D R A F T
Middle Rio Grande Valley
Cochiti Dam to Elephant Butte Reservoir
Physical Model Upgrades

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DESCRIPTION OF THE MIDDLE VALLEY PHYSICAL SYSTEM

The Middle Rio Grande Valley (Middle Valley) runs north to south through Central Ave. New Mexico from Cochiti Reservoir to the headwaters of Elephant Butte Reservoir, a distance of 180 miles (Figure 1). The valley is narrow with a maximum width of about five 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 farming that diverts 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 of fish and wildlife and is a common resource for communities in the region

The main conveyance system in the Middle Valley consists of the Rio Grande main stem (river), canals; riverside drains and the shallow groundwater systems. The following is a summary description of each component of the conveyance system.

River

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

Cochiti to San Felipe reach is a single unconfined straight channel in a broad alluvial valley without extensive urban developments. The channel width is about 400 ft and is stabilized by jetty jacks and most recently using riprap. The reach is considered mostly a gaining reach at low flow and losing reach at high flow (flow above 3000 cfs). Water diverted for irrigation at the top of this reach and return flows enter the reach at several waste ways. The reach length is 14.5 miles and is conceptually divided for groundwater simulation into two subreaches.

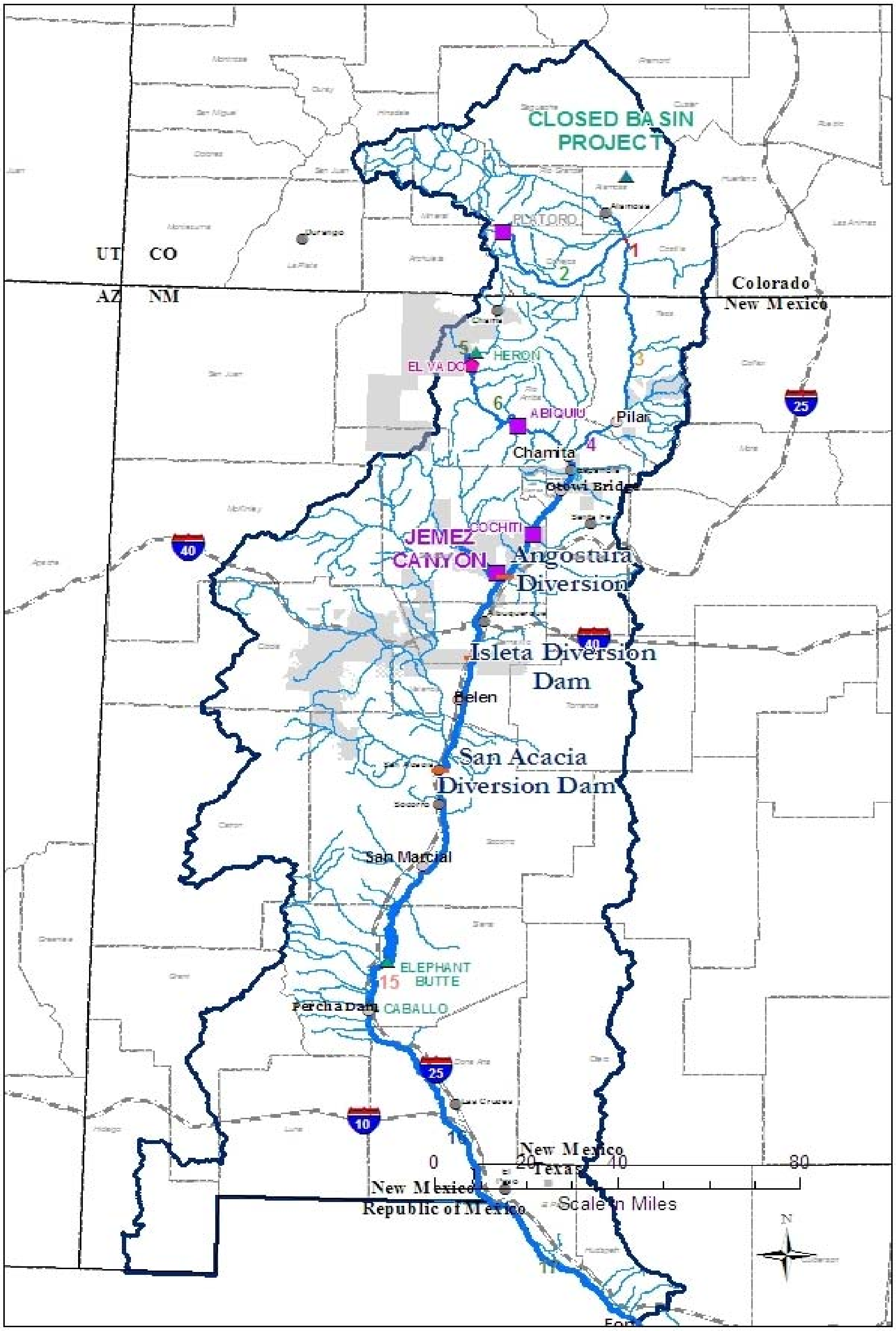


Figure 1. Map of Upper Rio Grande

San Felipe to Central Ave. river reach is a single relatively straight and braided channel with an average width of 600 ft. The channel is stabilized using jetty jacks and the flood plain is controlled by levees on the east and west. River seepage runs 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 irrigation return flow and monsoon storms. The reach length is 34.5 miles and is conceptually divided for groundwater simulation into four subreaches.

Central Ave. to Isleta Dam river reach is a single constraint channel with an average width of about 600 ft. The channel is constrained by levees on both sides and is a losing reach. The Albuquerque Bernalillo County Water Utility Authority (ABCWUA) returns sewage treatment plant effluent to the river in this reach. The length of this reach is 14 miles and is conceptually divided for groundwater simulation into two sub-reaches.

Isleta Dam to Bernardo is a single relatively braided channel with an average width of about 300 ft. The channel is constrained using jetty jacks and the flood plain is controlled by levees on both sides. River seepage runs indicates that this reach is a losing reach. This reach length is about 38 miles and is divided into five sub-reaches in the model conceptual design. At the top of this reach water is diverted for irrigation at Isleta Dam and several waste ways return excess irrigation water back to the river.

Bernardo to San Acacia reach is a single channel with an average width of about 600 ft. The channel is constrained using jetty jacks and the flood plain is controlled by levees mainly west of the river. River seepage runs 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 discharge to the surface. This reach is about 15 miles in length and was conceptualized as single reach in the model.

San Acacia to San Marcial reach is a single channel with an average width of 400 ft. 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 performed in this reach. Water is diverted at the top of the reach for irrigation and only one waste way can return irrigation water to the river at 9-Mile outfall. The reach length is 47 miles and is conceptually divided for groundwater simulation into 5 sub-reaches in the model.

San Marcial to Elephant Butte reach is single man made channel (pilot channel) that connects the river to the reservoir pool. It is mainly a straight channel about 150 ft wide.

Groundwater System

The groundwater in the Middle Valley occurs in the shallow aquifer near the river and a deeper regional aquifer. The shallow groundwater system represents the top 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 ft below the river bed to almost zero ft at the edges of the valley. Generally, the alluvial deposits are considered highly permeable with hydraulic conductivity rate varying from 5 ft/day to 325 ft/day and storage coefficients varying from 0.1 to 0.25 (McAda and Barroll, 2002). The shallow groundwater system is highly 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, p. II-4). The predominant basin deposit is the Santa Fe Group. The thickness of the Santa Fe Group ranges from about 3,000 to 4,000 ft along basin margins to greater than 14,000 ft in the center of the 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 discharges to the river channel or riverside drains or to riparian vegetation consumption. However, pumping of groundwater alters the flow lines and captures water that would have otherwise flowed toward a drain or river.

Irrigation Diversions

Surface water is the main source of irrigation water in the Middle Valley. In 1925, the State of New Mexico passed the Conservancy Act, which authorized creation of the Middle Rio Grande Conservancy District (MRGCD), which was accomplished by combining 79 independent acequia associations into a single entity. The main function of MRGCD is to divert and distribute water to farm land. The MRGCD diverts surface water at four locations on the Rio Grande: Cochiti, Angostura, Isleta and San Acacia diversion dams. Hence, MRGCD is organized into four divisions: Cochiti, Albuquerque, Belen and Socorro Divisions.

Table 1Table 1illustrates the gross annual diversion per each division since 1996. The following is a description of the supply for each division (Figure 2).

Table 1. MRGCD Gross Annual River Head Gate Diversions, acre-feet (Source: MRGCD)

Year	Cochiti	Angostura	Isleta	San Acacia	Total
1996	89,983	143,089	239,193	96,230	568,495
1997	N/A	N/A	N/A	N/A	N/A
1998	98,953	146,850	265,442	111,522	622,767
1999	95,424	120,627	230,558	117,812	564,421
2000	N/A	N/A	N/A	N/A	N/A
2001	95,000	122,160	232,720	30,720	480,600
2002	68,933	103,347	182,195	14,035	368,510
2003	58,766	86,792	173,861	14,500	333,919
2004	61,078	79,340	151,049	23,975	315,442
2005	66,514	76,998	192,733	29,493	365,738
2006	58,215	61,009	175,989	12,346	307,559
2007	56,636	85,179	204,905	19,113	365,833
2008	62,605	78,913	205,870	16,324	363,712
2009	60,290	82,303	205,217	16,797	364,606
Average	72,700	98,884	204,978	41,906	418,467
Average (2002 - 2009)	61,630	81,735	186,477	18,323	348,165

- Cochiti 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 acreages in Cochiti Division is about 5,000 acres, most of it is Pueblo land except the Pena Blanca area. Most recent average annual diversion for Cochiti Division is about 61,000 acre-feet (2002 to present). All excess water from the west side (Sili Main Canal) is returned to the river through intermediate waste ways (Seguro Waste way, 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 waste ways but the majority flows through Algodones Riverside Drain to Albuquerque Division.

- Albuquerque Division

Albuquerque Division extends from Angostura diversion dam to Isleta diversion dam. Two main canals distribute water in 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 Cochiti Division (Algodones Riverside Drain, Sana Ana Acequia and Algodones Lower Acequia). Average annual water supply to the division is about 102,000 acre-feet which include 82,000 af direct diversion at Angostura dam and about 20,000 acre-feet delivered to Albuquerque Main Canal from the east side of Cochiti Division. The irrigated area in Albuquerque Division varies between 6,000 to 10,000 acres including Pueblo land. Excess water returns to the river through several waste ways east and west of the river. However, excess water in Isleta Interior Drain and Isleta Riverside Drains (west of the river) can be directed to Belen Division during irrigation season.

- Belen Division

Belen Division is considered 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 Belen Division are direct diversion from the river at Isleta dam and the excess water from the west side of 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 there is one point of diversion, the Belen High Line Canal. Average annual direct diversion to the diversion is about 186,000 acre-feet in addition to about 25,000 acre-feet to 30,000 acre-feet flows from west side Albuquerque Division to west side Isleta Division. East of the river, all excess water returns to the river through numerous waste ways and on the west side some water returns to the river through intermediate waste ways, but the majority of the excess water flows to Socorro Division through Drain Unit 7.

- Socorro Division

Socorro Division extends from San Acacia diversion dam to the North Boundary of Bosque del Apache National Wildlife Refuge (NWR). Socorro Main Canal distributes water to all laterals in the division, which irrigate about 10,000 to 13,000 acres, all west of the river. Water supply for the division includes direct diversion from the river at San Acacia dam and excess water from west side of Belen 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 accounts for about 20,000 acre-feet. Excess irrigation water 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 LFCC, the main riverside drain in this division, or through the Elmendorf Drain outfall.

