Technical Completion Report

DEVELOPMENT OF RIVERWARE MODEL OF THE RIO GRANDE FOR WATER RESOURCES MANAGEMENT IN THE PASO DEL NORTE WATERSHED

Sponsored by U.S. Army Corps of Engineers, Gulf Coast Cooperative Ecosystem Studies Unit

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Executive Summary

The project was conducted by Zhuping Sheng (PI), Ari Michelsen, Binayak Mohanty, and Ricardo Marmalejo of Texas A&M University; J. Phillip King, Shalamu Abudu and Christopher Brown of New Mexico State University; Alfredo Granados and Víctor Esquivel-Ceballos, Universidad Autónoma de Ciudad Juárez, México. This report fulfills the deliverables under the cooperative agreement between the U.S. Army Corps of Engineers and Texas AgriLife Research, Texas A&M University System under Gulf Coast Cooperative Ecosystem Studies Unit (Project Number: W912HZ-10-2-0038) on behalf of the Paso del Norte Watershed Council.

The scope of work of this project covers two main objectives. (1) Collection and compilation of necessary data and performance of analyses to expand the URGWOM RiverWare® Model for Water Operations in Mesilla Basin. The model is developed to cover water operations in the Mesilla Basin and includes the proper physical layout of diversions, reaches, crop and riparian depletions, groundwater sub basins, drains, canals, etc., with an emphasis on surface and groundwater interaction, compiling and managing appropriate data, and simulate river flow and water operations planning as well as conjunctive management scenarios for Rincon and Mesilla Valleys. (2) Collection and compilation of necessary data and performance of analyses to expand the URGWOM RiverWare® Model to Simulate Flows and Water Operations Planning for the El Paso Lower Valley. The model is developed to cover the reaches between El Paso and Fort Quitman and includes the proper physical layout of diversions, reaches, crop and riparian depletions, groundwater sub basins, drain, canal, etc., compiling and managing appropriate data, and simulate river flow and water operations planning scenarios for entire Rio Grande Project area (Caballo Dam, NM to Fort Quitman, TX).

This report includes three parts, covering (I) Rincon Valley and Mesilla Basin RiverWare model, (II) El Paso-Juarez Valley RiverWare model; (III) Hydrologic Modeling of Main Tributaries to Estimate Runoff Potential into the Rio Grande-Rio Bravo at Irrigation

District 009 Valle de Juarez. All the numerical model deliverables are provided at the end of the report.

Part I of this report includes configuration of two RiverWare models for the Rincon Valley and Mesilla Basin (RV&MB). These models used groundwater objects to simulate surface-water/groundwater interaction within the valley by incorporating regional groundwater flow model (MODFLOW) results to define the deep aquifer hydrologic conditions. The RV&MB RiverWare models cover the Rio Grande reach between Caballo Dam, New Mexico and the Rio Grande at El Paso, Texas and irrigation network within Elephant Butte Irrigation District in New Mexico and upper part of El Paso County Water Improvement District #1 (EPCWID#1) in Texas. Multiple groundwater objects were used to simulate interaction of surface water and groundwater, namely seepage losses from the canals and the river and return flows in the drains. The historical flow data at the Leasburg gaging station from 2001 to 2003, which include full supply and drought limited supply years, were used to conduct preliminary calibration of the models. Both models will be integrated and further calibrated with extended historic data. This integrated RV&MB model will eventually be linked with the El Paso-Juarez Valley model to simulate different water operations planning scenarios in the future phases of this project. Future editing and calibration in the models will be necessary to reconcile methodology differences in application and achieve the daunting task of creating a region wide, functioning, accurate operations model, using a single consolidated operation rule set.

Part II of the report presents the El Paso-Juarez Valley (EP-JV) RiverWare model. In this phase, a conceptual model was developed for the reaches between El Paso and Fort Quitman, Texas. It covers part of El Paso County Water Improvement District No. 1 (EPCWID#1) (Lower El Paso Valley) and Hudspeth County Conservation and Reclamation District No. 1 (HCCRD#1) in the United States and Juarez Valley Irrigation District 009 in Mexico. The conceptual (EP-JV) model incorporated key features, the Rio Grande reach between El Paso and Fort Quitman, major canals and drains, key diversion points for water delivery within three irrigation districts as well as water supplies for the

City of El Paso. Preliminary results show that RiverWare can simulate the flows in the Rio Grande and within the irrigation network and capture patterns of water delivery. Though primarily physical constraints on delivery of water were simulated by the rule set, the EP-JV model produced good results in terms of water transfer between different canals as well as supplemental flows. Existing conditions and water balancing methods were simulated and applied successfully, while loosely adhering to stated operational policies of the EPCWID#1. This simultaneously mirrored some aspects of historically available data and policy while creating greater optimization in diversion decisions made autonomously by the model during a simulation. Additional improvements for the EP-JV RiverWare model, including better configuration of water demands using crop acreage and patterns, drain flows, and irrigation scheduling, have been identified and recommended for implementation in future phases of the project.

Part III of this report presents the results of a hydrologic modeling of most important tributaries connecting with the main stream of Rio Grande-Rio Bravo at Irrigation District 009-Valle de Juarez. Twelve main subwatersheds were identified, out of which three were classified as urban subwatersheds and nine were classified as rural-rangeland subwatersheds. Only nine rural-rangeland subwatersheds were modeled by estimating their main hydrologic characteristics considering that these regions were the areas contributing runoff into the ID-009. Three upstream urban subwatersheds were recommended for future hydrologic evaluation under an Urban Hydrology approach since they are located mostly on the urbanized areas of Ciudad Juarez, Chihuahua, where other hydraulic conditions prevail. The hydrologic analysis on the Rural-Rangeland Subwatersheds using HEC-HMS® show that the biggest subwatershed located at the Bandejas Subwatershed (RH24 e-2) with a total drainage density of 1 km/km^2 represents a watershed with a rapid response to storm events. Further analysis at an enhanced geographic scale is required in these regions where more refined hydrologic modeling might help on better characterizing upland hydrological conditions and potential hydrologic risks from flooding, since most of these tributaries connect into the irrigation channels impacting the irrigation infrastructure at the ID-009.

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Part I Rincon Valley & Mesilla Basin (RV&MB) RiverWare Model

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Introduction

The purpose of this report is to describe the implementation and results of using the RiverWare Groundwater Storage Objects (groundwater objects used in context or GWO used in tables and figures) to represent the interactions of surface water and groundwater in the Rincon Valley and Mesilla Basin of the Lower Rio Grande. A RiverWare model for the Rincon Valley has previously been developed using ARIMA Transfer Functions to predict the flow in the drains from the diversions at the headings (Tillery et. al. 2006), but this earlier statistical model had no provision for explicitly simulating the aquifer heads. In addition, a monthly time step was used in their model. In our work, a daily time step was used to develop RiverWare model. Groundwater objects were added to this model to simulate the heads in the alluvial aquifer, adding Reach Objects to represent each drain, and linking these Reach Objects to the groundwater objects. The objective of this task is to develop the model to simulate interaction between surface water and groundwater and to evaluate the hydrologic effects of different water management alternatives. The proposed model is based on RiverWare software. The scope of the work includes Rincon Valley area and Mesilla Basin Area (RV&MB) in the Lower Rio Grande. RiverWare models were developed for each area to simulate the surface/groundwater interaction, irrigation and drainage system, and crop water use in the project area.

RiverWare Modeling

Mainstem of the Rio Grande

The river system from Caballo Dam to the Leasburg Dam (Rincon Valley) and from Leasburg Dam to Rio Grande at El Paso (Mesilla Basin) is simulated with RiverWare reach objects that are linked directly to the groundwater objects to accomplish physical simulation of the surface-water/groundwater interaction through head-dependent flux calculations. Existing groundwater characteristics and the data necessary for simulating groundwater reactions were determined using MODFLOW. There are several parameters of the river that are needed to stimulate head-dependent flux that include the head (water surface elevation) in the river with discharge, the conductance of the riverbed, and the geometry of the river bed.

River Reaches in the Rincon Valley

To model this section of the Rio Grande in RiverWare, the river channel in the Rincon Valley, including Selden Canyon, is simulated by eight reaches. With the addition of groundwater objects to accomplish surface-water/groundwater interaction physical modeling, the 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 Rincon Valley indicated that a reach length of six to eight 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. The reaches in the Rincon model are: Below Caballo Dam to Percha Diversion Dam, Percha Diversion Dam to Arrey Canal Siphon, Arrey Siphon to Garfield Canal Siphon reach 1 and reach 2, Garfield Canal Siphon to Hatch Canal Siphon, Hatch Canal Siphon to Rincon Drain reach1 and Hatch Canal Siphon to Rincon Drain reach2, and the end of Rincon Drain to Leasburg Dam.

Figure I-1 shows the division of the river reaches in the Rincon Valley, from below Caballo Reservoir through Selden Canyon in New Mexico. The irrigated corridor along the Rio Grande eight linear river segments that approximately follow the curvature of the river are shown in Figure I-1 and the names of the reaches in the figure are slight abbreviations of the reaches listed in the previous paragraph. The locations of the three major agricultural drains in the Rincon Valley are also shown in this figure.

River Reaches in the Mesilla Basin

The river channel in the Mesilla Basin is divided into six reaches for the model development (Figure I-2). They are: Leasburg Dam to Picacho Flume, Picacho Flume to Mesilla Dam, Mesilla Dam to Anthony Bridge (MD-AB) Reach 1 and MD-AB Reach 2, Below Anthony to Rio Grande at El Paso Gaging Station (BA-RGEPGS) Reach 1 and BA-RGEPGS Reach 2. The division of reaches in the Mesilla Basin portion of the Lower

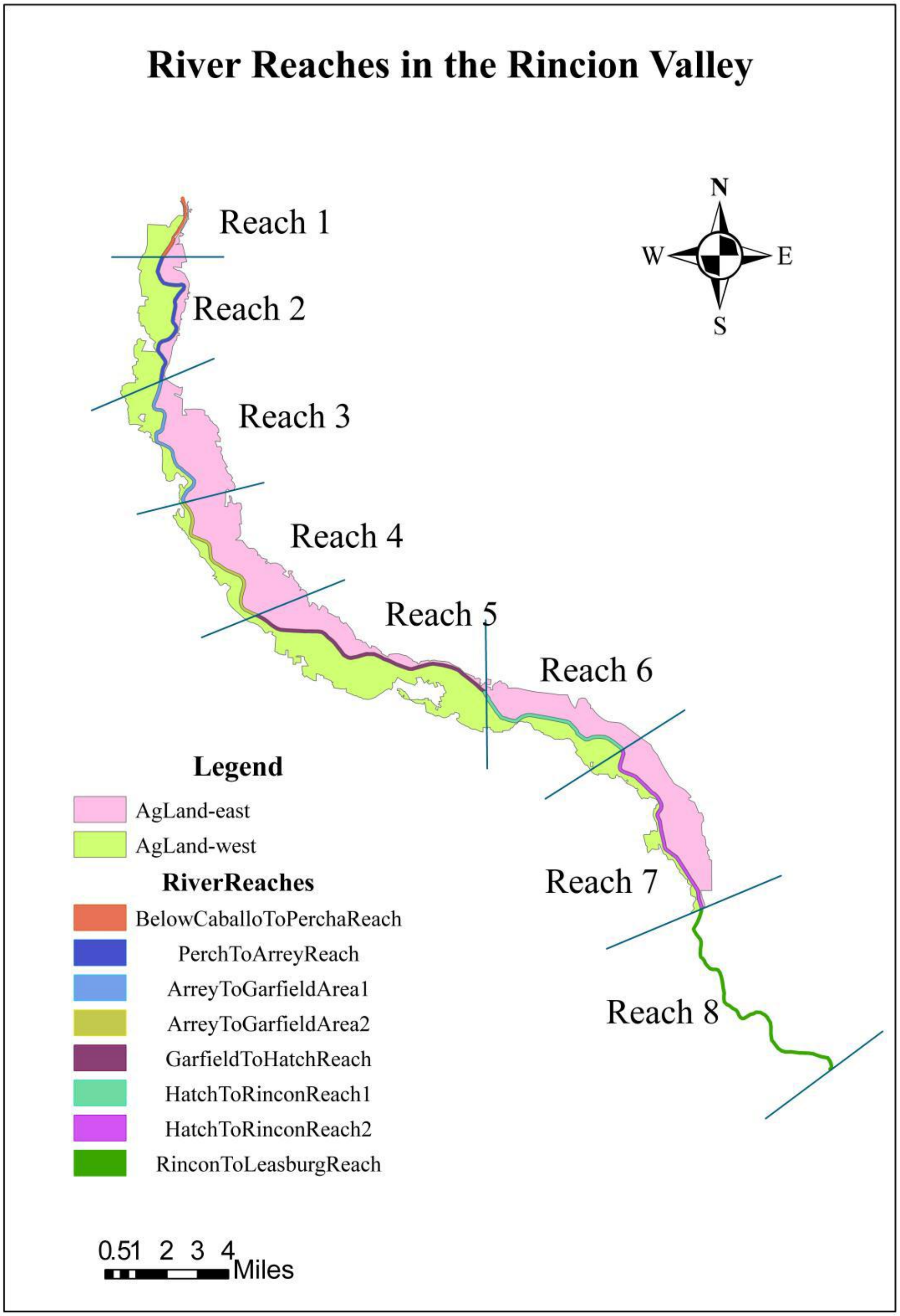


Figure I-1 River reaches division of the Rincon Valley.

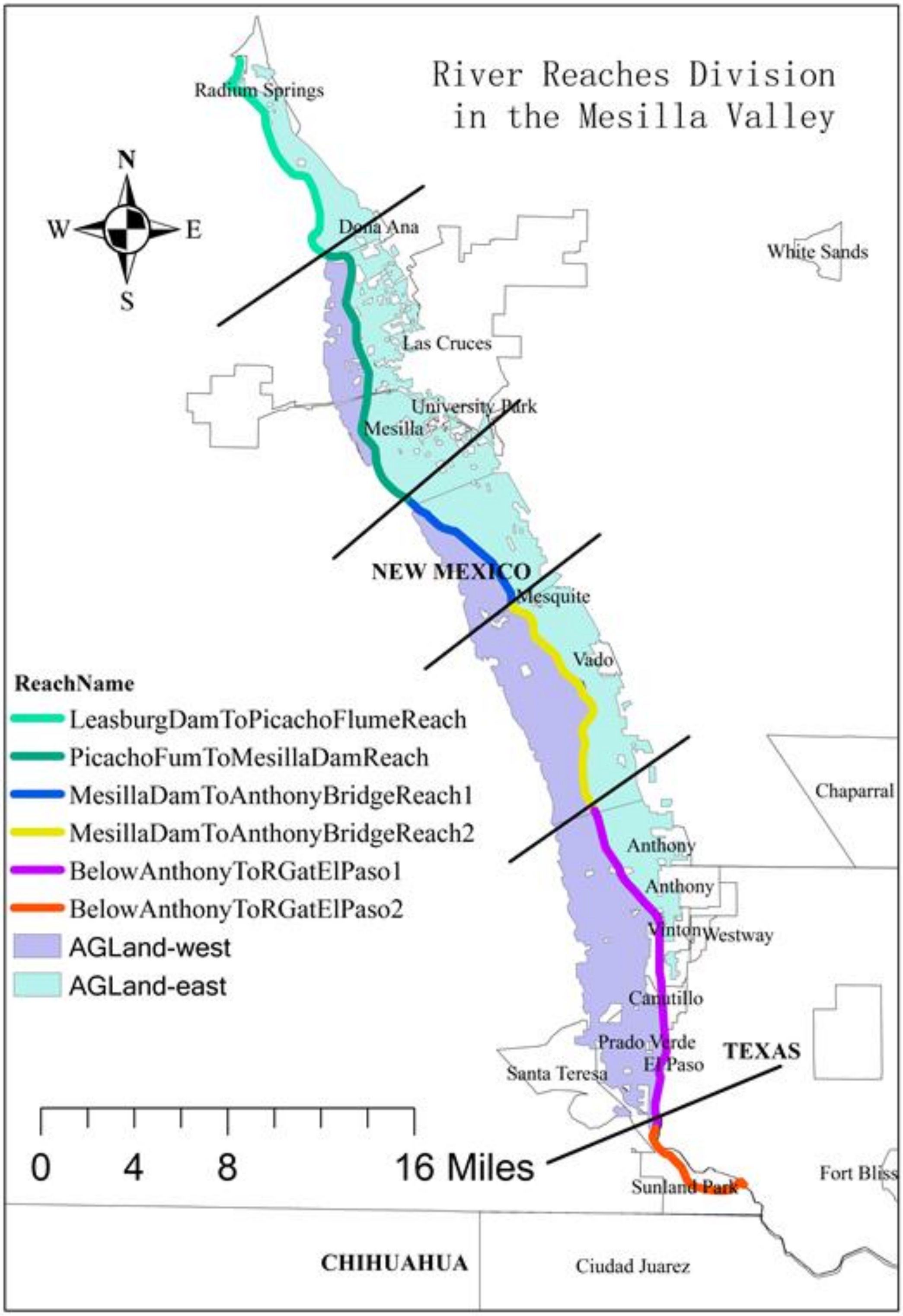


Figure I-2 River reaches division of the Mesilla Basin.

Rio Grande is shown in Figure I-2 and the figure labels for the reaches are slight abbreviations of this list. Based on cross-section survey data provided by the New Mexico Interstate Stream Commission (NMISC, 2007), average properties for each reach were derived and are given in Table I-1 and Table I-2.

