for irrigation at the top of this reach and return flows enter the reach at several wasteways. Galisteo Creek, an ephemeral channel which mostly carries monsoon flow, enters the Rio Grande in this reach. The reach length is 14.5 miles and is divided into two subreaches for groundwater simulation.
2) The San Felipe to Central Ave. river reach is a single relatively straight and braided channel with an average width of 600 feet, which extends from the gage Rio Grande at San Felipe to the gage Rio Grande at Albuquerque (this gage is located at the Central Ave. Bridge in Albuquerque, so it is often referred to as the Central gage and labeled as such in URGWOM). The channel is stabilized using jetty jacks and the flood plain is controlled by levees on the east and west. River seepage runs (S.S. Papadopoulos, 2007) indicated that this reach has the highest loss rate of about 20 cfs/mile between Alameda and Central Ave. Water is diverted from this reach for irrigation (at Angostura) and for drinking water near Alameda. Also, it receives flow from the Jemez River, as well as irrigation return flow and monsoon storm inflow including gaged inflows from Albuquerque's North Floodway Channel. The reach length is 34.5 miles and is divided into four subreaches for groundwater simulation.
3) The Central to Isleta reach is a single constrained channel with an average width of about 600 feet, which extends from the gage Rio Grande at Albuquerque to Isleta Dam. The channel is constrained by levees on both sides and is a losing reach. The ABCWUA returns wastewater treatment plant effluent to the river in this reach. Tijeras Arroyo and Albuquerque's South Floodway Channel deliver gaged flows to the Rio Grande in this reach. The length of this reach is 14 miles and is divided into two sub-reaches for groundwater simulation.
4) The Isleta to Bernardo reach is a single relatively braided channel with an average width of about 300 feet, which extends from Isleta Dam to the gage Rio Grande Floodway near Bernardo. The channel is constrained using jetty jacks and the flood plain is controlled by levees on both sides. River seepage runs indicate that this reach is a losing reach. At the top of this reach water is diverted for irrigation at Isleta Dam and several wasteways

return excess irrigation water back to the river. This reach length is about 38 miles and is divided into five sub-reaches for groundwater simulation.

5) The Bernardo to San Acacia reach is a single channel with an average width of about 600 feet, which extends from the gage Rio Grande Floodway near Bernardo to the gage Rio Grande Floodway at San Acacia. The channel is constrained using jetty jacks and the flood plain is controlled by levees mainly west of the river. The Rio Puerco enters the Rio Grande in this reach. River seepage runs (S.S. Papadopoulos, 2002) indicated that this reach is a gaining reach which is consistent with the fact that this reach is at the Albuquerque basin terminus where groundwater discharges to the surface. This reach is about 15 miles in length and is a single reach in the groundwater model.
6) The San Acacia to San Marcial reach is a single channel with an average width of 400 feet, which extends from the gage Rio Grande Floodway at San Acacia to the gage Rio Grande Floodway at San Marcial. The channel is constrained by jetty jacks and the flood plain is controlled by a levee west of the channel. In most of the reach the channel is perched above the flood plain and is a losing reach where the highest rate is between Escondida and Brown Arroyo, as indicated by extensive seepage runs (S.S. Papadopoulos, 2001, 2002) performed in this reach. Water is diverted at the top of the reach for irrigation and only one wasteway can return irrigation water to the river at 9-Mile outfall. The reach length is 47 miles and is divided into five sub-reaches for groundwater simulation. The Middle Valley groundwater representation ends at the end of this reach.
7) The San Marcial to Elephant Butte reach is single man made channel (pilot channel) for most of the reach. This reach extends from the gage Rio Grande Floodway at San Marcial to the point where the river empties into Elephant Butte Reservoir. It is mainly a straight channel about 150 feet wide, and surface water-groundwater interaction dynamics are discussed in Section 5.3.2.3.2.

5.3.1.2 Routing Travel Time in the Middle Valley

Prior to 2009, a variable time lag method was used to simulate the timing of river flows and the attenuation of peaks in URGWOM's Middle Valley representation. Starting in the 2009 version of URGWOM, the "time lag" method is used in the Middle Valley. The difference between the two methods is that in the variable time lag method the time lag is a function of the flow and in the time lag method the same time lag is used for all flows. The simpler time lag method was adopted after a comparison of the two methods demonstrated that there was little difference in results but that run times were reduced with the time lag method.

A separate Reach Object is used for time lag at the downstream end of the San Felipe to Central reach, Central to Bernardo reach, and the San Acacia to San Marcial reach. Each of the Reach Objects used for time lag was set to one day, thus simulating a total of three days of lag time between Cochiti Dam and San Marcial.

5.3.1.3 Water Surface Evaporation / Channel Losses in the Middle Valley

The RiverWare method *Inflow Exponent Pan Evap* was used in the 2005 and the 2009 versions of URGWOM to determine open-water and wetted-sand evaporation in the Middle Valley. This method took the evaporated water from the river which could cause negative flows in the river when reach inflows were smaller than evaporative demand. For this reason, the wetted sand component of the evaporation equation was set to zero in the 2009 version of the Middle Valley model. A RiverWare Reach Object was placed at the most upstream part of each reach to simulate the open-water evaporation for the entire surface water reach.

The methods for calculating open-water and wetted-sand evaporation were changed in the 2013 model to allow the water used in open-water evaporation to be taken from the river and the water used for wetted sand evaporation to come from the groundwater system for each groundwater object. The method for determining open-water evaporation uses the "Pan Evaporation" method in RiverWare in the Reach Object but the estimated open-water evaporation is input instead of the pan evaporation and the pan evaporation coefficient is set to unity. The estimated open-water evaporation is determined by multiplying the estimated potential evapotranspiration using the Hargreaves and Samani method of computing potential evapotranspiration using temperature (Hargreaves and Samani, 1985) and is corrected for open water evaporation by the FAO-56 (Allen, 1998) open-water coefficient for shallow (<2 meter depth.) moving water of 1.05.

The discussion of methods used to determine channel loss in the Middle Valley may be found in Section 5.3.2.3.

The Rio Grande Compact Commission has approved fixed loss rates for San Juan-Chama Project water flowing through the reaches in the Middle Valley. The same loss rate is applied to each San Juan-Chama Project water account. The difference between the total calculated physical loss and the loss from the San Juan-Chama Project water is accounted for as Rio Grande water loss.

5.3.1.4 Middle Valley Farm Operations

In the 2005 model of the Middle Valley, the drains and canal systems located on both sides of the river were simulated as one lumped reach. In the 2009 and newer versions of the Middle Valley model, the canal system is simulated separately on different sides of the river and also separately from the drain system. The canal system in most of the Middle Valley is not directly connected to the groundwater system. All of the irrigation conveyance is simulated by the simulated lumped canal system in RiverWare that simulates the canals on each side of the river. (Simulated drain dynamics are described in Section 5.3.2.5.) Two siphons are used to convey water under the river from the conveyance system on the east side of the river to the start of a canal system on the west side at points in the MRGCD system; the Corrales and Atrisco Siphons. The siphons take water from the riverside drains (Atrisco Feeder) through diversion structures. The model simulates the diversion to the siphons with Diversion Objects that are linked to the canal system east of the river and to Reach Objects on the west wide of the river that simulate the start of that section of the canal system.

Inflow into the canals is from the four major irrigation diversions, from siphons crossing the river, and from irrigation return flow. The simulation of the diversions to the canals in the model is accomplished by aggregated Diversion Objects, simulating the diversion, linked to an Aggregate Distribution Canal Object, simulating the canal. Water flows out of the canal system through diversion to croplands, diversion to other canals, and diversion or flow back to the river. Several RiverWare objects are used to simulate canal system outflow.

The diversion from the canal system to the croplands is simulated in the model by an Aggregate Diversion Canal Object in the canal system. The crop area is simulated by an Aggregate Diversion Site Object. The Aggregate Diversion Canal Object is linked to the Aggregate Diversion Site Object to determine the amount of water that is to be diverted and the links are shown below.

Aggregate Diversion Site Object (Crop Land)		Aggregate Distribution Canal Object (Canal System)
Total Available Water	↔	Available Flow
Total Diversion	↔	Delivered Flow
Total Unused Water	↔	Return Flow

Diversion to other canal system objects or to the conveyance part of the river side drains is through both Aggregate Diversion Canal Objects, representing the canal, and Diversion Objects, representing the diversion. These two objects are linked to accomplish the simulated diversion, links are shown below.

Diversion Object		Aggregate Distribution Canal Object
Available For Diversion	↔	Available Flow
Diversion	↔	Delivered Flow

The amount of water diverted to other canals or drains is determined in most cases by the slot "Percent of Available to Divert" in the Diversion Object. The locations in the model where water is diverted from a canal to either a canal or drains is at the Pena Blanca Drain return, the Eastside Santo Domingo Drain return, and the Corrales Siphon heading. The "Percent of Available to Divert" slot in each of the three Diversion Objects is set to 20% (URGWOM Technical Team, 2014).

Upstream of the Alameda stream gage is the Corrales Siphon which conveys water from the Atrisco Feeder under the river to the Corrales Main Canal on the west side of the river. The amount of water diverted into the siphon is set by Initialization rule.

Just upstream of the Central Avenue Bridge on the Atrisco Riverside Drain (Atrisco Feeder) is a diversion that is complex. Water is taken from the end of Atrisco Riverside drain and is diverted to one or all of three locations, return into the river, into the Albuquerque Riverside Drain, or into the Atrisco Siphon. The amount of water that is diverted to each of the three systems is determined by logic set as an expression slot in the Data Object "Central Wasteway Calc." The remainder of the water flowing down the Atrisco Feeder that is not diverted to the wasteway or the siphon is discharged to the Albuquerque Riverside Drain.

Irrigation water not used by the crop or that has not leaked to the groundwater system is returned to the canal system. The simulation of the total unused water in the model occurs in the link between the Aggregate Diversion Object that is simulating the irrigated crop land and the return flow slot in the Aggregate Distribution Canal Object.

5.3.1.4.1 Middle Valley Diversions

Surface water is the main source of irrigation water in the Middle Valley. In 1925, the state of New Mexico Legislature passed the Conservancy Act, which authorized creation of the Middle Rio Grande Conservancy District (MRGCD). The MRGCD was created by combining 79 independent Acequias into a single entity. The principal purpose of MRGCD is to divert and distribute water to farm land within the boundaries of the District. The MRGCD diverts surface water at four locations on the Rio Grande: Cochiti, Angostura, Isleta and San Acacia diversion dams, and is organized into four associated divisions: Cochiti, Albuquerque, Belen and Socorro Divisions (See Figure 5-2). The following is a description of the supply for each division.

MRGCD diverts water at Cochiti Dam to the Cochiti Main Canal (east of the river) and to the Sili Canal (west of the river). The irrigated area in Cochiti Division is about 5,000 acres, most of which is Pueblo Indian land with the exception of lands near Pena Blanca. Typical annual diversions to Cochiti Division average about 61,000 acre-feet per year. All excess water from the west side (Sili Main Canal) is returned to the river through intermediate wasteways (Seguro Wasteway, and Lower Westside Santo Domingo Riverside Drain) or at the end of the Sili Canal. On the east side, some excess water in Cochiti Main Canal returns to the river through wasteways but the majority flows through Algodones Riverside Drain to the Albuquerque Division.

The Albuquerque Division extends from Angostura diversion dam to Isleta diversion dam. Two main canals distribute water in the Albuquerque Division: Albuquerque Main Canal and Atrisco Feeder. The sources of water for the Albuquerque Division are the direct diversion at Angostura dam and the excess water from the east side of the Cochiti Division (Algodones Riverside Drain, Santa Ana Acequia, and Algodones Lower Acequia). Irrigated land on the west side of the river is served from the Atrisco Feeder Canal via the Corrales Siphon and the Atrisco Siphon. Average annual water supply to the division is about 102,000 acre-feet which include 82,000 acre-feet direct diversion at Angostura dam and about 20,000 acre-feet delivered to Albuquerque Main Canal from the east side of the Cochiti Division. The irrigated area in Albuquerque Division varies between 6,000 and 10,000 acres including Pueblo Indian land. Excess water returns to the river through several wasteways east and west of the river. Excess water in Isleta Interior Drain and Isleta Riverside Drains (west of the river) can be directed to the Belen Division during irrigation season. Excess water from the Albuquerque Division is delivered to the Belen Division on the east side via the Barr-Chical Diversion Connection.

The Belen Division is the largest of the MRGCD four divisions with respect to irrigated area, about 25,000 to 30,000 acres. It extends from Isleta diversion dam to San Acacia with irrigated land east and west of the river. The sources of water for the Belen Division are direct diversion from the river at Isleta dam and the excess water from the Albuquerque Division. On the east side of the Rio Grande, diverted water is delivered into four canals, the Peralta Main Canal, Chical Lateral, Chical Acequia, and Cacique Acequia. On the west side diverted water is delivered into the Belen High Line Canal. Average annual direct diversion to the Belen Division is about 186,000 acre-feet in addition to about 25,000 to 30,000 acre-feet of flows from the Albuquerque Division. East of the river, all excess water returns to the river through numerous wasteways and on the west side some water returns to the river through intermediate wasteways, but the majority of the excess water flows to Socorro Division through Drain Unit 7.

The Socorro Division extends from San Acacia diversion dam to the North Boundary of Bosque del Apache National Wildlife Refuge (NWR). The Socorro Main Canal distributes water to all laterals in the division, which irrigate about 10,000 to 13,000 acres, all located on the west side of the river. Water supply for the division includes direct diversion from the river at San Acacia dam and excess water from the west side of Belen Division which flows from the Belen Division to the Socorro Division through Drain Unit 7. Average annual water supply to Socorro Division is about 85,000 acre-feet, Drain Unit 7 supply accounts for about 65,000 acre-feet and direct river diversion at the San Acacia Diversion Dam accounts for about 20,000 acre-feet. Excess irrigation water in the Socorro Division can return to the river via the Low Flow Conveyance Channel (LFCC), at two locations: Nine Mile Outfall and Brown Arroyo. However, most of excess irrigation water flows to the NWR and eventually to the Elmendorf Drain or the LFCC, the main riverside drain in this division.

URGWOM simulates the four diversions for irrigation in the Middle Valley; at Cochiti Dam, at Angostura, at Isleta, and at San Acacia. The section of the river where the diversion occurs is simulated by a Reach Object. Each of the four Reach Objects uses the “Available Flow Based Diversion” method to calculate the amount of water taken from the river using input from an Aggregate Diversion Site Object linked to the Reach Object, links shown below.

Reach Object	Aggregate Diversion Site Object

Available For Diversion	↔	Total Available Water
Diversion	↔	Total Diversion

The Aggregate Diversion Site Objects were used because at each of the four diversions water is diverted into multiple canal systems. The amount of water diverted is determined by the value of diversion requested in the Diversion Object and the amount of water available in the river. The value of the diversion request is an input for this method.

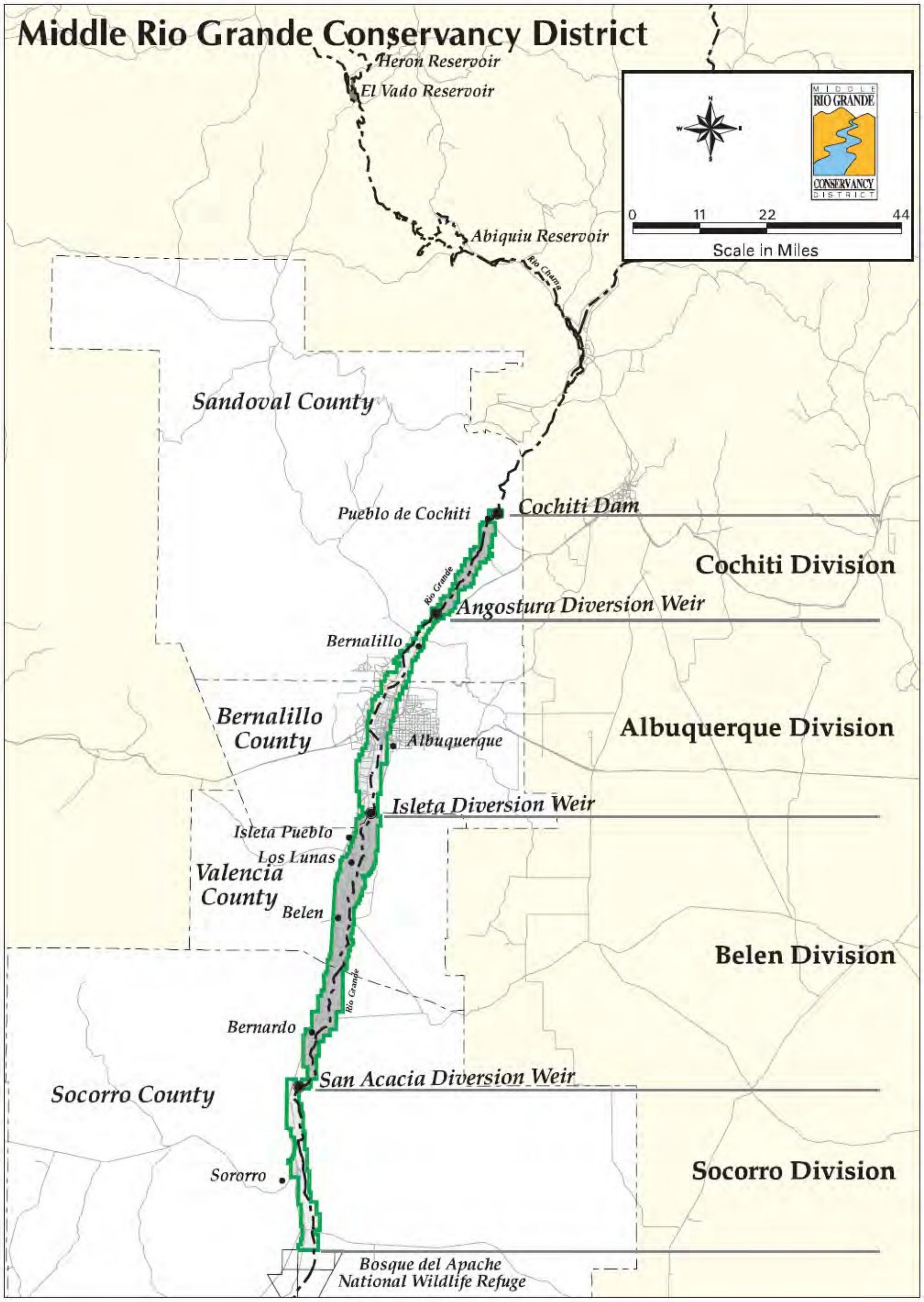


Figure 5-2. Map of the Middle Rio Grande Conservancy District divisions

5.3.1.4.2 Middle Valley Canal Losses

MRGCD distributes the water to the agricultural fields using a network of main canals and laterals. The canal system is designed to distribute the water to farms using gravity and therefore, most of the canals/laterals are above the water table. Seepage losses from canals/laterals are either intercepted by internal drains or percolate to the water table.