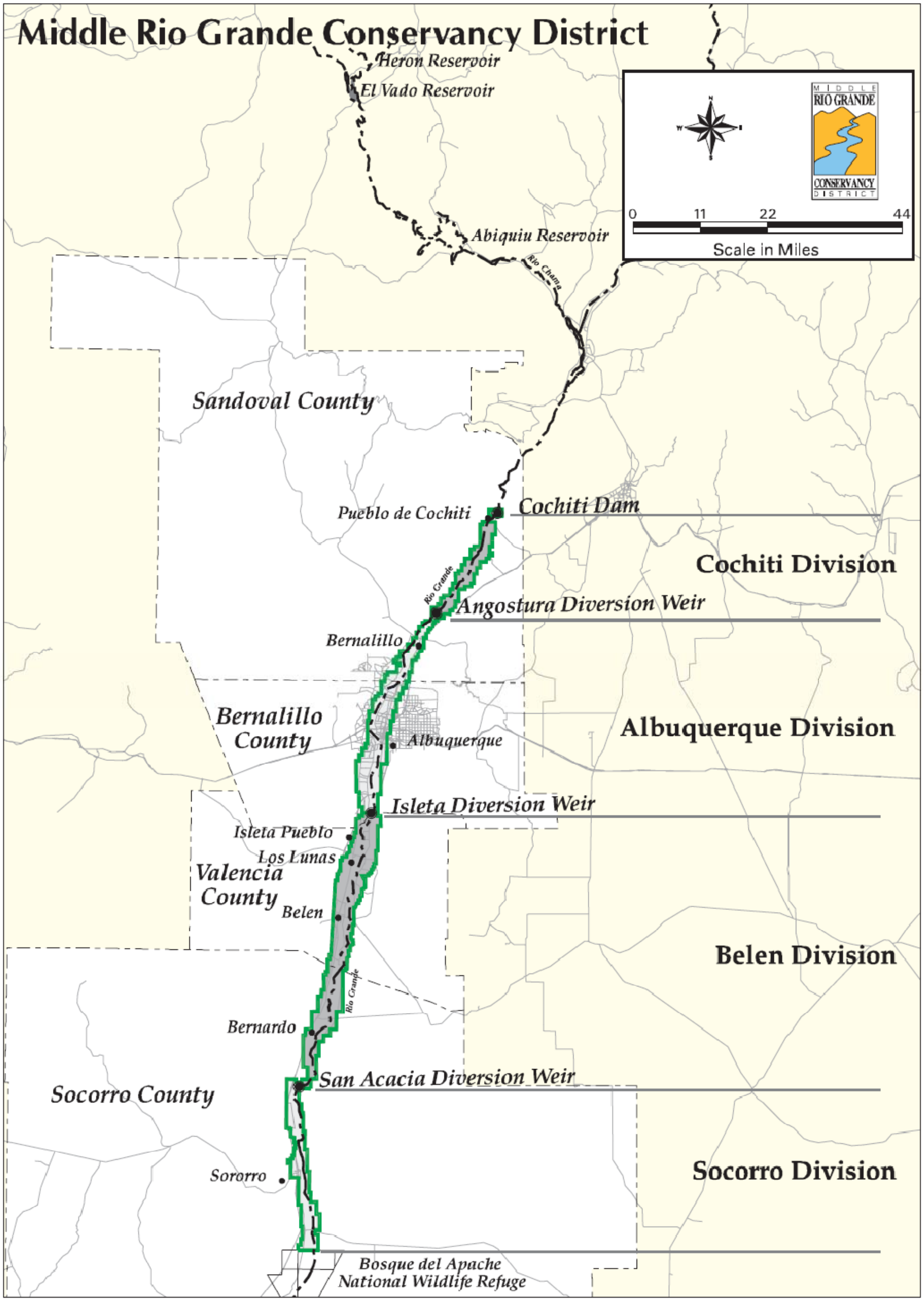


Figure 2. Map of Middle Rio Grande Conservancy District Divisions

Crop Lands

During the year 2000, the Middle Valley vegetation classification project was conducted by 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 infrared band). The project included field data collections during the time the satellite was capturing the images. A mix of supervised/unsupervised classification was used in vegetation classification process. Table 2 summarizes the results of the irrigated crop classification. (Strech and Mathews, 2000).

Table 2. Middle Valley total irrigated-crop acreage, 2000

	Crop Area, in acres												
Reach	Apples	Corn	Grapes	Nursery	Oats	Other Hay	Pasture	Peppers	Sorghum	Vegetables	Wheat	Alfalfa	Total
Below Cochiti to San Felipe	8	0	0	0	21	0	1,079	0	0	0	7	758	1,875
San Felipe to Central Ave.	117	137	2	100	0	697	4,256	88	0	81	3	1,076	6,559
Central Ave. to Isleta Dam	10	209	0	0	2	656	4,252	83	0	89	65	1,436	6,801
Isleta Dam to Bernardo	11	2,380	94	0	296	131	14,671	18	131	51	179	10,658	28,618
Bernardo to San Acacia	0	0	0	0	0	0	260	0	0	0	0	173	434
San Acacia to San Marcial	50	1,178	13	0	359	203	3,272	483	0	19	12	9,810	15,399
Total	195	3,904	109	100	679	1,688	27,790	672	131	240	267	23,911	59,685
% of Total	0.00	0.07	0.00	0.00	0.01	0.03	0.47	0.01	0.00	0.00	0.00	0.40	1.00

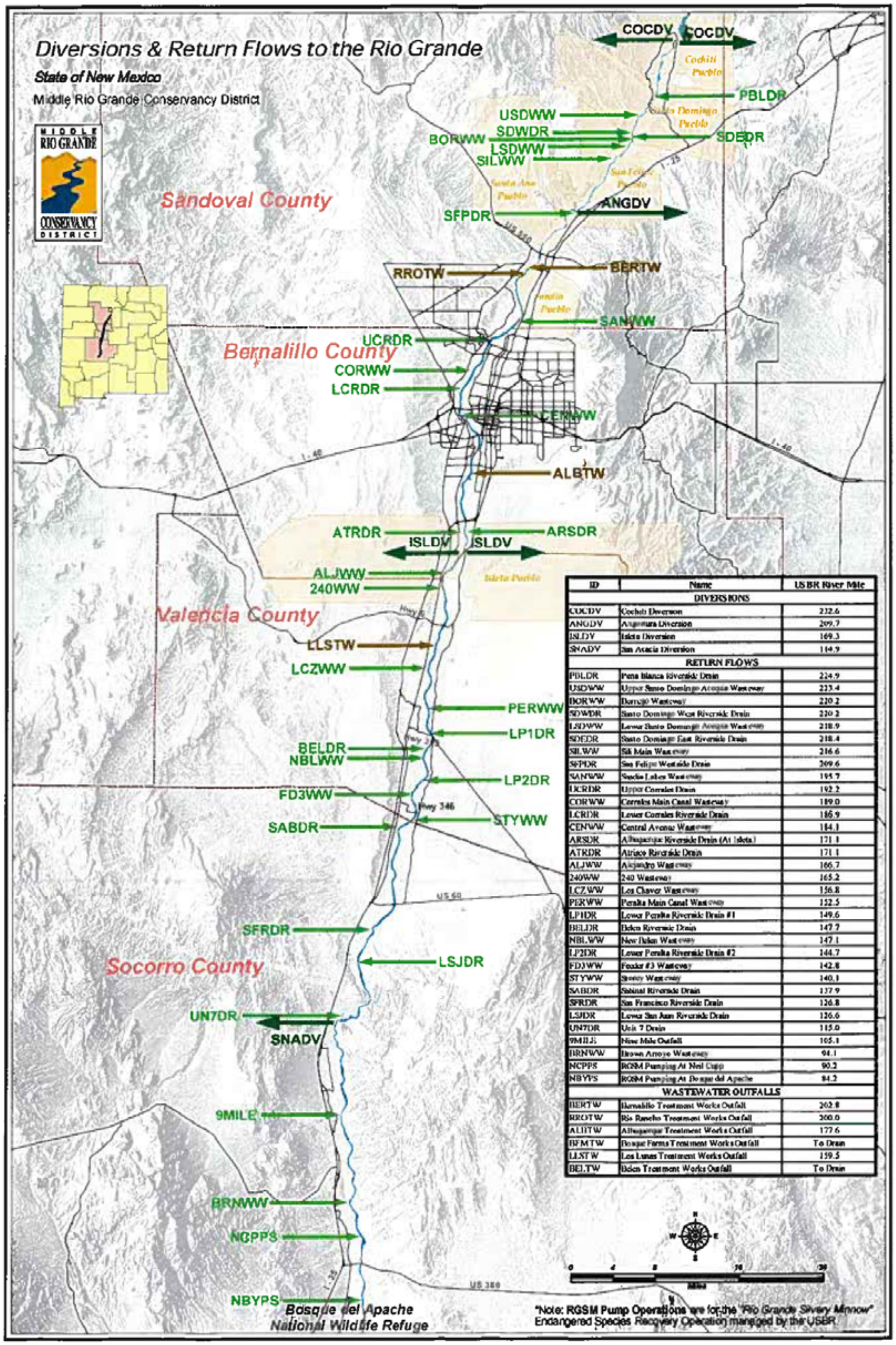


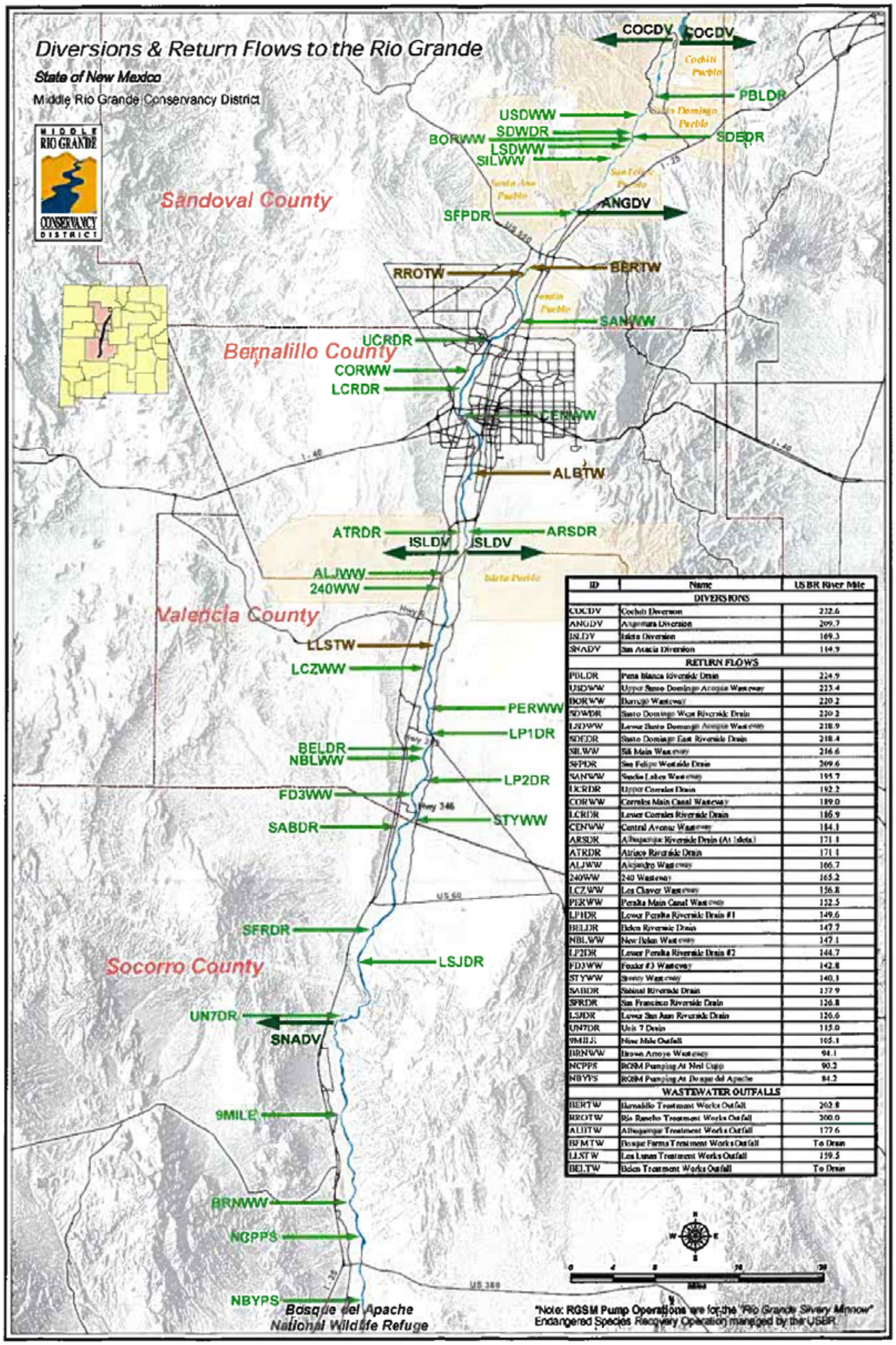
Figure 3). The canal system is designed to distribute the water to farms using gravity and therefore, most of the canals/laterals are above the water table. Seepage losses from canals/laterals are

either intercepted by internal drains or percolate to the water table. The most recent study by MRGCD indicated that canal seepage loss varies from 0.5 cfs/mile to 3.0 cfs/mile (Kinzli, 2009).

Riverside Drains

The riverside drains were rehabilitated and extended under the 1948 Flood Control Act which authorized the Bureau of Reclamation and the U.S. Army Corps of Engineers to construct levees and riverside drains and rehabilitate the MRGCD diversion and conveyance system. The main drains are constructed along side of the river to stabilize water table elevations and capture river seepage and during irrigation season to efficiently convey water through MRGCD divisions. The installation of these drains assisted in establishing the dense *bosque* area between the river and the riverside drains. 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 waste way locations, another overlap drain starts with its bed elevation below river bed and continues downstream.

These drains exist east and west of the river in 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 waste water to the river (except Drain Unit 7). Riverside drains are in direct connection with the shallow aquifer and interact with aquifer based on head difference and conductance.