Table I-1 Average Reach Properties of the Rincon Valley

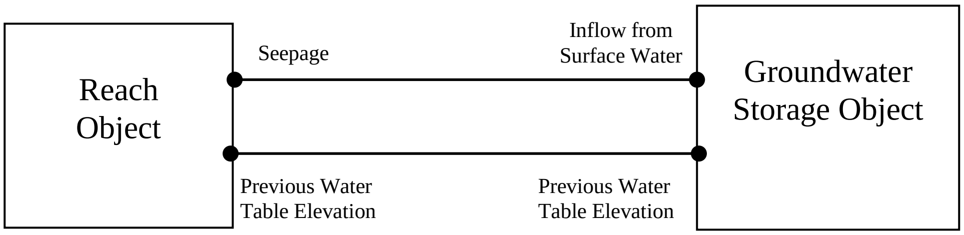
Reaches	Reach Name	Length [L] (ft)	Slope [S] (ft/ft)	Width [W] (ft)	Elev [E] (ft)
Reach 1	BelowCaballoToPerchaReach				
Reach 2	PerchaToArrey	28113.82	0.00115	137.25	4125.56
Reach 3	ArreyToGarfield1	26684.30	0.00085	165.00	4098.14
Reach 4	ArreyToGarfield2	25678.35	0.00061	242.00	4079.09
Reach 5	GarfieldToHatch	44315.00	0.00086	259.50	4052.26
Reach 6	HatchToRincon1	27531.42	0.00077	160.50	4022.61
Reach 7	HatchToRincon2	32667.09	0.00071	135.00	4000.37
Reach 8	RinconToLeasburg	42514.87	0.00065	125.17	3974.83

Table I-2 Average Reach Properties of the Mesilla Basin

Reaches	Reach Name	Length (ft)	Slope (ft/ft)	Width (ft)	Elevation (ft)
Reach 1	LeasburgDamToPicachoFlumeReach	57170.58	0.008476	247.50	3931.09
Reach 2	PicachoFlumeToMesillaDamReach	66288.84	0.007834	334.50	3881.07
Reach 3	MesillaDamToAnthonyBridgeReach1	33822.11	0.007338	242.25	3842.84
Reach 4	MesillaDamToAnthonyBridgeReach2	56009.11	0.007599	230.00	3809.27
Reach 5	BlowAnthonyToRgatElpaso1	77463.71	0.005918	213.00	3765.21
Reach 6	BlowAnthonyToRgatElpaso2	29581.21	0.000506	206.00	3734.90

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 and the river, and the conductance of the river bottom and banks. The RiverWare model has reach objects linked to groundwater objects to simulate the surface-water/groundwater interaction. The links are shown below.



The seepage is calculated two ways depending on the elevation difference between the shallow aquifer water table, interpreted as head in the model object, and the stream bed elevation. Equation 1 is used to calculate the seepage if the shallow aquifer head is higher than the stream bed, as automatically executed in RiverWare. For this calculation, RiverWare conducts a mass balance calculation that results in a designated Q (flow rate) that represents the transfer of water between reach objects and groundwater objects as shown in equation (1).

$$Q = C\,(h_s - h_a) \qquad (1)$$

where:

- Q is seepage to or from stream, in ft^3/day,
- C is conductance, in ft^2/day,
- h_s is the water surface elevation of the stream, in ft,
- h_a is the head of the shallow aquifer, in ft.

In the RiverWare model, in the case where the shallow aquifer water table is below the bottom of the stream bed of a reach object, the vertical flow from the river to the aquifer is calculated by equation 2.

$$Q = C\,(h_s - E) \tag{2}$$

where:

E is the streambed 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.

$$C = \frac{K'WL}{b'} \tag{3}$$

where:

b' is the thickness of the streambed, in ft,

K' is the vertical hydraulic conductivity of the streambed, in ft/day,

W is the width of the stream, assuming a rectangular channel, in ft,

L is the length of the reach in ft.

The initial vertical hydraulic conductivity and the riverbed thickness were used as 0.114 feet/day and 5 feet (Weeden and Maddock 1999), respectively. The river width and length were determined in ArcGIS by tracing over the active river channel and determining the area of the polygon (Table I-1 and Table I-2). The vertical hydraulic conductivity was adjusted during the calibration process to match observed seepage loss. The initial river conductance values used for RiverWare models for Rincon Valley and Mesilla Basin are listed in Table I-3 and Table I-4, respectively.

River Reach Rating Tables

Rivers, canals, channels, and drains are all represented by Reach objects in RiverWare models, and will hence be used interchangeably, as all are applied and termed the same

Table I-3 River Reach Conductance Parameters for Rincon Valley model

Reach Object Name	Streambed Conductance [C], ft^2/day
BelowCaballoToPerchaReach	
PerchaToArrey	105571.9
ArreyToGarfield1	120463.6
ArreyToGarfield2	170019.4
GarfieldToHatch	314633.0
HatchToRincon1	120898.2
HatchToRincon2	120659.2
RinconToLeasburg	145601.8

Table I-4 River Reach Conductance Parameters for Mesilla Basin Model

Reach Object Name	Streambed Conductance[C] ft^2/day
LeasburgDamToPicachoFlumeReach	322613.6
PicachoFlumeToMesillaDamReach	505558.5
MesillaDamToAnthonyBridgeReach1	186848.2
MesillaDamToAnthonyBridgeReach2	293711.8
BlowAnthonyToRgatElpaso1	376194.7
BlowAnthonyToRgatElpaso2	138937.0

within RiverWare, outside of specific methodology chosen for individual objects. Eight river reaches are represented by Reach objects in RiverWare (Figure I-1) and six river reaches in the Mesilla Basin (Figure I-2) are represented by Reach objects in the RiverWare models. A stage rating table is required for each river reach at both the top and bottom of the reach to represent the relationship between stage and discharge in the channel. A rectangular section is assumed for the channel and the rating table is developed from the New Mexico ISC cross-section survey data and Manning's equation for calculating flow rate (NMISC, 2007). Applied methodology in RiverWare uses volumes that result from mass balance calculations and the application of Manning's in order to determine a Q (flow rate) for each reach object. The roughness coefficient used in Manning's for the river reaches is 0.03 (Weeden and Maddock, 1999). The average

Table I-5 Rating Tables for River Reaches of the Rincon Valley

	PerchToArrey		*ArreyToGarfield1*		*Garfield1ToGarfield2*		*Garfield2ToHatch*		*HatchToRincon1*		*Rincon1ToRincon2*		*Rincon2ToLeasburg*	
	Flow (Q)	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*
	af/day	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*
TOP	0	4141.69	0	4109.42	0	4086.86	0	4071.32	0	4033.20	0	4012.01	0	3988.73
	226	4142.35	234	4110.08	343	4087.52	368	4071.98	227	4033.86	191	4012.67	177	3989.39
	714	4143.01	738	4110.74	1086	4088.18	1165	4072.64	718	4034.52	602	4013.33	558	3990.05
	1394	4143.66	1443	4111.39	2127	4088.83	2282	4073.29	1403	4035.17	1177	4013.98	1089	3990.70
	2238	4144.32	2319	4112.05	3423	4089.49	3674	4073.95	2254	4035.83	1889	4014.64	1748	3991.36
	3227	4144.98	3346	4112.71	4948	4090.15	5312	4074.61	3253	4036.49	2722	4015.30	2518	3992.02
	4346	4145.64	4511	4113.37	6681	4090.81	7175	4075.27	4385	4037.15	3666	4015.96	3390	3992.68
	5585	4146.30	5803	4114.03	8609	4091.47	9246	4075.93	5640	4037.81	4711	4016.62	4354	3993.34
	6936	4146.95	7214	4114.68	10717	4092.12	11513	4076.58	7009	4038.46	5850	4017.27	5404	3993.99
	8390	4147.61	8735	4115.34	12996	4092.78	13965	4077.24	8486	4039.12	7077	4017.93	6534	3994.65
	9943	4148.27	10360	4116.00	15438	4093.44	16593	4077.90	10064	4039.78	8385	4018.59	7739	3995.31
	11587	4148.93	12084	4116.66	18034	4094.10	19387	4078.56	11737	4040.44	9771	4019.25	9014	3995.97
BOTTOM														
	0	4109.42	0	4,086.86	0	4071.32	0	4033.20	0	4012.01	0	3988.73	0	3960.92
	226	4110.08	234	4,087.52	343	4071.98	368	4033.86	227	4012.67	191	3989.39	177	3961.58
	714	4110.74	738	4,088.18	1086	4072.64	1165	4034.52	718	4013.33	602	3990.05	558	3962.24
	1394	4111.39	1443	4,088.83	2127	4073.29	2282	4035.17	1403	4013.98	1177	3990.70	1089	3962.89
	2238	4112.05	2319	4,089.49	3423	4073.95	3674	4035.83	2254	4014.64	1889	3991.36	1748	3963.55
	3227	4112.71	3346	4,090.15	4948	4074.61	5312	4036.49	3253	4015.30	2722	3992.02	2518	3964.21
	4346	4113.37	4511	4,090.81	6681	4075.27	7175	4037.15	4385	4015.96	3666	3992.68	3390	3964.87
	5585	4114.03	5803	4,091.47	8609	4075.93	9246	4037.81	5640	4016.62	4711	3993.34	4354	3965.53
	6936	4114.68	7214	4,092.12	10717	4076.58	11513	4038.46	7009	4017.27	5850	3993.99	5404	3966.18
	8390	4115.34	8735	4,092.78	12996	4077.24	13965	4039.12	8486	4017.93	7077	3994.65	6534	3966.84
	9943	4116.00	10360	4,093.44	15438	4077.90	16593	4039.78	10064	4018.59	8385	3995.31	7739	3967.50
	11587	4116.66	12084	4,094.10	18034	4078.56	19387	4040.44	11737	4019.25	9771	3995.97	9014	3968.16

Table I-6 Rating Tables for River Reaches of the Mesilla Basin

	LeasburgDamTo PichachoFlume		*PicachoFumTo MesillaDam*		*MesillaDamTo AnthonyBridge1*		*AnthonyBridge1To AnthonyBridge2*		*BelowAnthonyTo RGatElPaso1*		*RGatElPaso1To RGatElPaso2*	
	Flow (Q)	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*	*Flow (Q)*	*Stage [Z]*
	af/day	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*	*af/day*	*(ft)*
TOP	0	3,955.24	0	3,906.95	0	3,855.20	0	3,830.48	0	3,788.06	0	3,742.37
	351	3,955.90	456	3,907.61	330	3,855.86	313	3,831.14	290	3,788.72	281	3,743.03
	1,110	3,956.56	1,445	3,908.27	1,045	3,856.52	991	3,831.80	918	3,789.38	887	3,743.69
	2,175	3,957.21	2,834	3,908.92	2,046	3,857.17	1,941	3,832.45	1,796	3,790.03	1,737	3,744.34
	3,501	3,957.87	4,565	3,909.58	3,294	3,857.83	3,124	3,833.11	2,890	3,790.69	2,793	3,745.00
	5,060	3,958.53	6,604	3,910.24	4,761	3,858.49	4,515	3,833.77	4,175	3,791.35	4,035	3,745.66
	6,833	3,959.19	8,927	3,910.90	6,429	3,859.15	6,095	3,834.43	5,635	3,792.01	5,445	3,746.32
	8,805	3,959.85	11,512	3,911.56	8,283	3,859.81	7,852	3,835.09	7,257	3,792.67	7,012	3,746.98
	10,962	3,960.50	14,345	3,912.21	10,311	3,860.46	9,773	3,835.74	9,030	3,793.32	8,724	3,747.63
	13,295	3,961.16	17,412	3,912.87	12,504	3,861.12	11,850	3,836.40	10,946	3,793.98	10,573	3,748.29
	15,793	3,961.82	20,702	3,913.53	14,854	3,861.78	14,074	3,837.06	12,996	3,794.64	12,552	3,748.95
	18,450	3,962.48	24,205	3,914.19	17,351	3,862.44	16,437	3,837.72	15,175	3,795.30	14,655	3,749.61
BOTTOM												
	0	3,906.95	0	3,855.20	0	3,830.48	0	3,788.06	0	3,742.37	0	3,727.44
	351	3,907.61	456	3,855.86	330	3,831.14	313	3,788.72	290	3,743.03	281	3,728.10
	1,110	3,908.27	1,445	3,856.52	1,045	3,831.80	991	3,789.38	918	3,743.69	887	3,728.76
	2,175	3,908.92	2,834	3,857.17	2,046	3,832.45	1,941	3,790.03	1,796	3,744.34	1,737	3,729.41
	3,501	3,909.58	4,565	3,857.83	3,294	3,833.11	3,124	3,790.69	2,890	3,745.00	2,793	3,730.07
	5,060	3,910.24	6,604	3,858.49	4,761	3,833.77	4,515	3,791.35	4,175	3,745.66	4,035	3,730.73
	6,833	3,910.90	8,927	3,859.15	6,429	3,834.43	6,095	3,792.01	5,635	3,746.32	5,445	3,731.39
	8,805	3,911.56	11,512	3,859.81	8,283	3,835.09	7,852	3,792.67	7,257	3,746.98	7,012	3,732.05
	10,962	3,912.21	14,345	3,860.46	10,311	3,835.74	9,773	3,793.32	9,030	3,747.63	8,724	3,732.70
	13,295	3,912.87	17,412	3,861.12	12,504	3,836.40	11,850	3,793.98	10,946	3,748.29	10,573	3,733.36
	15,793	3,913.53	20,702	3,861.78	14,854	3,837.06	14,074	3,794.64	12,996	3,748.95	12,552	3,734.02
	18,450	3,914.19	24,205	3,862.44	17,351	3,837.72	16,437	3,795.30	15,175	3,749.61	14,655	3,734.68

reach properties from Table I-1 and Table I-2 were used to calculate the rating table for the top of Reach 1, as given in Table I-5 and Table I-6. The values of stage in those tables show the elevation of the river or drain water stage. When the flow equals to zero, the stage is at the top of riverbed or drain bed.

Drains

Three main drains in the Rincon Valley and nine main drains in the Mesilla Basin were modeled in the RiverWare models. They are Garfield Drain, Hatch Drain, and Rincon Drain in the Rincon Valley. The drains in the Mesilla Basin are Selden Drain, Del Rio Drain, Anthony Drain, East Drain, Montoya Drain, Picacho Drain, La Mesa Drain, West Drain, and Nemexas Drain. These drains are simulated with RiverWare reach objects, and 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 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.

Division of Drains for Each River Reach

To 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 drain reaches is determined by the upstream to downstream length of the groundwater object to which a drain is linked if the drain is continuous through several groundwater objects. Based on the cross-section survey data provided by the NMISC (2007), average properties for each drain to the corresponding reaches were calculated and are given in Table I-7 for Rincon Valley and Table I-8 for Mesilla Basin, respectively. The average slope was calculated from the total length and top/bottom elevation of the drains. Since most of the drain widths are within the range of 20ft to 50ft according to the survey data (NMISC 2007), the average width for each drain was used as 30ft for the initial model run for simplicity. The midpoint elevation for each drain was calculated as the average of the elevation at the top and the bottom of the drain.

Table I-7 Average Drain Properties of the Rincon Valley

Drain Name	Corresponding River Reaches	Length (ft)	*Width (ft)*	Ave. Slope (ft/ft)	Elevation (ft)
Garfield Drain	Reach3	16685.90	30.0	0.000684	4097.17
	Reach4	27077.15	30.0	0.000754	4078.98
	Reach5	19837.91	30.0	0.000557	4063.92
Hatch Drain	Reach5	30371.42	30.0	0.000568	4050.83
	Reach6	14303.58	30.0	0.002362	4025.31
Rincon Drain	Reach6	29115.93	30.0	0.001171	4029.99
	Reach7	22744.96	30.0	0.000558	3999.90

Table I-8 Average Drain Properties of the Mesilla Basin

Drain Name	Corresponding River Reaches	Length (ft)	Width (ft)	Av slope (ft/ft)	Elevation (ft)
Selden Drain	Reach1	21322.51	30.0	0.000952	3944.92
Del Rio Drain	Reach1 Reach2	23642.22 63820.75	30.0 30.0	0.000972 0.000809	3919.06 3881.77
Anthony drain	Reach4 Reach5	17875.21 24206.72	30.0 30.0	0.000446 0.000622	3794.38 3781.62
East drain	Reach4 Reach5	33039.06 27981.80	30.0 30.0	0.000874 0.000478	3800.10 3778.98
Montoya Drain	Reach5	15795.22	30.0	0.000565	3741.17
Picacho Drain	Reach2	32668.07	30.0	0.001414	3892.71
LaMesa Drain	Reach3 Reach4	15903.95 49514.74	30.0 30.0	0.000772 0.000645	3830.08 3807.97
West Drain	Reach4 Reach5	49312.70 72109.38	30.0 30.0	0.000740 0.000727	3808.42 3763.97
Nemexas Drain	Reach4 Reach5	10975.94 77078.50	30.0 30.0	0.000688 0.000655	3789.56 3760.52

Drain Losses or Gains 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 drain 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 river reach objects. 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. Of course, if the shallow aquifer head is below the drain bed, the drain is usually dry and there is no seepage. The exception would be when a gaining reach flows into a losing reach.

Drain Conductance and Average bed elevation

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 be 0.641 ft/d and 3 ft, respectively. The drain width was used as 30 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 are listed in Table I-9 and Table I-10 .

Table I-9 Drain Conductance Parameters of the Rincon Valley

Drain Name	Corresponding River Reaches	Drain-bed Conductance [C], ft^2/day
Garfield Drain	Reach3	95891.10
	Reach4	164719.00
	Reach5	138849.00
Hatch Drain	Reach5	373229.00
	Reach6	186564.00
Rincon Drain	Reach6	225531.00
	Reach7	95891.00

Table I-10 Drain Conductance Parameters of the Mesilla Basin

Drain Name	Crossed Reaches	Drainbed Conductance [C], ft^2/day
Selden Drain	Reach1	136677.30
Del Rio Drain	Reach1 Rarch2	151546.60 409091.00
Anthony Drain	Reach4 Reach5	114580.10 155165.10
East Drain	Reach4 Reach5	211780.40 179363.30
Montoya Drain	Reach5	101247.40
Picacho Drain	Reach2	209402.30
LaMesa Drain	Reach3 Reach4	101944.30 317389.50
West Drain	Reach4 Reach5	316094.40 462221.10
Nemexas Drain	Reach4 Reach5	70355.80 494073.20

Drain Cross Sections and Rating Tables

Cross-section data for all the drains were taken from the NMISC (2007) cross-section survey data. The cross-sections along those drains for corresponding groundwater objects and reaches for both Rincon Valley and Mesilla Basin areas are shown in Appendix: Drain cross sections for both Rincon Valley and Mesilla Basin.

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 assuming normal flow conditions. 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. The rating tables for the top and bottom of drains of the Rincon and Mesilla Basin are given in Table I-11 through Table I-14, respectively.