The main factors that affect the rate of canal seepage are soil hydraulic properties, canal shape and slope, and depth to the water table. In the Middle Rio Grande valley most of the canals are earth lined with bed elevations above the water table. Several studies have been conducted to estimate seepage rates of the canal system. Reclamation (1997, Supporting Document 12) estimated that canal loss varies from 0.2 to 0.4 cfs/mile of canal. Kinzli (2009) used Acoustic Doppler current profile measurements to estimate canal losses between 0.5 and 3 cfs/mile. Seepage from irrigation canals and laterals was modeled as infiltration to the groundwater system. Water infiltrating the groundwater system was assumed to percolate to the underlying Groundwater Storage Object. Canal seepage was assumed to occur only during the irrigation season (March 1 – October 31).

The canal seepage is simulated using an Aggregate Distribution Canal Object at the most upstream section of the canal system just downstream of each one of the four major diversions from the river. Even though the seepage is simulated at the top of the canal the seepage is linked to each of the Groundwater Storage Objects that simulate the groundwater in the area that the canal serves. The link from the canal system to a Groundwater Storage Objects is shown below.

Groundwater Storage Object		Aggregate Distribution Canal Object
Inflow From Surface Water	↔	Canal Seepage

The actual calculations of seepage are made in each element of the Aggregate Distribution Canal Object with the seepage controlled by the Seepage Flow Fraction slot. The percentage of the flow in the canal that is seepage is calculated and that amount of water is sent to the Groundwater Storage Objects. The seepage flow fraction for each sub reach is shown in Table 5-4 (URGWOM Technical Team, 2014).

Table 5-4. Final seepage flow fraction values used for canal seepage

Canal System	Seepage Flow Fraction (Percent)
CochitiToSanFelipeEastSideCanalSeepage: Area1, 2	6.6
CochitiToSanFelipeWestSideCanalSeepage: Area1,2	10
SanFelipeToCentralEastSideCanalSeepage: Area1, 2, 3, 4	2
SanFelipeToCentralWestSideCanalSeepage: Area1, 2	2
CentralToIsletaEastSideCanalSeepage:Area 1, 2	4
CentralToIsletaWestSideCanalSeepage:Area1,2	4
IsletaToBernardoEastSideCanalSeepage:Area1, 2, 3, 4, 5	2
IsletaToBernardoWestSideCanalSeepage:Area1, 2, 3, 4, 5	4
BernardoToSanAcaciaEastSideCanalSeepage: Area 1	2
BernardoToSanAcaciaWestSideCanalSeepage: Area 1	2
SanAcaciaToSanMarcialWestSideCanalSeepage:Area 1, 2, 3, 4, 5	4

5.3.1.4.3 Middle Valley Irrigated Acreage

Prior to the year 2000, the irrigated crop areas for the model were determined from a tabulation of annual irrigated-crop acreage for 1975-1999 obtained from MRGCD and Reclamation annual crop acreage reports. The reporting of crop acreage categories by each entity was not consistent for 1975-1999, so simplifying assumptions were made to make the crop type categories consistent from one reporting period to the next and to consolidate crop type data. These assumptions consolidated forage crops into the hay category and vegetable and garden crops were consolidated into a single category. Although these assumptions and some unreliable data resulted in uncertainty associated with values of individual crop acreage, the data in these tables represent the best available effort at a comprehensive compilation of historical irrigated area in the Middle Valley.

For reaches above San Acacia, total irrigated area data was disaggregated into division data on the basis of percentage of irrigated acreage in each division. The data were also adjusted to estimate irrigated-crop acreage by URGWOM river reach. For example, irrigated acreage below San Acacia corresponds to the Socorro Division. The Socorro Division contains 18% of total MRGCD irrigated acreage. Annual crop acreage below San Acacia was estimated by multiplying total crop acreage by 0.18.

During the year 2000, the Middle Valley vegetation classification project was conducted by the New Mexico Interstate Stream Commission (ISC) and MRGCD. The purposes of the project were to develop a standardized vegetation classification system for the Middle Valley and to assess the usefulness of remotely-sensed information in management of water activities. At that time the IKONOS satellite was chosen since it could capture high resolution (4 m grid) and 4-

band imagery (including the infrared band). The project included field data collections during the time the satellite was capturing the images. A mix of supervised and unsupervised classification was used in the vegetation classification process.

The irrigated acreage values for 2015 are based on the 2015 NM Interstate Stream Commission inventory of irrigated acreage in the Middle Valley. The 2015 NMISC inventory did not classify individual crop type, so the 2015 irrigated crop type classifications are based on the same proportion that each individual 2014 crop type bears to the 2014 total crop area.

5.3.1.4.4 Middle Valley Crop ET

In models prior to 2011, the reference ET was derived from a Penman equation modified by Sammis (Sammis, et al. 1985) using data from many weather stations located in the middle valley. Analysis of the reference ET data for use in the URGSiM model demonstrated that the reference ET was 33% higher than several other methods used commonly to calculate reference ET (Roach 2012). The weather station data was analyzed by the URGWOM Technical Team and found to be of generally poor quality with the exception of the temperature data. In response to these findings, in 2011 URGWOM switched to the Hargreaves (Hargreaves and Samani 1985) approach for estimating the reference ET using temperature data and extraterrestrial radiation and that method was applied in the model after that date.

Climate data used to compute the reference ET were obtained from four stations in the middle valley. Maximum and minimum daily air temperature and daily precipitation data can be obtained from the Utah State University climate web page http://climate.usu.edu/.

Table 5-5. Climate station data

Id	Name	County	Latitude	Longitude	Elevation	Period of record
292100	CORRALES	SANDOVAL	35.2486	-106.595	5,015	10/03/1982 - 12/31/2010
290903	BERNALILLO	SANDOVAL	35.3167	-106.550	5,052	01/01/1975 - 08/31/1982
298387	SOCORRO	SOCORRO	34.0828	-106.883	4,585	01/01/1975 - 08/31/2010
295147	LOS LUNAS	VALENCIA	34.8000	-106.733	4,892	01/01/1975 - 12/31/2010

The Bernalillo station data from January 1, 1975 through August 31, 1982 were combined with the Corrales station data beginning October 3, 1982; data from the Los Lunas station was used to fill the intervening, missing record.

Missing temperature and precipitation data were estimated by plotting graphs of data for periods of record before and after the period of missing records, along with data from the stations upstream and downstream of the station with the missing record. Missing data were estimated based on daily trends of data from the adjoining weather station(s). It was assumed that data from stations that are downstream have higher temperature than the upstream stations, but with similar precipitation.

Data from the Bernalillo and Corrales stations were combined and used to compute reference ET for the Cochiti to San Felipe reach and the San Felipe to Central reach. Data from the Los Lunas weather station were used to compute reference ET for the Central to Isleta reach and the Isleta to Bernardo reach. Data from the Socorro weather station were used to compute reference ET for Bernardo to San Acacia reach and San Acacia to San Marcial reach. The REF-ET: Reference Evapotranspiration calculation software was used to compute reference ET (Allen, 2008).

The development of the crop growth coefficients (K_c) is based on the procedures and values described in FAO-56 (Allen, 1998). The duration of each crop growth development stage (initial, developing, mid-season and late season) were estimated and corresponding K_c coefficients were then selected for each crop and development stage, and a crop coefficient curve was constructed. The start date of the growing season was not varied to reflect year-to-year variations in frost dates; the same curves were applied each year. The crop coefficient curves for forage crops were adjusted based on the length of the growing seasons because the length of growing season increases in the downstream direction. Table 5-6 tabulates the growing season dates based on temperature. Table 5-7 tabulates the values of K_c, temperature of start and finish of growing season, and the lengths of crop development stages. The lengths of crop development stage in Table 5-7 are for the Bernalillo / Corrales weather station data only.

Table 5-6. Growing season temperatures

SEASON	MEAN DAILY TEMPERATURE	BERNALILLO /CORRALES	LOS LUNAS	SOCORRO
SPRING	45	Mar 11	Mar 3	Feb 23
	50	Apr 2	Mar 28	Mar 18
	55	Apr 19	Apr 17	Apr 11
	60	May 8	May 5	Apr 28
FALL	50	Oct 30	Oct 31	Nov 3
	45	Nov 11	Nov 12	Nov 16
	32*	Nov 2	Nov 1	Nov 5
	28*	Nov 14	Nov 11	Nov 16

* Minimum daily temperature

Table 5-7. Summary of crop coefficients and growing season – Bernalillo/Corrales station

	K_c					Lengths of crop development stages(days)				
CROP TYPE	initial	mid	end	Earliest moisture use or planting date as related to mean air temperature (°F)	Latest moisture use or maturing date as related to mean air temperature (°F)	Initial	Developing	Mid-season	Late-season	Total
ALFALFA	0.4	0.95	0.9	45	28° Frost	10	30	150	58	248
APPLES	0.5	1.2	0.83	50	45	20	70	83	45	218
BARLEY	0.3	1.15	0.25	45	--	20	25	60	30	135
CORN	0.3	1.15	1.05	55	32° Frost	30	40	40	30	140
COTTON	0.35	1.15	0.6	60	32° Frost	30	50	35	50	165
FAMGARD	0.7	1.05	0.95	50	--	30	40	60	40	170
GRAPES	0.3	0.77	0.45	55	50	20	50	62	60	192
MELONS	0.4	1	0.75	50	--	30	40	60	40	170
MFRUIT	0.5	1.2	0.83	50	45	20	70	83	45	218
NURSERY	0.5	1.1	0.65	50	45	30	30	100	30	190
OATS	0.3	1.15	0.25	45	--	20	25	60	30	135
OTHER HAY	0.4	0.95	0.9	45	45	10	30	150	58	248
PASTURE	0.4	0.95	0.85	45	45	10	30	150	58	248
PEPPERS	0.6	1.05	0.9	50	--	30	35	40	20	125
RIPARIAN	0.3	1.2	0.3	45	45	10	30	188	20	248
SILAGE	0.3	1.05	0.55	60	--	20	35	45	30	130
SORGHUM	0.3	1.05	0.55	60	--	20	35	45	30	130
VEGETABLES	0.7	1.05	0.95	50	--	30	40	40	20	130
WHEAT	0.7	1.15	0.32	45	--	20	25	60	30	135

The initial growth stage K_c values shown in Table 5-7 are applicable under typical irrigation management and soil wetting conditions. Mid-season and end-of-season values of K_c represent conditions under an average daytime minimum relative humidity of about 45% with wind speeds averaging 2 m/s (Allen, 1998).

The calculation of the Crop Irrigation Requirement (CIR) for the crop mix was calculated using the EffPrecip software written by Brian Westfall (2012) of Keller-Bliesner Engineering for the URGWOM Technical Team. The inputs for EffPrecip are daily crop ET, daily precipitation for the area, and the crop mix. The software follows the steps listed below.

1. Crop ET/Rain file is read which includes daily crop ET for each crop and the daily rain for the area.
2. The daily rain is summed to monthly for each crop.
   a. For the month the crop season starts the rainfall is summed for the whole month.
   b. For the month the crop season ends, only rainfall events are included that occur before the end of the season (daily crop ET > 0).

3. The daily crop ET is summed to monthly ET for each crop
4. The monthly effective precipitation is calculated for each crop using SCS TR-21 (USDA SCS, 1970).
5. The daily CIR for each crop is calculated.
   a. For each crop, the monthly effective precipitation is applied on the day of the first rainfall event in the month up to the amount of the crop ET.
   b. Effective precipitation greater than the daily crop ET is used on subsequent days until the effective precipitation balance is zero.
   c. An end of month effective precipitation balance is carried into the following month.
   d. In some cases there is a remaining effective precipitation balance at the end of the season. A run time message is displayed for each end of season date and crop when there is an end of season balance.

The EffPrecip software output file produces daily CIR values for each crop type for each day of the growing season. The output file is then used with the irrigated acreage file for each crop for each year as shown below. This procedure is applied to each groundwater object. This computation results in a single daily representative CIR, or a crop mix CIR, which is specific to each groundwater object.

1. Daily individual CIR (acre-feet) = daily individual crop CIR * individual crop acreage each year.
2. Compute a weighted average daily CIR = (sum of daily individual CIR (acre-feet)) / (total acreage of all crops for that year).

The crop mix CIR is then entered into DSS (US Army Corps of Engineers, Hydrologic Engineering Center HEC-DSSVue) for use in the model. The computed CIR value is then reduced by 20% in the model in recognition of the fact that the ET computed using the Hargreaves Samani method is considered a potential ET value. The potential ET is reduced to the actual ET to account for reductions in water use due to poor soil conditions (e.g., salinity), farm management practices, insect infestation, etc.

The crop evapotranspiration is simulated through the use of Aggregate Diversion Sites for each of the reaches with water users for each of the groundwater subreaches. The water users were set up with the method “Input Acreage and Rates”. This method uses one input per water user for crop ET.

5.3.1.4.5 Middle Valley Soil Moisture

Available Water Capacity (AWC) values were generated for each Middle Rio Grande subarea in the same manner as done for the Lower Rio Grande region (Hydros Consulting, 2016), see Section 6.3.1.4.5. Available Water Capacity is used along with maximum root depths, depletion fractions, and crop mix to calculate the Maximum Soil Moisture used in RiverWare. Results are shown in Table 5-8.

Table 5-8. Computed Soil Moisture Parameters for the MRG Portion of URGWOM

	AWC (in/in)	RAW (feet.)
CochitiToSanFelipe	0.11	0.24
SanFelipeToCentral	0.11	0.24
CentralToIsleta	0.10	0.20
IsletaToBernardo	0.10	0.23
BernardoToSanAcacia	0.07	0.17
SanAcaciaToSanMarcial	0.08	0.19

All of the Middle Rio Grande subareas are predominately loam and clay loam. Therefore, the average infiltration rates for these subareas are much larger than what it would take to fill the soil moisture reservoir (see the Readily Available Water (RAW) values in Table 5-8) in one day (the timestep of the model). Therefore, for daily RiverWare modeling purposes, the maximum infiltration rate will never be controlling. The URGWOM Technical Team has adopted a maximum infiltration rate value of 1 feet/day for use in all Middle Rio Grande subareas.

5.3.1.4.6 Middle Valley Return Flows/Interior Drains

Farm efficiency is a measure of the amount of water used by a crop given the amount of water diverted to irrigate the crop. In the model, the crop efficiency is used in the calculation of the amount of water to be diverted to the crop. The crop consumptive use is calculated from the crop ET rate and the crop area. The crop efficiency is multiplied by the consumptive use to determine the amount of the diversion request. A value of 50% is used in minimum efficiency slots of all the water users in all the Aggregate Diversion Site Objects.

Deep percolation is the amount of infiltrated water per irrigation event that is not used by crops that moves through the soil profile to the water table. Deep percolation from rainfall on crops is assumed to be negligible. Reclamation (1997, Supporting Document 7) analyzed soil texture and permeability in the Middle Rio Grande Valley. That investigation found that deep percolation rates for soil series and crop types range from 0.10 to 1.22 feet/year.

In the model the groundwater return flow is determined using the “Return Flow Split Calculation” method. This method calculates the total remaining water after the crop has consumed its water. The amount of the return that goes to the groundwater system is determined by a percent of the total return. The percentage is entered in the series slot "Groundwater Return Rate." The percentage used in the model for all the water users is 5%. The groundwater return water for each water user goes to the Groundwater Storage Objects associated with the area of the water user by links (shown below) between the water users in the Aggregate Diversion Object and the Groundwater Storage Object.

Groundwater Storage Object		Aggregate Diversion Site Object
Inflow From Surface Water	↔	GW Return Flow

The surface water that returns to the canal system after irrigation is also calculated by the "Return Flow Split Calculation" method. The amount of water returned to the canal system is the remainder after ET by the crop and seepage to the groundwater system. This water returns to the canal system through the links between the Aggregate Diversion Site Object and the Aggregate Distribution Canal Object.
Water is returned from the canal system to the river either at the end of a canal or by diverting a portion of the water in the canal to the river in a wasteway. Not all wasteways are represented in the model, only main wasteways are included. The amount of flow that is returned to the river is controlled usually by a gate in the drain or canal. A Diversion Object was used to simulate the diversion of water from each canal or drain to the river. The determination of the return flow to the river in many of the modeled wasteways was simulated by a percentage of the available flow in the canal input into the Diversion Object. The percent of available flow slot in the Diversion Object is a time series that may be set to a percentage. The percent of available flow returned during the irrigation season is shown in Table 5-9. Some of the wasteways that compute returns to the river using the Percent of Available method return all the flow during the non-irrigation season.