ID	Name	USBR River Mile
	DIVERSIONS	
COCDV	Cochiti Diversion	232.6
ANGDV	Angostura Diversion	209.7
ISLDV	Isleta Diversion	169.3
SNADV	San Acacia Diversion	114.9
	RETURN FLOWS	
PBLDR	Pena Blanca Riverside Drain	224.9
USDWW	Upper Santo Domingo Acequia Wasteway	223.4
BORWW	Borrego Wasteway	220.2
SDWDR	Santo Domingo West Riverside Drain	220.2
LSDWW	Lower Santo Domingo Acequia Wasteway	218.9
SDEDR	Santo Domingo East Riverside Drain	218.4
SILWW	Sili Main Wasteway	216.6
SFPDR	San Felipe Westside Drain	209.6
SANWW	Sandia Lakes Wasteway	195.7
UCRDR	Upper Corrales Drain	192.2
CORWW	Corrales Main Canal Wasteway	189.0
LCRDR	Lower Corrales Riverside Drain	186.9
CENWW	Central Avenue Wasteway	184.1
ARSDR	Albuquerque Riverside Drain (At Isleta)	171.1
ATRDR	Atrisco Riverside Drain	171.1
ALJWW	Alejandro Wasteway	166.7
240WW	240 Wasteway	165.2
LCZWW	Los Chavez Wasteway	156.8
PERWW	Peralta Main Canal Wasteway	152.5
LP1DR	Lower Peralta Riverside Drain #1	149.6
BELDR	Belen Riverside Drain	147.7
NBLWW	New Belen Wasteway	147.1
LP2DR	Lower Peralta Riverside Drain #2	144.7
FD3WW	Feeder #3 Wasteway	142.8
STYWW	Storey Wasteway	140.1
SABDR	Sabinal Riverside Drain	137.9
SFRDR	San Francisco Riverside Drain	126.8
LSJDR	Lower San Juan Riverside Drain	126.6
UN7DR	Unit 7 Drain	115.0
9MILE	Nine Mile Outfall	105.1
BRNWW	Brown Arroyo Wasteway	94.1
NCPPS	RGSM Pumping At Neil Cupp	90.2
NBYPS	RGSM Pumping At Bosque del Apache	84.2
	WASTEWATER OUTFALLS	
BERTW	Bernalillo Treatment Works Outfall	202.8
RROTW	Rio Rancho Treatment Works Outfall	200.0
ALBTW	Albuquerque Treatment Works Outfall	177.6
BFMTW	Bosque Farms Treatment Works Outfall	To Drain
LLSTW	Los Lunas Treatment Works Outfall	159.5
BELTW	Belen Treatment Works Outfall	To Drain

Figure 3. Map of the Middle Rio Grande Conservancy District diversions and returns

SIMULATION OF MIDDLE VALLEY

The Middle Valley is defined for this model as river, the crop lands adjacent to the river and groundwater system near the river from Cochiti Lake to Elephant Butte Reservoir. The Rio Grande is influenced to a great extent by surface-water / groundwater interaction in the Middle Valley. The URGWOM set of models has been modified to directly simulate the influence of the groundwater system on the Rio Grande.

Changes to Setup of the 2009 Model from the Previous Model

The Middle Valley part of the 2005 URGWOM model was set up with a simplified approach because of the limitations in simulating the ground-water system at the time the model was developed. The surface water system simulated in the model consisted of the river, simulated by several reach objects, and all the rest of the surface water system simulated as one set of lumped stream reaches. The lumped stream reaches included all the drains, canals, and ditches for both the east and west side on the river. 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. The seepage calculations were completed in the reach objects and the groundwater system was not simulated. This approach gave good results in some cases when the flows in the river were near average but had some problems when there were extreme conditions.

The 2009 Middle Valley model uses a physical processes approach instead of using a statistical approach to simulating the interaction between the groundwater and surface-water systems. The groundwater system is actually 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 (Figure 4, Figure 5). The surface water system on the east and west side of the river are simulated separately because of the physical process approach. 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.

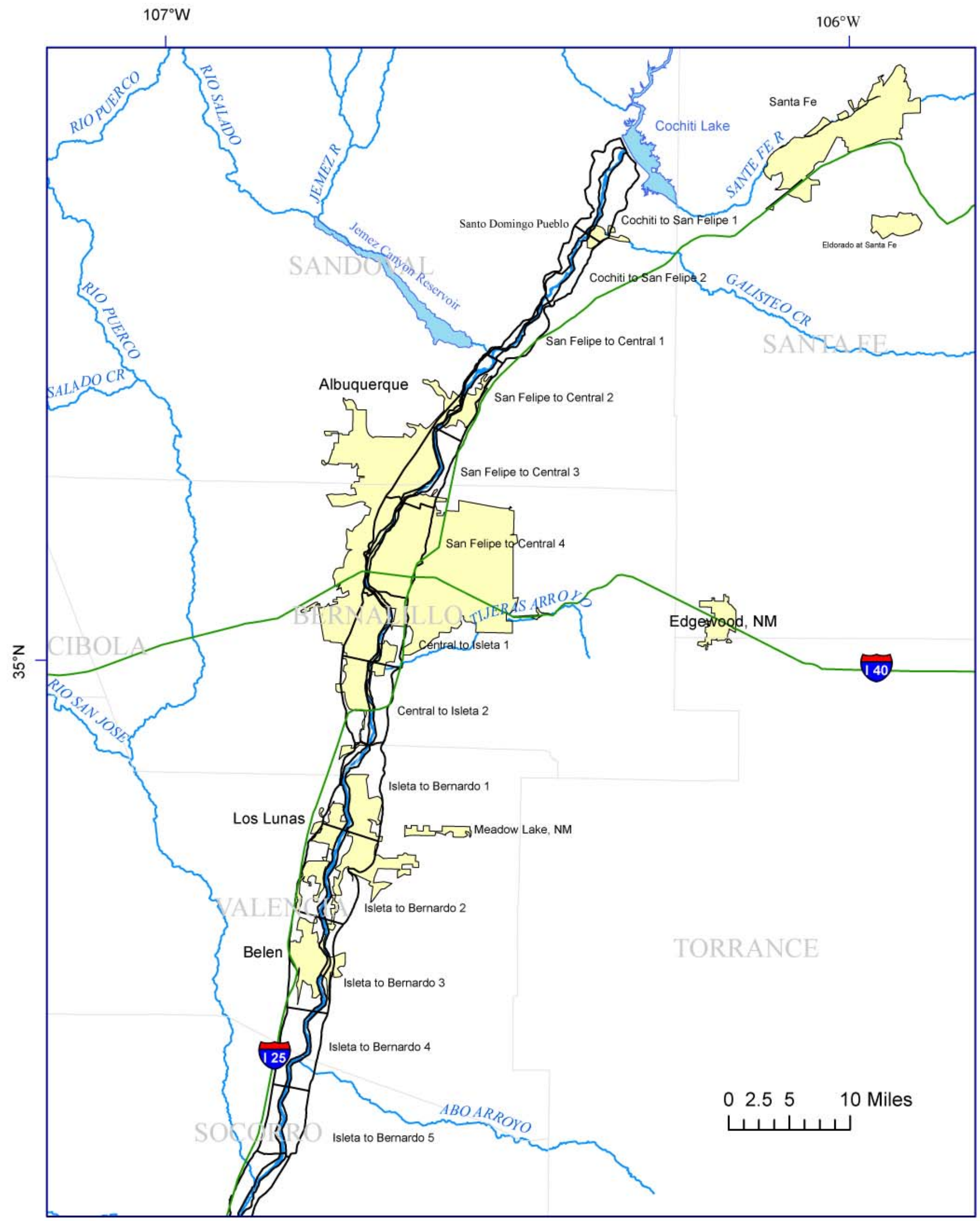


Figure 4. Diagram of simulated reaches and groundwater areas in the Middle Valley simulation (North).

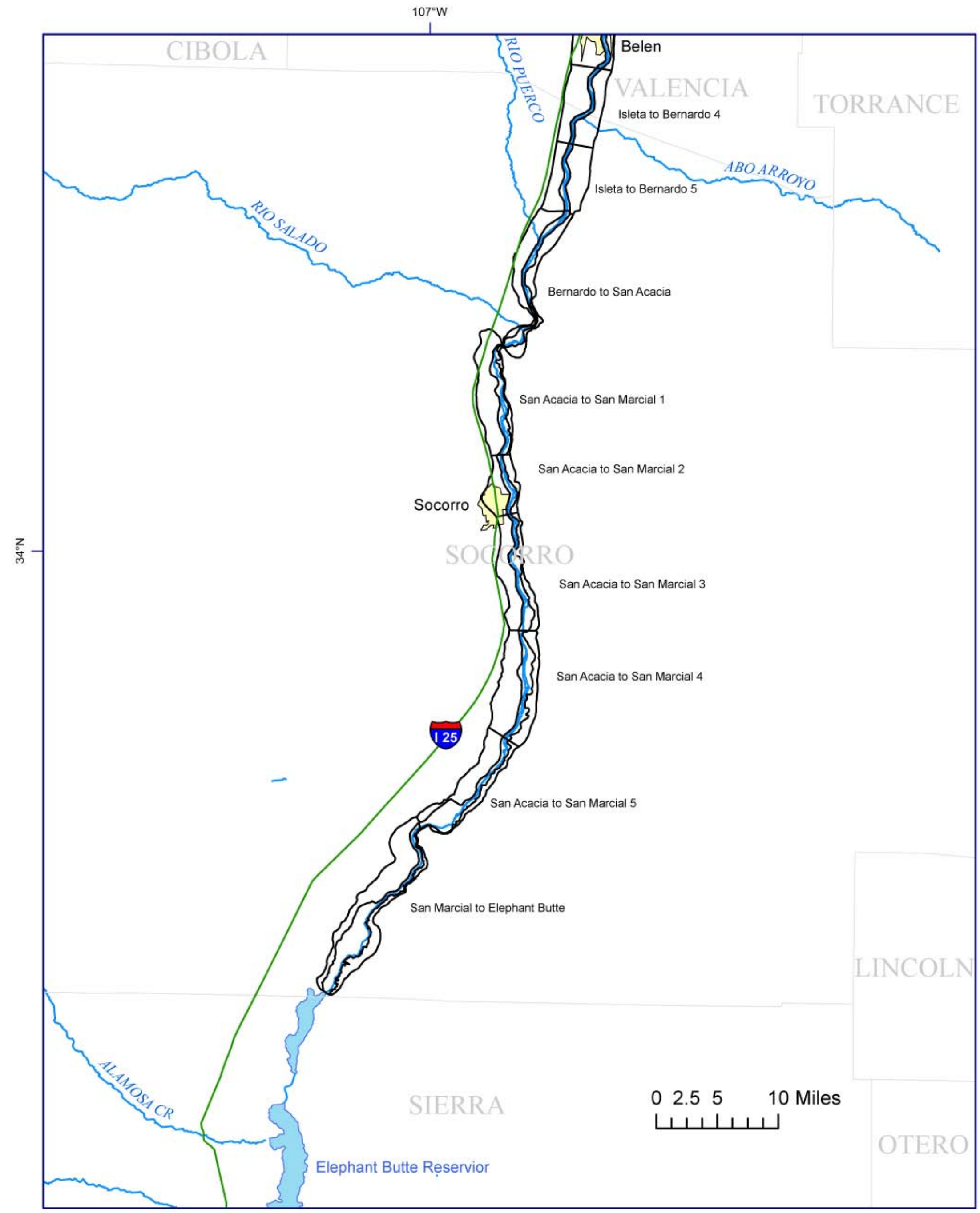


Figure 5. Diagram of simulated reaches and groundwater areas in the Middle Valley simulation (South).

River

In the 2009 Middle Valley model, the river system from Cochiti Dam to the gage at San Marcial is simulated with RiverWare reach objects that are linked directly to the groundwater system simulated by RiverWare groundwater objects to accomplish physical simulation of the surface-water/groundwater interaction through head-dependent flux calculations. There are several parameters of the river that are needed to stimulate head-dependent flux: the head (water surface elevation) in the river with discharge, the conductance of the riverbed, and the geometry of the river.

The reach from San Marcial was simulated differently than the rest of the river in the Middle Valley. It was assumed that any water seeping to or from the river would enter Elephant Butte Reservoir as surface water or groundwater or would be consumed as evapotranspiration (ET).

There are several other reach objects that simulate functions of the river system. The functions that are simulated by these reach objects are open-water and wetted-sand evaporation, river time lag, and diversions. RiverWare confluence objects or reach objects are used to simulate the section of the river where there is an inflow into the river system.

Physical Description of River Reach Boundaries

In the 2005 URGWOM model configuration, the Middle Valley was analyzed in 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 are referred to as “full cross sections” and provide calibration points for each canal and drain as well as the river.

In the 2009 Middle Valley model, with the addition of groundwater objects to accomplish surface-water/groundwater interaction physical modeling, the river reaches were broken up into sub-reaches whose reach length was determined by the length in the downstream direction of the groundwater objects. Analysis of the slope of the Rio Grande in the Middle Valley indicated that a reach length of six to 7 miles would be sufficient to adequately simulate the groundwater system in the surface-water/groundwater interaction. The boundaries of some of the reaches were adjusted to the location of gages or other physical structures in the river. There are nineteen simulated river reaches in the revised Middle Valley model.

The boundaries of river reaches were also determined by the location of the important features on the river. The river reach from San Felipe gage to the gage at Central Ave. Bridge was subdivided at the surface water diversion for the Albuquerque Bernalillo County Water Utility Authority to enable the simulation of the diversion. The river reach from the gage at Central Ave. Bridge to the gage near Bernardo was broken up at the Isleta diversion. The final location of the reach boundaries are shown in figure 1.

Calculation of River Gains or Losses to the Shallow Aquifer

There are two main factors that control the amount of seepage from the river, the head difference between the aquifer in the river, and the conductance of the river bottom. The simulation of flow from the river to or from the shallow aquifer is handled by the groundwater objects 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 model has reach objects linked to ground water storage objects to simulate the groundwater/surface-water 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 1 is used to calculate the seepage if the shallow aquifer head is higher than the stream bed.

$$Q_{str} = C \bullet (h_s - h_a) \quad (1)$$

where:

Q_{str} is seepage to or from stream , in ft^3/s

C is conductance, in ft^2/day

h_s is the head of the stream, in ft

h_a is the head of the shallow aquifer, in ft.