Table I-11 Rating Tables for Drains of the Rincon Valley

	Garfield Drain-Reach3		*Garfield Drain-Reach4*		*Garfield Drain-Reach5*		*Hatch Drain*		*Rincon Drain Reach6*		*Rincon Drain-Reach7*	
	Flow (Q) af/day	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*
TOP	0	4105.40	0	4093.20	0.00	4067.79	0	4059.54	0	4030.06	0	4006.25
	2	4105.53	2	4093.33	2.10	4067.93	2	4059.67	3	4030.19	3	4006.38
	7	4105.66	7	4093.46	6.62	4068.06	7	4059.80	9	4030.32	9	4006.51
	13	4105.79	13	4093.59	12.93	4068.19	13	4059.93	17	4030.45	17	4006.64
	21	4105.93	21	4093.72	20.77	4068.32	20	4060.07	27	4030.59	27	4006.78
	30	4106.06	30	4093.85	29.96	4068.45	30	4060.20	39	4030.72	39	4006.91
	40	4106.19	40	4093.99	40.36	4068.58	40	4060.33	53	4030.85	53	4007.04
	52	4106.32	52	4094.12	51.89	4068.72	51	4060.46	68	4030.98	68	4007.17
	64	4106.45	64	4094.25	64.47	4068.85	63	4060.59	85	4031.11	85	4007.30
	78	4106.58	78	4094.38	78.02	4068.98	77	4060.72	103	4031.24	103	4007.43
	92	4106.72	92	4094.51	92.49	4069.11	91	4060.86	122	4031.38	122	4007.57
	108	4106.85	108	4094.64	107.82	4069.24	106	4060.99	142	4031.51	142	4007.70
BOTTOM	0	4093.20	0	4067.79	0.00	4050.78	0	4008.65	0	4006.25	0	3993.88
	3	4093.33	3	4067.93	2.54	4050.91	5	4008.78	2	4006.38	2	3994.01
	8	4093.46	8	4068.06	8.02	4051.04	16	4008.91	8	4006.51	8	3994.14
	16	4093.59	16	4068.19	15.67	4051.17	32	4009.04	15	4006.64	15	3994.27
	25	4093.72	25	4068.32	25.16	4051.31	51	4009.18	24	4006.78	24	3994.41
	36	4093.85	36	4068.45	36.29	4051.44	74	4009.31	35	4006.91	35	3994.54
	49	4093.99	49	4068.58	48.90	4051.57	99	4009.44	47	4007.04	47	3994.67
	63	4094.12	63	4068.72	62.87	4051.70	128	4009.57	60	4007.17	60	3994.80
	78	4094.25	78	4068.85	78.10	4051.83	158	4009.70	75	4007.30	75	3994.93
	95	4094.38	95	4068.98	94.52	4051.96	192	4009.83	91	4007.43	91	3995.06
	112	4094.51	112	4069.11	112.05	4052.10	227	4009.97	107	4007.57	107	3995.20
	131	4094.64	131	4069.24	130.63	4052.23	265	4010.10	125	4007.70	125	3995.33

Table I-12 Rating Tables for Drains of the Mesilla Basin

	Selden Drain		*Del Rio Drain-Reach1*		*Del Rio Drain-Reach2*		*Anthony Drain-Reach4*		*Anthony Drain-Reach5*	
	Flow (Q) af/day	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*
TOP	0.00	3961.58	0.00	3930.55	0.00	3907.57	0.00	3799.62	0.00	3789.14
	2.64	3961.71	2.64	3930.68	2.64	3907.70	1.81	3799.75	2.26	3789.27
	8.34	3961.84	8.34	3930.81	8.34	3907.83	5.71	3799.88	7.12	3789.40
	16.30	3961.97	16.30	3930.94	16.30	3907.96	11.16	3800.01	13.92	3789.53
	26.17	3962.11	26.17	3931.08	26.17	3908.10	17.93	3800.15	22.37	3789.67
	37.75	3962.24	37.75	3931.21	37.75	3908.23	25.85	3800.28	32.28	3789.80
	50.87	3962.37	50.87	3931.34	50.87	3908.36	34.84	3800.41	43.51	3789.93
	65.41	3962.50	65.41	3931.47	65.41	3908.49	44.80	3800.54	55.96	3790.06
	81.27	3962.63	81.27	3931.60	81.27	3908.62	55.66	3800.67	69.54	3790.19
	98.36	3962.76	98.36	3931.73	98.36	3908.75	67.36	3800.80	84.19	3790.32
	116.61	3962.90	116.61	3931.87	116.61	3908.89	79.86	3800.94	99.83	3790.46
	135.96	3963.03	135.96	3932.00	135.96	3909.02	93.11	3801.07	116.43	3790.59
BOTTOM	0.00	3928.26	0.00	3907.57	0.00	3855.97	0.00	3789.14	0.00	3774.09
	2.64	3928.39	2.64	3907.70	2.64	3856.10	1.77	3789.27	2.26	3774.22
	8.34	3928.52	8.34	3907.83	8.34	3856.23	5.58	3789.40	7.12	3774.35
	16.30	3928.65	16.30	3907.96	16.30	3856.36	10.90	3789.53	13.92	3774.48
	26.17	3928.79	26.17	3908.10	26.17	3856.50	17.50	3789.67	22.37	3774.62
	37.75	3928.92	37.75	3908.23	37.75	3856.63	25.24	3789.80	32.28	3774.75
	50.87	3929.05	50.87	3908.36	50.87	3856.76	34.01	3789.93	43.51	3774.88
	65.41	3929.18	65.41	3908.49	65.41	3856.89	43.73	3790.06	55.96	3775.01
	81.27	3929.31	81.27	3908.62	81.27	3857.02	54.32	3790.19	69.54	3775.14
	98.36	3929.44	98.36	3908.75	98.36	3857.15	65.74	3790.32	84.19	3775.27
	116.61	3929.58	116.61	3908.89	116.61	3857.29	77.93	3790.46	99.83	3775.41
	135.96	3929.71	135.96	3909.02	135.96	3857.42	90.84	3790.59	116.43	3775.54

Table I-13 Rating Tables for Drains of the Mesilla Basin-continued

	East Drain-Reach4		*East Drain-Reach5*		*Montoya Drain*		*Picacho Drain*		*LaMesa Drain-Reach3*	
	Flow (Q) af/day	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*
TOP	0.00	3814.54	0.00	3785.66	0.00	3745.63	0.00	3915.80	0.00	3836.22
	2.26	3814.67	1.87	3785.79	1.87	3745.76	1.87	3915.93	2.38	3836.35
	7.12	3814.80	5.91	3785.92	5.91	3745.89	5.91	3916.06	7.51	3836.48
	13.92	3814.93	11.55	3786.05	11.55	3746.02	11.55	3916.19	14.68	3836.61
	22.37	3815.07	18.54	3786.19	18.54	3746.16	18.54	3916.33	23.57	3836.75
	32.28	3815.20	26.75	3786.32	26.75	3746.29	26.75	3916.46	34.00	3836.88
	43.51	3815.33	36.04	3786.45	36.04	3746.42	36.04	3916.59	45.82	3837.01
	55.96	3815.46	46.34	3786.58	46.34	3746.55	46.34	3916.72	58.91	3837.14
	69.54	3815.59	57.58	3786.71	57.58	3746.68	57.58	3916.85	73.19	3837.27
	84.19	3815.72	69.69	3786.84	69.69	3746.81	69.69	3916.98	88.59	3837.40
	99.83	3815.86	82.62	3786.98	82.62	3746.95	82.62	3917.12	105.02	3837.54
	116.43	3815.99	96.32	3787.11	96.32	3747.08	96.32	3917.25	122.44	3837.67
BOTTOM	0.00	3785.66	0.00	3772.29	0.00	3736.71	0.00	3869.62	0.00	3823.94
	2.26	3785.79	1.87	3772.42	1.87	3736.84	1.87	3869.75	2.32	3824.07
	7.12	3785.92	5.91	3772.55	5.91	3736.97	5.91	3869.88	7.34	3824.20
	13.92	3786.05	11.55	3772.68	11.55	3737.10	11.55	3870.01	14.33	3824.33
	22.37	3786.19	18.54	3772.82	18.54	3737.24	18.54	3870.15	23.02	3824.47
	32.28	3786.32	26.75	3772.95	26.75	3737.37	26.75	3870.28	33.20	3824.60
	43.51	3786.45	36.04	3773.08	36.04	3737.50	36.04	3870.41	44.73	3824.73
	55.96	3786.58	46.34	3773.21	46.34	3737.63	46.34	3870.54	57.50	3824.86
	69.54	3786.71	57.58	3773.34	57.58	3737.76	57.58	3870.67	71.44	3824.99
	84.19	3786.84	69.69	3773.47	69.69	3737.89	69.69	3870.80	86.45	3825.12
	99.83	3786.98	82.62	3773.61	82.62	3738.03	82.62	3870.94	102.48	3825.26
	116.43	3787.11	96.32	3773.74	96.32	3738.16	96.32	3871.07	119.46	3825.39

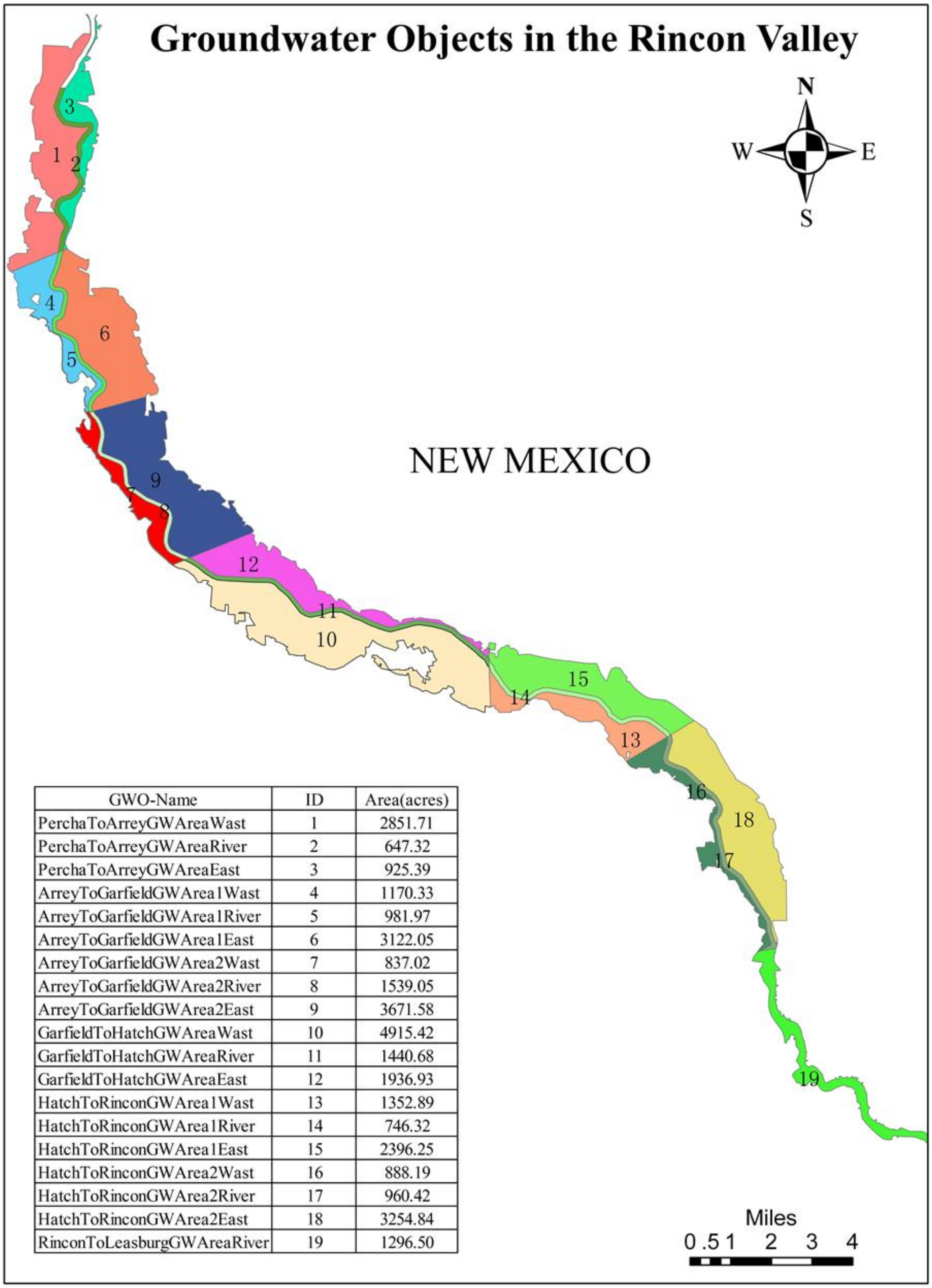
Table I-14 Rating Tables for Drains of the Mesilla Basin-continued

	LaMesa Drain-Reach4		*West Drain-Reach4*		*West Drain-Reach5*		*Nemexas Drain Reach4*		*Nemexas Drain Reach5*	
	Flow (Q) af/day	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*	*Flow (Q) af/day*	*Stage [Z] (ft)*
TOP	0.00	3823.94	0.00	3826.67	0.00	3790.17	0.00	3793.33	0.00	3785.78
	2.30	3824.07	2.30	3826.80	2.31	3790.30	2.31	3793.46	2.31	3785.91
	7.26	3824.20	7.26	3826.93	7.29	3790.43	7.29	3793.59	7.29	3786.04
	14.19	3824.33	14.19	3827.06	14.24	3790.56	14.24	3793.72	14.24	3786.17
	22.79	3824.47	22.79	3827.20	22.87	3790.70	22.87	3793.86	22.87	3786.31
	32.88	3824.60	32.88	3827.33	32.99	3790.83	32.99	3793.99	32.99	3786.44
	44.32	3824.73	44.32	3827.46	44.45	3790.96	44.45	3794.12	44.45	3786.57
	57.01	3824.86	57.01	3827.59	57.16	3791.09	57.16	3794.25	57.16	3786.70
	70.84	3824.99	70.84	3827.72	71.01	3791.22	71.01	3794.38	71.01	3786.83
	85.77	3825.12	85.77	3827.85	85.95	3791.35	85.95	3794.51	85.95	3786.96
	101.71	3825.26	101.71	3827.99	101.89	3791.49	101.89	3794.65	101.89	3787.10
	118.61	3825.39	118.61	3828.12	118.80	3791.62	118.80	3794.78	118.80	3787.23
BOTTOM	0.00	3791.99	0.00	3790.17	0.00	3737.76	0.00	3785.78	0.00	3735.26
	2.30	3792.12	2.30	3790.30	2.31	3737.89	2.31	3785.91	2.31	3735.39
	7.26	3792.25	7.26	3790.43	7.29	3738.02	7.29	3786.04	7.29	3735.52
	14.19	3792.38	14.19	3790.56	14.24	3738.15	14.24	3786.17	14.24	3735.65
	22.79	3792.52	22.79	3790.70	22.87	3738.29	22.87	3786.31	22.87	3735.79
	32.88	3792.65	32.88	3790.83	32.99	3738.42	32.99	3786.44	32.99	3735.92
	44.32	3792.78	44.32	3790.96	44.45	3738.55	44.45	3786.57	44.45	3736.05
	57.01	3792.91	57.01	3791.09	57.16	3738.68	57.16	3786.70	57.16	3736.18
	70.84	3793.04	70.84	3791.22	71.01	3738.81	71.01	3786.83	71.01	3736.31
	85.77	3793.17	85.77	3791.35	85.95	3738.94	85.95	3786.96	85.95	3736.44
	101.71	3793.31	101.71	3791.49	101.89	3739.08	101.89	3787.10	101.89	3736.58
	118.61	3793.44	118.61	3791.62	118.80	3739.21	118.80	3787.23	118.80	3736.71

Groundwater system

Discretization of Groundwater Objects for the Rincon Valley

The model has a physically based groundwater component to better simulate the losses and gains to the river. The shallow groundwater system (upper 70 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. The simulation of the shallow groundwater system was completed using a course horizontal discretization. In each reach, a set of three groundwater objects were used to simulate the river and the surrounding irrigated areas. 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. Groundwater objects were assigned to the reaches based on the assumption that there is one groundwater object associated with each River Reach object, and this may be one groundwater object on each side of each River Reach object, for a maximum of three groundwater objects that may be associated with each Reach Object. For the Rincon Valley, the River Reaches 2-7 each have three groundwater objects associated with it, and Reach 8 has only one groundwater object since it is located in Selden Canyon with no irrigated area on either side. For the Reach 1 no groundwater object is assigned as there is little surface water-groundwater interaction in that reach. The groundwater objects are numbered sequentially from 1 to 19. The shallow aquifer (upper 70 feet) was simulated with groundwater objects. The groundwater objects also interact with deeper ground-water layers by use of the deep percolation option of the groundwater object. The locations of the areas represented by groundwater objects are shown in Figure I-3. Average groundwater object parameters based on information from Weeden and Maddock's (1999) report are given in Table I-15.