These include *IsletaToBernardoArea1Wasteway*, *IsletaToBernardoArea3WestCanalReturns*, and *DrainUnit7Wasteway and NineMileWasteWay*. The percent of flow was determined based on discussions with David Gensler of MRGCD (Gensler, 2013).

Table 5-9. Percent diverted from canals to drains or the Rio Grande during irrigation season

Diversion Object	Percent to Divert
SeguroWasteway	75
PenaBlancaSWReturnRate	20
EastSideSantoDomingoSWReturnRate	20
SandiaWastewayDiversion	0
UpperCorralesWasteWay	75
IsletaToBernardoArea1Wasteway	100
IsletatoBernardoArea3WestCanalReturns	100
DrainUnit7WasteWay	100
NineMileWasteWay	100

There are three pump stations located between San Acacia and San Marcial that pump water from the LFCC to the river during times of low flow as part of the Reasonable and Prudent Alternative (RPA) of the 2016 Biological Opinion. These pumps are simulated by Diversion Objects in the model. The amount diverted is set by the Policy Rule Set.

5.3.1.5 Middle Valley Inflows

5.3.1.5.1 Gaged Tributary Inflow/Ungaged Local Inflow

Water flows into the Rio Grande from gaged tributaries, wastewater treatment plants, or return flows from the canal and drain systems. Ungaged tributary inflow is not simulated in the Middle Valley model. Most of the ungaged tributary streams are ephemeral and only contribute flow during rainfall events. For the Real-Time model application, URGWOM does have Reach Objects above gage and reservoir locations (San Felipe, Paseo Del Norte, Rio Grande nr. Alameda, Central, Isleta Lakes, Bosque Farms, State Highway 346, Bernardo, San Acacia Floodway, Escondida, US Hwy 380, San Marcial Floodway, and Elephant Butte Reservoir) that can utilize ungaged values derived from rainfall-runoff models. For other applications the values are set to zero.

There are several gaged tributaries to the Rio Grande simulated in the Middle Valley model, and discharge from a large part of the drainage area to the Middle Valley is captured by these gages. The simulated tributaries are the Galisteo Creek, Jemez River, North Floodway Channel, Tijeras Arroyo, South Diversion Channel, and Rio Puerco. The gaged flows, except for the Jemez River, are input to the model through Gage Objects linked to the river Confluence Objects. Table 5-10 is a list of the stream gages in the Middle Valley that are used in the Model.

Table 5-10. Stream Gages in the RiverWare Model for the Middle Valley Portion of the Model

Gage Name	URGWOM Gage Name	ID	Period of Record
Rio Grande below Cochiti Dam	BlwCochiti	08317400	1970 to present
Galisteo Creek below Galisteo Dam	Galisteo	08317950	1970 to present
Rio Grande at San Felipe	SanFelipe	08319000	1925 to present
Jemez River nr. Jemez	NrJemez	08324000	1936 to present
Jemez River below Jemez Canyon Dam	BlwJemez	08329000	1936 to present
North Floodway Channel nr. Alameda	NorthFloodwayChannel	08329900	1968 to present
Rio Grande at Alameda Bridge at Alameda	AlamedaBridge	08329918	2003 to present
Rio Grande nr. Alameda	PaseoDelNorteBridge	08329928	1989 to present
Rio Grande at Albuquerque	Central	08330000	1941 to present
Tijeras Arroyo nr. Albuquerque	TijerasArroyo	08330600	1951 to present
South Diversion Channel above Tijeras Arroyo nr. Albuquerque	SouthDiversionChannel	08330775	1988 to present
Rio Grande at Isleta Lakes nr. Isleta	IsletaLakes	08330875	2002 to present
Rio Grande nr. Bosque Farms	BosqueFarms	08331160	2007 to present
Rio Grande at State Highway 346 nr. Bosque	StateHighway346	08331510	2006 to present
Rio Grande Conveyance Channel nr. Bernardo	--	08331880	1952 to 2004
Rio Grande Floodway nr. Bernardo	Bernardo	08332010	1990 to present
Rio Puerco nr. Bernardo	RioPuerco	08353000	1939 to present
Rio Grande Conveyance Channel at San Acacia	SanAcaciaLFCC	08354800	1958 to 2004
Rio Grande Floodway at San Acacia	SanAcaciaFloodway	08354900	1936 to present
Rio Grande at Bridge nr. Escondida	Escondida	08355050	2006 to present

Rio Grande above US Highway 380 nr. San Antonio	USHighway380	08355490	2006 to present
Rio Grande Conveyance Channel at San Marcial	SanMarcialLFCC	08358300	1951 to present
Rio Grande Floodway at San Marcial	SanMarcialFloodway	08358400	1895 to present

The Jemez River is simulated from the gage Jemez River nr. Jemez to the confluence with the Rio Grande. The Jemez River reach is 23.5 miles long. Outflow from Jemez Canyon Dam is measured and recorded by the gage Jemez River below Jemez Canyon Dam and the outflow is determined by rule simulation of reservoir operating criteria. No lag time or losses are considered between Jemez Canyon Dam and the confluence with the Rio Grande due to the short distance between the Dam and the mouth of the Jemez River.

Table 5-11 tabulates the river travel time lag in the reach between Jemez, NM and Jemez Canyon Reservoir. Table 5-12 tabulates the loss coefficients for the reach between Jemez, NM and Jemez Canyon Reservoir.

Table 5-11. Travel time lags for the Jemez River from at Jemez to Jemez Canyon Reservoir

	Time lag (hours) for indicated flow rate (cfs)					
Reach	**25**	**50**	**100**	**200**	**400**	**10,000**
NrJemezToJemez	11	7	5	4	3	1

Table 5-12. Adopted monthly loss coefficients for the Jemez River reach

	Adopted monthly loss coefficient
Month	**Jemez, NM to Jemez Canyon Reservoir (NrJemezToJemez)***
Jan	-0.06
Feb	-0.06
Mar	-0.12
Apr	-0.10
May	-0.13
June	-0.21
July	-0.16
Aug	-0.16
Sept	-0.16
Oct	-0.14
Nov	-0.14
Dec	-0.06

*URGWOM reach name

5.3.1.5.2 Waste Water Inflow

Inflows to the Rio Grande in the Middle Valley from wastewater treatment plants are simulated using RiverWare Data Objects with the time series data for the reported flows linked to the return flow slot on river Reach Objects. The wastewater treatment plants delivering inflow in the model are the wastewater treatment plants for Albuquerque and the communities of Bernalillo, Rio Rancho, Los Lunas, Belen, and Socorro.

5.3.1.6 Middle Valley Municipal and Industrial Diversions

The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) drinking water diversion is simulated in URGWOM with a RiverWare Water User Object. The Water User Object is set up the same way as the Diversion Objects to link with the river and input the amount diverted. The diversion request is set by the Policy Rule Set. The links between the Water Use Object and the Reach Object is shown below.

Water User Object		Reach Object
Available Water	↔	Available For Diversion
Diversion	↔	Diversion

5.3.2 Middle Valley Groundwater System Hydrology

The groundwater in the Middle Valley occurs in the shallow alluvial aquifer and a deeper regional aquifer. The shallow groundwater system represents the alluvial aquifer which extends to cover the entire Middle Valley. The alluvial aquifer consists of the most recent erosion and deposition sequence of the Rio Grande which vary in thickness from about 80 feet below the river bed to almost zero feet at the edges of the inner valley. Generally, the alluvial deposits are considered highly permeable with hydraulic conductivity rate varying from 5 feet/day to 325 feet/day and storage coefficients varying from 0.1 to 0.25 (McAda and Barroll, 2002). The shallow groundwater system is directly connected to the surface water system mainly to the river and the riverside/interior drains.

The deeper regional aquifer occurs in two groundwater basins in the Middle Valley, the Albuquerque Basin and the Socorro Basin. Both of these basins are located in one of several structural basins that are part of the Rio Grande Rift, a region formed by Cenozoic extension that extends from Colorado through the length of central New Mexico into northern Mexico. (Hawley and Haase, 1992). The predominant basin deposit is the Santa Fe Group. The thickness of the Santa Fe Group ranges from about 3,000 to 4,000 feet along basin margins to greater than 14,000 feet in the center of the Albuquerque basin.

In general, the movement of the groundwater is from the basin boundaries (east and west) where recharge occurs to the center of the basin where water flows to the shallow alluvial aquifer. Water in the shallow alluvial aquifer discharges to the river channel or riverside drains or to riparian vegetation consumption. In some areas of the Middle Rio Grande valley where pumping of groundwater occurs, water moves downward from the shallow aquifer to the deeper regional aquifer.

5.3.2.1 Middle Valley Groundwater Storage Objects

In each subreach, a set of three Groundwater Storage Objects are used to simulate the aquifer under the river and the surrounding irrigated areas. The east-west boundaries of the Groundwater Storage Objects were determined from aerial photography and the MRGCD conveyance system. The boundaries of the Groundwater Storage Objects under the river were either the boundary of the riverside drains or the extent of the bosque. In most locations in the Middle Valley the bosque was bounded by the river side drains. For the Groundwater Storage Objects that were to the east and west of the river, one boundary was the boundary of the river Groundwater Storage Object and the other boundary was either the extent of the irrigated area or the canal furthest from the river.

The locations of the areas represented by Groundwater Storage Objects are shown in Figure 5-3 and Figure 5-4. The method Head Based Groundwater Grid is used as the solution type to simulate the interconnected Groundwater Storage Objects. The appropriate link directions must be specified in the Groundwater Storage Objects for the lateral linkages. A sample of the proper link structure is shown below.

Groundwater Storage Object West		Groundwater Storage Object River
Elevation Previous	↔	Elevation Left Previous
Elevation Right Previous	↔	Elevation Previous

There are several assumptions about the surface water-groundwater interaction in the Middle Valley used in determining the vertical discretization. An assumption was made that the interaction of the river and the groundwater system occurs in the shallow aquifer (upper 80 feet) at the daily timescale and the deep aquifer interaction with the river occurs over far longer time periods. The Groundwater Storage Objects simulate the head dependent flux between the surface water and the shallow aquifer but the deep aquifer boundary is simulated by input data for the deep aquifer head and the vertical conductance derived from the regional MODFLOW models (McAda and Barroll, 2002 and Shafike, 2005).

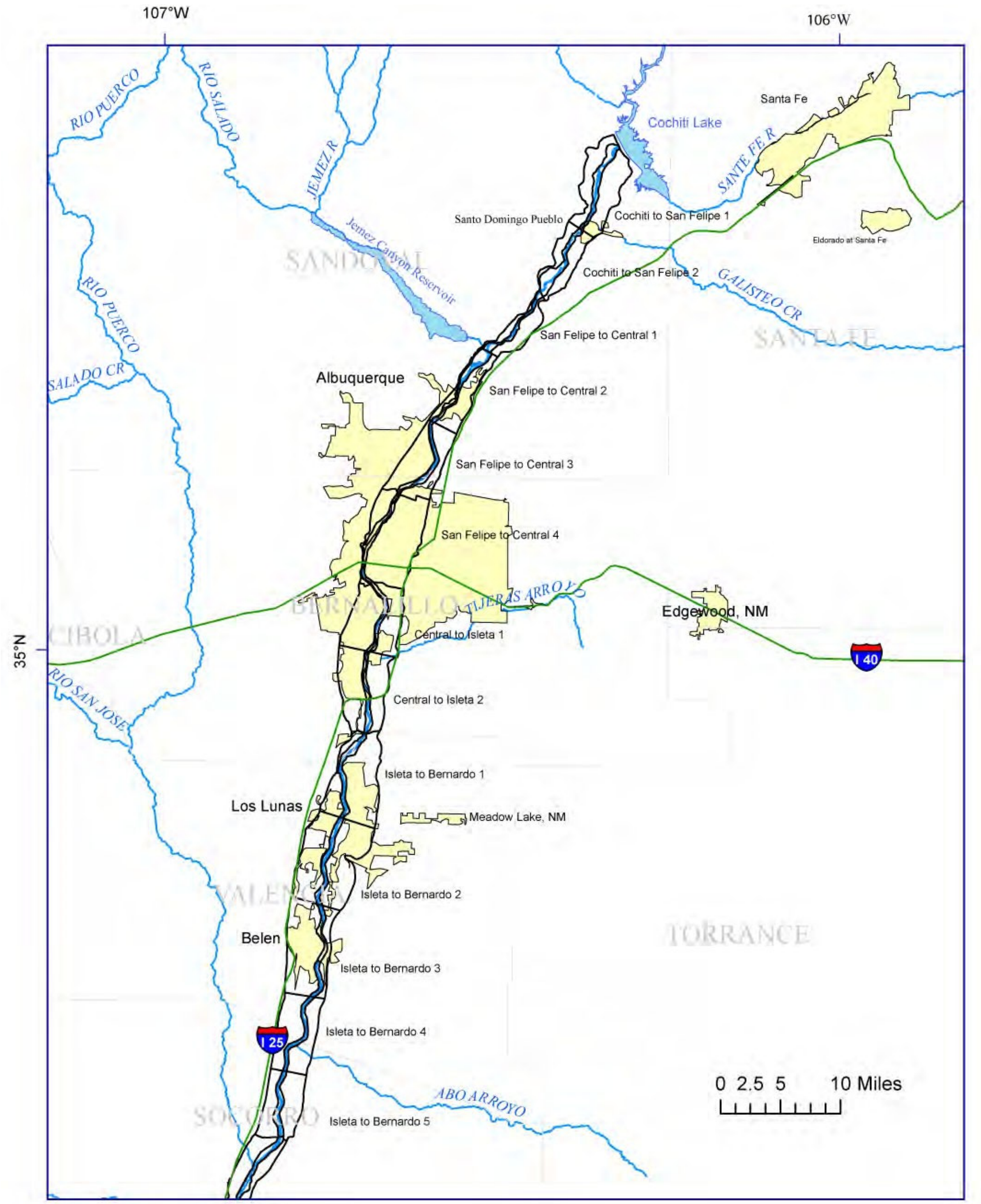


Figure 5-3. Simulated reaches and groundwater areas in the Middle Valley (North).

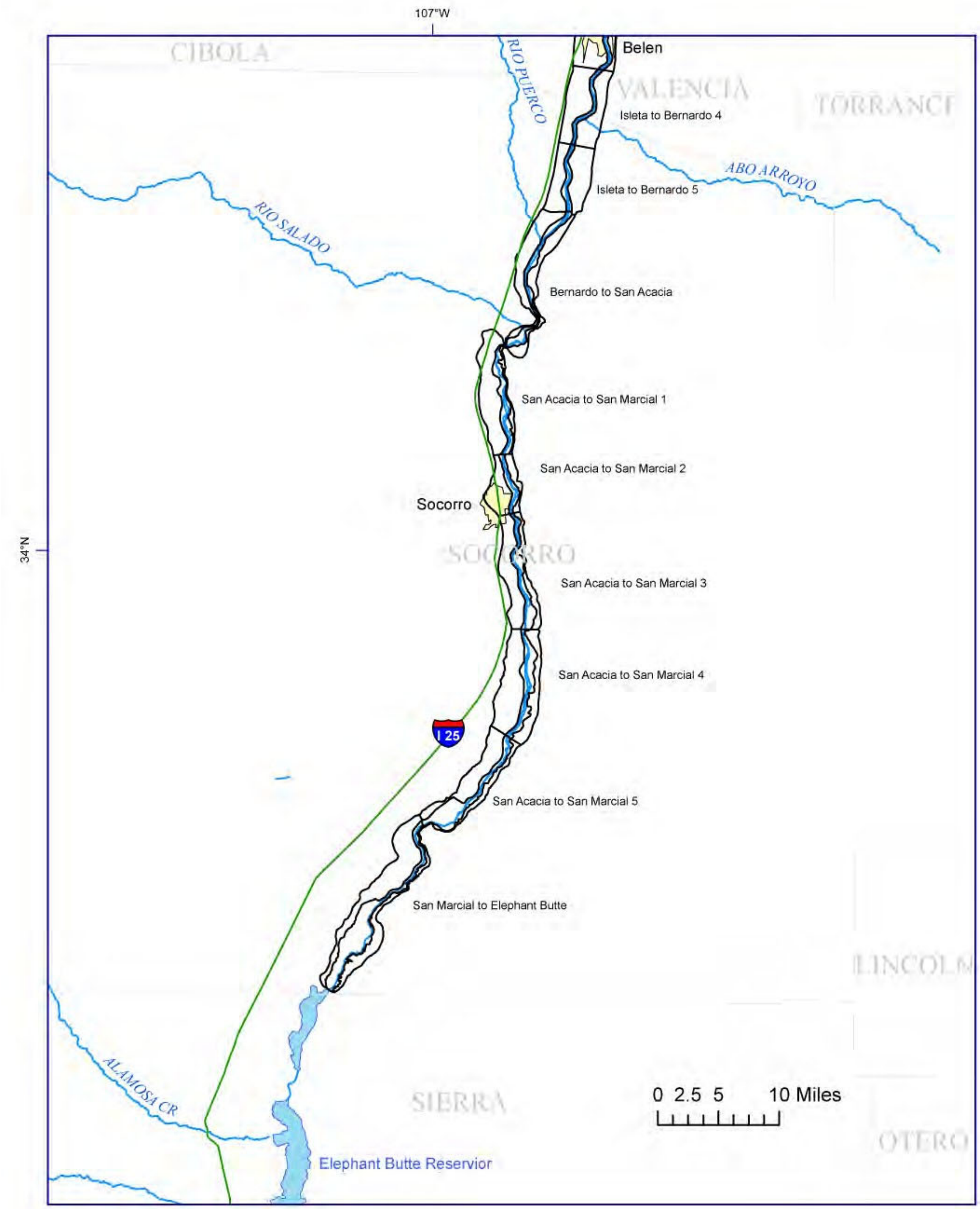


Figure 5-4. Simulated reaches and groundwater areas in the Middle Valley (South)

5.3.2.2 Middle Valley Aquifer Characteristics

Aquifer storage is the volume of water an aquifer can yield to pumping. The storage term for unconfined aquifers is specific yield. The specific yield is defined by Lohman (1972) as "the change that occurs in the amount of water in storage per unit area of unconfined aquifer as the result of a unit change in head. Such a change in storage is produced by the draining or filling of pore space and is therefore dependent upon particle size, rate of change of the water table, time, and other variables. Hence, specific yield is only an approximate measure of the relation between storage and head in un-confined aquifers". Specific yields in basin fill, such as in the Santa Fe Group aquifer system, typically range from about 0.1 to 0.25 (Johnson, 1967, p. 1). The shallow aquifer simulated by the Groundwater Storage Objects was assumed to be unconfined.