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 by equation 2.

$$Q_{str} = C \bullet (h_s - E) \quad (2)$$

where:

E is stream bed elevation, in ft

River Conductance

In the case of seepage to or from a stream the conductance of the stream bottom is used to calculate the flow. Conductance is the rate that a volume of material can transmit fluid. Conductance was initially calculated for each of the river reaches using equation 3. The conductance was then adjusted during the calibration process.

$$C = \frac{W_s \bullet L_s \bullet K_v}{T_{sb}} \tag{3}$$

Where:

C is conductance, in ft^2/day

W_s is stream width, in feet

L_s is stream length, in feet

K_v is vertical hydraulic conductivity, in feet/day

T_{sb} is stream bed thickness, in feet

The initial vertical hydraulic conductivity and the riverbed thickness were assumed to be 0.1 feet/day and 1 foot, respectively. The river width and length were determined in ArcGIS by tracing over the active river channel and determining the area of the polygon. The vertical hydraulic conductivity's were adjusted during the calibration process to simulate the proper amount of seepage. The final vertical hydraulic conductivity's and river conductance are listed in table 4.

Table 3. Vertical hydraulic conductivity and river conductance

Reach Object Name	Length (feet)	Width (feet)	Vertical Hydraulic Conductivity (feet/day)	Conductance (feet2/day)
Cochiti to San Felipe 1	44,250	437	0.11	2,130,000
Cochiti to San Felipe 2	37,050	459	0.10	1,700,000
San Felipe to Central Ave. 1	38,300	383	0.10	1,470,000
San Felipe to Central Ave. 2	42,600	523	0.10	2,230,000
San Felipe to Central Ave. 3	41,365	491	0.10	2,030,000
San Felipe to Central Ave. 4	45,680	512	0.10	2,340,000
Central Ave. to Isleta 1	35,666	250	0.10	890,000
Central Ave. to Isleta 2	37,923	480	0.01	180,000
Isleta to Bernardo 1	42,036	550	0.10	2,310,000
Isleta to Bernardo 2	41,518	585	0.10	2,430,000
Isleta to Bernardo 3	44,867	540	0.10	2,420,000
Isleta to Bernardo 4	39,504	430	0.10	1,700,000

Reach Object Name	Length (feet)	Width (feet)	Vertical Hydraulic Conductivity (feet/day)	Conductance (feet2/day)
Isleta to Bernardo 5	30,484	510	0.01	160,000
Bernardo to San Acacia 1	79,048	415	0.05	1,640,000
San Acacia To San Marcial 1	53,526	242	1.0	12,950,000
San Acacia To San Marcial 2	27,791	120	1.0	3,330,000
San Acacia To San Marcial 3	55,379	331	1.0	18,330,000
San Acacia To San Marcial 4	51,020	137	1.0	6,990,000
San Acacia To San Marcial 5	62,024	516	0.05	1,600,000
San Marcial to EB 1	46,785	180	0	340,000
San Marcial to EB 2	44,611	102	1.0	4,550,000

Streambed Elevation

The average riverbed elevations for each reach associated with a particular groundwater object were determined using the 2002 estimated riverbed elevations from the Aggregation / Degradation river cross sections survey by Reclamation (BOR, 2002), which were superimposed on the area of the groundwater 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. The same was done for the riverside drain bottom elevations. The average river elevation and drain bottom were adjusted during the calibration. The final simulated river reach object average elevations and east and west drain bottom elevations are listed in table 5

Table 4. River and drain average bottom elevations

Reach	Elevation (ft.) West Drain	Elevation (ft.) River	Elevation (ft.) East Drain
CochitiToSanFelipe-1	--	5,191.68	5,186.56
CochitiToSanFelipe-2	5,133.80	5,138.80	5,133.80
SanFelipeToCentral Ave.-1	5,068.40	5,094.23	5,088.00
SanFelipeToCentral Ave.-2	--	5,049.49	5,046.00
SanFelipeToCentral Ave.-3	4,995.00	5,010.74	4,995.00
SanFelipeToCentral Ave.-4	4,955.00	4,969.85	4,960.25
Central Ave.ToIsleta-1	4,910.00	4,931.50	4,910.00
Central Ave.ToIsleta-2	4,885.00	4,899.20	4,885.00
IsletaToBernardo-1	4,858.00	4,864.60	4,858.00
IsletaToBernardo-2	4,823.80	4,828.30	4,823.70
IsletaToBernardo-3	4,788.00	4,793.30	4,788.00

Reach	Elevation (ft.) West Drain	River	East Drain
IsletaToBernardo-4	4,756.00	4,761.80	4,756.00
IsletaToBernardo-5	4,730.20	4,732.20	4,730.00
BernardoToSanAcacia-1	4,692.70	4,687.80	4,697.90
SanAcaciaToSanMarcial-1	4,631.05	4,630.60	--
SanAcaciaToSanMarcial-2	4,591.20	4,597.90	--
SanAcaciaToSanMarcial-3	4,557.70	4,565.80	--
SanAcaciaToSanMarcial-4	4,516.70	4,527.00	--
SanAcaciaToSanMarcial-5	4,478.50	4,493.00	--

Upstream and Downstream Ratings

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 called in the simulation uses 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 (Eq. 2).

$$Q = \left(1.486/n\right) \bullet A \bullet R^{2/3} \bullet S^{1/2} \qquad (2)$$

Where:

Q is discharge, in feet^3/second

n is the Manning's Roughness Coefficient

A is the cross-sectional area, in feet^2

R is the hydraulic radius (cross-sectional area/wetted perimeter), in feet

S is the stream slope.

The width of the channel at each location was measured using aerial photography from 2002 at a flow of approximately 1000 ft^3/s. The values ranged from 175 ft to 600 ft. The Manning's roughness coefficient is 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.

Open-water Evaporation

The RiverWare method (Inflow Exponent Pan Evap) that was used in the 2005 version of the Middle Valley model to determine open-water and wetted-sand evaporation was also used in this version (2009). The current method in RiverWare for open-water and wetted sand evaporation take the evaporated water from the river which can cause negative flows in the river when there is zero flow in the river and much wetted sand. For this reason, the wetted sand component of the evaporation equation was set to zero in the current version of the Middle Valley model. A RiverWare reach object was placed at the most upstream part of each reach to simulate only the open-water evaporation for all of the reach that the equation applies.

The method for calculating open-water and wetted-sand evaporation is currently being changed 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. A full description of the current method of computing loss from wetted sands and water surface can be found in the URGWOM Physical Model Documentation, third Technical Review Committee Draft (June, 2005) at *http://www.spa.usace.army.mil/urgwom/documentation/Physical%20Model%20Documentation%20%28June,%202005%29%20%28PHYMOD%29.pdf*

Flow Routing and Timing

In the 2005 Middle Valley model, a variable time lag method was used to simulate the timing of river flows and the attenuation of peaks. In the 2009 version of the Middle Valley model "time lag" method is used. 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 reason for the use of the time lag method in the newer version of the Middle Valley model is a comparison of the two methods demonstrated that there was little difference in the result and that the run time of the model was reduced.

A separate reach object was used for time lag at the downstream end of the San Felipe to Central Ave. reach, Central Ave. 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 time lag, thus simulating a total of a three day time lag between Cochiti Dam and San Marcial.

Diversions from the Rio Grande

There are four diversions for irrigation in the Middle Valley, at Cochiti Dam, at Angostura, at Isleta Dam, 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 set by the rule set.

The other diversion from the Rio Grande in the Middle Valley is the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) drinking water diversion. The diversion is simulated using 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 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

Inflows to the Rio Grande

Water flows into the Rio Grande from tributaries, wastewater treatment plants, or return flows from the canal and drain systems.

Tributary Inflow

There are several tributaries to the Rio Grande simulated in the Middle Valley model. The simulated tributaries are all gaged streams. At this time no un-gaged streams are simulated, however, discharge from most of the drainage area to the Middle Valley is captured through the gage inflow. 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.

The Jemez River is simulated from the gage Jemez River at Jemez to the confluence with the Rio Grande. The Jemez River reach is 23.5 miles long. Inflow to this reach is recorded by the gage Jemez River near Jemez. Jemez Canyon Dam is in this reach near the confluence with the Rio Grande. Outflow from Jemez Canyon Dam is recorded by the gage Jemez River below Jemez Canyon Dam and is determined by rule simulation of reservoir operating criteria.

Waste Water Inflow

The second group of inflows is the water from wastewater treatment plants. These inflows are simulated using RiverWare data objects with the time series data for the reported flows. The data objects are linked to confluence objects simulating the confluence with the Rio Grande in the model. The wastewater treatment plants simulated as inflow in the model are the wastewater treatment plants for, Bernalillo, Rio Rancho, ABCWUA , Los Lunas, Belen, and Socorro.

Return Flows from the Canals and Drains

There are numerous inflows into the Rio Grande from canals and drains. In several areas of the Middle Valley the riverside drains and canals end and all of the water that is in the drain or canal flows into the river. The flow into the river is simulated as a link from the reach object simulating the canal or drain to either a confluence or reach object that simulated part of the river. See section on canals for information about the diversions to the river from canals and drains.

There are three pump stations located between San Acacia and San Marcial that pump water from the conveyance channel to the river during times of low flow as part of the RPA of the 2003 Biological Opinion. These pumps are simulated by diversion objects in the model. The amount diverted is set by the rule set.

Simulation of the River from San Marcial to Elephant Butte

The reach from San Marcial is different than the other river reaches in the Middle Valley because the amount of ET is of greater importance in simulating flow in the river than groundwater and surface-water interaction. Water from both the Rio Grande and the Low Flow Conveyance Channel were simulated as coming together into one river reach before entering the reservoir. The amount of riparian ET in the area between San Marcial and Elephant Butte Reservoir is a function of the riparian area, which varies depending on the elevation of the reservoir surface. The riparian ET is calculated using an expression (Figure 6) in the data object named "San Marcial to Elephant Butte Riparian Loss Calc". A look up table consisting of the riparian area and the reservoir elevation (Table 5) is used to calculate the riparian area.

Table 5. Look up table for Elephant Butte Reservoir elevation and riparian area

Reservoir Elevation (ft)	Riparian Area (acre)
4,246.7	19,694
4,316.7	19,694
4,326.7	18,777
4,336.7	17,365
4,346.7	17,083
4,356.7	14,677
4,366.7	13,961
4,376.7	11,176
4,386.7	9,446
4,396.7	7,016
4,406.7	5,011

The table relating reservoir elevation to riparian area was developed by calculating the area using GIS tools at several elevations. The pool elevation at Elephant Butte Reservoir uses a different datum than the National Geodetic Vertical Datum of 1929 (NGVD 1929). The elevation and riparian area table was developed from topographic maps that use NGVD 1929 so a -43.3 feet offset was used to correct the table to the datum used for the reservoir elevation.

The expression in the data object calculates the riparian ET from the product of the riparian area based on the reservoir elevation multiplied by the ET rate from the ET Tool Box, if the flow in the reach is greater than the riparian ET. If the Riparian ET is greater than the inflow, then the expression sets the ET equal to the reach inflow. The calculated ET is linked to the San Marcial to Elephant Butte reach object's return flow slot as a negative value thus removing water from the reach.

Figure 6. Expression for Calculating Riparian ET

```
IF ( ( SanMarcialToElephantButteRiparianLossCalc.ETRate [ ]
       * TableInterpolation ( SanMarcialToElephantButteRiparianLossCalc.RiparianAreaReservoirElevationTable ,
                              0.00000000 ,
                              1.00000000 ,
                              ElephantButteReservoir.ReserviorElevation [ @"t - 1" ] ,
                              @"t" ) )
     <= SanMarcialConfluenceToElephantButte.Inflow [ ] ) THEN
   ( SanMarcialToElephantButteRiparianLossCalc.ETRate [ ]
     * TableInterpolation ( SanMarcialToElephantButteRiparianLossCalc.RiparianAreaReservoirElevationTable ,
                            0.00000000 ,
                            1.00000000 ,
                            ElephantButteReservoir.ReserviorElevation [ @"t - 1" ] ,
                            @"t" ) )
   * - 1.00000000
ELSE
   SanMarcialConfluenceToElephantButte.Inflow [ ]
   * - 1.00000000
ENDIF
```

Riverside Drains

In the 2005 model of the Middle Valley the riverside drains physically located on both sides of the river were stimulated as one lumped reach along with the canals. In the 2009 version of the Middle Valley model the riverside drains are simulated separately from the rest of the canal/drain system because of their close proximity to the river and their close interaction with the river through the shallow groundwater system. In the revised Middle Valley model the riverside drains, simulated with RiverWare reach objects, are linked directly to the groundwater storage object under the river to accomplish physical simulation of the surface-water/groundwater interaction. The links 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. The same parameters as the river system are needed to stimulate head-dependent flux in the riverside drains, the head (water surface elevation) in the drain with discharge, the conductance of the drain bed, and the geometry of the drain channel cross section.

Physical Description of Riverside Drain Boundaries

In the 2005 version of the Middle Valley model, the gains and losses of riverside drains were lumped in with all gains and losses to the groundwater system except for the loss from canals. The riverside drains are an important component in the groundwater and surface water interactions. In an effort to physically simulate the interaction between the surface water and groundwater system, the drains on the east and west side of the Rio Grande are simulated independently.

As with the river reaches, the length of each one of the drain reaches is determined by the upstream downstream length of the groundwater object to which drain is linked if the drain is continuous through several groundwater 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.

Calculation of Drain Gains or Losses to the Shallow Aquifer

As in the river, 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 of the drain and the conductance of the river bottom. The simulation of flow from the drain to or from the shallow aquifer is handled by the groundwater objects the same way as in the River Package of the groundwater model, MODFLOW (McDonald and Harbaugh, 1988), all of the seepage is through the bottom of the drain channel.