GWO-Name	ID	Area(acres)
PerchaToArreyGWAreaWast	1	2851.71
PerchaToArreyGWAreaRiver	2	647.32
PerchaToArreyGWAreaEast	3	925.39
ArreyToGarfieldGWArea1Wast	4	1170.33
ArreyToGarfieldGWArea1River	5	981.97
ArreyToGarfieldGWArea1East	6	3122.05
ArreyToGarfieldGWArea2Wast	7	837.02
ArreyToGarfieldGWArea2River	8	1539.05
ArreyToGarfieldGWArea2East	9	3671.58
GarfieldToHatchGWAreaWast	10	4915.42
GarfieldToHatchGWAreaRiver	11	1440.68
GarfieldToHatchGWAreaEast	12	1936.93
HatchToRinconGWArea1Wast	13	1352.89
HatchToRinconGWArea1River	14	746.32
HatchToRinconGWArea1East	15	2396.25
HatchToRinconGWArea2Wast	16	888.19
HatchToRinconGWArea2River	17	960.42
HatchToRinconGWArea2East	18	3254.84
RinconToLeasburgGWAreaRiver	19	1296.50

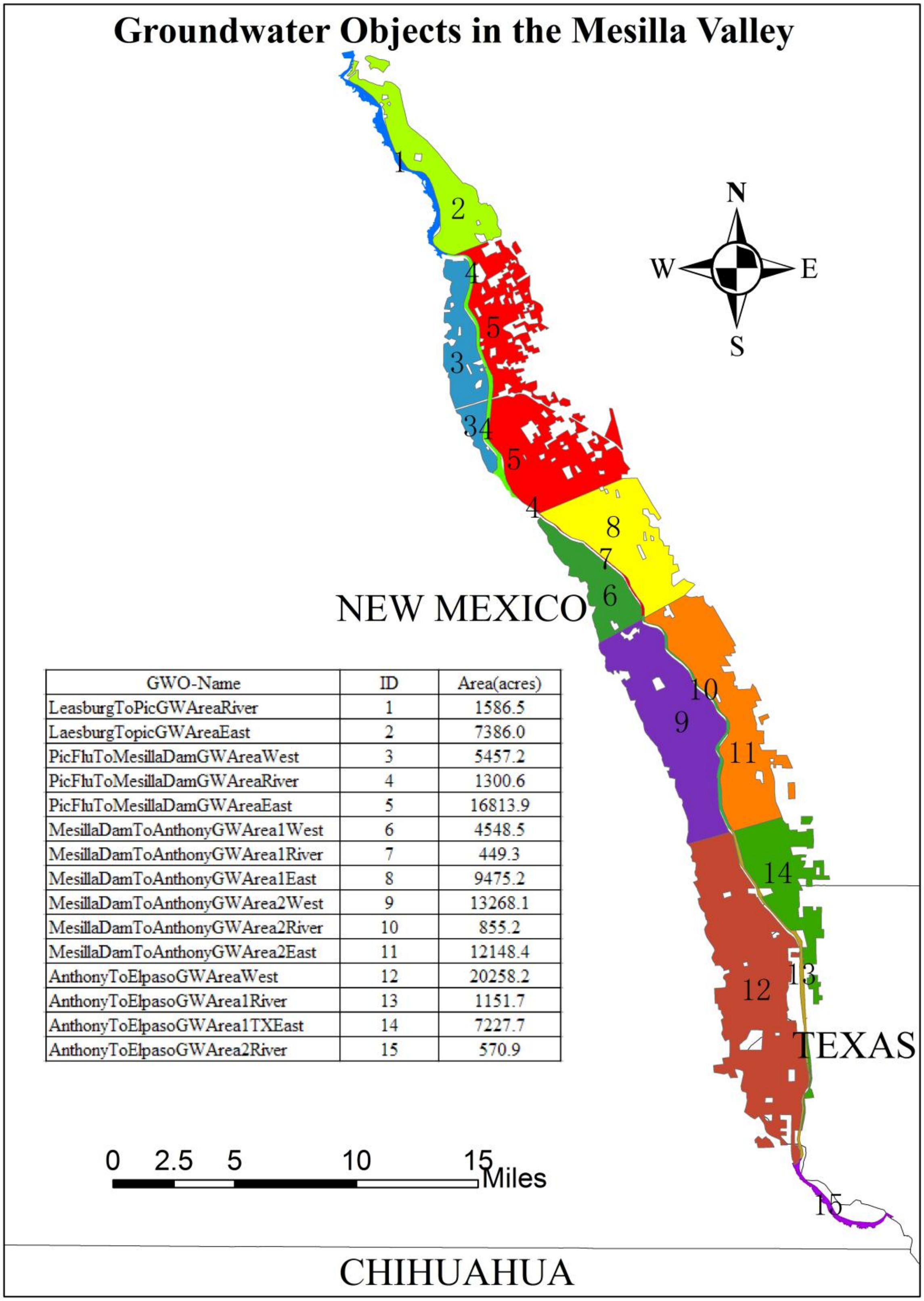
Figure I-3 Groundwater Storage Objects in the Rincon Valley.

Table I-15 Groundwater Storage Object Average Parameters

Parameter	*Value*
Alluvial aquifer horizontal conductivity, K_H	20.05 ft/day
Alluvial aquifer vertical conductivity, K_V	0.401 ft/day
Average thickness of alluvial aquifer, D_A	70 ft
Streambed vertical conductivity, K'	0.114 ft/day
Thickness of streambed, b'	5 ft
Depth to the Center of Deep Aquifer, D_V (ft)	201 ft
Drainbed vertical conductivity, K_D'	0.641 ft/day
Thickness of drainbed, b_D'	3 ft

Discretization Groundwater Objects for the Mesilla Valley

The basic principle of the discretization of the groundwater objects in the Mesilla Basin is essentially the same as Rincon Valley. For the Mesilla Basin, the River Reaches 2-5 each has three groundwater objects associated with it, and Reach 6 has only one groundwater object since no irrigated area occurs on either side. For the Reach 1 no groundwater object is assigned to the west side, so there are only two groundwater objects. The groundwater objects are numbered sequentially from 1 to 15. The groundwater objects also interact with deeper ground-water layers by use of the deep percolation option of the groundwater object. The locations of the areas represented by groundwater objects are shown in Figure I-4. Average groundwater object parameters are used as that of Rincon Valley for the first run of the model.



GWO-Name	ID	Area(acres)
LeasburgToPicGWAreaRiver	1	1586.5
LaesburgTopicGWAreaEast	2	7386.0
PicFluToMesillaDamGWAreaWest	3	5457.2
PicFluToMesillaDamGWAreaRiver	4	1300.6
PicFluToMesillaDamGWAreaEast	5	16813.9
MesillaDamToAnthonyGWArea1West	6	4548.5
MesillaDamToAnthonyGWArea1River	7	449.3
MesillaDamToAnthonyGWArea1East	8	9475.2
MesillaDamToAnthonyGWArea2West	9	13268.1
MesillaDamToAnthonyGWArea2River	10	855.2
MesillaDamToAnthonyGWArea2East	11	12148.4
AnthonyToElpasoGWAreaWest	12	20258.2
AnthonyToElpasoGWArea1River	13	1151.7
AnthonyToElpasoGWArea1TXEast	14	7227.7
AnthonyToElpasoGWArea2River	15	570.9

Figure I-4 Groundwater Storage Objects in the Mesilla Basin.

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. 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. 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 20.05ft/day (Weeden and Maddock, 1999). The saturated thickness was assumed to be 70 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.

The horizontal conductance is calculated by Equation (4):

$$C_H = \frac{A_V K_H}{D_H} \tag{4}$$

where

C_H	is the horizontal conductance between GWOs, in ft^2/day;
A_V	is the vertical cross-sectional area between the GWOs, in ft^2;
K_H	is the horizontal hydraulic conductivity between the GWOs, in ft/day;
D_H	is the horizontal distance between the centers of the GWOs, in ft;

with

$$A_V = D_A L_G \tag{5}$$

where

D_A	is the average thickness of the alluvial aquifer, in ft.
L_G	is the average length between GWOs, in ft.

The horizontal conductance and hydraulic properties of the groundwater objects are listed in Table I-16 and Table I-17, respectively.

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Table I-16 Horizontal Conductance for the Groundwater Storage Objects of the Rincon Valley

GWO ID in Figure I-3	*Dist. Between Centers of GWOs, D_H (ft)*	*Average Length Between GWOs, L_G (ft)*	*Vert Area Between GWOs, A_V (ft^2)*	*Horiz Cond. Between GWOs, C_H (ft^2/day)*
1 to 2	3,346	11,414	799,008	4,778.6
2 to 3	2,788	11,414	799,008	5,748.6
1 to 4	15,318	6,626	463,792	607.4
2 to 5	19,962	702	49,134	49.4
3 to 6	23,357	600	42,017	36.1
4 to 5	2,772	27,490	1,924,278	13,926.6
5 to 6	3,319	27,490	1,924,278	11,628.4
4 to 7	24,197	1,633	114,341	94.8
5 to 8	23,836	813	56,941	47.9
6 to 9	21,746	8,597	601,782	555.1
7 to 8	3,349	52,719	3,690,361	22,104.3
8 to 9	4,471	52,719	3,690,361	16,557.9
7 to 10	31,147	5,114	357,946	230.5
8 to 11	28,789	1,197	83,804	58.4
9 to 12	25,013	1,253	87,707	70.3
10 to 11	4,812	45,015	3,151,030	13,135.8
11 to 12	7,961	45,015	3,151,030	7,939.9
10 to 13	28,238	1,879	131,561	93.5
11 to 14	32,925	695	48,675	29.7
12 to 15	36,451	262	18,368	10.1
13 to 14	5,058	60,536	4,237,498	16,805.7
14 to 15	2,729	60,536	4,237,498	31,147.2
13 to 16	27,116	436	30,537	22.6
14 to 17	25,627	597	41,787	32.7
15 to 18	24,944	151	10,562	8.5
16 to 17	1,742	27,437	1,920,604	22,119.5
17 to 18	1,686	27,437	1,920,604	22,851.1
17 to 19	25,804	597	41,787	32.5

K_h=20.05 ft/day

Table I-17 Horizontal Conductance for the Groundwater Objects of the Mesilla Basin

GWO ID in Figure I-4	*Dist. Between Centers of GWOs, DH (ft)*	*Average Length Between GWOs, LG (ft)*	*Vert Area Between GWOs, AV (ft2)*	*Horiz Cond. Between GWOs, CH (ft^2/day)*
1 to 2	8,129	46,515	3,256,046	8,031.4
1 to 4	53,029	1,538	107,660	40.7
2 to 5	53,629	9,095	636,650	238.0
3 to 4	6,734	48,661	3,406,270	10,141.9
4 to 5	10,435	59,046	4,133,220	7,941.6
3 to 6	57,209	300	21,000	7.4
4 to 7	45,412	649	45,430	20.1
5 to 8	36,187	19,035	1,332,450	738.3
6 to 7	5,667	30,816	2,157,120	7,631.9
7 to 8	7,023	30,341	2,123,870	6,063.4
6 to 9	34,431	10,513	735,910	428.5
7 to 10	41,474	674	47,180	22.8
8 to 11	43,491	10,071	704,970	325.0
9 to 10	6,419	50,138	3,509,660	10,962.6
10 to 11	5,195	51,835	3,628,450	14,003.9
9 to 12	60,123	9,383	656,810	219.0
10 to 13	57,886	857	59,990	20.8
11 to 14	39,969	10,563	739,410	370.9
12 to 13	8,139	73,759	5,163,130	12,719.1
13 to 14	18,921	67,139	4,699,730	4,980.2
13 to 15	51,411	800	56,000	21.8

K_h=20.05 ft/day

Groundwater Storage

Aquifer storage is the volume of water an aquifer can yield to pumping. The groundwater objects have three inputs related to storage: specific yield, aquifer area, 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 used for all of the groundwater objects is 0.25. 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 6.

$$S_o = S_y A_H D_A \tag{6}$$

Where

S_y is the specific yield;

S_o is the initial storage of the GWO, in acre-ft;
A_H is the horizontal area of the GWO, in acres.
D_a is the average thickness of the alluvial aquifer, in ft.

The calculated initial storage of the groundwater objects are listed in Table I-18 and Table I-19.

Table I-18 Initial Storage and Vertical Conductance for the GWOs of the Rincon Valley

Reaches	*GWO*	*Aquifer Area (acre)*	*GWO Initial Storage, S_o (acre-ft)*	*GWO Deep Aquifer Conductance, C_v (ft^2/day)*
Reach 2	1 (L*)	2101.3	36779.79	182156.09
	2 (M)	647.3	11328.08	56114.13
	3 (R)	644.4	11277.75	55864.83
Reach 3	4 (L)	702.2	12290.79	60871.55
	5 (M)	982.0	17184.37	85123.49
	6 (R)	3317.1	58048.71	287546.72
Reach 4	7 (L)	55.9	977.96	4843.47
	8 (M)	1539.1	26933.41	133415.79
	9 (R)	3014.7	52757.99	261338.93
Reach 5	10(L)	4350.2	76142.79	377105.83
	11 (M)	1440.7	25211.80	124887.73
	12 (R)	1651.0	28892.50	143120.23
Reach 6	13(L)	1066.7	18671.08	92470.67
	14 (M)	746.3	13060.54	64695.93
	15(R)	2307.5	40381.11	200029.50
Reach 7	16(L)	559.6	9794.95	48510.60
	17 (M)	960.4	16807.40	83256.17
	18 (R)	3088.2	54042.63	267702.43
Reach 8	19(M)	1296.5	22688.64	7284.43

- L – Left; M – Middle, R – Right; looking north.

Vertical conductance between shallow and deep aquifers

In order to simulate interactions of the shallow aquifer with the deeper regional aquifer, the deeper aquifer must be simulated as a specified-head boundary in the groundwater object. Fluxes between the shallow and deeper component of the groundwater object are computed for each time step based on the head difference and the conductance. The vertical distance between shallow and deep aquifer was estimated to be 201 ft. The vertical hydraulic conductivity was estimated as 0.401 ft/day (Weeden and Maddock, 1999). The area for each groundwater object was determined in ArcGIS. The vertical conductance for each groundwater object is calculated from Equation (7):

$$C_V = \frac{A_H K_V}{D_V} \tag{7}$$

where

A_H	is the horizontal area of the GWO, in acres.
C_V	is the average vertical conductance of the GWO, in ft^2/day;
K_V	is the average vertical conductivity of the alluvial aquifer, in ft/day;
D_V	is the average depth to the center of deep aquifer, in ft.

The calculated vertical conductance values in the Rincon and Mesilla Basin are listed in Table I-18 and Table I-19.

Table I-19 Initial Storage and Vertical Conductance for the GWOs of the Mesilla Basin

Reaches	*GWO*	*Aquifer Area (acre)*	*GWO Initial Storage, S_o (acre-ft)*	*GWO Deep Aquifer Conductance, C_v (ft^2/day)*
Reach 1	1 (M)	1586.5	27763.17	137525.37
	2 (R)	7386.0	129255.82	640271.05
Reach 2	3(L)	5457.2	95500.43	473063.12
	4 (M)	1300.6	22760.60	112745.05
	5 (R)	16813.9	294243.245	1457539.25
Reach 3	6 (L)	4548.5	79599.39	394297.01
	7 (M)	449.3	7863.38	38951.39
	8 (R)	9475.2	165816.39	821374.47
Reach 4	9 (L)	13268.1	232192.05	1150167.51
	10 (M)	855.2	14965.59	74132.32
	11 (R)	12148.4	212596.66	1053101.42
Reach 5	12(L)	20258.2	354519.62	1756119.35
	13 (M)	1151.7	20153.98	99833.08
	14 (R)	7227.7	126484.78	626544.66
Reach 6	15 (M)	570.9	9990.48	49488.02

GWO Initial Conditions

The initial conditions required for the groundwater objects are the initial elevation of the alluvial aquifer and all elevations of the deep aquifer (Table I-20). Initially, these values were taken from the results of the Weeden and Maddock (1999) MODFLOW model at the location of the row and column designated as the center of the groundwater object. However, comparing these heads to the NMISC (2007) cross-section data showed that the MODFLOW ground-water levels were typically above the ground-surface of the cross-section. Therefore the initial elevations for the middle GWOs were taken as near the streambed bottom of the corresponding reach.

Table I-20 Rincon Valley Groundwater Object Initial Elevations and Initial Deep Aquifer Elevations

	MODFLOW Init.Heads (ft)	*RiverWare Preliminary Init. Elev. (ft)*	*RiverWare Initial Deep Aq. Elev. (ft)*
GWO 1	4117.40	4117.39	4117.39
GWO 2	4123.40	4123.02	4123.02
GWO 3	4125.80	4125.99	4125.99
GWO 4	4107.10	4107.1	4107.13
GWO 5	4089.80	4090.37	4090.37
GWO 6	4089.00	4089.02	4089.02
GWO 7	4049.34	4048.93	4048.93
GWO 8	4044.97	4045.33	4045.33
GWO 9	4044.48	4044.46	4044.46
GWO 10	4017.80	4017.79	4017.79
GWO 11	4009.50	4009.13	4009.13
GWO 12	4017.80	4017.58	4017.58
GWO 13	3988.62	3988.6	3988.60
GWO 14	3986.82	3986.80	3986.80
GWO 15	3988.68	3988.76	3988.76
GWO 16	3987.62	3987.60	3987.60
GWO 17	3985.82	3985.80	3985.80
GWO 18	3987.68	3987.76	3965.83
GWO 19	3965.85	3965.83	3,965.85

Then the differences in elevations between the middle and right groundwater object, and the middle and left groundwater object from the MODFLOW results were used to calculate the initial elevations for the right and left groundwater object. To get the deep aquifer elevations, the variation of the heads from Layer 2 of the MODFLOW model were used, however, the magnitudes of the elevation were shifted to be consistent with the physical conditions at the midpoint of each river reach. The resulting initial elevation values, alongside the corresponding MODFLOW initial head values and the initial values for the deep aquifer elevations are given in Table I-20 and Table I-21.

Table I-21 Mesilla Basin Groundwater Object Initial Elevations and Initial Deep Aquifer Elevations

Groundwater Objects	*MODFLOW Init.Heads (ft)*	*RiverWare Preliminary Init. Elev. (ft)*	*RiverWare Initial Deep Aq. Elev. (ft)*
GWO 1	3931.0	3931.1	3931.0
GWO 2	3925.5	3925.6	3925.0
GWO 3	3884.3	3884.0	3884.1
GWO 4	3881.3	3881.1	3881.0
GWO 5	3876.1	3875.9	3875.0
GWO 6	3840.2	3841.2	3841.0
GWO 7	3841.8	3842.8	3842.0
GWO 8	3843.9	3844.9	3844.0
GWO 9	3809.4	3810.6	3810.0
GWO 10	3808.1	3809.3	3809.0
GWO 11	3808.5	3809.7	3809.0
GWO 12	3765.5	3766.4	3766.0
GWO 13	3764.3	3765.2	3765.0
GWO 14	3780.4	3781.4	3781.0
GWO 15	3664.7	3734.9	3734.0

Groundwater Object Evapotranspiration

Each groundwater object under the river can be assigned evapotranspiration (ET) parameters, which in this case are for the riparian vegetation along the river. An Elevation-ET rate table was created for each middle groundwater object, based on the following factors from Weeden and Maddock (1999): (a) an ET extinction depth of 12-feet; (b) the ET rate varies linearly with depth between the ET surface and extinction depth; and (c) below the extinction depth the ET rate is zero. A typical maximum ET rate for riparian vegetation (i.e. salt cedar) along the Lower Rio Grande is approximately 1 ft/month. A graph of ET rates (Bawazir, 2005) for saltcedar in the Bosque Del Apache during the year 2003 (Day of Year, DOY) is shown in Figure I-5, and a max rate is 0.033 ft/day or 1 ft/month. While the riparian ET can be handled with more sophisticated simulation in future work, it is a relatively small term in the hydrologic balance, and handled rather simply here.