RiverWare Groundwater Storage Objects have two inputs related to storage, specific yield and initial aquifer storage. The specific yield used for all of the Groundwater Storage Objects is 0.20, representing an average value for the shallow aquifer system which overlays the Santa Fe Group.

Initial aquifer storage at the initialization time step of each model run is needed on each of the Groundwater Storage Objects. An initial storage was calculated for each Groundwater Storage Object from the aquifer cell area, the aquifer thickness, and the specific yield using equation (14).

$$S_i = A_c * T * S_y \tag{14}$$

Where:

S_i	= initial storage, in acre-feet
A_c	= aquifer cell area, in acres
T	= aquifer thickness, in feet
S_y	= specific yield

5.3.2.3 Middle Valley River Gains/Losses to Shallow Aquifer

There are two main factors that control the amount of seepage from the river, the head difference between the aquifer and the river, and the conductance of the river bottom. The simulation of flow between the river and the shallow aquifer in RiverWare is simulated the same way as in the River Package of the groundwater model, MODFLOW (McDonald and Harbaugh, 1988), in that all of the seepage is through the bottom of the river channel. The "Head Based Seepage" method is used to calculate the river seepage in RiverWare for each of the seepage Reach Objects. The model has Reach Objects linked to Groundwater Storage Objects to simulate the surface water-groundwater interaction. The links are shown below.

Groundwater Storage Object		Reach Object
Previous Water Table Elevation	↔	Previous Water Table Elevation
Inflow From Surface Water	↔	Seepage

The seepage is calculated two ways depending on the elevation difference between the shallow aquifer head and the stream bed elevation. Equation (15) is used to calculate the seepage if the shallow aquifer head is higher than the stream bed.

$$Q_{str} = C * (h_s - h_a) \tag{15}$$

Where:

Q_{str} = seepage to or from stream, in feet^3/day
C = conductance, in feet^2/day
h_s = the head of the stream, in feet
h_a = the head of the shallow aquifer, in feet

In the case where the shallow aquifer head is below the bottom of the stream bed the vertical flow from the river to the aquifer is calculated with equation (16).

$$Q_{str} = C * (h_s - E) \tag{16}$$

Where:

E = elevation of the bottom of the stream bed, in feet.

Conductance of the stream bottom is one of the parameters used to calculate the seepage to or from a stream. Conductance is the rate that a volume of material can transmit fluid.

In the Middle Valley model conductance was the input to the model and was initially calculated for each of the river reaches using equation (17). The conductance was then adjusted during the calibration process.

$$C = \frac{W_s * L_s * K_v}{T_{sb}} \tag{17}$$

Where:

C = conductance, in ft^2/day
W_s = stream width, in feet
L_s = stream length, in feet
K_v = vertical hydraulic conductivity, in feet/day
T_{sb} = stream bed thickness, in feet

The stream bed thickness was assumed to be 1 foot. The river width and length were determined in ArcGIS by tracing over the active river channel and determining the area of the polygon. A new functionality was used in RiverWare for the 2013 model to calculate the conductance in RiverWare (Compute Conductance method) using the input of hydraulic conductivity as part of the model run initialization given the variables listed in the above equation. The seepage area and streambed thickness are fixed variables. Initial values of vertical hydraulic conductivity were taken from the 2009 model. Vertical hydraulic conductivity was varied as well as several surface water variables to calibrate the simulated seepage with seepage measured by several seepage investigations and downstream flow at gage locations. The final vertical hydraulic conductivity's are listed in Table 5-13.

Table 5-13. River vertical hydraulic conductivity

	Length	Width	Seepage Area	Vertical Hydraulic Conductivity
Reach Object Name	**(feet)**	**(feet)**	**(acres)**	**(feet/day)**
CochitiToSanFelipeSeepageArea1	44,250	437	443.92	0.03
CochitiToSanFelipeSeepageArea2	37,050	459	390.40	0.40
SanFelipeToCentralSeepageArea1	38,300	383	336.75	0.40
SanFelipeToCentralSeepageArea2	42,600	523	511.47	0.60
SanFelipeToCentralSeepageArea3	41,365	491	466.26	0.55
SanFelipeToCentralSeepageArea4	45,680	512	536.92	0.55
CentralToIsletaSeepageArea1	35,666	488	400.00	0.40
CentralToIsletaSeepageArea2	37,923	480	417.88	0.25
IsletaToBernardoSeepageArea1	42,036	550	530.76	0.10
IsletaToBernardoSeepageArea2	41,518	585	557.58	0.1974
IsletaToBernardoSeepageArea3	44,867	540	556.20	0.1979
IsletaToBernardoSeepageArea4	39,504	430	389.96	0.25
IsletaToBernardoSeepageArea5	30,484	510	356.91	0.10
BernardoToSanAcaciaSeepageArea1	79,048	415	753.10	0.45
SanAcaciaToSanMarcialSeepageArea1	53,526	242	297.37	0.01
SanAcaciaToSanMarcialSeepageArea2	27,791	120	75.56	1.0
SanAcaciaToSanMarcialSeepageArea3	55,379	331	420.81	0.1
SanAcaciaToSanMarcialSeepageArea4	51,020	137	160.46	1.0
SanAcaciaToSanMarcialSeepageArea5	62,024	516	734.72	0.40

The average riverbed elevations for each reach associated with a particular Groundwater Storage Object were determined using the 2002 estimated riverbed elevations from the Aggregation/Degradation river cross sections survey by Reclamation (Pacific Western Technologies LTD, 2002), which were superimposed on the area of the Groundwater Storage Objects in ArcGIS. Point values from the closest measurement to the upstream and downstream locations were used. These values were averaged to calculate an average river elevation for a given reach. In the 2009 model, the average river elevation and drain bottom elevation were adjusted during the calibration. For the 2013 model the average river bottom elevations determined for the 2009 model were used, unchanged. The final simulated river Reach Object average elevations are listed in Table 5-14.

Table 5-14. River average bottom elevations

Reach	Elevation River
CochitiToSanFelipeSeepageArea1	5,191.68
CochitiToSanFelipeSeepageArea2	5,138.80
SanFelipeToCentralSeepageArea1	5,094.23
SanFelipeToCentralSeepageArea2	5,049.49
SanFelipeToCentralSeepageArea3	5,010.74
SanFelipeToCentralSeepageArea4	4,969.85
CentralToIsletaSeepageArea1	4,931.50
CentralToIsletaSeepageArea2	4,899.20
IsletaToBernardoSeepageArea1	4,864.60
IsletaToBernardoSeepageArea2	4,828.30
IsletaToBernardoSeepageArea3	4,793.30
IsletaToBernardoSeepageArea4	4,761.80
IsletaToBernardoSeepageArea5	4,732.20
BernardoToSanAcaciaSeepageArea1	4,687.80
SanAcaciaToSanMarcialSeepageArea1	4,630.60
SanAcaciaToSanMarcialSeepageArea2	4,597.90
SanAcaciaToSanMarcialSeepageArea3	4,560.80
SanAcaciaToSanMarcialSeepageArea4	4,527.00
SanAcaciaToSanMarcialSeepageArea5	4,493.00

The amount of river seepage is determined by the head of the water surface on the river compared to the head in the aquifer. The RiverWare method, Stage Table Lookup, called in the simulation computes the average head in the reach as determined by the relation between discharge and elevation both at the upstream and downstream end of the reach. The relation between discharge and elevation (rating) were determined from several sources. Where the boundary of a reach was at a gaging station, the rating for the gaging station was used. At reach boundaries in between gaging stations a theoretical rating was determined using Manning's equation:

$$Q = \frac{1.486}{n} * A * R^{2/3} * S^{1/2} \tag{18}$$

Where:

Q	= discharge, in feet^3/second (cfs)
n	= Manning's roughness coefficient
A	= cross-sectional area, in feet^2
R	= hydraulic radius (cross-sectional area/wetted perimeter), in feet
S	= stream slope, in feet/feet.

The width of the channel at each location was measured using 2002 aerial photography at a flow of approximately 1000 cfs. The values ranged from 175 feet to 600 feet. The Manning's roughness coefficient was set to 0.025, which is consistent with the values in the FLO2D model (Tetra Tech, Inc, 2004), which range from 0.025 to 0.03. The ratings for each reach boundary were entered into RiverWare in the Reach Object's Inflow or Outflow Stage Table. The slope was calculated from the elevations at the upstream and downstream locations. The depth-discharge relationship was converted to a stage elevation-discharge relationship using the upstream and downstream elevations determined in ArcGIS. The base elevation for some of the ratings were adjusted during the calibration process of the 2009 model but not changed for the 2013 model.

5.3.2.3.1 Middle Valley Deep Aquifer Shallow Aquifer Interaction

The December, 1999 shallow groundwater heads from the Albuquerque Basin Model were used as the initial heads to calibrate the 2009 Middle Valley model. The initial shallow aquifer heads for the 2013 model were taken from the 2009 Middle Valley Model final heads. After calibration of the 2013 model the initial heads were adjusted to be consistent with the calibrated heads for each Groundwater Storage Object.

Deep aquifer heads for each Groundwater Storage Object were extracted from layer 4 of the Albuquerque Basin Model (McAda and Barroll, 2002) and the Socorro Basin Model (Shafike, 2005) and are assumed to represent average conditions for each Groundwater Storage Object. The areas simulated by each Groundwater Storage Object were intersected with the Albuquerque Basin Model finite difference grid, and all nodes located within a Groundwater Storage Object were extracted. These head values at each node were averaged to develop the average head for a given Groundwater Storage Object. The average head at the end of each year for the area of each Groundwater Storage Object was selected for input into the Middle Valley model. This head data is used in the Groundwater Storage Object's Deep Aquifer Elevation slot. The deep groundwater heads were adjusted during the calibration in reaches where the MODFLOW models were not well calibrated. Table 5-15 lists the difference in the calibrated heads and the MODFLOW heads for the reaches where adjustments were made to the heads.

Table 5-15. Additive adjustments to the Deep Aquifer heads

Reach	Additive Adjustment [feet]
CochitiToSanFelipeGWArea1West	5
CochitiToSanFelipeGWArea1East	10
CochitiToSanFelipeGWArea2West	12
CochitiToSanFelipeGWArea2East	12
CochitiToSanFelipeGWArea2River	12
SanAcaciaToSanMarcialGWArea2East	11.3
SanAcaciaToSanMarcialGWArea2River	10.3
SanAcaciaToSanMarcialGWArea2West	11.3
SanAcaciaToSanMarcialGWArea3East	10
SanAcaciaToSanMarcialGWArea3River	12.7
SanAcaciaToSanMarcialGWArea3West	10
SanAcaciaToSanMarcialGWArea4River	15
SanAcaciaToSanMarcialGWArea5East	8.5
SanAcaciaToSanMarcialGWArea5River	8
SanAcaciaToSanMarcialGWArea5West	14.3

The flow between adjacent Groundwater Storage Objects was determined by multiplying the head difference between the two shallow Groundwater Storage Objects by the conductance (parallel to the direction of flow). Therefore, it was necessary to calculate conductance values for each face (side) of a Groundwater Storage Object interacting with another Groundwater Storage Object. Any face not interacting with either a shallow or deep Groundwater Storage Object is simulated as a no flow boundary condition.

Conductance for each face of the shallow Groundwater Storage Objects was determined using equation (19):

$$C_h = \frac{l_f * t_s * k}{l_c} \tag{19}$$

Where:

C_h = horizontal conductance, in feet^2/day,
l_f = face length, in feet,
t_s = saturated thickness, in feet,
k = horizontal hydraulic conductivity, in feet/day,
l_c = length between centroids of Groundwater Storage Objects, in feet.

The values for face length and the distance from the centroid of the Groundwater Storage Object to the corresponding object were determined in ArcGIS. The initial horizontal hydraulic conductivity was assumed to be 1 foot/day. The saturated thickness was assumed to be 80 feet. In the 2009 version of the model the conductance was an input to the model. It was calculated externally to the model using the variables in equation (6). With this approach, care had to be taken not to mismatch the conductance on adjoining Groundwater Storage Objects. For the 2013 version of the model a new method (Compute Conductance) was developed to calculate the conductance internally during the initialization part of the simulation with the input into the model of the variables in equation (6). In the new method a hydraulic conductivity was entered for the horizontal flow between the river Groundwater Storage Objects and the east and west Groundwater Storage Objects. An anisotropy ratio is entered for the flow in the upstream and downstream direction between Groundwater Storage Objects. An anisotropy ratio relates hydraulic conductivities in different directions. Anisotropy in a horizontal plane is given by Ky/Kx where Kx and Ky are horizontal hydraulic conductivities in the x and y directions, respectively.

In order to simulate interactions of the shallow aquifer with the deep, regional aquifer, shallow groundwater is able to interact with deep groundwater in each of the Groundwater Storage Objects. The deep groundwater component act as variable head boundaries, and thus represent infinite reservoirs. Fluxes between the two components are computed for each time step based on the head difference between the shallow and deep groundwater heads and the conductance. Similar to the equation used to compute horizontal conductance, the vertical conductance is calculated by the same method as the vertical conductance of the river reaches. Inputs are shown in equation (20):

$$C_v = \frac{A * k}{l_c} \tag{20}$$

Where:

C_v = vertical conductance, in feet^2/day,

A = Groundwater Storage Object simulated area feet^2.

l_c = length between centroids of Groundwater Storage Objects, in feet.

In this case the distance between centroids is the distance from the center of the Groundwater Storage Object (40 feet based on an estimated saturated thickness of 80 feet) and the elevation of the finite difference node from layer 4 of the Albuquerque Basin Model (310 feet below ground surface). Therefore, the vertical distance was estimated to be 270 feet. The vertical hydraulic conductivity from the 2009 model was used as the initial values for the calibration. Hydraulic conductivity was adjusted during the calibration. The area for each Groundwater Storage Object was determined in ArcGIS.

5.3.2.3.2 Elephant Butte Reservoir Surface Water Groundwater Exchanges

Two Groundwater Storage Objects, one object upstream of Elephant Butte Reservoir and the other located under Elephant Butte Reservoir, simulate the interaction of groundwater and surface water between San Marcial and Elephant Butte Reservoir. The Upstream Groundwater Storage Object is linked to the three San Marcial Groundwater Storage Objects and the Under Elephant Butte Groundwater Storage Object is linked to the Upstream Groundwater Storage Object and the Elephant Butte Reservoir Object (Tetra Tech, 2018).

An assumed tributary groundwater inflow of 5,000 acre-feet/year into the Upstream Elephant Butte Groundwater Storage Object (and into Elephant Butte Reservoir) when the reservoir is low is met by changing hydraulic conductivity in both Upstream Elephant Butte and Under Elephant Butte Groundwater Storage Objects, and the anisotropy ratio in the Upstream Elephant Butte Groundwater Storage Object. The aquifer length of the Under Elephant Butte Groundwater Storage Object was set to 17 miles based on the direct line distance between the gage on the Rio Grande in the Narrows and Elephant Butte Dam. The aquifer width of Under Elephant Butte Groundwater Storage Object was set to 6 miles during testing to help move the target inflow of 5,000 acre/year from the Upstream Elephant Butte Groundwater Storage Object to the Under Elephant Butte Groundwater Storage Object. The parameters selected during model testing are shown in Table 5-16. Specific Yield for both objects was set to 0.05.

Table 5-16. Geohydrologic Parameters of Groundwater Storage Objects between San Marcial and Elephant Butte Reservoir

Groundwater Storage Object	K_x (ft/day)	Anisotropy	Width (mi)	Length (mi)	Thickness (ft)
Upstream Elephant Butte	1.65	0.1	2	22	80
Under Elephant Butte	1000	1	6	17	5,280

5.3.2.4 Middle Valley Riparian Vegetation and Wetted Sands Depletion

The riparian vegetation evapotranspiration of the bosque area was simulated in RiverWare using the *Input ET Rate* method in the Groundwater Storage Object since the water for evapotranspiration is coming from the groundwater system. This method has area and evaporation rate as inputs. The riparian area for each Groundwater Storage Object was determined by subtracting the area of the active river channel polygon from the river Groundwater Storage Object polygon (riverside drain to riverside drain), the remainder of which was assumed to represent riparian area. A weighted average of riparian area was developed for each Groundwater Storage Object and in the simulation is multiplied by the evapotranspiration rate. Riparian vegetation evapotranspiration was simulated in the Groundwater Storage Objects simulating the area beneath the river. The aggregated evapotranspiration rate is used for simulation of bosque evaporation in each Groundwater Storage Object. The evaporation rate for the riparian areas is the potential evapotranspiration rather than actual.