The seepage is calculated two ways, depending on the elevation difference between the shallow aquifer head and the stream bed elevation. As in the river seepage, equation 1 is used to calculate the seepage if the shallow aquifer head is higher than the drain bed. In the case where the shallow aquifer head is below the bottom of the drain bed the vertical flow from the river to the aquifer is calculated by equation 2.

Drain Conductance

The conductance for each drain was determined just as the conductance for the river reaches using equation 1. The vertical hydraulic conductivity and the drain bed thickness were assumed to 0.1 ft/d and 1 ft, respectively. The drain width was assumed to be 25 ft (bottom width) and the drain length was calculated in ArcGIS for the total length of riverside drain in the area simulated by the groundwater object. The drain conductance and other hydraulic properties for the east side drains are listed in Table 6 and for the west side drains are listed in Table 7.

Table 6. East riverside drain groundwater hydraulic properties

GW Object Polygon	Drain Length (feet)	Upstream Drain Width (feet)	Drain Conductance	Hydraulic Conductivity (ft/day)
Cochiti to San Felipe 1	33,288	25	165,800	0.199
Cochiti to San Felipe 2	27,083	25	135,400	0.200
San Felipe to Central Ave. 1	27,666	25	207,500	0.300
San Felipe to Central Ave. 2	41,295	25	309,700	0.300
San Felipe to Central Ave. 3	42,118	25	421,200	0.400
San Felipe to Central Ave. 4	45,182	25	158,100	0.140
Central Ave. to Isleta 1	35,896	25	164,740	0.184
Central Ave. to Isleta 2	38,031	25	246,550	0.259
Isleta to Bernardo 1	43,555	25	148,875	0.137
Isleta to Bernardo 2	41,810	25	404,525	0.387
Isleta to Bernardo 3	43,522	25	808,805	0.743
Isleta to Bernardo 4	39,245	25	728,100	0.742
Isleta to Bernardo 5	31,068	25	326,700	0.421
Bernardo to San Acacia 1	46,385	25	1,159,600	1.000

Table 7. West riverside drain groundwater hydraulic properties

GW Object Polygon	Drain Length (feet)	Upstream Drain Width (feet)	Drain Conductance	Hydraulic Conductivity (ft/day)
Cochiti to San Felipe 1	0	25	0	--
Cochiti to San Felipe 2	17,446	25	130,800	0.300
San Felipe to Central Ave. 1	8,931	25	67,000	0.300
San Felipe to Central Ave. 2	0	25	0	--
San Felipe to Central Ave. 3	38,116	25	476,500	0.500
San Felipe to Central Ave. 4	27,758	25	347,000	0.500
Central Ave. to Isleta 1	34,590	25	326,475	0.378
Central Ave. to Isleta 2	37,007	25	362,518	0.392
Isleta to Bernardo 1	43,591	25	164,750	0.151
Isleta to Bernardo 2	41,931	25	445,175	0.425
Isleta to Bernardo 3	45,969	25	649,775	0.565
Isleta to Bernardo 4	39,209	25	645,250	0.658
Isleta to Bernardo 5	30,809	25	440,500	0.572
Bernardo to San Acacia 1	80,310	25	115,963	0.058
San Acacia To San Marcial 1	51,391	25	128,478	0.100
San Acacia To San Marcial 2	27,128	25	6,782,000	10.000
San Acacia To San Marcial 3	54,040	25	465,100	0.344
San Acacia To San Marcial 4	49,160	25	614,500	0.500
San Acacia To San Marcial 5	58,828	25	160,000	0.109

Average Drain Bed Elevation

The upstream and downstream elevations were determined based on the values used in the Upper Albuquerque Basin Riparian Model (S.S. Papadapolos 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 object. Table 4 shows the final riverside drain average bed elevations.

Upstream and Downstream Ratings

Theoretical ratings curves were developed for the drains at the upstream and downstream end of each groundwater object. The curves were developed using Manning's equation (equation 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 the each of the riverside drain reach object's Inflow and Outflow Stage table.

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. The inflows to the drains are simulated by diversion objects. The amount of inflow to the drain is determined in the diversion object as a percentage of the flow in the canal reach object that the diversion object is connected. 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 determined from historic practice (MRGCD personnel).

Groundwater System

The model has a physically based groundwater component to better simulate the losses and gains to the river. The shallow groundwater system (upper 80 feet) is simulated by RiverWare groundwater objects in the model with head dependent flux between groundwater objects and the river, drains other groundwater objects, and the deep aquifer.

Discretization of the Groundwater System

The simulation of the shallow groundwater system was completed using a course horizontal discretization. As stated in the previous section "Discretization of the River", the river reaches were broken up into smaller reaches whose reach length was determined by the length in the downstream direction of the groundwater objects. The assumptions used in determining the reach lengths are also discussed in that section.

In each reach, a set of three groundwater objects were used to simulate the river and the surrounding irrigated areas. The east-west boundaries of the groundwater objects were determined from aerial photography and the MRGCD conveyance system. The boundaries of the groundwater 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 objects that were to the east and west of the river, one boundary was the boundary of the river groundwater 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 objects are shown in Figure 4 and Figure 5.

Figure 5There 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 part of the aquifer in the daily timescale simulated in the URGWOM and the deep aquifer interaction with the river occurs over far longer time periods. The shallow aquifer (upper 80 feet) was simulated with groundwater objects.

Aquifer Storage

Aquifer storage is the volume of water an aquifer can yield to pumping. The groundwater objects have two inputs related to storage, specific yield and initial aquifer storage. The shallow aquifer simulated by the groundwater objects was assumed to be unconfined. The storage term for unconfined aquifers is specific yield. The specific yield is defined by Lohman and others (1972), "In the natural environment, specific yield is generally observed 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". The specific yield used for all of the groundwater objects is 0.20. 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 value of 0.20 is an average for the basin fill of the shallow aquifer.

Initial aquifer storage at the first time step of each model run is needed on each of the groundwater objects. An initial storage was calculated for each groundwater object from the aquifer cell area, the aquifer thickness, and the specific yield using equation 15.

$$S_i = A_c \bullet T \bullet Sy \qquad (15)$$

Where:

S_i initial storage, in acre-ft

A_c aquifer cell area, in ft2

T aquifer thickness, in ft

Sy specific yield

Initial Shallow Aquifer Heads and Deep Aquifer Head Time Series

Initial shallow and deep aquifer heads for each groundwater object were extracted from the Albuquerque Basin Model (McAda and Barroll, 2002). The areas simulated by each groundwater object were intersected with the Albuquerque Basin Model finite difference grid, and all nodes located within a groundwater object were extracted. These head values at each node were averaged to develop the average head for a given groundwater object. The last time step from the model (December 1999) was used for the initial head for each shallow groundwater object's Elevation slot.

Since the groundwater objects simulate the shallow aquifer, a deep aquifer interaction was simulated using the differences in the heads between the shallow and deep aquifers. The head for the deep aquifer is an input time series for each groundwater object. The deep aquifer heads were taken from the model runs of the Albuquerque Basin Model. The average head at the end of each stress period for the area of each groundwater object was selected for input into the Middle Valley model. This head data is used in the groundwater object's Deep Aquifer Elevation slot.

Groundwater horizontal conductance

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

Conductance for each face of the shallow groundwater objects was determined using equation 16.

$$C_h = \frac{l_f \bullet t_s \bullet k}{l_c} \qquad (16)$$

Where:

C_h is horizontal conductance, in ft^2/d,

l_f is face length, in ft,

t_s is saturated thickness, in ft,

k is horizontal hydraulic conductivity, in ft/d,

l_c is length between centroids of groundwater objects, in ft.

The values for face length and the distance from the centroid of the groundwater object to the corresponding object were determined in ArcGIS. The initial horizontal hydraulic conductivity was assumed to be 1 ft/day. The saturated thickness was assumed to be 80 ft. In order to maintain mass balance, the conductance between cells must match in each of the two groundwater objects for the interacting face direction, as it represents the average properties between the two centroids of each cell. Table 10, at the back of the report, lists the horizontal conductance and hydraulic properties of the groundwater objects.

Vertical conductance between shallow and deep aquifers

In order to simulate interactions of the shallow aquifer with the regional aquifer, shallow groundwater objects are able to interact with deep groundwater objects. The deep groundwater objects act as variable head boundaries, and thus represent infinite reservoirs. Fluxes between the two objects are computed for each time step based on the head difference between the shallow and deep groundwater objects and the conductance. The head values for the deep groundwater objects were extracted from layer 4 of the Albuquerque Basin Model (see below), and are assumed to represent average conditions for each deep groundwater object. Similar to the above equation used to compute horizontal conductance, the vertical conductance is computed using equation 17.

$$C_v = \frac{A \bullet k}{l_c} \qquad (17)$$

where:

Cv is vertical conductance, in ft^2/d,

A is groundwater object simulated area ft^2.

In this case the distance between centroids is the distance from the center of the groundwater object (40 ft based on an estimated saturated thickness of 80 ft) and the elevation of the finite difference node from layer 4 of the Albuquerque Basin Model (310 ft below ground surface). Therefore, the vertical distance was estimated to be 270 ft. The vertical hydraulic conductivity was estimated as 0.1 ft/day. The area for each groundwater object was determined in ArcGIS. Table 11 at the back of the report lists the vertical conductance and hydraulic properties.

Bosque Evapotranspiration

The riparian area for each groundwater object was determined by subtracting the area of the active river channel polygon from the groundwater object polygon associated with the river (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 object and was multiplied by the total evapotranspiration for the entire reach, as computed by the ET Toolbox (BOR, 2004). Riparian evapotranspiration was simulated in the groundwater objects simulating the area beneath the river.

Crop lands

A major component of water use in the Middle Valley is the crop consumptive use. The model simulates the crops consumptive use using an aggregate diversion site object with an element for each of the areas that is simulated by one of the east and west groundwater objects. All of the calculations are done in each of the elements. Each element uses data for crop ET rate, crop area and farm efficiency to determine the volume of crop ET, surface water return flow and groundwater return flow.

Crop ET data

Each element representing an area of cropland has the slot “Evaporation Rate By Crop”. The slot is a multi-slot that has daily ET rate data for each of the crops in the Middle Valley in inches per day. The crop ET rate data used in the model is from the ET Toolbox (BOR, 2004).

Crop Area data

Each element representing an area of cropland has the slot “Irrigated Area By Crop”. The slot is a multi-slot that has crop area data for each of the crops in the Middle Valley in acres. The crop area in the Middle Valley changes over time due to crop pricing and other factors. All of the different crop areas were included in the model to keep flexibility in the simulation of the effects of changing the distribution of crops on the riverside drains and the river.

Farm Efficiency

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 all the objects

Groundwater return flow

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. The USBR (1997, supporting document 7) analyzed soil texture and permeability in the Middle Rio Grande Valley. Deep percolation rates for soil series and crop types range from 0.10 to 1.22 ft/yr in that document.

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 percent. The groundwater return water for each water user goes to the groundwater storage objects associated with the area of the water user by a links (shown below) between the water user in the aggregate diversion object and the groundwater storage object

groundwater storage object		aggregate diversion site object
Inflow From Surface Water	↔	GW Return Flow

Surface-water 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.

Canal System

In the 2005 model of the Middle Valley, the canal system physically located on both sides of the river were stimulated as one lumped reach along with the drains. In the 2009 version of the Middle Valley model, the canal system is simulated separately from the rest of the drain system because of the different type of interaction with the groundwater system. The canal system in most of the Middle Valley is not directly connected to the groundwater system. All of the irrigation conveyance, by both the canal system and the drains, is simulated by the simulated lumped canal system in RiverWare.

Canal Inflows

In the new 2009 Middle Valley Model, 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.

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 several 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.

Water not used by the crop or that has leaked to the groundwater system is returned to the canal system. The total unused water slot in the aggregate diversion object that is simulating the irrigated crop land is linked to the return flow slot in the aggregate distribution canal objects.

Canal Outflow

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.

Diversion to croplands

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 a 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. 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 canals or drains

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 percent.

Just upstream of the Central Ave. Bridge on the Atrisco Riverside Drain (Atrisco Feeder) is a return flow to the river that is complex. Water is taken from the end of Atrisco Riverside drain and is diverted into one of three directions, 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 a expression slot in the data object " Central Ave. Wasteway Calc". The logic for the amount of water that is diverted to the Albuquerque Riverside Drain is:

```
IF ( @"t" >= @"March 15" AND @"t" <= @"October 15" ) THEN
   IF ( AngosturaEastSideAgDepletionsCanal.Total Outflow [ ] >= 180.00000000 "cfs" ) THEN
      60.00000000 "cfs"
   ELSE
      AngosturaEastSideAgDepletionsCanal.Total Outflow [ ] * 0.33000000
   ENDIF
ELSE
   AngosturaEastSideAgDepletionsCanal.Total Outflow [ ] * 0.00000000
ENDIF
```

The symbol [ ] indicates current timestep in the model. The logic for the amount of water that is diverted to the Atrisco siphon is:

```
IF ( @"t" >= @"March 15" AND @"t" <= @"October 15" ) THEN
   IF ( AngosturaEastSideAgDepletionsCanal.Total Outflow [ ] >= 180.00000000 "cfs" ) THEN
      120.00000000 "cfs"
   ELSE
      AngosturaEastSideAgDepletionsCanal.Total Outflow [ ] * 0.67000000
   ENDIF
ELSE
   AngosturaEastSideAgDepletionsCanal.Total Outflow [ ] * 0.00000000
ENDIF
```

Water returned to the river

Water is returned from the canal system to the river either at the end of a canal or by diverting water to the river. In the Middle Valley there are wasteways and returns that return a portion of the flow in a canal or drain back to the Rio Grande. Not all waste ways are represented in the model, only main waste ways 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 use to simulate the diversion of water from each canal or drain to the river. The determination of the flow return to the river 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 constant percentage. The percent of available flow for each of the returns is shown in Table 8. The percent of flow was determined from discussions with David Gensler (MRGCD). On the east side of Albuquerque Division, water returns to the river if there is above 180 cfs in Atrisco Riverside Drain and the rest of the water is distributed between Atrisco Siphon and Albuquerque River Side Drain.