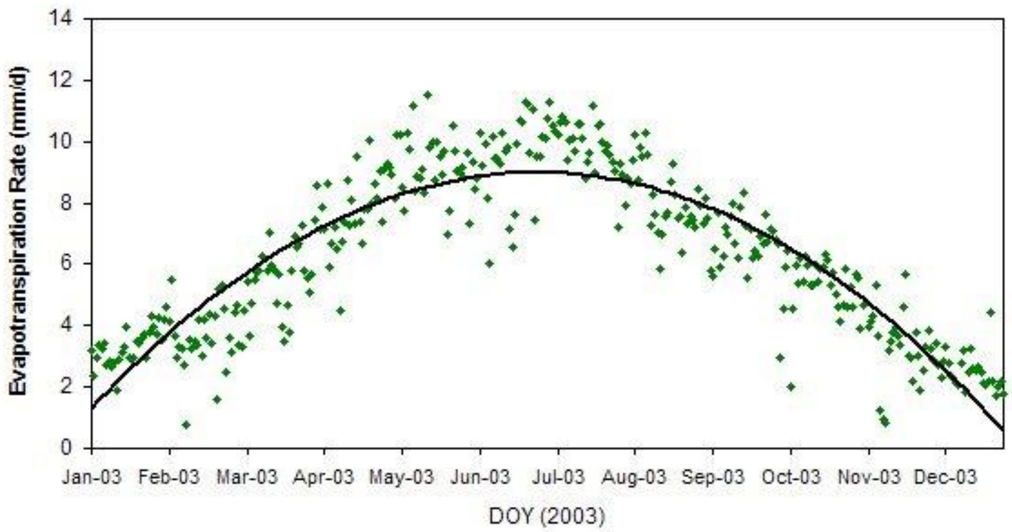


Figure I-5 Typical ET Rates (Bawazir, 2005).

The relationships between ET and the depth of the water table below ground surface within the river groundwater objects, is shown in Table I-22 and Table I-23 for the Rincon Valley and Mesilla Basin, respectively.

Table I-22 ET Rate vs Water Table Elevation of the Rincon Valley

		Water Table Elev (ft)						
Depth (ft)	*ET Rate (ft/day)*	*GWO 2*	*GWO 5*	*GWO 8*	*GWO 11*	*GWO 14*	*GWO 17*	*GWO 19*
48	0.0000	4,080.00	4,048.00	4,004.00	3,969.50	3,946.50	3,935.90	3,925.30
12	0.0000	4,116.00	4,084.00	4,040.00	4,005.50	3,982.50	3,971.90	3,961.30
11	0.0028	4,117.00	4,085.00	4,041.00	4,006.50	3,983.50	3,972.90	3,962.30
10	0.0056	4,118.00	4,086.00	4,042.00	4,007.50	3,984.50	3,973.90	3,963.30
9	0.0083	4,119.00	4,087.00	4,043.00	4,008.50	3,985.50	3,974.90	3,964.30
8	0.0111	4,120.00	4,088.00	4,044.00	4,009.50	3,986.50	3,975.90	3,965.30
7	0.0139	4,121.00	4,089.00	4,045.00	4,010.50	3,987.50	3,976.90	3,966.30
6	0.0167	4,122.00	4,090.00	4,046.00	4,011.50	3,988.50	3,977.90	3,967.30
5	0.0194	4,123.00	4,091.00	4,047.00	4,012.50	3,989.50	3,978.90	3,968.30
4	0.0222	4,124.00	4,092.00	4,048.00	4,013.50	3,990.50	3,979.90	3,969.30
3	0.0250	4,125.00	4,093.00	4,049.00	4,014.50	3,991.50	3,980.90	3,970.30
2	0.0278	4,126.00	4,094.00	4,050.00	4,015.50	3,992.50	3,981.90	3,971.30
1	0.0306	4,127.00	4,095.00	4,051.00	4,016.50	3,993.50	3,982.90	3,972.30
0	0.0333	4,128.00	4,096.00	4,052.00	4,017.50	3,994.50	3,983.90	3,973.30

Table I-23 ET Rate vs Water Table Elevation for GWOs of the Mesilla Basin

		Water Table Elev (ft)					
Depth (ft)	*ET Rate (ft/day)*	*GWO 1*	*GWO 4*	*GWO 7*	*GWO 10*	*GWO 13*	*GWO 15*
48	0.0000	3891.1	3841.1	3802.8	3769.3	3725.2	3694.9
12	0.0000	3927.1	3877.1	3838.8	3805.3	3761.2	3730.9
11	0.0028	3928.1	3878.1	3839.8	3806.3	3762.2	3731.9
10	0.0056	3929.1	3879.1	3840.8	3807.3	3763.2	3732.9
9	0.0083	3930.1	3880.1	3841.8	3808.3	3764.2	3733.9
8	0.0111	3931.1	3881.1	3842.8	3809.3	3765.2	3734.9
7	0.0139	3932.1	3882.1	3843.8	3810.3	3766.2	3735.9
6	0.0167	3933.1	3883.1	3844.8	3811.3	3767.2	3736.9
5	0.0194	3934.1	3884.1	3845.8	3812.3	3768.2	3737.9
4	0.0222	3935.1	3885.1	3846.8	3813.3	3769.2	3738.9
3	0.0250	3936.1	3886.1	3847.8	3814.3	3770.2	3739.9
2	0.0278	3937.1	3887.1	3848.8	3815.3	3771.2	3740.9
1	0.0306	3938.1	3888.1	3849.8	3816.3	3772.2	3741.9
0	0.0333	3939.1	3889.1	3850.8	3817.3	3773.2	3742.9

Crop water use

A major component of water use in the Rincon and Mesilla Valley is the crop consumptive use. The model simulates the crops consumptive use using a water user object for each of the areas that is simulated by one of the east and west groundwater objects. Each water user object uses data for crop ET rate, crop area and farm efficiency to determine the volume of crop ET, and total return flow from surface water and groundwater.

Crop ET and Area Data

The total aggregated daily ET values and total crop land for the water user object were utilized to calculate daily total crop water use. However, the crop area in the Rincon Valley and Mesilla Basin changes over time due to crop pricing and other factors. For the next stage of the model development, the daily ET values and cultivated area for each crop will be used for better model accuracy. 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. Table I-24 and Table I-25 show the total crop acreage in the Rincon and Mesilla Basin, respectively.

Table I-24 Crop Acreage in the Rincon Valley

Water Users	Crop Acreage
ArreyWaterUser1	2101.3
ArreyWaterUser2	702.2
GarfieldWaterUser1	3014.7
GarfieldWaterUser2	3317.1
HatchWaterUser1	4350.2
GarfieldWaterUser3	1651.0
HatchWaterUser2	1066.7
RinconWaterUser1	2307.5
HatchWaterUser3	559.6
RinconWaterUser2	3088.2

Table I-25 Crop Acreage in the Mesilla Basin

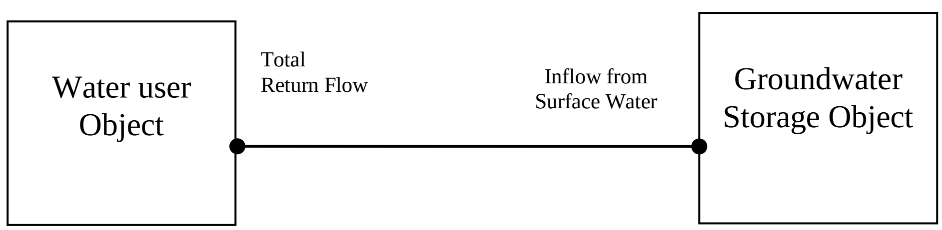
Water Users	Crop Acreage
AnthonytoElPasoWaterUser	7227.7
EastSideWaterUser1	9475.2
EastSideWaterUser2	12148.3
LaUnionWaterUser	20258.2
LeasburgWaterUser1	7386.0
LeasburgWaterUser2	16813.9
PicachoWaterUser	5457.2
WestSideWaterUser1	4548.5
WestSideWaterUser2	13268.1

Minimum Efficiency

In the model, the minimum 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 ET rate and the irrigated area. The crop efficiency for each water user is multiplied by the consumptive use to determine the amount of the diversion request. A minimum efficiency value of 50% is used in all the objects.

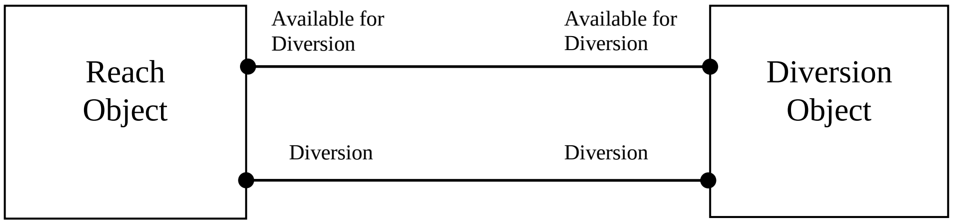
Return Flow

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. In the model the total return flow is determined using the "variable efficiency" method. This method calculates the total remaining water after the crop has consumed its water. The amount of the return water that goes to the groundwater system is determined by water use efficiency. The return water for each water user goes to the groundwater storage objects associated with the area of the water user by a link (shown below) between the water user object and the groundwater storage object.



Diversions from the River

The Rincon Valley water is diverted from Percha Dam. Three diversions in the Mesilla Basin are Leasburg Dam diversion, and the East Side Canal and West Side Canal diversions at Mesilla Dam. The section of the river where the diversion occurs is simulated by a reach object. The reach object uses the "Available Flow Diversion" method to calculate the amount of water taken from the river. The links are shown below by looking upstream of the river.



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 input request.

Canal system

The canal systems in the Rincon Valley and Mesilla Basin are simulated separately from the rest of the drain system because of the different type of interaction with the groundwater system. In this model, the aggregate distribution canal object is used to model the canal system. The aggregate distribution canal object contains distribution canal objects as its elements. It also routes flow from the diversion object down to the water users.

Canal Inflows

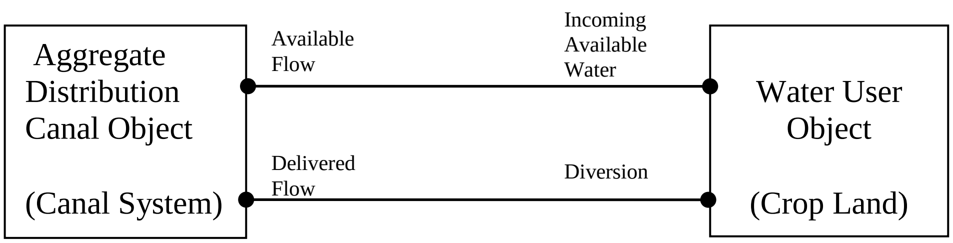
In the Rincon Valley, inflows into canal systems are only from Percha Diversion from siphons crossing the river, and from irrigation return flow. In the Mesilla Basin, the water is diverted from Leasburg Dam and from the Mesilla Dam. Diversions from the Leasburg Dam are delivered and distributed through Leasburg canal. Diversions from the Mesilla Dam are delivered to water users via the Eastside and Westside canals. The Eastside canal also receives 1.5% of the Leasburg canal flow. The simulation of the diversion to the canals in the model is accomplished by linking the diversion object, simulating the diversion, with an aggregate distribution canal object, simulating the canal delivered flow.

Canal Outflows

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.

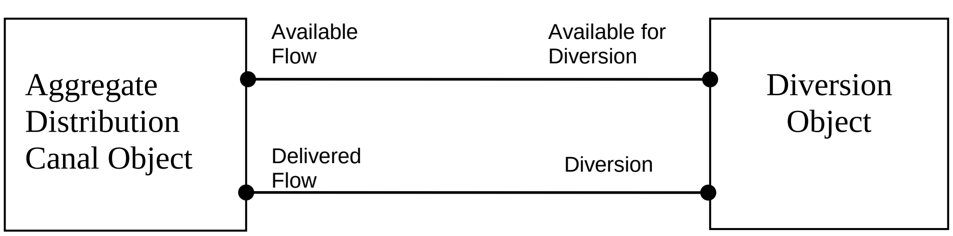
Diversion to croplands

The diversion from the canal system to the croplands is simulated in the model by an aggregate distribution canal object. The crop area is simulated by a water user object. The distribution canal objects in the aggregate distribution canal object are linked to the water user objects to determine the amount of water that is to be diverted. The links are shown below.



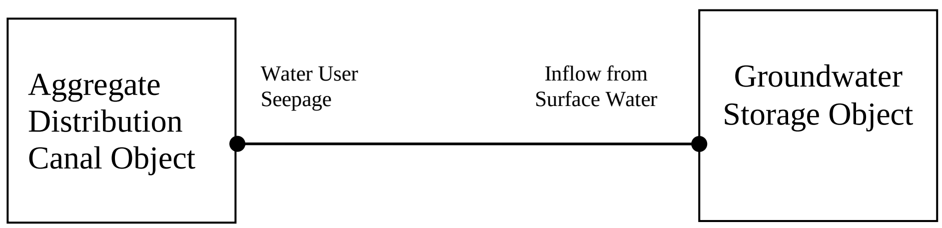
Diversion to canals or returned water to drains and river

In the model the diversion to other canal system objects, to the conveyance part of the river side drains, and to canal returns to the river through wasteways are modeled by both aggregate distribution canal objects representing the canal and diversion objects representing the diversion. The amount of water diverted to other canals or drains is determined by the slot "Percent of Available to Divert" in the diversion object. The "Percent of Available to Divert" slot in each of the three diversion objects is set to 10 percent. These two objects are linked to accomplish the simulated diversion, links are shown below:



Canal seepage

The main factors that affect the rate of canal seepage are soil hydraulic properties, canal shape and slope, and depth to water table. Seepage from irrigation canals and laterals was modeled as recharge to the groundwater system represented by the underlying groundwater object. Canal seepage was assumed to occur during the irrigation season. In the model the canal seepage is simulated using an element in the aggregated distribution canal object. The actual calculations of seepage are made in each element of the aggregated distribution canal object using variable seepage flow fraction. 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 rate of 10% is used in the all the aggregated distribution canal objects. The link from the canal system to a groundwater objects is shown below.



RiverWare Model Layout

Rincon Valley Model layout

Figure I-6 and Figure I-7 show the layout for the Rincon Valley portion of the RiverWare model with Reach Objects linked to the GWOs as the method to simulate drain flow.

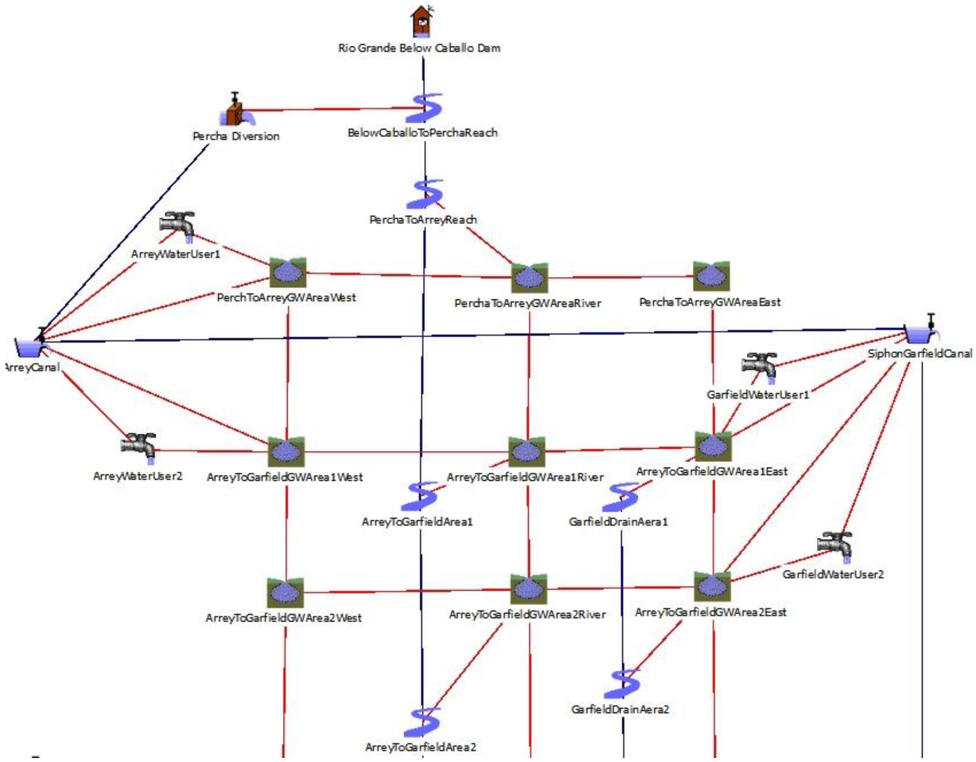


Figure I-6 Top of RiverWare Model Layout for Rincon Valley.

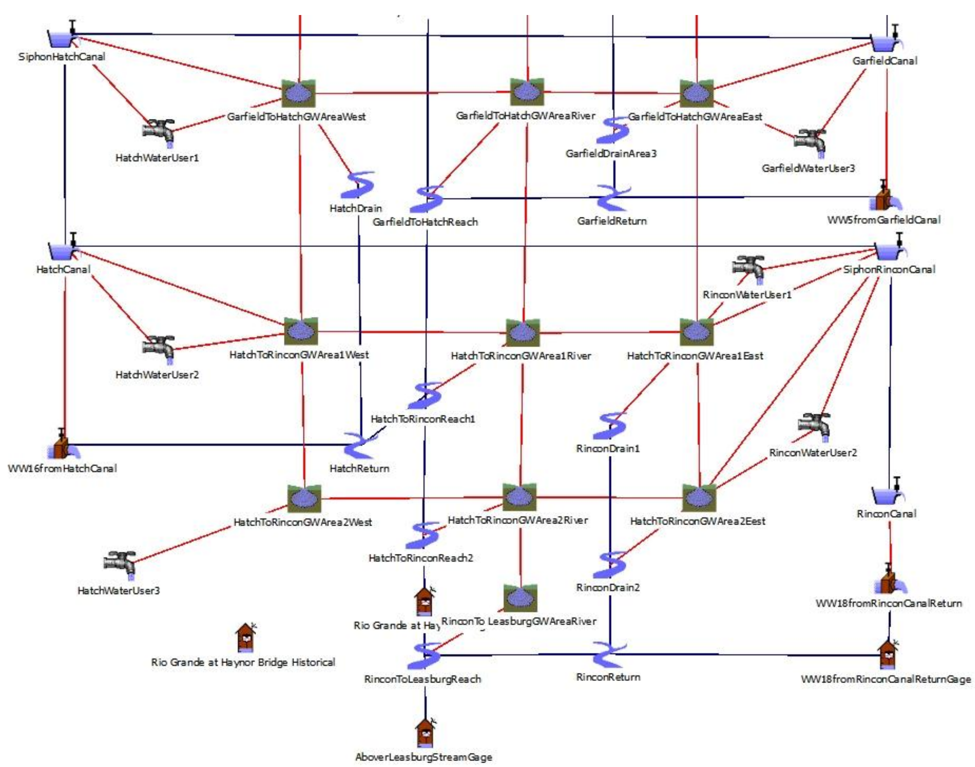


Figure I-7 Bottom of RiverWare Model Layout for Rincon Valley.