The wetted sand evaporation was calculated using the new RiverWare "Soil Limited Evaporation" method in the river Groundwater Storage Objects. This method uses data from the linked river Reach Object to compare the total area of the river channel to the area covered by the river to determine the wetted sand area. The wetted sand evaporation is determined from a table of groundwater elevations and coefficients (Soil Limit Evaporation Table) which are applied not to the evaporation rate but to the Soil Limited Evaporation Rate that has a value for each month if the groundwater elevation reaches a set elevation (Soil Limited Evaporation Elevation). The Soil Limited Evaporation Elevation for each river Groundwater Storage Object is listed in Table 5-17.

Table 5-17. Soil Limited Evaporation Elevation for each River Groundwater Storage Object

Reach	Soil Limited Evaporation Elevation (feet)
CochitiToSanFelipeGWArea1River	5191.68
CochitiToSanFelipeGWArea2River	5138.80
SanFelipeToCentralGWArea1River	5094.23
SanFelipeToCentralGWArea2River	5049.49
SanFelipeToCentralGWArea3River	5010.74
SanFelipeToCentralGWArea4River	4969.85
CentralToIsletaGWArea1River	4931.50
CentralToIsletaGWArea2River	4930.00
IsletaToBernardoGWArea1River	4864.60
IsletaToBernardoGWArea2River	4828.30
IsletaToBernardoGWArea3River	4793.30
IsletaToBernardoGWArea4River	4761.80
IsletaToBernardoGWArea5River	4732.20
BernardoToSanAcaciaGWArea1River	4687.80
SanAcaciaToSanMarcialGWArea1River	4630.60
SanAcaciaToSanMarcialGWArea2River	4597.90
SanAcaciaToSanMarcialGWArea3River	4565.80
SanAcaciaToSanMarcialGWArea4River	4527.00
SanAcaciaToSanMarcialGWArea5River	4493.00

A Soil Limited Evaporation Rate was determined for each of the Groundwater objects below the river within each reach and the rates are shown in Table 5-18.

Table 5-18. Soil Limited Evaporation Rate for each reach

Month	Cochiti To San Felipe in/day	San Felipe To Central in/day	Central To Isleta in/day	Isleta To Bernardo in/day	Bernardo To San Acacia in/day	San Acacia To San Marcial in/day
Jan	0.05	0.05	0.05	0.05	0.06	0.06
Feb	0.07	0.07	0.08	0.08	0.09	0.10
Mar	0.13	0.13	0.13	0.13	0.16	0.16
Apr	0.22	0.22	0.22	0.22	0.24	0.25
May	0.28	0.28	0.28	0.28	0.3	0.30
Jun	0.31	0.32	0.32	0.32	0.34	0.32
Jul	0.28	0.28	0.29	0.29	0.29	0.28
Aug	0.25	0.25	0.25	0.25	0.24	0.25
Sep	0.22	0.21	0.22	0.22	0.2	0.22
Oct	0.16	0.16	0.16	0.16	0.15	0.17
Nov	0.09	0.09	0.09	0.09	0.09	0.10
Dec	0.04	0.05	0.05	0.05	0.05	0.05

5.3.2.5 Middle Valley Riverside Drains

The riverside drains were rehabilitated and extended under the 1948 Flood Control Act which authorized the Bureau of Reclamation and the USACE to construct levees and riverside drains and rehabilitate the MRGCD diversion and conveyance system. The main drains are constructed alongside of the river to stabilize water table elevations and capture river seepage and during irrigation season to efficiently convey water through MRGCD divisions. The bed elevations of these drains are, in general, below river bed except at the end of each drain where they discharge into the river. Usually, at the location where the drain discharges to the river, another overlap drain starts with its bed elevation below river bed and continues downstream.

These drains exist east and west of the river in the Cochiti, Albuquerque and Belen divisions and only west of the river in Socorro divisions of the MRGCD. Most of the canals and interior drains terminate at these drains where irrigation excess water is returned to the river. At the end of the Albuquerque Basin (just above San Acacia Dam) the river is constricted at the lowest point and all drains, except Drain Unit 7, waste water to the river. Riverside drains are in direct connection with the shallow aquifer and interact in URGWOM with the aquifer based on head difference and conductance.

In the 2005 model of the Middle Valley the riverside drains physically located on both sides of the river were simulated as one lumped reach along with the canals. Since 2009, the riverside drains have been simulated separately from the rest of the canal/drain system because of their close proximity to the river and their interaction with the river through the shallow groundwater system. Since 2009, the riverside drains, simulated with RiverWare Reach Objects, have been linked directly to the Groundwater Storage Object under the river for a more physically based simulation of the surface water-groundwater interaction. The slots linked are the same as for the river. The riverside drains in much of the Middle Valley are used as both drains to capture groundwater and as irrigation conveyance. The Riverside Drain Objects in the model only simulate the drain function of the riverside drains and do not simulate the irrigation conveyance. The irrigation conveyance function of the drains is simulated by the lumped canal Reach Objects.

5.3.2.5.1 Physical Description of Riverside Drain Boundaries

The riverside drains are an important component to surface water-groundwater interactions. Since 2009, the drains on the east and west side of the Rio Grande have been simulated independently in URGWOM. As with the river reaches, the length of each drain reach is determined by the upstream to downstream length of the Groundwater Storage Object(s) to which the drain is linked if the drain is continuous through one or more Groundwater Storage Objects. In the portion of the Middle Valley near Cochiti Lake, there are several discontinuous drains on both sides of the Rio Grande. The length of the simulated reaches for these discontinuous drains is the actual drain's length.

5.3.2.5.2 Calculation of Drain Gains or Losses to the Shallow Aquifer

As in the river seepage, there are two main factors that control the amount of seepage to and from the drain, the head difference between the aquifer and the water surface in the drain and the conductance of the drain bed. The simulation of flow from the drain to or from the shallow aquifer is handled by the reach and Groundwater Storage Objects in a conceptually analogous way to the River Package of the groundwater model, MODFLOW (McDonald and Harbaugh, 1988), in which all of the seepage is through the bottom of the drain channel.

The same parameters developed to model surface water groundwater interactions for the river system are needed to stimulate head-dependent flux in the riverside drains: head (water surface elevation) in the drain as a function of discharge, the conductance and thickness of the drain bed, and the elevation and geometry of the drain channel cross section. As with river seepage, different equations are used to calculate the seepage depending upon whether the shallow aquifer head is higher or lower than the bottom of the drain bed (See Section 5.3.2.3).

5.3.2.5.3 Drain Hydraulic Conductivity

As is done for river seepage, hydraulic conductivity is used to compute the conductance for each drain during the simulation initialization. The drain bed thicknesses were assumed to be 1 foot. The drain width was assumed to be 25 feet (bottom width) and the drain length was calculated in ArcGIS. The seepage area and streambed thickness are fixed variables and the model was calibrated by varying the vertical hydraulic conductivity.

In February 2010 a seepage investigation of the riverside drains on both sides of the river from Cochiti to San Acacia was completed to determine the winter seepage to or from the riverside drains for calibration of the model. The winter seepage values determined for each drain and used for the calibration of the drain hydraulic conductivity are listed in Table 5-19.

Table 5-19. Winter drain seepage used for calibration

	Winter seepage for calibration	
Reach	**West Drain (ft^3/day)**	**East Drain (ft^3/day)**
CochitiToSanFelipeSeepageArea1	--	-18.1
CochitiToSanFelipeSeepageArea2	-0.17	-0.86
SanFelipeToCentralSeepageArea1	-0.52	-3.78
SanFelipeToCentralSeepageArea2	--	-4.7
SanFelipeToCentralSeepageArea3	-10.8	-4.8
SanFelipeToCentralSeepageArea4	-3.7	-31.5
CentralToIsletaSeepageArea1	-25.3	-22.5
CentralToIsletaSeepageArea2	-1.6	-17.9
IsletaToBernardoSeepageArea1	-15.5	-29.9
IsletaToBernardoSeepageArea2	-37.1	-33.1
IsletaToBernardoSeepageArea3	-27.1	-13.6
IsletaToBernardoSeepageArea4	-19.6	-25.4
IsletaToBernardoSeepageArea5	-8.7	-20.5
BernardoToSanAcaciaSeepageArea1	-21.8	-29.3

The drain seepage was calibrated by matching the winter simulated seepage in each drain to the seepage measured in February 2010. The final vertical hydraulic conductivities for the east riverside drains are listed in Table 5-20 and for the west riverside drains are listed in Table 5-21.

Table 5-20. East riverside drain groundwater hydraulic properties

GW Object Polygon	URGWOM Reach Name	Drain Length (feet)	Hydraulic Conductivity (feet/day)
Cochiti to San Felipe 1	PenaBlancaRiversideDrain	33,288	0.303
Cochiti to San Felipe 2	EastSideSantaDomingoRiversideDrain	27,083	0.019
San Felipe to Central Ave. 1	SanFelipeToCentralDrainEast:Reach1	27,666	0.060
San Felipe to Central Ave. 2	SanFelipeToCentralDrainEast:Reach2	41,295	0.100
San Felipe to Central Ave. 3	SanFelipeToCentralDrainEast:Reach3	42,118	0.026
San Felipe to Central Ave. 4	SanFelipeToCentralDrainEast:Reach4	45,182	0.260
Central Ave. to Isleta 1	CentralToIsletaDrainEast:Reach1	35,896	0.140
Central Ave. to Isleta 2	CentralToIsletaDrainEast:Reach2	38,031	0.119
Isleta to Bernardo 1	IsletaToBernardoDrainsEast1_UpperPeralta	43,555	1.200
Isleta to Bernardo 2	IsletaToBernardoDrainsEast2	41,810	0.900
Isleta to Bernardo 3	IsletaToBernardoDrainsEast3	43,522	0.250
Isleta to Bernardo 4	IsletaToBernardoDrainsEast4	39,245	0.400
Isleta to Bernardo 5	IsletaToBernardoDrainsEast5	31,068	1.500
Bernardo to San Acacia 1	BernToSanAcaArea1DrainsEast	46,385	1.100

Table 5-21. West riverside drain groundwater hydraulic properties

GW Object Polygon	URGWOM Reach Name	Drain Length (feet)	Hydraulic Conductivity (feet/day)
Cochiti to San Felipe 1	--	--	--
Cochiti to San Felipe 2	LowerWestSideSantoDomingoDrain	17,446	0.0055
San Felipe to Central Ave. 1	SanFelipeToCentralDrainWest1	8,931	0.0073
San Felipe to Central Ave. 2	--	--	--
San Felipe to Central Ave. 3	SanFelipeToCentralDrainWest3	38,116	0.0600
San Felipe to Central Ave. 4	SanFelipeToCentralDrainWest4	27,758	0.0300
Central Ave. to Isleta 1	CentralToIsletaDrainWest1	34,590	0.1600
Central Ave. to Isleta 2	CentralToIsletaDrainWest2	37,007	0.0106
Isleta to Bernardo 1	IsleatToBernardoDrainsWest1	43,591	0.5000
Isleta to Bernardo 2	IsleatToBernardoDrainsWest2	41,931	0.9000
Isleta to Bernardo 3	IsleatToBernardoDrainsWest3	45,969	0.4000
Isleta to Bernardo 4	IsleatToBernardoDrainsWest4	39,209	0.3000
Isleta to Bernardo 5	IsleatToBernardoDrainsWest5	30,809	1.0000
Bernardo to San Acacia 1	BernardoToSanAcaciaDrainWest1	80,310	0.0800
San Acacia To San Marcial 1	SanAcaciaToSanMarcialArea1LowFlow	51,391	0.1000
San Acacia To San Marcial 2	SanAcaciaToSanMarcialArea2LowFlow	27,128	0.9000
San Acacia To San Marcial 3	SanAcaciaToSanMarcialArea3LowFlow	54,040	0.5000
San Acacia To San Marcial 4	SanAcaciaToSanMarcialArea4LowFlow	49,160	0.4000
San Acacia To San Marcial 5	SanAcaciaToSanMarcialArea5LowFlow	58,828	0.4000

5.3.2.5.4 Average Drain Bed Elevation

The upstream and downstream drain bed elevations were determined based on the values used in the Upper Albuquerque Basin Riparian Model (S.S. Papadopoulos and Associates, and New Mexico Interstate Stream Commission, 2006), which were developed using interpolated values from surveyed riverside drain elevations. These values were averaged to calculate an average drain bed elevation for each Groundwater Storage Object. The average drain stream bed elevations were adjusted during the calibration. The final simulated river Reach Object average elevations are listed in Table 5-22.

Table 5-22. Drain average bottom elevations

		Elevation	
Reach	**URGWOM Reach Name**	**West Drain (feet)**	**East Drain (feet)**
CochitiToSanFelipe-1	PenaBlancaRiversideDrain		5,186.56
CochitiToSanFelipe-2	EastSideSantaDomingoRiversideDrain		5,133.80
SanFelipeToCentral Ave.-1	SanFelipeToCentralDrainEast:Reach1		5,088.00
SanFelipeToCentral Ave.-2	SanFelipeToCentralDrainEast:Reach2		5,046.00
SanFelipeToCentral Ave.-3	SanFelipeToCentralDrainEast:Reach3		4,995.00
SanFelipeToCentral Ave.-4	SanFelipeToCentralDrainEast:Reach4		4,960.25
Central Ave.ToIsleta-1	CentralToIsletaDrainEast:Reach1		4,910.00
Central Ave.ToIsleta-2	CentralToIsletaDrainEast:Reach2		4,885.00
IsletaToBernardo-1	IsletaToBernardoDrainsEast1_UpperPeralta		4,858.00
IsletaToBernardo-2	IsletaToBernardoDrainsEast2		4,823.70
IsletaToBernardo-3	IsletaToBernardoDrainsEast3		4,788.00
IsletaToBernardo-4	IsletaToBernardoDrainsEast4		4,756.00
IsletaToBernardo-5	IsletaToBernardoDrainsEast5		4,730.00
BernardoToSanAcacia-1	BernToSanAcaArea1DrainsEast		4,687.90
Cochiti to San Felipe 1	--	--	
Cochiti to San Felipe 2	LowerWestSideSantoDomingoDrain	5,133.80	
San Felipe to Central Ave. 1	SanFelipeToCentralDrainWest1	5,068.40	
San Felipe to Central Ave. 2	--	--	
San Felipe to Central Ave. 3	SanFelipeToCentralDrainWest3	4,995.00	
San Felipe to Central Ave. 4	SanFelipeToCentralDrainWest4	4,955.00	
Central Ave. to Isleta 1	CentralToIsletaDrainWest1	4,910.00	
Central Ave. to Isleta 2	CentralToIsletaDrainWest2	4,885.00	
Isleta to Bernardo 1	IsleatToBernardoDrainsWest1	4,858.00	
Isleta to Bernardo 2	IsleatToBernardoDrainsWest2	4,823.80	
Isleta to Bernardo 3	IsleatToBernardoDrainsWest3	4,788.00	
Isleta to Bernardo 4	IsleatToBernardoDrainsWest4	4,756.00	
Isleta to Bernardo 5	IsleatToBernardoDrainsWest5	4,730.20	

		Elevation	
Reach	URGWOM Reach Name	West Drain (feet)	East Drain (feet)
Bernardo to San Acacia 1	BernardoToSanAcaciaDrainWest1	4,692.70	
San Acacia To San Marcial 1	SanAcaciaToSanMarcialArea1LowFlow	4,631.05	
San Acacia To San Marcial 2	SanAcaciaToSanMarcialArea2LowFlow	4,591.20	
San Acacia To San Marcial 3	SanAcaciaToSanMarcialArea3LowFlow	4,557.70	
San Acacia To San Marcial 4	SanAcaciaToSanMarcialArea4LowFlow	4,516.70	
San Acacia To San Marcial 5	SanAcaciaToSanMarcialArea5LowFlow	4,478.50	

5.3.2.5.5 Upstream and Downstream Ratings

Theoretical rating curves were developed for the drains at the upstream and downstream end of each Groundwater Storage Object. The curves were developed using Manning's equation, shown in Section 5.3.2.2. The slope was calculated from the elevations at the upstream and downstream locations. The depth-discharge relationship was converted to a stage elevation-discharge relationship using the elevations determined in ArcGIS. These rating tables were imported into each of the riverside drain Reach Object's Inflow and Outflow Stage Table slots.

5.3.2.5.6 Inflows into the Drains from Canal System

In the area between Cochiti Dam and the streamflow gage at San Felipe, where the riverside drains are discontinuous, there are inflows to the drains from the canal system on the east side of the river. As discussed in section 5.3.1.4.6, these drain inflows are simulated by Diversion Objects. The amount of inflow to the drain is determined as a percentage of the flow in the canal feeding the drain in question. Twenty percent of flow in the canals is diverted to each of the Pena Blanca and East Side Santo Domingo Riverside Drains. The percent of flow was based on MRGCD historical operations (Gensler, 2013).