Table 8. Percent diverted from canals and drains to the Rio Grande

Diversion Object	Percent to Divert
Upper Corrales Wasteway	75
Atrisco Drain Outfall	40
Isleta to Bernardo Area 1 Wasteway	2
Isleta to Bernardo Area 3 East Wasteway	20
Isleta to Bernardo Area 3 West Wasteway	40
Drain Unit 7 Wasteway	0
Nine Mile Wasteway	100

The amount of water returned to the river at the head of the Atrisco Siphon is the remainder of the water in the conveyance system after water has been diverted into the Albuquerque Riverside Drain, or into the Atrisco Siphon.

Canal seepage

Main factors that affect the rate of canal seepage are soil hydraulic properties, canal shape and slope, and depth to water table. In the Middle Rio Grande valley most of the canals are earth lined and with its bed above water table. Several studies were conducted to estimate seepage rates of the canal system. Reclamation (1975 and 1993) estimated that canal loss varies from 0.2 to 0.4 cfs/mile of canal. A more recent study (Kinzli, 2009), using ADCP measurements, estimated that canals loss varies from 0.5 to 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 object. Canal seepage was assumed to occur during the irrigation season (March 1 – October 31).

In the model the canal seepage is simulated using an aggregate distribution canal object at the most upstream of 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 objects that simulate the groundwater in the area that the canal serves. The link from the canal system to a groundwater 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 object. The Seepage Flow fraction for each sub reach is shown in Table 9.

Table 9. Final seepage flow fraction values used for canal seepage

Canal System	Seepage Flow Fraction (Percent)
CochitiToSanFelipe- East	14
CochitiToSanFelipe- West	14
SanFelipeToCentral Ave.-East	4
SanFelipeToCentral Ave.-West	4
Central Ave.ToIsleta-East	3
Central Ave.ToIsleta-West	3
IsletaToBernardo-East	2
IsletaToBernardo-West	7
BernardoToSanAcacia-East	2
BernardoToSanAcacia-West	2
SanAcaciaToSanMarcial-West	2

MIDDLE VALLEY CALIBRATION

Model calibration was performed to the Middle Valley portion of the model. During the calibration process selected model parameters were adjusted to minimize the difference between observed and simulated flow at gage locations. Model parameters that were allowed to change are vertical hydraulic conductivities of river bed, aquifer's horizontal hydraulic conductivity, vertical conductance between shallow and deep aquifers and canal seepage percentage. The model was calibrated to river seepage, flow at gage locations and total surface water depletion. The model was calibrated against the historical period from 1990 to 2000; additional calibration was done during 2009 which extended the calibration period to 2007.

The difference between the observed gage flow and the simulated flow at San Felipe, Albuquerque, San Acacia and San Marcial are illustrated in Figures 7 to 10. Under ideal conditions the residual should be zero, however, due to the lack of consistent water operations and ignoring un-gaged tributary inflows, the residual may be above or below zero. In addition, the error between measured and simulated flow includes measurement error. It is clear from the residual figures that the model tends to overestimate the simulated flow at the San Felipe, Albuquerque and San Marcial gages and under estimate the flow at San Acacia gage.

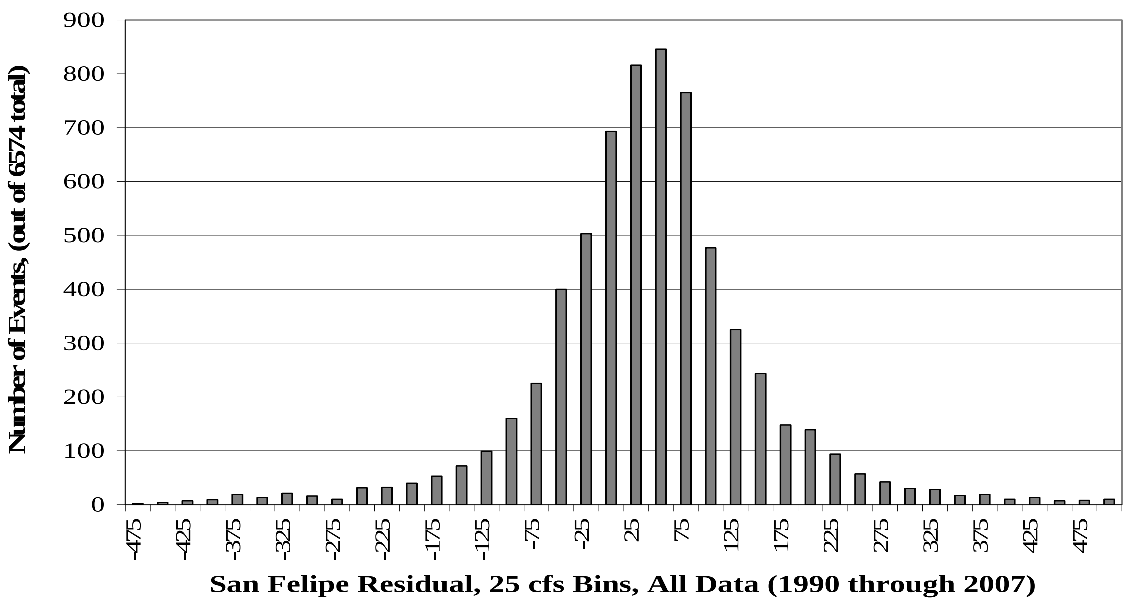


Figure 7. Residual of observed gage flow and the simulated flow at San Felipe.

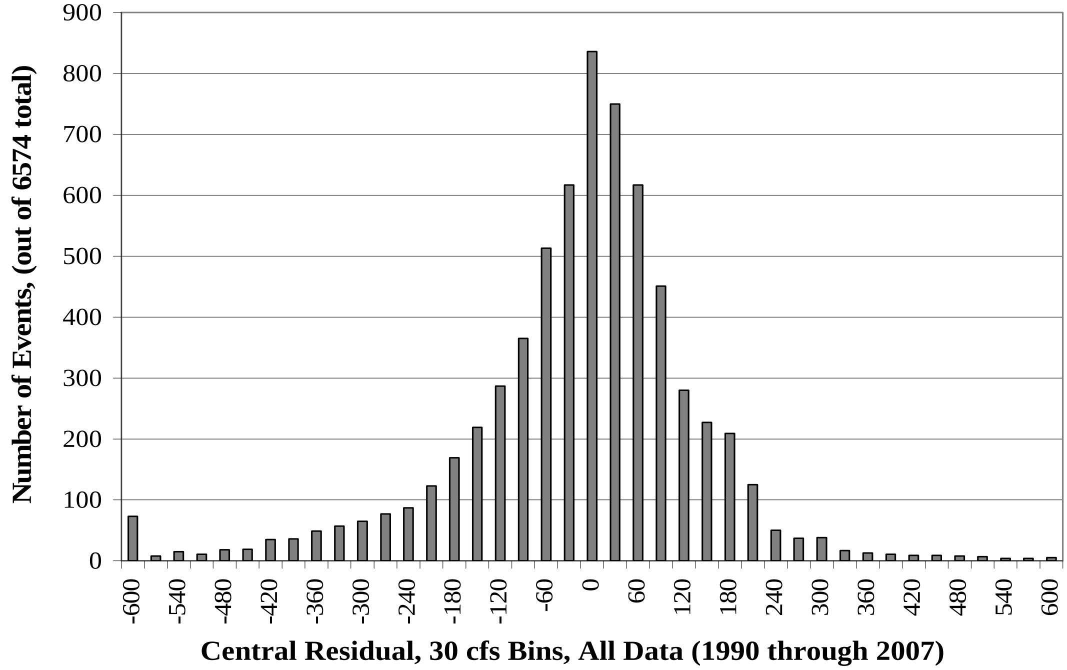


Figure 8. Residual of observed gage flow and the simulated flow at Central Ave..

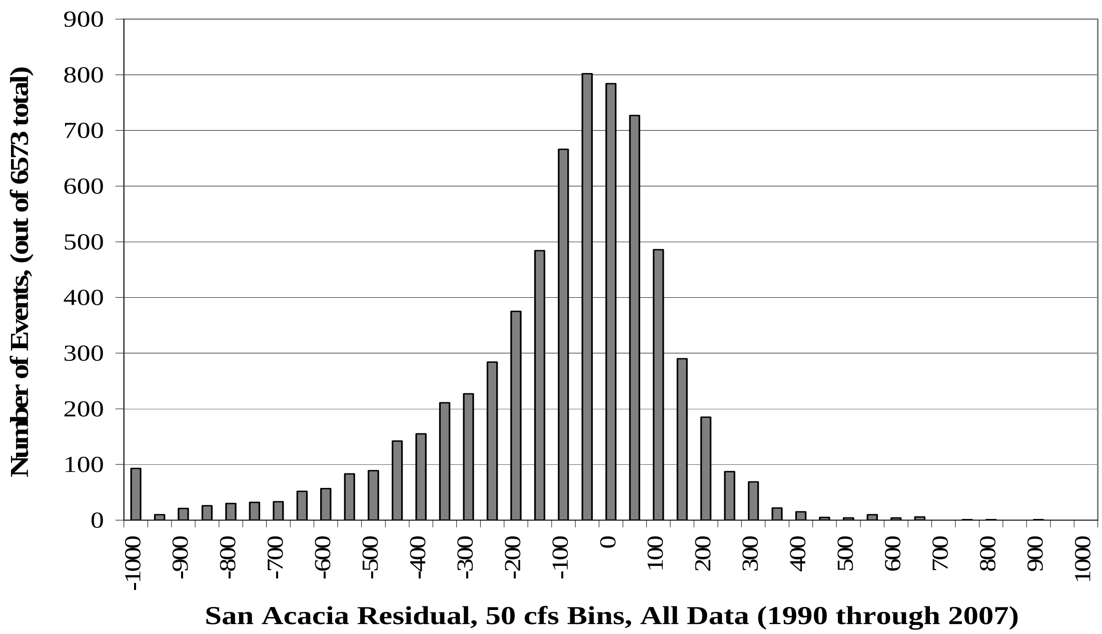


Figure 9. Residual of observed gage flow and the simulated flow at San Acacia.

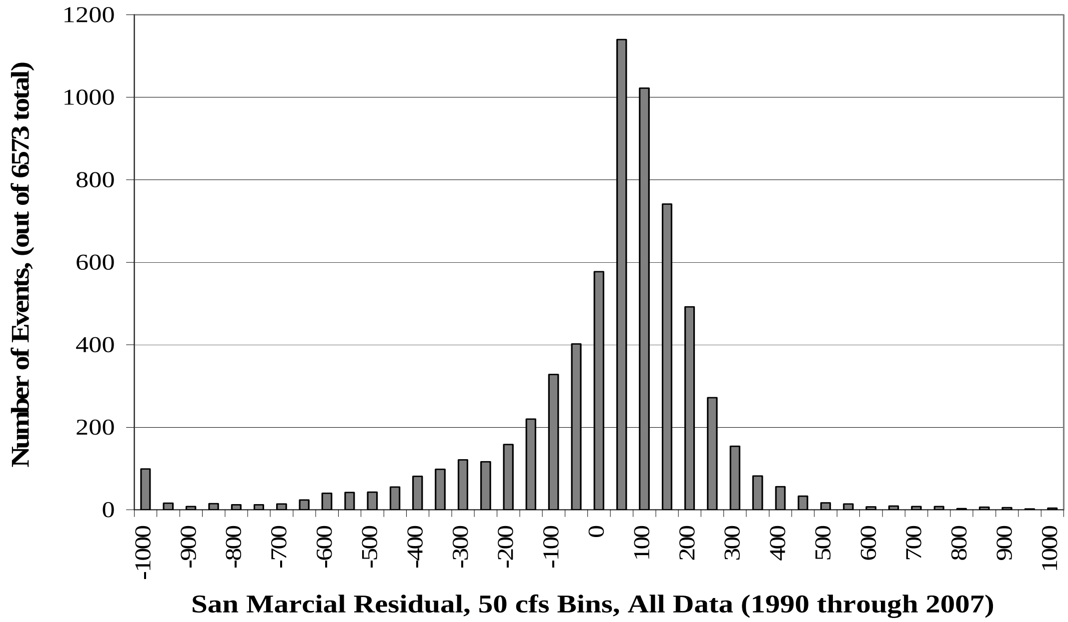


Figure 10. Residual of observed gage flow and the simulated flow at San Marcial.

The model was also calibrated against river seepage loss. Several seepage runs were done on river reaches from Angostura to San Marcial to establish range of gain/loss rate for each river reach (SSPA 2001, 2002 & 2008). Figure 11 indicates that, in general, the river is a losing stream except under certain conditions in Cochiti and Bernardo to San Acacia reaches. On average the simulated seepage is within the range of the measurements.

Total surface water depletion in the Middle Valley was estimated as all surface water inflow including gage tributaries below Cochiti dam minus to total surface water outflow at San Marcial (LFCC plus river channel). Figure 12 shows the measured vs. simulated total surface water depletion in the Middle Valley. On average, the simulated total depletion (347,000 acre-feet) is comparable to measured total depletion (365,000 acre-feet).