Mesilla Basin Model layout

Figure I-8 and Figure I-9 show the layout for the Mesilla Basin portion of the RiverWare model.

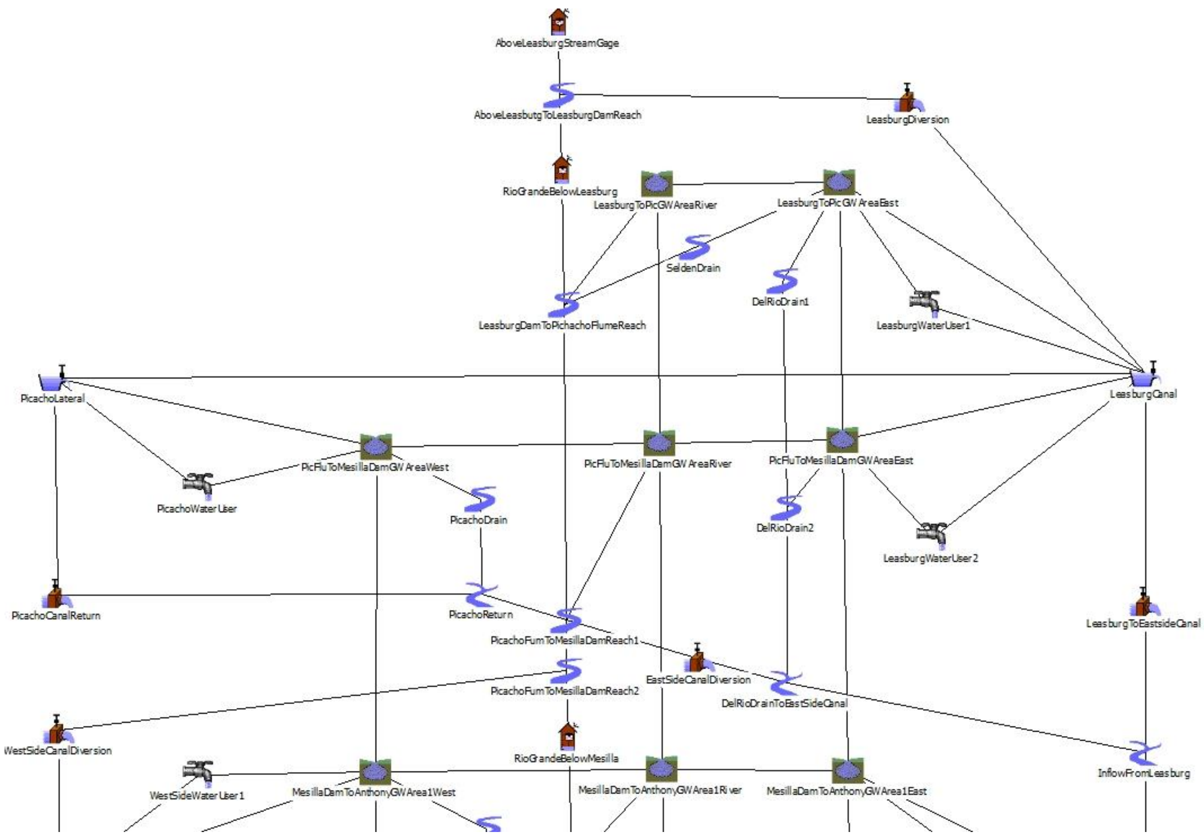


Figure I-8 Top of the Mesilla Basin RiverWare Model Layout.

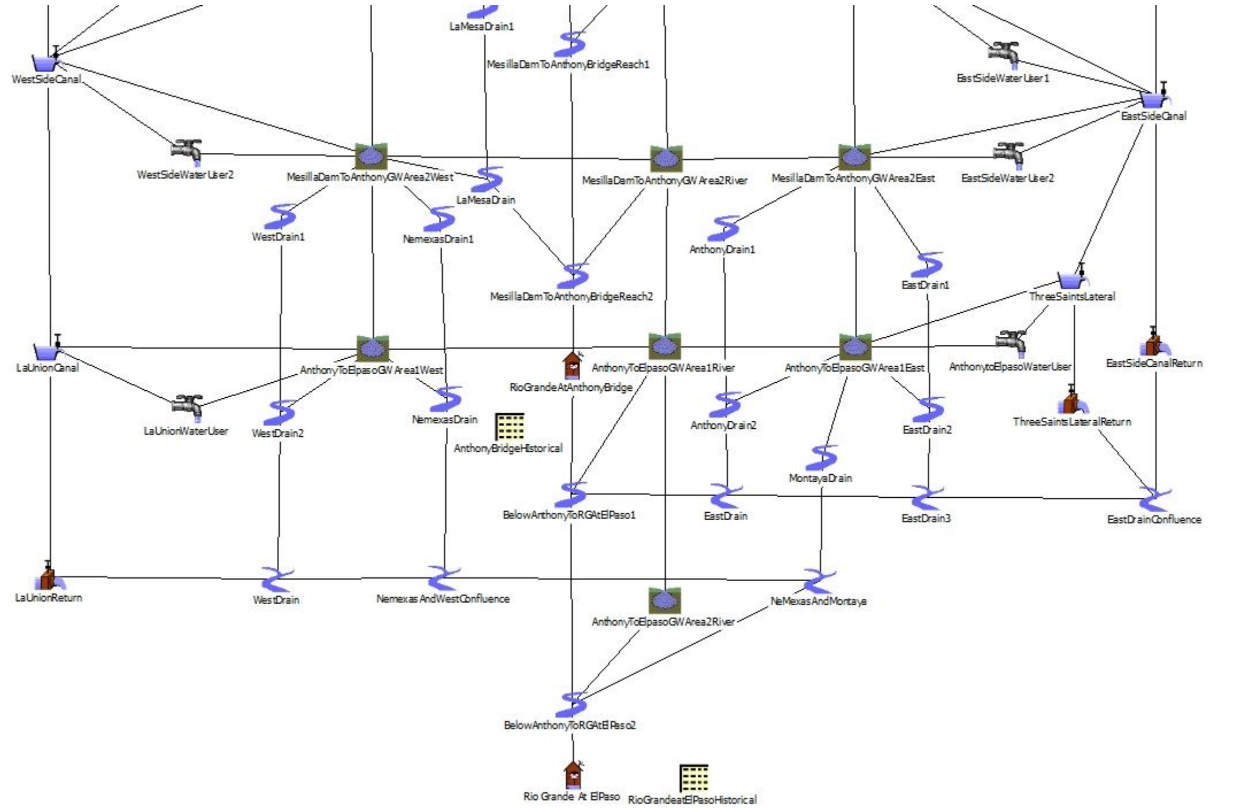


Figure I-9 Bottom of the Mesilla Basin RiverWare Model Layout.

<u>RiverWare Model specifications</u>

Time Range

The time range for this model was selected as daily time step from December 31, 2000 to December 31, 2003 due to availability of data set. This period also includes full allocation years (2001-2002) and a very short supply year (2003).

Reach Objects

- Under the **Stage Calculation** method for each Reach Object, including the drains for the second method, the *Stage Table Lookup* method was selected. Slots added for this method require input and output stage rating tables for the beginning and end of each reach.

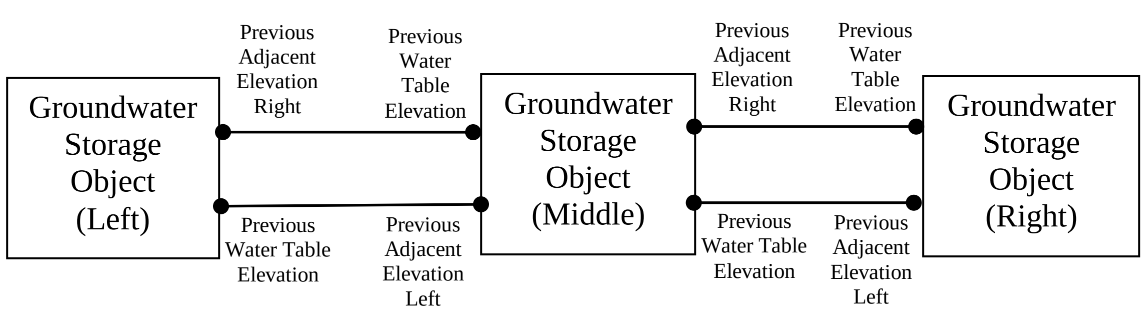
- Under the **Seepage Calculation** method for each Reach Object, the *Head Based Seepage* method was selected. Slots added for this method require input values for streambed Conductance and initial Streambed Elevation.

Groundwater Storage Objects

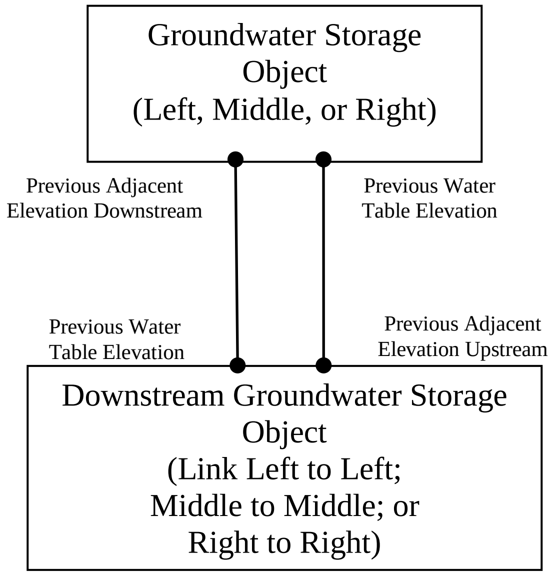
- Under the **GW Solution Type** method for each GWO, the *Connected Groundwater Objects* method was selected. Slots added for this method require input values for horizontal area of the aquifer, specific yield and initial ground-water elevation. The specific yield was set to 0.25 for the alluvial aquifer.
- Under the **Specify Connected Groundwater Objects** method for each GWO, the corresponding methods were selected, depending on the location of the GWO.
- Under the **GW Deep Percolation** method for each GWO, the *Head Based Percolation* method was selected. Slots added for this method require input values for vertical conductance between the alluvial aquifer and the deep aquifer, plus elevation values for the entire time range of the simulation for the deep aquifer.
- Under the **Evapotranspiration** method for the middle GWOs the *Elevation ET Table* method was selected. Slots added for this method require an input Elevation-ET Table, and input riparian area values for the entire time range of the simulation. All other GWOs specified were assigned the *No Evapotranspiration* method.

Links

Additional links between the various objects are also necessary: GWOs links to other GWOs associated with the same reach: *Previous Water Table Elevation* slots link to *Previous Adjacent Elevation Right/Left* slots. The link is shown below:



GWOs link to other GWOs in upstream or downstream directions: *Previous Water Table Elevation* slots link to *Previous Adjacent Elevation Upstream/Downstream* slots. The link is shown below:



RiverWare Model Calibration

Rincon Valley RiverWare Model Calibration

Model calibration was performed for the Rincon 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. The model was calibrated to river seepage, flow at gage locations. The model was calibrated against the historical period from 2001 to 2003;

The objectives in calibrating this model were:

1) To adjust the initial groundwater object elevations such that the groundwater object elevations were realistic representations of the alluvial aquifer heads, which was considered to be when:
   a. the ground-water elevation was within 8 to 15 ft of the ground surface;
   b. the riparian surface was less than 12 ft above the ground-water elevation; and
   c. the resulting maximum ET depths were approximately between 5 and 12 inches.

2) To adjust vertical hydraulic conductivities of river bed, aquifer's horizontal hydraulic conductivity, vertical conductance between shallow and deep aquifers, and canal seepage percentage to simulate the river and drain flows.
3) To verify the flow Above Leasburg simulated from the model matches the historic flow Above Leasburg; and
4) The flow values at the Rio Grande above Leasburg from the RiverWare simulation were compared to historic flows (calculated as Leasburg Canal Diversion plus Rio Grande below Leasburg) to verify that the overall flows in the model are still correct. A graph of these flow values is given in Figure I-10, which indicates good agreement between the simulation and historical values.

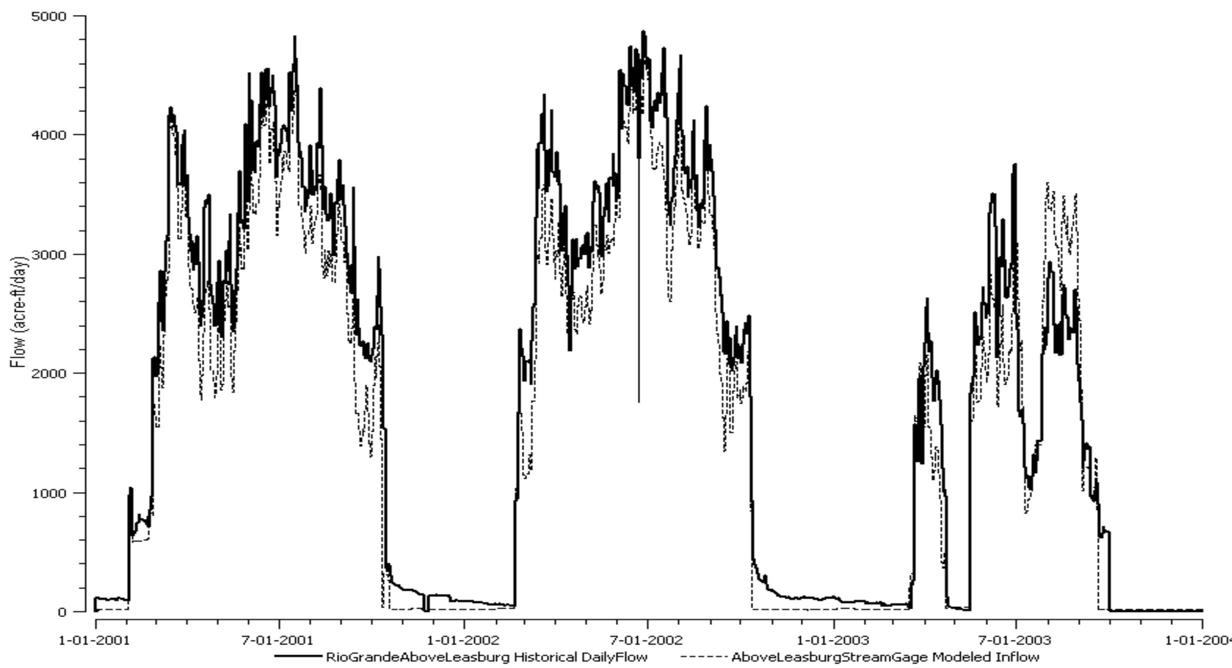


Figure I-10 Flow at Rio Grande Above Leasburg.

A scatter plot of the simulation flow vs. the historical flow Above Leasburg is shown in Figure I-11. The Figure I-10 shows good correlation between the simulation and the historical flow values.

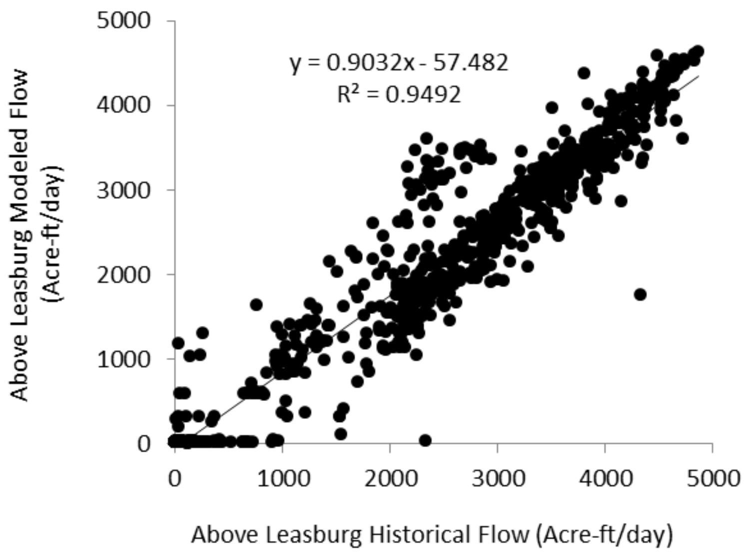


Figure I-11 Scatter plot between historical and modeled daily flow Rio Grande Above Leasburg.

Mesilla Basin RiverWare Model Calibration

To calibrate the Mesilla Basin model, the flow values at the Rio Grande at El Paso gaging station from the RiverWare simulation were compared to historic flows to verify that the overall flows in the model are still correct. A graph of these flow values is given in Figure I-12, which indicates fairly good agreement between the simulation and historical values. A scatter plot of the simulation flow versus the historical observations at El Paso gaging station is shown in Figure I-13. The Figure I-12 shows fair correlation between the simulation and the historical flow values. This indicates that more work should be done to get a better selection of model parameters in the next stage, probably the discretization of GWOs into smaller objects in the valley for better results. A longer simulation period would also be an improvement.