5.3.3 Water Quality Simulation in the Middle Valley

URGWOM has also been used to demonstrate the potential to simulate dissolved solids concentrations or salinity in the Middle Valley. Water Quality has not yet been fully implemented in the URGWOM suite of applications, and the following documentation provides information that there is the ability to use URGWOM for some water quality analyses. For the purposes of this report, the term salinity refers to dissolved solids concentration. The URGWOM Technical Team developed a conceptual design and tested the functionality of RiverWare to allow for salinity modeling with the use of multilayer Groundwater Storage Objects and surface water-groundwater interactions in a complex hydrologic setting. Development of a historical salinity simulation in URGWOM was achieved with the following three steps: (1) Selection of appropriate salinity methods and setting associated links between objects; (2) Entering necessary salinity input data; and (3) Calibration of the salinity model by comparing modeled and measured salinity values and modifying input data until temporal and spatial trends in simulated salinity approached observed values. Each of these is described briefly below. For more detailed information, refer to the detailed documentation of this process (Roark, et al., 2017).

5.3.3.1 Salinity Simulation Setup

URGWOM was reconfigured for salinity simulation by setting the Simulation Run Parameters in the Run Control to Water Quality and selecting the inline process. Setting the Simulation Run Parameters to Water Quality enabled the selection of salinity methods on objects associated with salinity calculations. The salinity method for each object was chosen on the basis of the type of object and the other objects with which it interacted (Roark, et al., 2017). After the methods were setup, links were added to pass salinity data between objects. Each RiverWare object type set up for salinity calculations and associated links with surrounding objects are discussed below.

5.3.3.1.1 <u>Groundwater Storage Objects</u>

In Groundwater Storage Objects, the "Groundwater Water Quality" category was set to layered salt and the "Show Salt Mass and Flux" category was set the same directions as the "Lateral Link Direction" category. The thickness of the upper salt layer for the layered salt methods test was set to 10 feet. Links between river and lateral, and upstream and downstream Groundwater Storage Objects are shown below. A more complex set of links between Groundwater Storage Objects is necessary than in the flow model because of layered nature of the Groundwater Storage Objects with respect to salinity.

Groundwater Storage Object - River		**Groundwater Storage Object – East (or West)**
Salt Concentration Lower Previous	↔	Salt Concentration Lower Left Previous
Salt Concentration Lower Right Previous	↔	Salt Concentration Lower Previous
Salt Concentration Upper Previous	↔	Salt Concentration Upper Left Previous
Salt Concentration Upper Right Previous	↔	Salt Concentration Upper Previous
Storage Proportion Previous	↔	Storage Proportion Left Previous
Storage Proportion Right Previous	↔	Storage Proportion Previous
Groundwater Storage Object - Upstream		**Groundwater Storage Object - Downstream**
Salt Concentration Lower Downstream Previous	↔	Salt Concentration Lower Previous
Salt Concentration Lower Previous	↔	Salt Concentration Lower Upstream Previous
Salt Concentration Upper Downstream Previous	↔	Salt Concentration Upper Previous
Salt Concentration Upper Previous	↔	Salt Concentration Upper Upstream Previous
Storage Proportion Downstream Previous	↔	Storage Proportion Previous
Storage Proportion Previous	↔	Storage Proportion Downstream Previous

5.3.3.1.2 <u>Reach Objects</u>

All Reach Objects, except the time-lag Reach Objects, had the Reach Water Quality category set to "Discretized Salt" and the Water Quality Routing category set to "Salinity." This included all river reaches, canals, riverside drains, and wasteways. The time lag Reach Objects had the Reach Water Quality category set to “Discretized Salt” and Water Quality Routing category set to “Time Lag Salt.” Aggregate Reach Objects had “Discretized Salt” and “Salinity” methods initiated. The links from the Reach Objects varied depending on the function of the object to which it was connected. The Reach Object salinity links are shown below.

Reach - 1		**Reach - 2**
Outflow Salt Concentration	↔	Inflow Salt Concentration
Reach		**Groundwater Storage Object**
Seepage Salt Concentration	↔	Inflow from Surface Salt Concentration
Reach - Return Flow		**Diversion or Gage Object**
Return Flow Salt Concentration	↔	Salt Concentration
Aggregated Reach Object - Drains		**Groundwater Storage Object**
Seepage Salt Concentration	↔	Inflow From Surface Water Salt Concentration

5.3.3.1.3 Water User Type Objects

Several different methods were setup on the Water User Objects and Aggregated Water User Objects such as Aggregate Depletion Objects and Aggregate Diversion Objects. Aggregated Depletion Objects were set to the “SW GW Fractional Split” method. The Aggregate Diversion Objects had the Ag Diversion Site Water Quality category set to “Propagate Salt” and the Return Flow Salt category set to “Sequential Salt.” Links from Water User, and Diversion Objects to other objects associated with salinity modeling are shown below.

Water User		**Reach**
Diversion Salt Concentration	↔	Diversion Salt Concentration
Aggregate Diversion Object- AgDepletions		**Aggregate Distribution Canal**
Diversion Salt Concentration	↔	Delivered Flow Salt Concentration
Total Unused Salt Concentration	↔	Return Flow Salt Concentration
Aggregate Diversion Object- AgDepletions		**Groundwater Storage Object**
Return Flow Salt Concentration	↔	Inflow From Surface Water Salt Concentration
Aggregate Diversion Object - Diversions		**Reach**
Diversion Salt Concentration	↔	Diversion Salt Concentration
Aggregate Diversion Object - Diversions		**Aggregate Distribution Canal**
Diversion Salt Concentration	↔	Inflow Salt Concentration

5.3.3.1.4 Stream Gage, Diversion, and Confluence Objects

The Water Quality Category method was set to “Propagate Salt” on Middle Valley Stream Gage and Diversion Objects. In Confluence Objects the Water Quality Category method was set to “Solve Outflow Salt.” The links between Stream Gage and Diversion Objects are a straight forward connection of salt concentrations. The Confluence Objects combines salinity by mixing the two inflows and also have straight forward links to other objects. The two inflow salt concentrations were linked to the upstream object outflow salt concentration and the Conveyance Object outflow salt concentration was linked to the inflow salt concentration of the object downstream of the confluence.

5.3.3.2 Salinity Input Data

Data necessary for the salinity simulations included inflow below Cochiti Dam salinity, tributary inflow salinity, groundwater salinity, and model calibration salinity data. Data used to determine input salinity were based on all available data which in some cases included data collected prior to the period of salinity simulation (December 2002 to January 2010). All of the existing data used for the salinity model were collected by and obtained from the USGS. Most of the data was obtained from the online USGS website (https://waterdata.usgs.gov/nm/nwis/nwis) or by requesting specific data from the New Mexico USGS Office Information Officer or other USGS employees. The existing data included continuous data collected with a water-quality sonde, daily samples collected as part of the daily suspended sediment data program, and discrete samples collected as part of a periodic water quality monitoring program. For more detailed information on salinity data used refer to the detailed documentation of this process (Roark, et al., 2017).

5.3.3.3 Calibration

The salinity model was calibrated by modifying the initial and boundary condition salinity concentrations to minimize error in the modeled salinity at five sites along the Rio Grande: near Alameda in Albuquerque, at Central in Albuquerque, at Bernardo, at San Acacia, and at San Marcial. The amount of measured salinity data available at each site varied considerably. Time series plots of modeled minus measured salinity and boxplots of model error (modeled minus measured salinity) were made at each site and the error was evaluated at each site to determine if error was related to season, inflow from tributaries, or error at adjacent sites on the Rio Grande. After the error was evaluated at each site, the initial and boundary condition salinity concentrations were adjusted and the model was rerun. Calibration proceeded until a strong correlation emerged between error in modeled salinity and error in modeled flow such that further improvements in calibration of the salinity model will require improvements in the quality of the underlying hydrology. For specific model calibration plots, refer to the more detailed documentation of this process (Roark, et al., 2017).

6 Lower Rio Grande

6.1 Nature of Water use and Depletion in the Lower Rio Grande

Water users in the Lower Rio Grande include agricultural and municipal users, with agriculture being the primary water user in the area. The Rio Grande Project, which includes Elephant Butte and Caballo reservoirs, provides irrigation water to approximately 178,000 acres in New Mexico served by the Elephant Butte Irrigation District (EBID) and in Texas served by the El Paso County Water Improvement District No. 1 (EPCWID). Project water is also provided to Mexico in fulfillment of the United States' obligation under the Rio Grande Convention of 1906. EBID diverts water into its canal system at three primary locations: Percha, Leasburg, and Mesilla diversion dams. Water for EPCWID's use in the El Paso Valley is diverted from the river at American Dam. EPCWID also receives water in the northern parts of its service area (in the southern Mesilla Valley) via canal deliveries from Mesilla Dam. Prior to completion of the American Canal extension in 1999, EPCWID diverted water to its southern sections at Riverside diversion dam, roughly 12 miles downstream from American Dam. The Riverside diversion dam no longer exists, and EPCWID now uses the American Canal extension to deliver water to lands previously irrigated by diversions at Riverside. Mexico diverts up to 60,000 acre-feet annually at the International diversion dam just downstream from the American Dam. The City of El Paso has acquired some EPCWID water for its municipal water supply. El Paso, Las Cruces, and other municipalities use ground water for the majority of their domestic supply. Ground water is also used by water users in EBID and EPCWID as a supplemental water supply and by other irrigators as a primary supply.

6.2 URGWOM Storage Reservoirs in the Lower Rio Grande

Elephant Butte and Caballo reservoirs are the two water supply reservoirs for the Rio Grande Project. Elephant Butte Reservoir is authorized to operate for conservation storage and generation of hydroelectric power. Caballo Reservoir is operated for conservation storage and flood control.

Reservoir evaporation and precipitation is modeled using the "Pan and Ice Evaporation" RiverWare method based upon daily pan evaporation (in/day), precipitation rate (in/day), and Pan Evaporation Coefficient (0.70) for these reservoirs. Table 6-1summarizes general information about these dams in the Lower Rio Grande. Table 6-2 and Table 6-3 provide physical data for reservoirs in the Lower Rio Grande.

Table 6-1. General information about dams in the Lower Rio Grande

	Elephant Butte	Caballo
Type:	Concrete gravity	Earth fill
Year completed:	1916	1938
Structural height (feet):	301	96
Top width (feet):	18	--
Dam crest length (feet):	1674	4590
Spillway crest elevation	4407	4161
Dam crest elevation (feet, Project Datum):	4414	4190
Outlet works discharge capacity (cfs):	10800	5000

6.2.1 Elephant Butte Reservoir

Elephant Butte Reservoir is owned and operated by Reclamation, and is the principal water storage facility for 178,000 irrigated acres of the Rio Grande Project in south-central New Mexico and west Texas. The reservoir is operated to maintain a 25,000 acre-foot pool vacant for flood-control purposes in the winter months and 50,000 acre-foot pool for flood control in the summer months. Elephant Butte Reservoir is also operated to ensure that the U.S. 1906 Treaty obligation with Mexico to deliver 60,000 acre-feet per year at the Acequia Madre headgate in Mexico can be met. Table 6-2 provides physical data for Elephant Butte Reservoir.

Table 6-2. Elevation-related information about Elephant Butte Reservoir

	Elevation (feet Project Datum)	Area (acres)	Capacity (acre-feet)
Top of dam:	4414.00	39,570	2,289,484
Total storage at spillway crest:	4407.00	35,825	2,024,586
Top of dead pool:	4231.50	0	0

6.2.2 Caballo Reservoir

Caballo Dam and Reservoir is operated for conservation storage purposes by Reclamation and for flood-control purposes by the U.S. Section of the International Boundary and Water Commission (IBWC). Completed in 1938, Caballo Dam provides flood protection for the El Paso/Juarez area by the reservation of 100,000 acre-feet of total capacity for a dedicated flood-control pool, which is under the jurisdiction of IBWC. The reservoir also serves to re-regulate releases made from Elephant Butte Reservoir for the generation of hydroelectric power. Table 6-3 provides physical data for Caballo Reservoir.

Table 6-3 Elevation –related information about Caballo Reservoir

	Elevation (feet Project Datum)	Area (acres)	Capacity (acre-feet)
Top of dam:	4190.00	13,250	423,500
Maximum pool:	4186.00	12,180	372,840
Total storage at spillway crest:	4161.00	7,152	131,725
Top of dead pool:	4104.00	0	0

The accounting of the operation of Elephant Butte and Caballo Reservoirs follows the general mass-balance equation for reservoirs as described previously in Section 2.2.1.1, Section 4.2.3 or Section 5.2.2.

6.3 Simulation of Physical Processes in the Lower Rio Grande

6.3.1 Lower Rio Grande Surface Water System

6.3.1.1 Description of Reaches in the Lower Rio Grande

The surface water system from San Marcial, New Mexico, to Hudspeth County, Texas is divided into 7 reaches defined by gages on the Rio Grande as follows:

1. San Marcial to below Elephant Butte Dam
2. Below Elephant Butte Dam to Below Caballo Dam
3. Below Caballo Dam to Leasburg Dam
4. Leasburg Dam to Mesilla Dam
5. Mesilla Dam to El Paso (Courchesne Bridge Gage)
6. El Paso to American Dam
7. American Dam to Fort Hancock near Tornillo, TX

6.3.1.2 Routing Travel Time in the Lower Rio Grande

The travel time lag for the Elephant Butte to Caballo Dam reach is based on the variable time lag method. See Section 3.3.1.2. There is a 1-day lag modeled on the main stem of the Rio Grande at the downstream end of the Rincon Valley, a 1-day lag at the bottom of Leasburg valley, and a 1-day lag at the bottom of the Mesilla Valley. These 1-day lags are rounded from the hourly travel times listed in Table 1 of the Reclamation, 2010 Rio Grande Project Operations Manual (the model is configured to use an integer number of days for lag times).

Table 6-4 tabulates river travel time lags in the reach between Elephant Butte Dam and Caballo Dam.

Table 6-4. Travel time lags for the Rio Grande from Elephant Butte Dam to Caballo Dam

URGWOM Reach	Time lag (hours) for indicated flow rate (cfs)						
	50	200	500	750	1,000	3,000	6,000
ElephantButteToCaballo	39	27	21	19	18	13	11

6.3.1.3 Water Surface Evaporation/Channel Losses in the Lower Rio Grande

River seepage losses (or gains) from the underlying alluvial aquifer are computed based on a conductance term and the head gradient between the water surface elevation of each Reach Object (a function of bed elevation and stage) and the water surface elevation of the underlying alluvial Ground Water Object. Increases in river seepage caused by increases in aquifer pumping that draw down the alluvial aquifer levels are reflected by this method.

River water surface evaporation is computed for five different reaches in the Lower Rio Grande: Elephant Butte to Caballo, Percha Dam to Leasburg Dam, Leasburg Dam to Mesilla Dam, the upper portion of Mesilla Valley, and the lower portion of Mesilla Valley. The evaporation from the Elephant Butte to Caballo reach is a percentage of the flow, and the percentage varies from month to month. The percentage ranges from 5% to 10%. The evaporation from the latter four reaches is a constant percentage of the flow throughout the year, and the percentages range from 1% to 2% depending on the location. The percentages were all calibration parameters.

The loss coefficients for the Elephant Butte to Caballo reach were developed according to the methods described in Section 2.3.1.2.2. Table 6-5 is a tabulation of the computed loss coefficients for the Elephant Butte Dam to Caballo Dam reach.

Table 6-5. Adopted monthly loss coefficients for the reach of the Rio Grande from Elephant Butte to Caballo Dam

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Loss Coefficient	-0.10	-0.07	-0.05	-0.08	-0.08	-0.08	-0.05	-0.09	-0.10	-0.10	-0.10	-0.10

6.3.1.4 Lower Rio Grande Farm Operations

6.3.1.4.1 Lower Rio Grande Diversions

There are five major diversion structures represented in the Lower Rio Grande. From immediately below Caballo to the bottom of EPCWID, these are the Percha, Leasburg, Mesilla, American, and International (Acequia Madre) Diversion Dams. These river headgates serve irrigators in the Rincon Valley (Percha), Mesilla Valley (Leasburg and Mesilla), EPCWID irrigators downstream of El Paso (American), and the Republic of Mexico (International). The

Bonito Lateral below Caballo Dam, which has a small average annual diversion of less than 1,000 acre-feet, is not modeled. The model network structure is similar for each of these valleys and irrigated areas with the exception of Mexico, which is simply represented as a diversion out of the river that is fully consumed (i.e., there is no representation of ground water use or return flows).

In each valley there are Project water users who use surface water but may supplement their supplies with ground water pumping. There are also primary ground water users, which do not receive surface water deliveries from the Project, but have an impact on return flows and surface water-groundwater interaction due to pumping. In both the Rincon and Leasburg valleys, there are multiple objects used to represent the EBID water users and primary ground water users. In the Mesilla Valley, there are multiple objects representing water users east and west of the Rio Grande, again distinguished as Project water users or primary ground water users. In the El Paso valley, there are EPCWID water users who use surface water but may also supplement their supplies with groundwater pumping.

Each valley is divided into irrigation subreaches. The subreaches are delineated to capture naturally occurring features (e.g. an irrigated area isolated within a bend in the river) and to divide the valley into roughly equally-sized segments (based on GIS coverage of current irrigated area). The Rincon Valley is divided into five subreaches (Figure 6-1), the Leasburg Valley into five subreaches (Figure 6-2), the Mesilla Valley into eleven subreaches (Figure 6-3), and the El Paso Valley into four subreaches (Figure 6-4). Within the Mesilla Valley five of those subreaches comprise the Mesilla west side and six comprise the Mesilla east side. On the Mesilla west side, four subreaches apply to New Mexico and one subreach applies to Texas. On the Mesilla east side, three subreaches apply to New Mexico and three apply to Texas.