In general, the model is well calibrated to known flows and water operations of the Middle Valley. However, more calibration will be done due to changes in the open water evaporation method and canal seepage rates.

Figure 11. Simulated seepage versus measured seepage, by reach

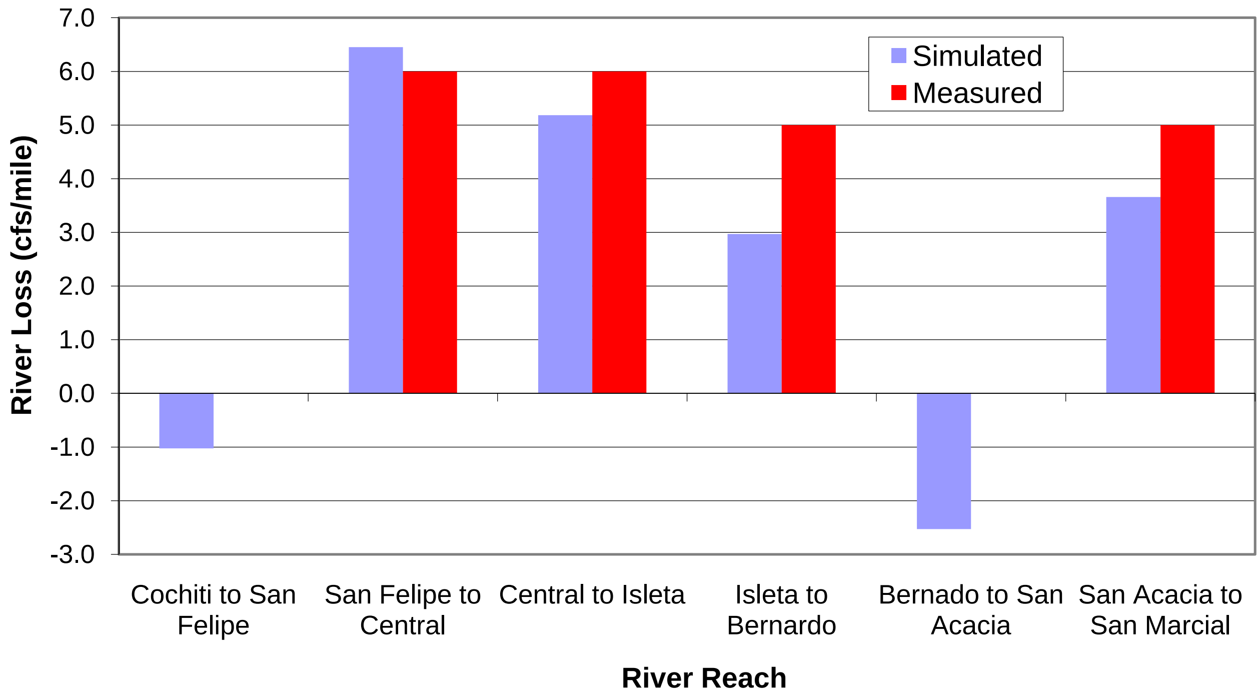
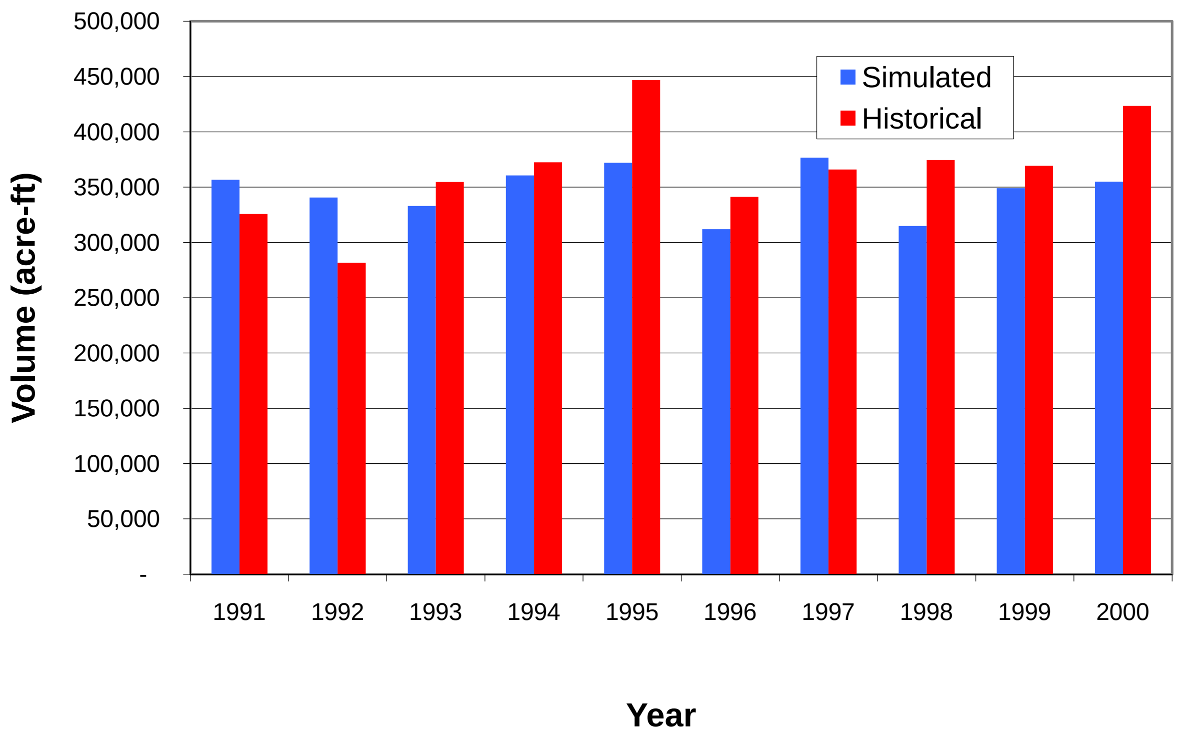


Figure 12. Simulated vs. measured total Middle Valley surface water depletion



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TABLES

Table 10. Groundwater object horizontal hydraulic properties

Groundwater Object	Conductance (ft2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
CochitiToSanFelipe 1East Downstream	1,025	80	5,798	36,196	80
CochitiToSanFelipe 1East Left	84,000	160	41,559	6,336	80
CochitiToSanFelipe 1River Downstream	313	80	1,866	38,174	80
CochitiToSanFelipe 1River Left	150,000	160	47,916	4,080	80
CochitiToSanFelipe 1River Right	84,000	160	41,559	6,336	80
CochitiToSanFelipe 1West Downstream	919	80	5,757	40,087	80
CochitiToSanFelipe 1West Right	150,000	160	47,916	4,080	80
CochitiToSanFelipe 2East Downstream	392	80	2,087	34,117	80
CochitiToSanFelipe 2East Left	126,000	159	36,894	3,727	80
CochitiToSanFelipe 2East Upstream	1,025	80	5,798	36,196	80
CochitiToSanFelipe 2River Downstream	578	80	3,139	34,758	80
CochitiToSanFelipe 2River Left	160,000	163	38,214	3,110	80
CochitiToSanFelipe 2River Right	126,000	159	36,894	3,727	80
CochitiToSanFelipe 2River Upstream	313	80	1,866	38,174	80
CochitiToSanFelipe 2West Downstream	19	76	109	34,758	80
CochitiToSanFelipe 2West Right	160,000	163	38,214	3,110	80
CochitiToSanFelipe 2West Upstream	919	80	5,757	40,087	80
SanFelipeToCentral Ave. 1East Downstream	588	80	3,330	36,229	80
SanFelipeToCentral Ave. 1East Left	67,947	80	36,925	3,478	80
SanFelipeToCentral Ave. 1East Upstream	392	80	2,087	34,117	80
SanFelipeToCentral Ave. 1River Downstream	733	80	4,254	37,154	80
SanFelipeToCentral Ave. 1River Left	158,339	80	38,892	1,572	80
SanFelipeToCentral Ave. 1River Right	67,947	80	36,925	3,478	80
SanFelipeToCentral Ave. 1River Upstream	578	80	3,139	34,758	80
SanFelipeToCentral Ave. 1West	146	80	886	38,709	80

Groundwater Object	Conductance (ft2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thicknes s (ft)
Downstream					
SanFelipeToCentral Ave. 1West Right	158,339	80	38,892	1,572	80
SanFelipeToCentral Ave. 1West Upstream	19	80	109	36,624	80
SanFelipeToCentral Ave. 2East Downstream	2,013	264	3,330	35,003	80
SanFelipeToCentral Ave. 2East Left	61,987	90	36,925	4,272	80
SanFelipeToCentral Ave. 2East Upstream	588	128	2,087	36,229	80

Table 10. Groundwater object horizontal hydraulic properties - continued

Groundwater Object	Conductance (ft2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
SanFelipeToCentral Ave. 2River Downstream	258	80	1,630	40,469	80
SanFelipeToCentral Ave. 2River Left	166,234	80	42,052	1,619	80
SanFelipeToCentral Ave. 2River Right	61,987	80	41,376	4,272	80
SanFelipeToCentral Ave. 2River Upstream	733	81	4,254	37,694	80
SanFelipeToCentral Ave. 2West Downstream	197	80	1,160	37,718	80
SanFelipeToCentral Ave. 2West Right	166,234	80	42,052	1,619	80
SanFelipeToCentral Ave. 2West Upstream	146	80	886	38,623	80
SanFelipeToCentral Ave. 3East Downstream	2,881	80	15,600	34,653	80
SanFelipeToCentral Ave. 3East Left	57,083	80	41,376	4,639	80
SanFelipeToCentral Ave. 3East Upstream	2,013	80	11,008	35,003	80
SanFelipeToCentral Ave. 3River Downstream	220	80	1,458	42,493	80
SanFelipeToCentral Ave. 3River Left	46,484	80	40,688	5,602	80
SanFelipeToCentral Ave. 3River Right	57,083	80	41,376	4,639	80
SanFelipeToCentral Ave. 3River Upstream	258	80	1,630	40,469	80
SanFelipeToCentral Ave. 3West Downstream	1,367	80	8,036	37,628	80
SanFelipeToCentral Ave. 3West Right	46,484	80	40,688	5,602	80
SanFelipeToCentral Ave. 3West	197	80	1,160	37,718	80

Groundwater Object	Conductance (ft2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
Upstream					
SanFelipeToCentral Ave. 4East Downstream	1,233	40	13,687	35,513	80
SanFelipeToCentral Ave. 4East Left	25,547	80	44,640	11,183	80
SanFelipeToCentral Ave. 4East Upstream	2,881	80	15,600	34,653	80
SanFelipeToCentral Ave. 4River Downstream	200	39	2,404	37,912	80
SanFelipeToCentral Ave. 4River Left	92,612	80	47,319	3,270	80
SanFelipeToCentral Ave. 4River Right	25,547	80	44,640	11,183	80
SanFelipeToCentral Ave. 4River Upstream	220	80	1,458	42,493	80
SanFelipeToCentral Ave. 4West Downstream	541	41	6,035	36,272	80
SanFelipeToCentral Ave. 4West Right	92,612	80	47,319	3,270	80
SanFelipeToCentral Ave. 4West Upstream	1,367	80	8,036	37,628	80
Central Ave.ToIsleta 1East Downstream	2,377	80	11,798	31,762	80
Central Ave.ToIsleta 1East Left	44,923	40	36,031	2,567	80
Central Ave.ToIsleta 1East Upstream	1,233	40	13,687	35,513	80

Table 10. Groundwater object horizontal hydraulic properties - continued

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
Central Ave.ToIsleta 1River Downstream	392	80	1,889	30,875	80
Central Ave.ToIsleta 1River Left	34,011	40	34,338	3,231	80
Central Ave.ToIsleta 1River Right	44,923	40	36,031	2,567	80
Central Ave.ToIsleta 1River Upstream	200	40	2,404	38,472	80
Central Ave.ToIsleta 1West Downstream	2,434	80	11,933	31,379	80
Central Ave.ToIsleta 1West Right	34,011	40	34,338	3,231	80
Central Ave.ToIsleta 1West Upstream	541	40	6,035	35,712	80
Central Ave.ToIsleta 2East Downstream	735	40	7,186	31,307	80
Central Ave.ToIsleta 2East Left	8,498	40	7,186	2,706	80
Central Ave.ToIsleta 2East Upstream	2,377	86	11,798	34,124	80
Central Ave.ToIsleta 2River Downstream	293	88	1,289	30,875	80
Central Ave.ToIsleta 2River Left	6,364	40	6,327	3,182	80

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
Central Ave.ToIsleta 2River Right	8,498	40	7,186	2,706	80
Central Ave.ToIsleta 2River Upstream	392	80	1,889	30,875	80
Central Ave.ToIsleta 2West Downstream	666	40	6,327	30,411	80
Central Ave.ToIsleta 2West Right	6,364	40	6,327	3,182	80
Central Ave.ToIsleta 2West Upstream	2,434	80	11,933	31,379	80
IsletaToBernardo 1East Downstream	2,766	80	14,196	32,848	80
IsletaToBernardo 1East Left	37,589	40	44,608	3,797	80
IsletaToBernardo 1East Upstream	735	40	7,186	31,307	80
IsletaToBernardo 1River Downstream	475	80	2,066	27,861	80
IsletaToBernardo 1River Left	58,644	40	43,280	2,362	80
IsletaToBernardo 1River Right	37,598	40	44,608	3,797	80
IsletaToBernardo 1River Upstream	293	40	1,289	14,096	80
IsletaToBernardo 1West Downstream	1,952	80	9,315	30,543	80
IsletaToBernardo 1West Right	58,644	40	43,280	2,362	80
IsletaToBernardo 1West Upstream	666	40	6,327	30,411	80
IsletaToBernardo 2East Downstream	1,570	80	7,970	32,490	80
IsletaToBernardo 2East Left	35,252	40	41,915	3,805	80
IsletaToBernardo 2East Upstream	2,766	80	14,196	32,848	80