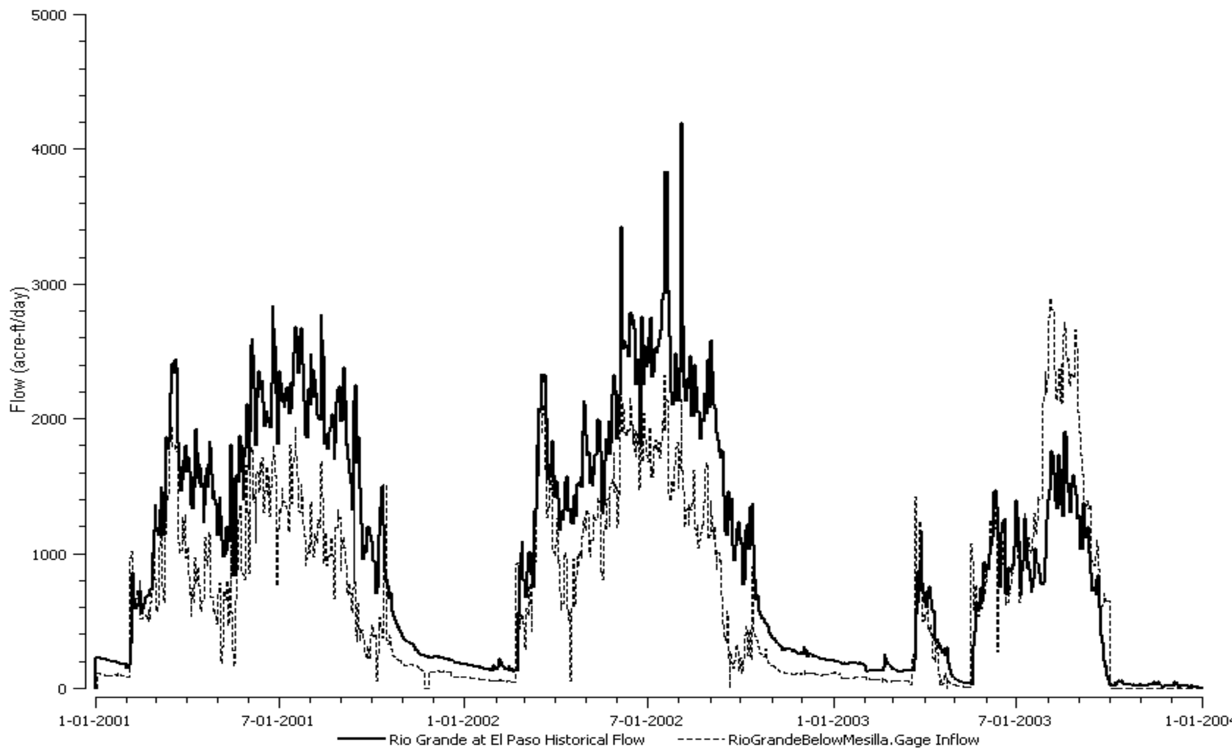


Figure I-12 Flow at Rio Grande at El Paso Gaging Station.

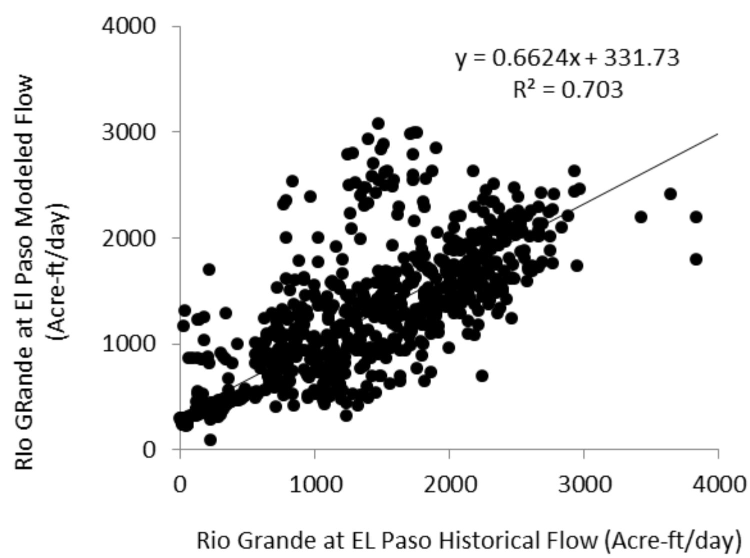


Figure I-13 Scatter plot between historical and modeled daily flow Rio Grande at El Paso.

Recommendations

In RiverWare, model configurations for both Rincon Valley and Mesilla Basin, the river reaches were divided based on the length of reach and shape of river reach, as well as locations of gaging stations. Groundwater objects have been used to simulate exchange of groundwater in the shallow aquifer and surface water. Further refinement and integration will help us better characterize hydrological process within both areas. In future phase of this project, the following improvements are recommended.

1. Combine two models within the Rincon Valley and Mesilla Basin. The model will be integrated with the model for the El Paso-Juarez Valley presented in Part II of this report to cover entire Rio Grande Project area. The integrated model is expected to link with RiverWare model that have been developed for the Rio Grande reaches above the Elephant Butte Reservoir.
2. To better calibrate the integrated model, more gaging stations with long-term historical flow data will be used to calibrate the model.
3. To better simulate groundwater and surface interaction, the simulated seepage losses will be verified with seepage measurements to further validate hydraulic conductivity values of the riverbed and drain bed. In addition, impacts of groundwater pumping on such interactions will also be evaluated. Impacts of seepage losses from the canals will also be evaluated.
4. Surface return flows and deep percolation from irrigation will be further evaluated so that drain flows and impacts of irrigation on groundwater storage can be better understood. Groundwater objects will be further refined to better simulate the relationship between the shallow aquifer and deep aquifer as well as lateral regional hydrological boundary conditions simulated by MODFLOW models.
5. Crop acreage and crop consumptive uses including riparian vegetation will be incorporated to better simulate consumptive uses of water within the basin.
6. Different diversions patterns, for example, low flow/drought conditions, will be further evaluated based on conjunctive uses of groundwater and surface water. Different routing methods and travel time lags will be further evaluated. It is anticipated that different water operations planning scenarios based on water operations agreement, Rio Grande

Compact and US-Mexico Treaty, and/or other policy can be evaluated by the integrated RiverWare model.

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Appendix A. Cross-Section Survey Data from NMISC (2007)

Table I-A 1 Garfield Drain Cross-Sections

POINT ID	*Y*	*X*	*Z (ft)*	*XSect Location*	*Width Type*	*Width (ft)*
GD-4A	630061.843	1331985.429	4085.60	TOP		
GD-4B	630049.749	1331981.582	4078.67	TOE		
GD-4C	630030.248	1331973.303	4078.82	TOE	Toe Width	21.19
GD-4D	630016.149	1331975.912	4085.34	TOP	Top Width	46.67
GD-5A	622915.281	1335397.278	4080.51	TOP		
GD-5B	622916.745	1335377.07	4068.94	TOE		
GD-5C	622917.209	1335365.28	4068.77	TOE	Toe Width	11.80
GD-5D	622917.964	1335351.297	4078.37	TOP	Top Width	46.06
GD-6A	619084.827	1342092.208	4071.39	TOP		
GD-6B	619096.114	1342100.026	4063.93	TOE		
GD-6C	619105.664	1342100.972	4063.92	TOE	Toe Width	9.60
GD-6D	619118.564	1342106.057	4071.70	TOP	Top Width	36.47
GD-7A	614127.669	1353135.938	4059.76	TOP		
GD-7B	614129.284	1353116.54	4050.82	TOE		
GD-7C	614126.063	1353081.847	4056.78	TOP	Toe Width	34.84
GD-7D	614120.625	1353090.793	4050.73	TOE	Top Width	45.69
GD-1A	654152.274	1323159.462	4114.77	TOP		
GD-1B	654149.684	1323175.083	4105.15	TOE		
GD-1C	654150.82	1323184.119	4105.65	TOE	Toe Width	9.11
GD-1D	654147.406	1323196.393	4114.09	TOP	Top Width	37.25
GD-2A	643921.06	1324554.368	4106.53	TOP		
GD-2B	643916.493	1324539.446	4098.28	TOE		
GD-2C	643908.593	1324527.22	4097.17	TOE	Toe Width	14.56
GD-2D	643909.598	1324509.914	4106.38	TOP	Top Width	45.91
GD-3A	636259.223	1327052.785	4096.56	TOP		
GD-3B	636257.08	1327067.204	4087.86	TOE		
GD-3C	636252.826	1327081.14	4087.26	TOE	Toe Width	14.57
GD-3D	636261.658	1327096.625	4097.13	TOP	Top Width	43.91

Table I-A 2 Hatch Drain Cross-Sections

POINT ID	*Y*	*X*	*Z (ft)*	*XSect Location*	*Width Type*	*Width (ft)*
HD-1A	615718.663	1341550.339	4071.50	TOP		
HD-1B	615697.205	1341547.507	4059.46	TOE		
HD-1C	615688.656	1341551.584	4059.62	TOE	Toe Width	9.47
HD-1D	615673.19	1341542.886	4071.00	TOP	Top Width	46.08
HD-2A	611966.489	1350292.852	4063.59	TOP		
HD-2B	611981.695	1350295.183	4052.70	TOE		
HD-2C	612013.151	1350283.149	4063.79	TOP	Toe Width	33.68
HD-2D	611999.36	1350290.65	4052.43	TOE	Top Width	32.94
HD-3A	610071.089	1358736.92	4056.96	TOP		
HD-3C	610096.167	1358762.644	4047.48	TOE		
HD-3D	610080.166	1358752.232	4046.90	TOE	Toe Width	19.09
HD-3B	610108.289	1358762.61	4055.57	TOP	Top Width	45.21
HD-4A	607336.731	1367449.159	4052.46	TOP		
HD-4C	607356.414	1367471.952	4042.21	TOE		
HD-4D	607346.741	1367460.214	4042.45	TOE	Toe Width	15.21
HD-4B	607367.211	1367494.03	4051.51	TOP	Top Width	54.24
HD-5A	605881.392	1362697.588	4056.06	TOP		
HD-5B	605892.588	1362698.162	4047.95	TOE		
HD-5C	605900.264	1362698.615	4047.97	TOE	Toe Width	7.69
HD-5D	605911.944	1362697.383	4054.98	TOP	Top Width	30.55
HD-6A	602730.323	1372856.555	4043.35	TOP		
HD-6B	602718.212	1372852.173	4035.51	TOE		
HD-6C	602702.032	1372845.773	4035.67	TOE	Toe Width	17.40
HD-6D	602692.324	1372839.07	4042.39	TOP	Top Width	41.83
HD-7A	602792.072	1378779.826	4034.40	TOP		
HD-7B	602805.530	1378762.246	4008.88	TOE		
HD-7C	602812.040	1378753.742	4008.42	TOE	Toe Width	10.71
HD-7D	602817.274	1378746.905	4018.95	TOP	Top Width	41.46

Table I-A 3 Rincon Drain Cross-Sections

POINT ID	*Y*	*X*	*Z (ft)*	*XSect Location*	*Width Type*	*Width (ft)*
RD-1A	606022.96	1380863.695	4039.76	TOP		
RD-1B	606037.226	1380865.848	4029.99	TOE		
RD-1C	606061.095	1380859.998	4030.13	TOE	Toe Width	24.58
RD-1D	606073.973	1380860.861	4039.52	TOP	Top Width	51.09
RD-2A	603014.208	1390198.845	4028.10	TOP		
RD-2B	603026.941	1390204.794	4019.14	TOE		
RD-2C	603042.372	1390214.239	4018.96	TOE	Toe Width	18.09
RD-2D	603057.984	1390220.162	4027.16	TOP	Top Width	48.69
RD-3A	598280.096	1398494.67	4018.96	TOP		
RD-3B	598283.842	1398501.121	4006.25	TOE		
RD-3C	598296.708	1398523.277	4006.98	TOE	Toe Width	25.62
RD-3D	598302.109	1398532.578	4019.90	TOP	Top Width	43.84
RD-4A	591181.845	1405674.526	4010.64	TOP		
RD-4B	591197.85	1405676.494	4001.20	TOE		
RD-4C	591213.198	1405678.819	4001.71	TOE	Toe Width	15.52
RD-4D	591223.305	1405683.7	4010.69	TOP	Top Width	42.46
RD-5A	582928.77	1408552.599	4001.59	TOP		
RD-5B	582929.401	1408543.038	3994.20	TOE		
RD-5C	582932.467	1408529.709	3993.55	TOE	Toe Width	13.68
RD-5D	582933.692	1408519.598	4001.15	TOP	Top Width	33.37

Table I-A 4 Rio Grande Cross-Sections

POINT ID	*Y*	*X*	*Z (ft)*	*XSect Location*	*Terrace Width (ft)*	*River Bed Width (ft)*
RG1	677547.069	1315967.585	4124.75	BED	141	129
RG2	672015.39	1318574.487	4122.67	BED	174	159
RG3	662519.079	1316978.325	4111.59	BED	129	114
RG4	651704.881	1316906.134	4102.92	BED	168	147
RG5	643655.7	1322192.96	4091.85	BED	168	150
RG6	633413.631	1323353.455	4082.50	BED	168	153
RG7	627109.328	1330583.323	4072.50	BED	195	168
RG8	622316.527	1331039.574	4071.80	BED	204	189
RG9	617755.237	1342026.422	4056.51	BED	231	219
RG10	617754.013	1343776.794	4057.16	BED	ND[1]	ND
RG11	613289.496	1351012.12	4051.26	BED	363	267
RG12	611511.649	1361191.454	4042.54	BED	219	198
RG13	609058.612	1370976.354	4038.00	BED	324	315
RG14	602808.976	1377195.918	4023.34	BED	231	213
RG15	601361.681	1388461.947	4018.14	BED	270	240
RG16	595711.548	1396589.867	4010.42	BED	363	348
RG17	587960.576	1403497.792	4000.15	BED	219	171
RG18	581028.796	1404506.638	3996.85	BED	195	180

[1] ND indicates ‘Not Measured’

Drain Cross Sections of the Rincon Valley

Garfield Drain

Cross-section data for the Garfield Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and river reaches shown in Figure I-A 1 through Figure I-A 3. Each figure shows one or more survey cross-sections from upstream (high elevation) to downstream (low elevation), for example, in Figure I-A 2 blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

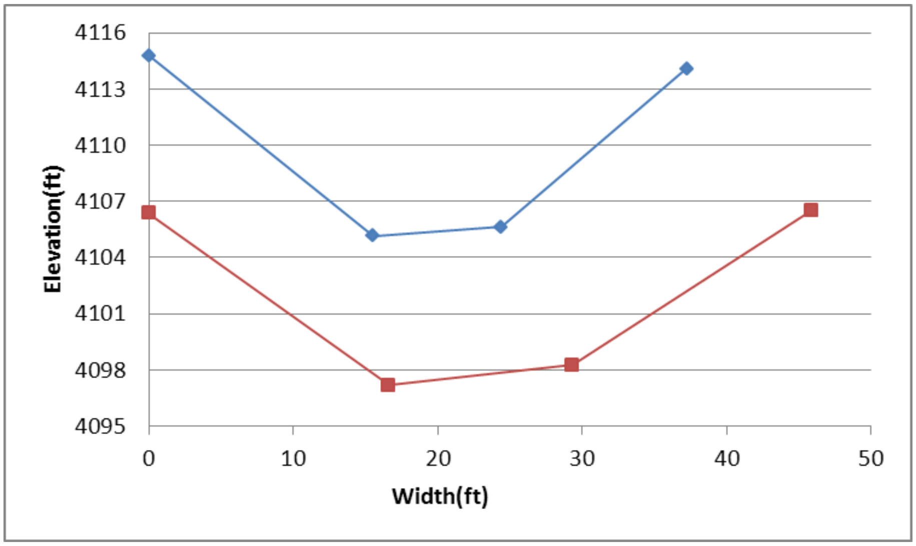


Figure I-A 1 Garfield Drain Reach3 Cross-Sections.

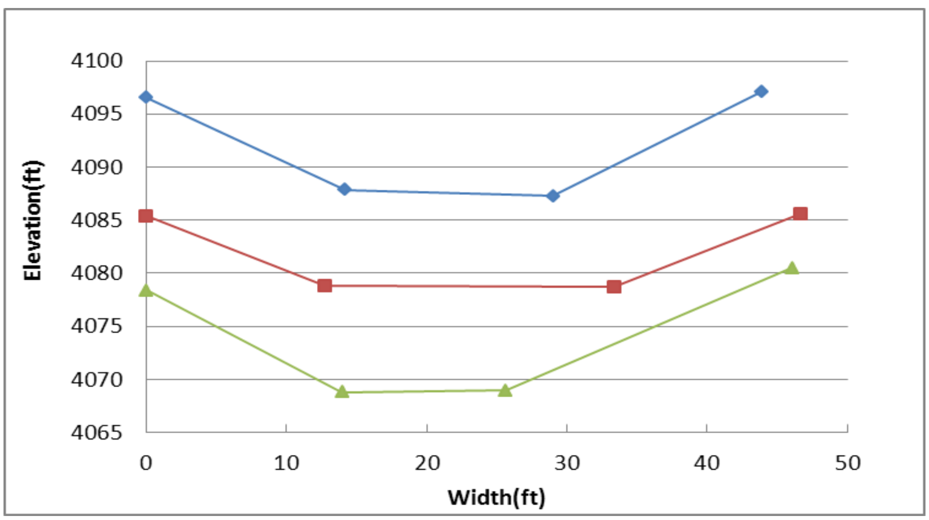


Figure I-A 2 Garfield Drain Reach4 Cross-Sections.

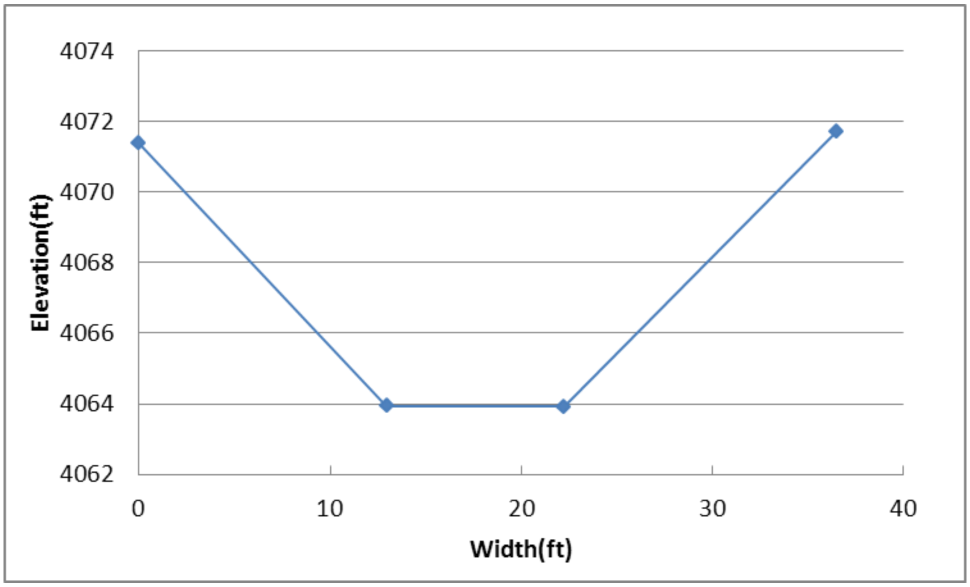


Figure I-A 3 Garfield Drain Reach5 Cross-Sections.