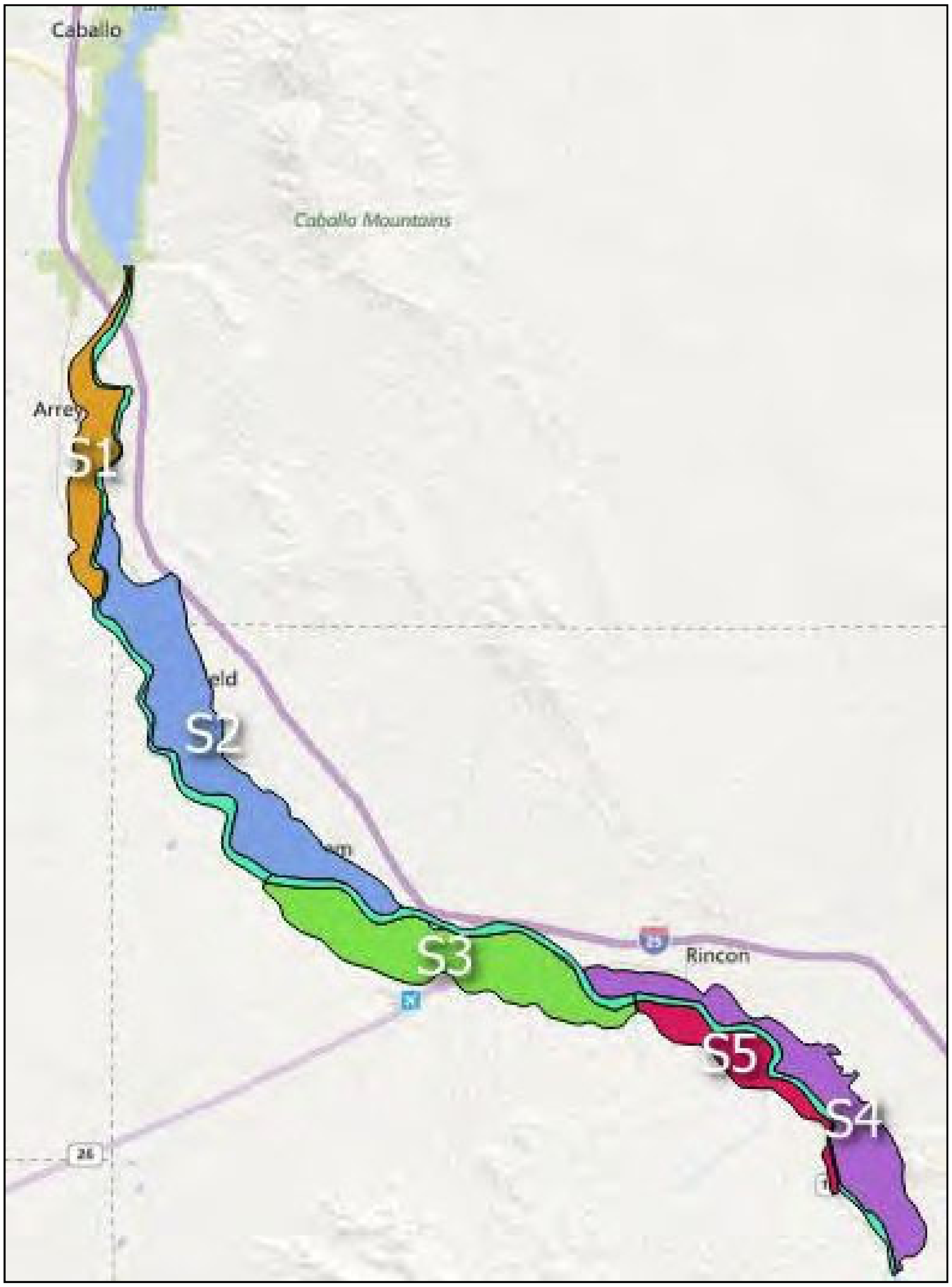


Figure 6-1. Map of five Rincon subareas

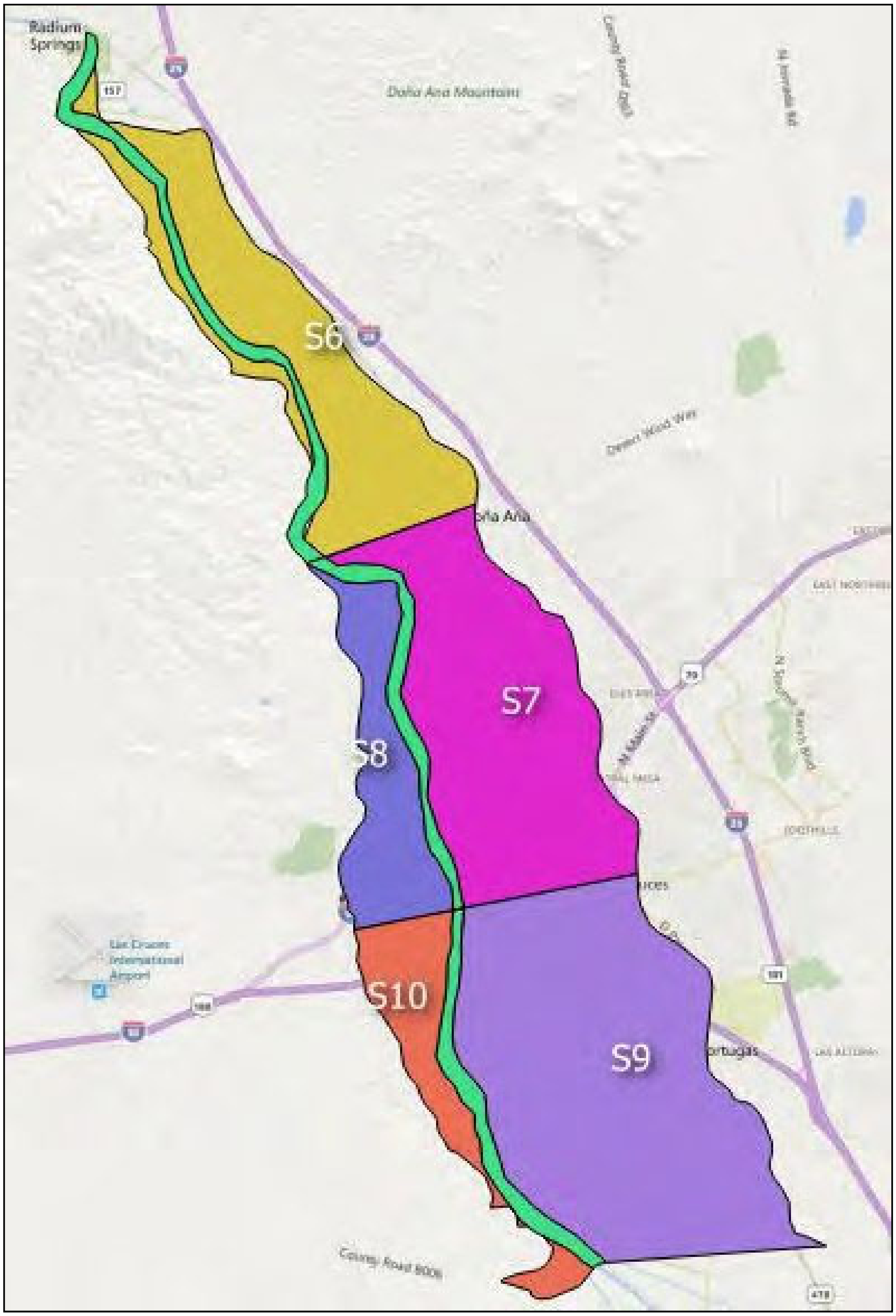


Figure 6-2. Map of five Leasburg subareas

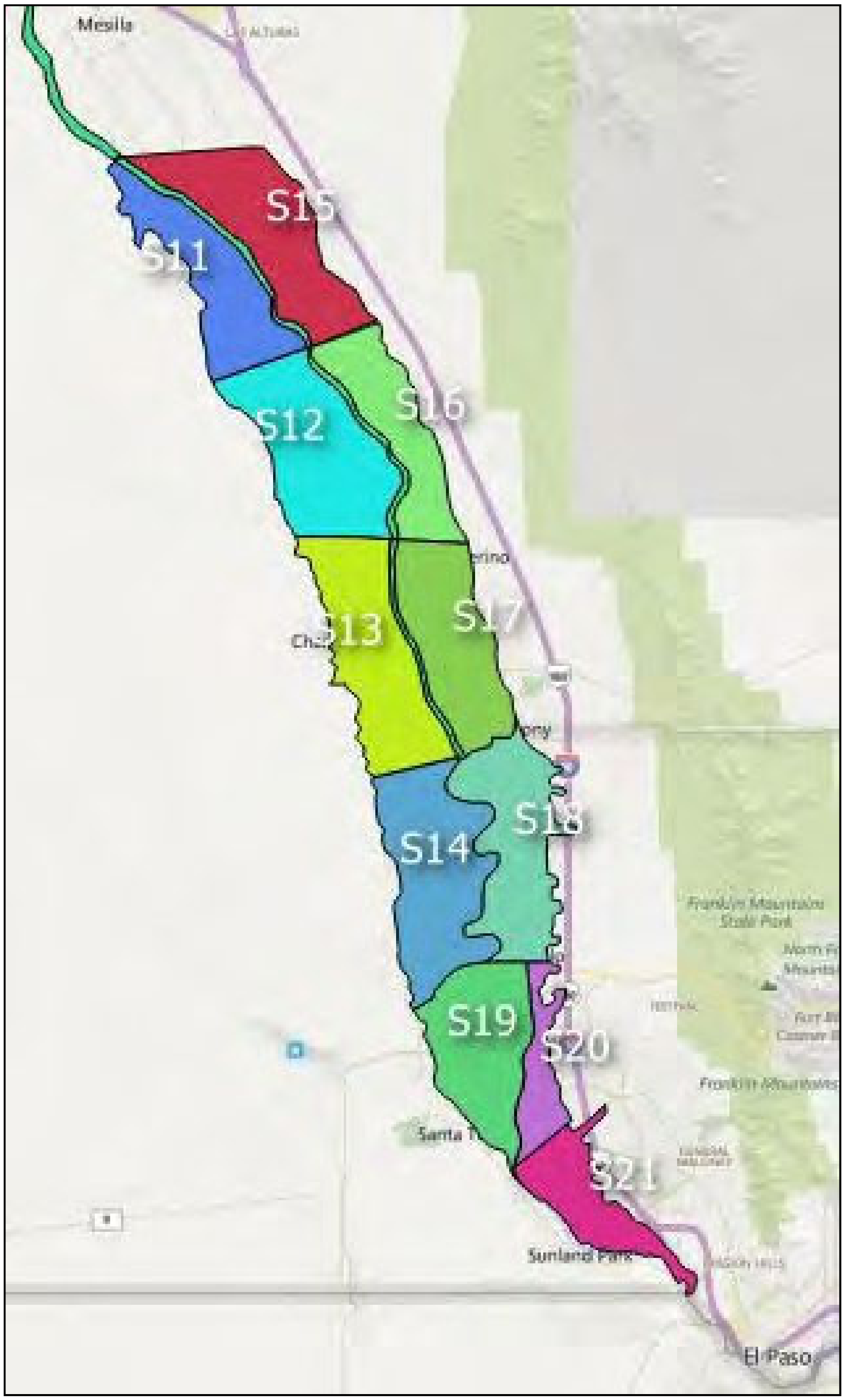


Figure 6-3. Map of five west and six east side Mesilla subareas

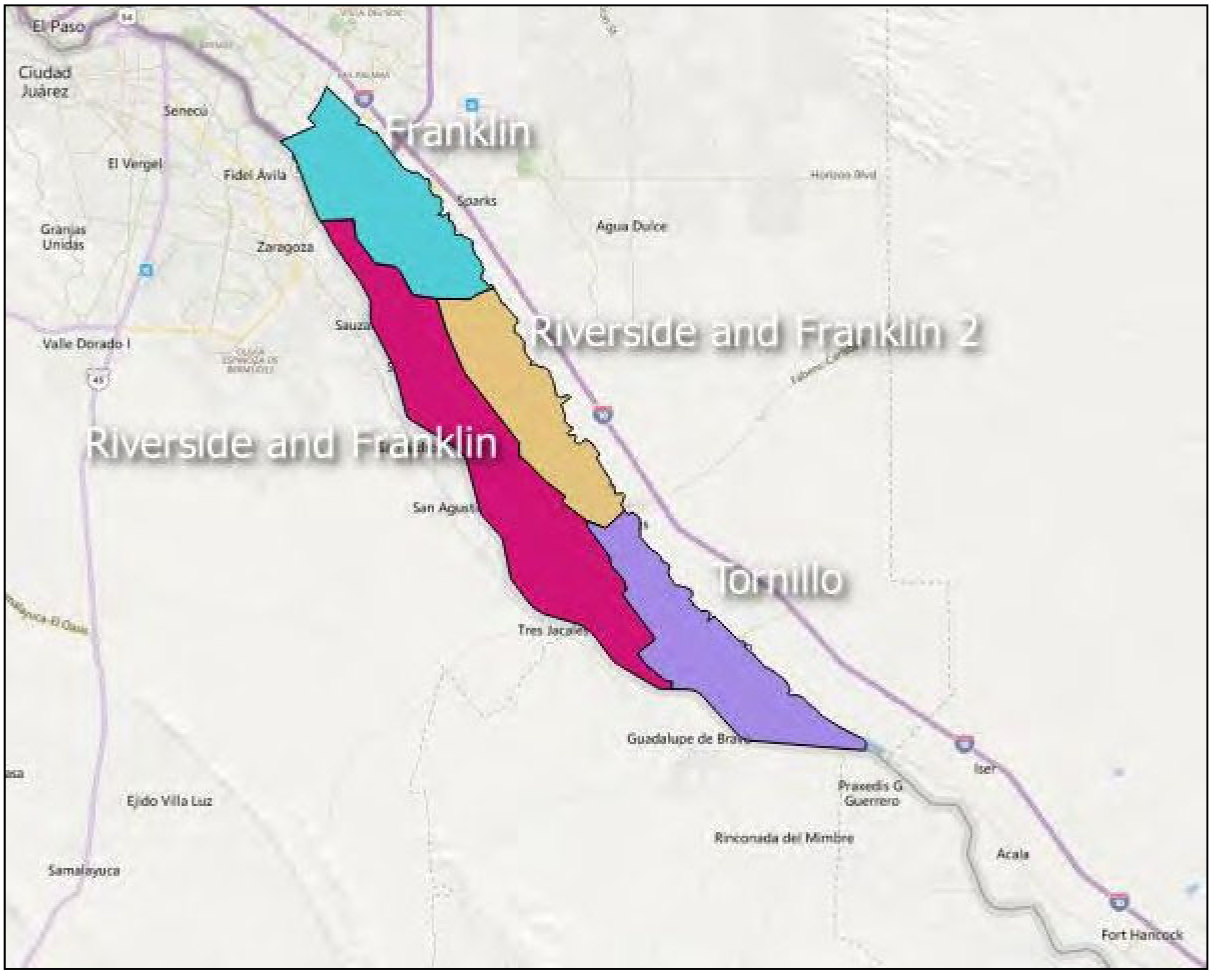


Figure 6-4. Map of four El Paso Valley subareas

Rio Grande diversions are either historical river headgate data (in Calibration mode or during the Accounting portion of a run), are hand-input, or are determined by rules as a function of reservoir storage, project operating rules, and either irrigation demands or historical diversion patterns.

6.3.1.4.2 Lower Rio Grande Canal Losses

Canal Objects have a seasonal seepage term that is applied to all diverted water before it is made available to the irrigators. Within each valley (Rincon, Leasburg, Mesilla east side, Mesilla west side, and the El Paso Valley), the total canal seepage is split up according to the number of subreaches within the valley. Each subreach receives a percentage of the canal seepage based on its contributing percentage of the total irrigated area within the valley. This seepage is applied directly to the Groundwater Storage Object associated with the irrigation subreach.

After the canal seepage has been determined, a portion of the canal flow may be diverted (wasted) directly back to the Rio Grande through a series of Diversion Objects that represent the wasteways. This water may be bypass water or carriage water intended for use downstream. In a calibration run, the total wasteway flow for each valley is based on historical carriage and bypass information. In an AOP or Planning Run, the total wasteway flow is set to 1% of the total river headgate diversion. The total wasteway flow is split among the various Wasteway Objects according to percentages which are based on historical flow through the various Wasteway Objects.

6.3.1.4.3 Lower Rio Grande Irrigated Acreage

The remaining water total headgate diversion minus canal seepage, wasteway/carriage water, and Water Treatment Plant (WTP) diversions, plus Wastewater Treatment Plant (WWTP) returns (Section 6.3.1.6) is allocated to each of the subreaches in the basin according to the fraction of the total irrigated area within the basin that each subreach represents. Each subreach is limited to this amount, or to the diversion requested computed from the consumptive irrigation requirement (CIR) and soil moisture demands (see below), whichever is less. Excess water that is not diverted by the subreaches to meet the CIR or soil moisture demand remains in the canal and either returns to the river, or, in EPCWID, remains in the Tornillo Canal and enters Hudspeth County at the Tornillo Canal at Alamo Alto gage.

Within each subreach, the water users compute diversion requests for crops using the "Irrigation Requests with Soil Moisture" diversion and depletion method. This method sets demands based on the total potential CIR, farm efficiency (which ranges from 70% to 80%, and was a calibration parameter), and irrigated acreage. Diversion Requested for Crops = (Acreage * CIR) / efficiency.

Historical EBID irrigated acreage is from an annual EBID assessment of irrigated acreage. This total EBID irrigated acreage is split into irrigated acreage for each subarea based on GIS measurements.

Historical EPCWID irrigated acreage is based on annual Reclamation crop reports (identified as “Form 7-316” before 1979, and “Form 7-2045” thereafter). This total EPCWID irrigated acreage is split into irrigated acreage for each subarea based on GIS measurements.