Table 10. Groundwater object horizontal hydraulic properties - continued

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
IsletaToBernardo 2River Downstream	630	80	2,755	27,977	80
IsletaToBernardo 2River Left	42,690	40	42,007	3,149	80
IsletaToBernardo 2River Right	35,252	40	41,915	3,805	80
IsletaToBernardo 2River Upstream	475	80	2,066	27,861	80
IsletaToBernardo 2West Downstream	2,350	80	11,644	31,708	80
IsletaToBernardo 2West Right	42,690	40	42,007	3,149	80
IsletaToBernardo 2West Upstream	1,952	80	9,315	30,543	80
IsletaToBernardo 3East Downstream	931	80	4,408	30,313	80
IsletaToBernardo 3East Left	121,961	40	44,378	1,164	80
IsletaToBernardo 3East Upstream	1,570	80	7,970	32,490	80
IsletaToBernardo 3River Downstream	505	80	2,178	27,616	80

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
IsletaToBernardo 3River Left	29,637	40	46,327	5,002	80
IsletaToBernardo 3River Right	121,961	40	44,378	1,164	80
IsletaToBernardo 3River Upstream	630	80	2,755	27,977	80
IsletaToBernardo 3West Downstream	2,271	80	11,073	31,210	80
IsletaToBernardo 3West Right	29,637	40	46,327	5,002	80
IsletaToBernardo 3West Upstream	2,350	80	11,644	31,708	80
IsletaToBernardo 4East Downstream	2,046	80	8,774	27,439	80
IsletaToBernardo 4East Left	64,301	40	39,216	1,952	80
IsletaToBernardo 4East Upstream	931	80	4,408	30,313	80
IsletaToBernardo 4River Downstream	454	80	1,794	25,292	80
IsletaToBernardo 4River Left	40,132	40	39,285	3,132	80
IsletaToBernardo 4River Right	64,301	40	39,216	1,952	80
IsletaToBernardo 4River Upstream	505	80	2,178	27,616	80
IsletaToBernardo 4West Downstream	1,212	80	5,360	28,295	80
IsletaToBernardo 4West Right	40,132	40	39,285	3,132	80
IsletaToBernardo 4West Upstream	2,271	80	11,073	31,210	80
IsletaToBernardo 5East Downstream	155	40	1,509	31,158	80
IsletaToBernardo 5East Left	27,934	40	31,409	3,598	80
IsletaToBernardo 5East Upstream	2,046	80	8,774	27,439	80

Table 10. Groundwater object horizontal hydraulic properties - continued

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
IsletaToBernardo 5River Downstream	352	40	3,405	30,913	80
IsletaToBernardo 5River Left	37,916	40	31,071	2,622	80
IsletaToBernardo 5River Right	27,934	40	31,409	3,598	80
IsletaToBernardo 5River Upstream	454	80	1,794	25,292	80
IsletaToBernardo 5West Downstream	1,093	40	10,660	31,205	80
IsletaToBernardo 5West Right	37,916	40	31,071	2,622	80
IsletaToBernardo 5West Upstream	1,212	80	5,360	28,295	80
BernardoToSanAcacia 1East Downstream	78	40	738	30,269	80
BernardoToSanAcacia 1East Left	491,422	80	81,852	1,066	80
BernardoToSanAcacia 1East Upstream	155	40	1,509	31,158	80

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
BernardoToSanAcacia 1River Downstream	77	40	754	31,309	80
BernardoToSanAcacia 1River Left	282,551	80	76,024	1,722	80
BernardoToSanAcacia 1River Right	491,422	80	81,852	1,066	80
BernardoToSanAcacia 1River Upstream	352	40	3,405	30,913	80
BernardoToSanAcacia 1West Downstream	92	40	899	31,350	80
BernardoToSanAcacia 1West Right	282,551	80	76,024	1,722	80
BernardoToSanAcacia 1West Upstream	1,093	40	10,660	31,205	80
SanAcaciaToSanMarcial 1East Downstream	628	80	2,480	25,276	80
SanAcaciaToSanMarcial 1East Left	368,243	80	53,503	930	80
SanAcaciaToSanMarcial 1East Upstream	78	40	738	30,269	80
SanAcaciaToSanMarcial 1River Downstream	821	80	3,339	26,028	80
SanAcaciaToSanMarcial 1River Left	151,883	80	54,838	2,311	80
SanAcaciaToSanMarcial 1River Right	368,243	80	53,503	930	80
SanAcaciaToSanMarcial 1River Upstream	77	40	754	31,309	80
SanAcaciaToSanMarcial 1West Downstream	617	80	2,568	26,625	80
SanAcaciaToSanMarcial 1West Right	151,883	80	54,838	2,311	80
SanAcaciaToSanMarcial 1West Upstream	92	40	899	31,350	80
SanAcaciaToSanMarcial 2East Downstream	450	80	2,795	39,745	80
SanAcaciaToSanMarcial 2East Left	165,670	80	28,274	1,092	80
SanAcaciaToSanMarcial 2East Upstream	628	80	2,480	25,276	80

Table 10. Groundwater object horizontal hydraulic properties - continued

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
SanAcaciaToSanMarcial 2River Downstream	309	80	1,942	40,273	80
SanAcaciaToSanMarcial 2River Left	73,675	80	27,224	2,365	80
SanAcaciaToSanMarcial 2River Right	165,670	80	28,274	1,092	80
SanAcaciaToSanMarcial 2River Upstream	821	80	3,339	26,028	80
SanAcaciaToSanMarcial 2West Downstream	792	80	4,740	38,283	80
SanAcaciaToSanMarcial 2West Right	73,675	80	27,224	2,365	80
SanAcaciaToSanMarcial 2West Upstream	617	80	2,568	26,625	80
SanAcaciaToSanMarcial 3East Downstream	414	80	3,378	52,221	80
SanAcaciaToSanMarcial 3East Left	299,301	80	58,289	1,246	80
SanAcaciaToSanMarcial 3East Upstream	450	80	2,795	39,745	80

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
SanAcaciaToSanMarcial 3River Downstream	532	80	4,264	51,332	80
SanAcaciaToSanMarcial 3River Left	162,104	80	54,582	2,155	80
SanAcaciaToSanMarcial 3River Right	299,301	80	58,289	1,246	80
SanAcaciaToSanMarcial 3River Upstream	309	80	1,942	40,273	80
SanAcaciaToSanMarcial 3West Downstream	572	80	4,264	47,731	80
SanAcaciaToSanMarcial 3West Right	162,104	80	54,582	2,155	80
SanAcaciaToSanMarcial 3West Upstream	792	80	4,740	38,283	80
SanAcaciaToSanMarcial 4East Downstream	587	80	5,176	56,386	80
SanAcaciaToSanMarcial 4East Left	288,037	80	63,107	1,402	80
SanAcaciaToSanMarcial 4East Upstream	414	80	3,378	52,221	80
SanAcaciaToSanMarcial 4River Downstream	364	80	3,014	52,928	80
SanAcaciaToSanMarcial 4River Left	94,976	80	49,892	3,362	80
SanAcaciaToSanMarcial 4River Right	288,037	80	63,107	1,402	80
SanAcaciaToSanMarcial 4River Upstream	532	80	4,264	51,332	80
SanAcaciaToSanMarcial 4West Downstream	972	80	7,455	49,069	80
SanAcaciaToSanMarcial 4West Right	94,976	80	49,892	3,362	80
SanAcaciaToSanMarcial 4West Upstream	572	80	4,264	47,731	80
SanAcaciaToSanMarcial 5East Left	259,346	80	67,122	1,656	80
SanAcaciaToSanMarcial 5East Upstream	587	80	5,176	56,386	80
SanAcaciaToSanMarcial 5River Left	141,850	80	59,358	2,678	80

Table 10. Groundwater object horizontal hydraulic properties - concluded

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Face Length (ft)	Average Centroid Length (ft)	Aquifer Thickness (ft)
SanAcaciaToSanMarcial 5River Right	259,346	80	67,122	1,656	80
SanAcaciaToSanMarcial 5River Upstream	364	80	3,014	52,928	80
SanAcaciaToSanMarcial 5West Right	141,850	80	59,358	2,678	80
SanAcaciaToSanMarcial 5West Upstream	972	80	7,455	49,069	80

Table 11. Groundwater object vertical conductance and hydraulic properties

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Cell Area (ft^2)	Average Centroid Length (ft)
CochitiToSanFelipe 1East	112,490	10.5	318,291,356	270
CochitiToSanFelipe 1River	392,700	1.0	106,032,295	270
CochitiToSanFelipe 1West	81,640	10.1	222,402,460	270
CochitiToSanFelipe 2East	54,290	10.8	158,261,024	270
CochitiToSanFelipe 2River	30,000	13.6	110,323,410	270
CochitiToSanFelipe 2West	32,940	10.8	95,622,384	270
SanFelipeToCentral Ave. 1East	57,430	10.8	167,000,492	270
SanFelipeToCentral Ave. 1River	64,122	3.6	62,114,374	270
SanFelipeToCentral Ave. 1West	18,270	10.7	52,978,022	270
SanFelipeToCentral Ave. 2East	82,080	10.8	238,878,943	270
SanFelipeToCentral Ave. 2River	71,489	5.4	103,523,123	270
SanFelipeToCentral Ave. 2West	16,620	10.8	48,282,016	270
SanFelipeToCentral Ave. 3East	74,970	10.8	218,070,306	270
SanFelipeToCentral Ave. 3River	79,089	3.6	76,380,230	270
SanFelipeToCentral Ave. 3West	96,430	10.8	280,291,584	270
SanFelipeToCentral Ave. 4East	242,930	10.8	705,786,372	270
SanFelipeToCentral Ave. 4River	87,356	3.6	85,050,789	270
SanFelipeToCentral Ave. 4West	44,630	10.7	129,413,285	270
Central Ave.ToIsleta 1East	90,900	10.8	264,075,018	270
Central Ave.ToIsleta 1River	21,800	10.7	63,256,572	270
Central Ave.ToIsleta 1West	119,400	10.7	346,528,335	270
Central Ave.ToIsleta 2East	89,000	10.8	258,531,561	270
Central Ave.ToIsleta 2River	27,764	10.0	74,961,612	270
Central Ave.ToIsleta 2West	128,000	10.8	371,715,562	270
IsletaToBernardo 1East	176,390	10.8	512,627,117	270
IsletaToBernardo 1River	91,440	3.7	91,385,578	270
IsletaToBernardo 1West	57,290	10.8	166,504,675	270
IsletaToBernardo 2East	170,690	10.8	496,058,047	270
IsletaToBernardo 2River	29,270	10.8	85,067,041	270
IsletaToBernardo 2West	147,930	10.8	429,918,674	270

Table 11. Groundwater object vertical conductance and hydraulic properties – concluded

Groundwater Object	Conductance (ft^2/day)	Hydraulic Conductivity (ft/day)	Cell Area (ft^2)	Average Centroid Length (ft)
IsletaToBernardo 3East	41,190	10.8	119,707,130	270
IsletaToBernardo 3River	37,900	7.9	81,088,036	270
IsletaToBernardo 3West	199,100	10.8	578,628,509	270
IsletaToBernardo 4East	78,290	10.8	227,528,404	270
IsletaToBernardo 4River	22,610	10.8	65,698,325	270
IsletaToBernardo 4West	97,290	10.8	282,736,188	270
IsletaToBernardo 5East	80,870	10.8	235,032,629	270
IsletaToBernardo 5River	53,970	4.8	69,664,298	270
IsletaToBernardo 5West	59,540	10.8	173,042,529	270
BernardoToSanAcacia 1West	98,550	7.4	197,567,218	270
BernardoToSanAcacia 1East	55,140	10.8	160,260,490	270
BernardoToSanAcacia 1River	67,980	15.6	286,404,907	270
SanAcaciaToSanMarcial 1East	16,260	10.8	47,255,920	270
SanAcaciaToSanMarcial 1River	51,830	10.8	150,630,465	270
SanAcaciaToSanMarcial 1West	141,260	10.8	410,519,094	270
SanAcaciaToSanMarcial 2East	222,500	1.1	64,675,130	270
SanAcaciaToSanMarcial 2River	23,820	10.8	69,216,243	270
SanAcaciaToSanMarcial 2West	60,100	10.8	174,659,547	270
SanAcaciaToSanMarcial 3East	37,020	10.8	107,577,779	270
SanAcaciaToSanMarcial 3River	55,430	10.8	161,088,653	270
SanAcaciaToSanMarcial 3West	99,800	10.8	290,070,760	270
SanAcaciaToSanMarcial 4East	65,180	10.8	189,420,109	270
SanAcaciaToSanMarcial 4River	63,660	10.8	185,018,971	270
SanAcaciaToSanMarcial 4West	137,450	10.8	399,471,326	270
SanAcaciaToSanMarcial 5East	34,540	10.8	100,367,852	270
SanAcaciaToSanMarcial 5River	82,790	10.8	240,611,945	270
SanAcaciaToSanMarcial 5West	99,780	10.8	290,010,365	270