In a calibration run, the actual historical acreages are used, and in an AOP or Planning run, the historical acreages from a recent year (user-selected) are used.

6.3.1.4.4 Lower Rio Grande Crop ET

Historical CIR is computed using historical climate data from Hatch, NM, Las Cruces, NM, and Fort Hancock, TX and crop mix data for EBID and EPCWID from annual EBID and Reclamation crop reports. The historical climate data from each station, after infilling missing data using standard regression-based methods, was used to estimate a daily reference evapotranspiration based upon the Hargreaves-Samani 1985 method (Hargreaves and Samani, 1985). Crop coefficients and growing season lengths were determined based upon FAO Irrigation and Drainage Paper No. 56 (FAO 56) (Allen et al., 1998) for all crops except pecan orchards, where crop coefficients and growing season lengths developed by Keller-Bliesner Engineering (2011) were used. The Effective Precipitation application, also developed by Keller-Bliesner Engineering (Westfall, 2012), was then used to process the crop mix, evapotranspiration data and daily rainfall data, based upon the methodology outlined in SCS TR-21 (USDA SCS, 1970), to calculate daily CIR as the difference between potential evapotranspiration and effective precipitation. EBID crop mix data was combined with Hatch climate data to estimate CIR for EBID subareas in the Rincon Valley, and with Las Cruces climate data for EBID subareas in the Mesilla Valley. EPCWID crop mix data was combined with Fort Hancock climate data for all EPCWID subareas. The CIR values resulting from these calculations were reduced for all areas within the model and this reduction percentage varies between each modeled subreach within a range of 0-20% as a result of model calibration.

In a Calibration run, the historical estimated CIR values are used. In an AOP run, the historical estimated CIR values from the Forecasted year are used. In a Planning Run, the historical estimated CIR values sampled from the user-input Historical years are used.

6.3.1.4.5 Lower Rio Grande Soil Moisture

The Water User Object in each subarea is configured to model the soil moisture column accessible by crops. The method was configured to represent the Readily Available Water (RAW) as defined in FAO 56 (Allen, et al., 1998). A value of 0.3 feet is used for the effective depth of the RAW for all objects. A value of 1 feet/day was used for maximum infiltration rate, which will never be controlling given the daily timestep and the maximum soil moisture depth of 0.3 feet. For each timestep in the model, the soil moisture demand, which is the flow rate required to fill the soil moisture column, is added to the Diversion Requested for Crops (described above) to compute the total Diversion Requested (demand) for each subarea. If the total water diverted into a given subarea is greater than the Diversion Requested for crops, the excess enters the soil moisture column limited by the maximum soil moisture depth and the maximum infiltration rate. Excess that cannot enter the soil moisture column goes to return flow and ultimately the underlying aquifer object. If the amount diverted into a subarea is less than the Diversion Requested for Crops, the crops draw on water stored in the soil moisture column to make up the shortage. Once the soil moisture column is empty, supplemental groundwater is pumped from the underlying Ground Water Object (for those subareas that are configured to use supplemental groundwater) to make up the remaining shortage (Section 6.3.2.1).

6.3.1.4.6 Lower Rio Grande Return Flows / Interior Drains

The "Proportional Shortage" return flow calculation method determines return flows based upon farm efficiency values. All return flows accrue to the underlying Groundwater Storage Object. Drains are also modeled alongside each of the irrigation subareas. Drains interact with the underlying Groundwater Storage Objects. Gains or losses from the Groundwater Storage Object to the drains are computed based on a conductance term and the head gradient between the water surface elevation of each Drain Object (a function of bed elevation and stage) and the water surface elevation of the underlying alluvial Ground Water Object. Increases in drain seepage caused by increases in aquifer pumping that draw down the shallow aquifer levels are reflected by this method. Drain flows eventually return to the Rio Grande.

6.3.1.5 Lower Rio Grande Inflows

Nine Stream Gage Objects are used in the Lower Rio Grande portion of the model for all the key stream gages. See Table 6-6. Inflows to the Lower Rio Grande region come from the Rio Grande at San Marcial, and a separate Reach Object for ungaged local inflows in the each of the reaches above Courchesne Bridge.

Table 6-6. Gages in the RiverWare Model for the Lower Rio Grande Portion of the Rio Grande Basin

	Gage Name	URGWOM Gage Name	ID	Period of Record
1	Rio Grande below Elephant Butte Dam	BlwElephantButte	08-3610.00	1915 to present
2	Rio Grande below Caballo Dam	BlwCaballo	08-3625.00	1938 to present
3	Rio Grande above Leasburg Dam	RGabvLeasburg	--	--
4	Rio Grande below Leasburg Dam	RGblwLeasburg	08-3635.00	--
5	Rio Grande below Mesilla Dam	RGblwMesilla	RGBMES	--
6	Rio Grande at Anthony	RG At Anthony	--	--
7	Rio Grande at Courchesne Bridge (El Paso)	RGatCourchesneBridge	08-3640.00	1889 to present
8	Rio Grande below American Dam	RGblwAmericanDiversionDam	08-3650.00	1938 to present
9	Rio Grande at Fort Quitman	RG to Hudspeth	08-3705.00	1923 to present

6.3.1.6 Lower Rio Grande Municipal and Industrial Diversions

In the Mesilla valley, municipal returns from the City of Las Cruces to the Rio Grande are modeled. In the El Paso Valley, municipal diversions are modeled at Robertson Umbenhauer and Jonathon Rogers WTPs, and returns are modeled from the Canutillo area of El Paso, from Haskell WWTP, and from Bustamante WWTP. Between the months of March and October, 50% of the Haskell WWTP return is modeled as returning to the Riverside canal. Otherwise, Haskell WWTP returns to the Rio Grande. Municipal diversion and return data are sampled from a user-specified recent year of historical data.

6.3.2 Lower Rio Grande Groundwater System Hydrology

6.3.2.1 Lower Rio Grande Groundwater Storage Objects

Alluvial aquifers are represented by RiverWare Groundwater Storage Objects. Each Ground Water Object may be connected to adjacent Ground Water Objects, to an underlying deep aquifer, to an overlying river or drain, and may have multiple water users pumping from it. The basic structure of these Ground Water Objects is to have a single Ground Water Object under each of the irrigated subreaches, and a single Ground Water Object beneath the river, adjacent to the irrigated areas. In the model, beneath the irrigated areas of the Rincon, Leasburg, Mesilla, and El Paso basins, there are 5, 5, 11, and 3 Groundwater Storage Objects or "cells," respectively. Beneath the river, and adjacent to the irrigated areas of the Rincon, Leasburg, Mesilla, and El Paso basins, there are 4, 3, 6, and 3 Groundwater Storage Objects, respectively. On the Mexican side of the border, there are 3 Groundwater Storage Objects to represent groundwater fluxes across the border. There are also 2 Groundwater Storage Objects downstream of El Paso on the U. S. side, to represent groundwater fluxes into Hudspeth County, Texas.

6.3.2.2 Lower Rio Grande Aquifer Characteristics

Each of these Ground Water Objects has a specific yield, elevation, storage, and area. Specific yield is 0.2 and aquifer thickness is 100 feet for all Groundwater Storage Objects in the model. The hydraulic conductivity is a calibration parameter which varies by location. Flux between adjacent aquifer "cells" is based on head gradient and conductance. Conductance is computed based on hydraulic conductivity, anisotropy ratio (always 1.0), aquifer length, width, thickness, and deep aquifer depth.

6.3.2.3 Lower Rio Grande River Gains/Losses to Shallow Aquifer

River gains and losses to and from the underlying alluvial aquifer are computed based on a calibrated conductance value and the head gradient between the water surface elevation of each Reach Object (a function of bed elevation and stage) and the water surface elevation of the underlying alluvial Ground Water Object. Increases in river seepage caused by increases in aquifer pumping that draw down the aquifer levels are reflected by this method.

6.3.2.4 Lower Rio Grande Deep Aquifer Shallow Aquifer Interactions

Percolation from the shallower aquifer into a deep aquifer is modeled in the Rincon, Leasburg, and Mesilla areas. This percolation is based on a calibrated deep aquifer conductance and the head difference between the modeled shallow aquifer elevation and a deep aquifer elevation. The deep aquifer elevation is sampled from a recent year of modeled data from the NMOSE Groundwater Administration Model.

Conjunctive use and primary groundwater users in the Mesilla valley pump 60% of their pumping demand from the shallow aquifer and 40% from the deep aquifer. The deep aquifer is not explicitly modeled but is represented in the deep aquifer elevations imported from the NMOSE Groundwater Administration Model.

6.3.2.5 Lower Rio Grande Riparian Vegetation and Wetted Sands Depletion

Riparian vegetation evapotranspiration and wetted sand depletion is modeled at each of the under-river Groundwater Storage Objects mentioned in Section 6.3.2.1. The riparian evapotranspiration and wetted sand depletion is sampled from a recent year of modeled data from the NMOSE Groundwater Administration Model.

6.3.2.6 Lower Rio Grande Riverside Drains

Drain gains and losses to and from the underlying alluvial aquifer are computed based on a calibrated conductance term and the head gradient between the water surface elevation of each Drain Object (a function of bed elevation and stage) and the water surface elevation of the underlying alluvial Ground Water Object. Increases in drain seepage caused by increases in aquifer pumping that draw down the aquifer levels are reflected by this method.

This page intentionally left blank

7 References

Allen, R.G., 2008, REF-ET, Reference Evapotranspiration Calculator Version Windows 2.0, University of Idaho Research and Extension Center, Kimberly, Id. 82 p.

Allen, R.G., Pereira, L. S., Raes, D. and Smith M., (1998). "Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements." *Irrig. and Drain. Paper No. 56*, United Nations Food and Agriculture Organization, Rome, Italy, 300 pp.

Boroughs Ph.D., PE, Craig. URGWOM Accounting Model User Manual, version 3.1. September, 2010.

Colorado Water Conservation Board (CWCB), 2006. Rio Grande Basin, Statewide Water Supply Initiative Fact Sheet. Denver, Colorado.

Colorado Division of Water Resources (CDWR) and Colorado Water Conservation Board (CWCB). 2009. Colorado Decision Support Systems. Denver, Colorado. http://cdss.state.co.us/DNN/RioGrande/tabid/57/Default.aspx

Cotten, Craig. 2015. Personal email communication to Jesse Roach of Tetra Tech March 14, 2015.

Gensler, David, 2013. Personal communication with Nabil Shafike and Mike Roark during Middle Valley model calibration.

Hargreaves, George H and Samani, Zohrab A., Reference Crop Evapotranspiration from Temperature, Applied Engineering in Agriculture, 1985: 96-99.

Hawley, J. W., and Haase, C. S., Hydrogeologic framework of the northern Albuquerque Basin: Socorro, New Mexico Bureau of Mines and Mineral Resources Open-File Report 387, p. II-4, 1992.

Hydros Consulting, 2016. Soil Moisture Parameter Development in URGWOM. Technical Memorandum Prepared for the Corps of Engineers and the URGWOM Technical Team, March 16, 2016.

Johnson, A.I., 1967, Specific yield—Compilation of specific yields for various materials: U.S. Geological Survey Water-Supply Paper 1662-D, 74 p.

Keller Bliesner Engineering, 2011, Development of Pecan K_c Curve. Technical Memo, Aaron Buetler Author. Logan, Utah. April 21, 2011.

Kinzli, K., M. Martinez, R. Oad, A. Prior, and D. Gensler, 2010, Using an ADCP to Determine Canal Seepage Loss in an Irrigation District. Journal of Agriculture Water Management Vol. 97, PP. 801–810.

Lohman, S. W., 1972, Definitions of Selected Ground-Water Terms- Revisions and Conceptual Refinements, U.S. Geological Survey Water-supply Paper 1988, 25p.

McAda, D.P. and Barroll, P., 2002, Simulation of Ground-Water Flow in the Middle Rio Grande Basin between Cochiti and San Acacia, New Mexico. Water-Resources Investigation Report 02-4200, 81p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three-dimensional finite-difference ground-water model: Techniques of Water-Resources Investigations of the U.S. Geological Survey, book 6, chap. A1, 586 p.

New Mexico Water Resources Research Institute. 2017. "New Mexico Dynamic Statewide Water Budget Model", Las Cruces. https://nmwrri.nmsu.edu/category-blocks-swa/#DSWB.

Pacific Western Technologies, LTD, 2002. 2002 Cochiti to Elephant Butte Aggradation-Degradation Rangelines, Middle Rio Grande Project, Contract No. 1425-97-CA-40-2058B, Delivery Order No. 97E140058B with U.S. Bureau of Reclamation, Albuquerque Area Office, Albuquerque, New Mexico, 87110.

Roach, Jesse D. 2012. "Evapotranspiration Calculations in the Upper Rio Grande Simulation Model (URGSiM)", Albuquerque.

Roark, M., Anderholm, S., Louise, A., Neumann, D., and Shafike, N., Testing of RiverWare Salinity Methods with Groundwater/Surface water Interaction Using the URGWOM Middle Valley Simulation, February 2, 2017.

S.S. Papadopoulos & Associates, Inc., 2001. Field assessment of flow and seepage conditions along the Rio Grande and the low flow conveyance channel, San Acacia to Elephant Butte. Prepared for the New Mexico Interstate Stream Commission.

S.S. Papadopoulos & Associates, Inc., 2002. Assessment of Flow Conditions and Seepage on the Rio Grande and Adjacent Channels, Isleta to San Marcial, Summer 2001. Prepared for the New Mexico Interstate Stream Commission.

S.S. Papadopoulos and Associates, and New Mexico Interstate Stream Commission, 2006, Riparian Groundwater Models for the Middle Rio Grande: Endangered Species Act Collaborative Program FY04, 58 p.

S.S. Papadopoulos & Associates, Inc., 2007. October 2007 Albuquerque Seepage Study. Technical Memorandum to Nabil Shafike, NMISC, December 20, 2007.

Sammis, T. W., C. L. Mapel, D. G. Lugg, R. R. Lansford, and J. T. McGuckin., Evapotranspiration Crop Coefficients Predicted Using Growing-Degree-Days, Transactions of the ASAE. American Society of Agricultural Engineers, 1985: 773-780.

San Luis Valley Development Resources Group and San Luis Valley Council of Governments. 2015. “San Luis Valley Statistical Profile.” https://www.slvdrg.org/wp-content/uploads/2017/05/2015-SLV-Statistical-Profile.pdf.

Shafike, Nabil, 2005. Linked Surface Water and Groundwater Model for Socorro and San Marcial Basins between San Acacia and Elephant Butte Reservoir. Appendix J, Upper Rio Grande Water Operations Review DEIS. J-59 to J-94.

States of Arizona, Colorado, New Mexico, Utah, and Wyoming. 1948. Upper Colorado River Basin Compact. https://www.usbr.gov/lc/region/pao/pdfiles/ucbsnact.pdf Accessed March 26, 2018

States of Colorado, New Mexico, and Texas, 1939. Rio Grande Compact.

Tetra Tech, Inc, 2004, Development of the Middle Rio Grande FLO-2D flood routing model, Cochiti Dam to Elephant Butte Reservoir, Surface Water Group, Albuquerque, New Mexico: Prepared for the Bosque Initiative Group, U.S. Fish and Wildlife Service, and the U.S. Army Corps of Engineers.

Tetra Tech Inc. 2017. “URGWOM Ruleset Changes, Task 6.” Technical Memo, June 19, 2017.

Tetra Tech Inc. 2018. “2018-19 Task 2: URGWOM Model Development – Draft Memo, October 31, 2018.

URGWOM Technical Team, Draft Upper Rio Grande Water Operations Model Physical Model Documentation: Third Technical Review Committee Draft, Revised June, 2005.

URGWOM Technical Team, Technical Review Committee Draft, Middle Rio Grande Valley Physical Model Upgrades, October 14, 2010.

URGWOM Technical Team Middle Rio Grande Valley, Cochiti Dam to Elephant Butte Reservoir Physical Model Upgrades, Phase 3, October 1, 2014.

U.S. Bureau of Reclamation (Reclamation), 1997. Middle Rio Grande Water Assessment. Final Report and Supporting Documents Number 7 and 12. Albuquerque Area Office

U.S. Department of Agriculture Soil Conservation Service (USDA SCS), 1970. Irrigation water requirements. Technical Release no. 21. Technical Release, Washington D.C.

U.S. Fish and Wildlife Service, 2003. Biological and conference opinions on the effects of actions associated with the Programmatic Biological Assessment of Bureau of Reclamation's Water and River Maintenance Operations, Army Corps of Engineers Flood Control Operation, and Related Non-Federal Actions on the Middle Rio Grande, New Mexico. Consultation No. 2-22-03-F-0129. New Mexico Ecological Services Field Office, Albuquerque, New Mexico. https://www.fws.gov/southwest/es/NewMexico/documents/BO/2003-0129%20Middle%20Rio%20Grande%20Water%20Ops%20BO.pdf Accessed March 26, 2018.

U.S. Fish and Wildlife Service, 2016. Final Biological and Conference Opinion for Bureau of Reclamation, Bureau of Indian Affairs, and Non-Federal Water Management and Maintenance Activities on the Middle Rio Grande, New Mexico. Consultation No. 02ENNM00-2013-F-0033. New Mexico Ecological Services Field Office, Albuquerque, New Mexico. https://www.fws.gov/southwest/es/NewMexico/BO_MRG.cfm Accessed March 26, 2018.

Westfall, B. 2012, Draft EffPrecip Software Documentation and User Manual. EffPrecip Version 1.0.x. Keller-Bliesner Engineering, LLC. Logan, Utah.