Hatch Drain

Cross-section data for the Hatch Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 4 and Figure I-A 5. The blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

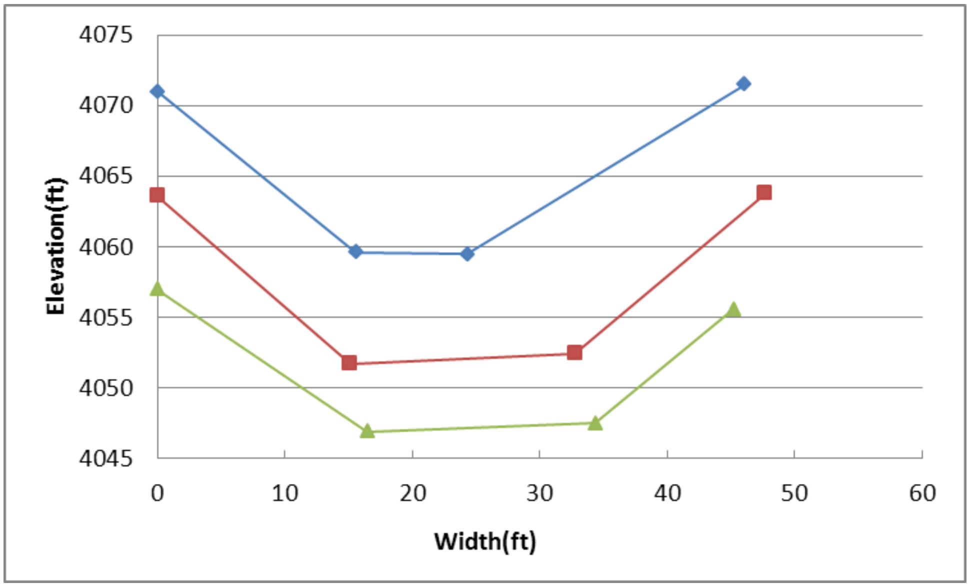


Figure I-A 4 Hatch Drain Reach5 Cross-Sections.

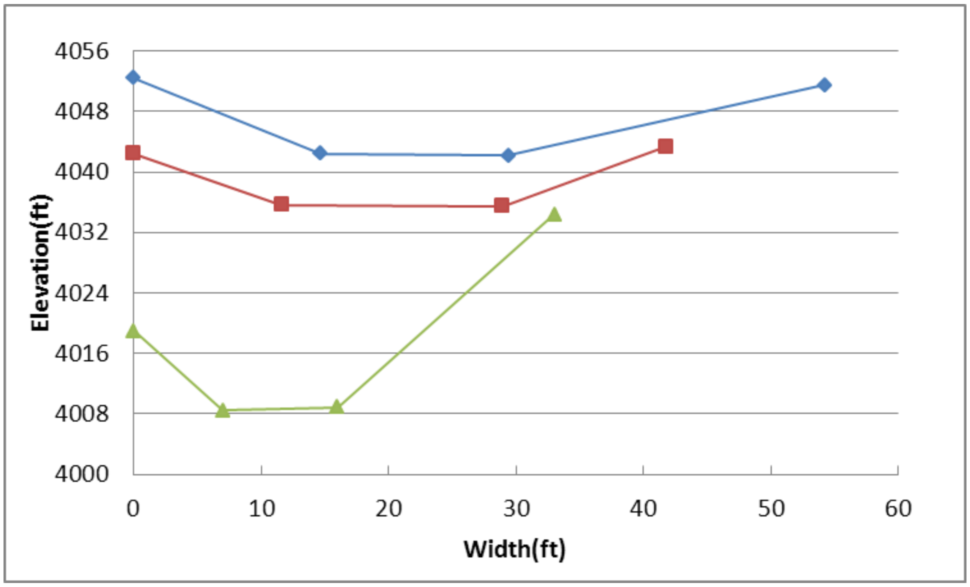


Figure I-A 5 Hatch Drain Reach6 Cross-Sections.

Rincon Drain

Cross-section data for the Rincon Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 6 and Figure I-A 7. The blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

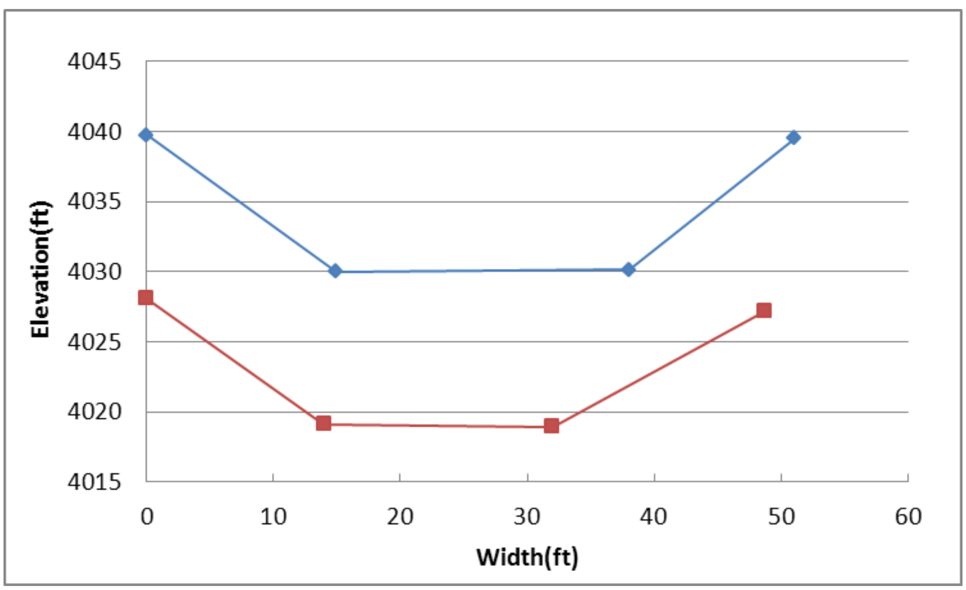


Figure I-A 6 Rincon Drain Reach6 Cross-Sections.

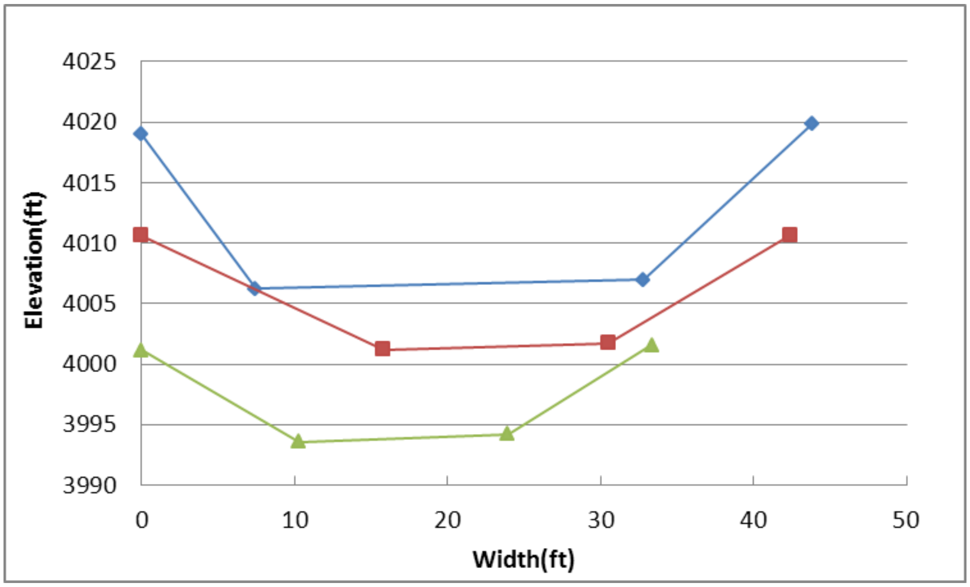


Figure I-A 7 Rincon Drain Reach7 Cross-Sections.

Drain Cross Sections of the Mesilla Basin

Selden Drain

Cross-section data for the Selden Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 8. There are three cross sections surveyed with this reach, where blue line is upstream, red is middle and green is downstream.

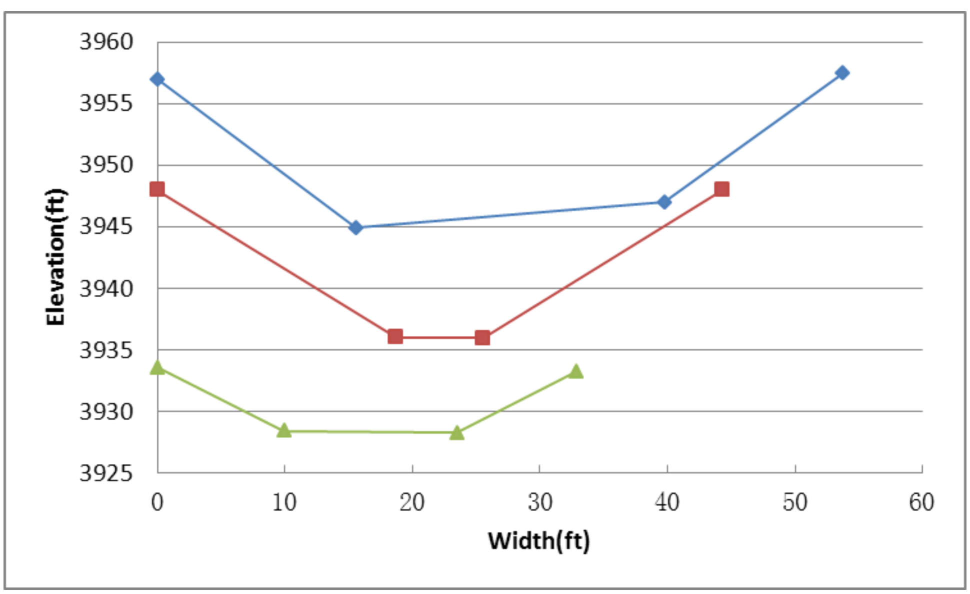


Figure I-A 8 Selden Drain Cross-Sections.

Del Rio Drain

Cross-section data for the Del Rio Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 9 and Figure I-A 10. The blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

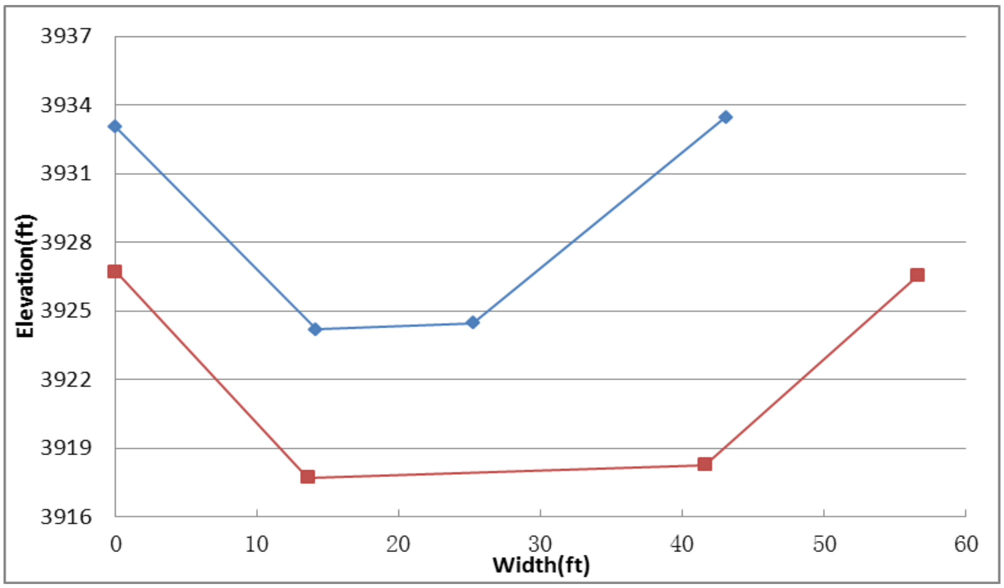


Figure I-A 9 Del Rio Drain Reach1 Cross-Sections.

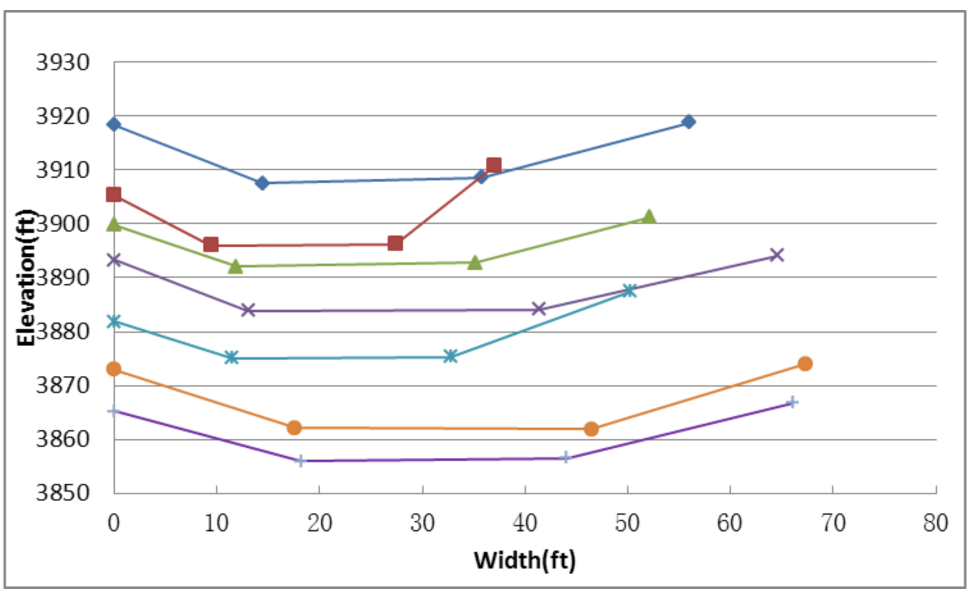


Figure I-A 10 Del Rio Drain Reach2 Cross-Sections.

Anthony Drain

Cross-section data for the Anthony Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 11and Figure I-A 12. The blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

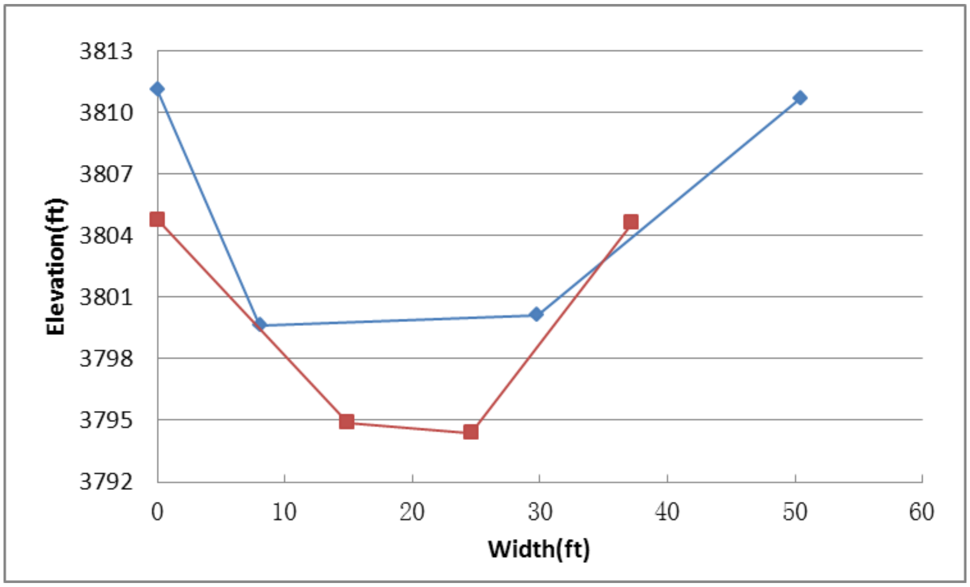


Figure I-A 11 Anthony Drain Reach4 Cross-Sections.

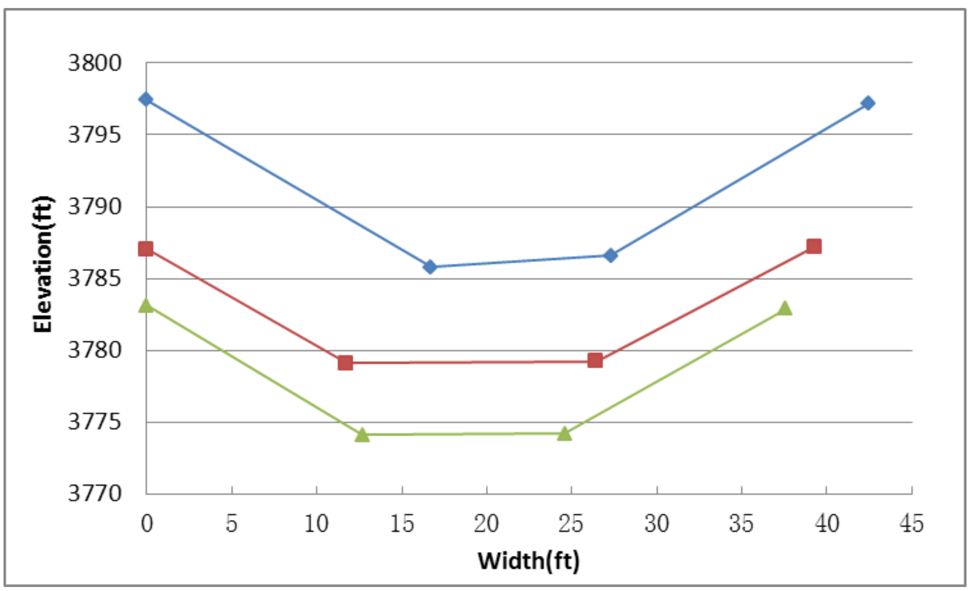


Figure I-A 12 Anthony Drain Reach5 Cross-Sections.

East Drain

Cross-section data for the East Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 13 and Figure I-A 14. The blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

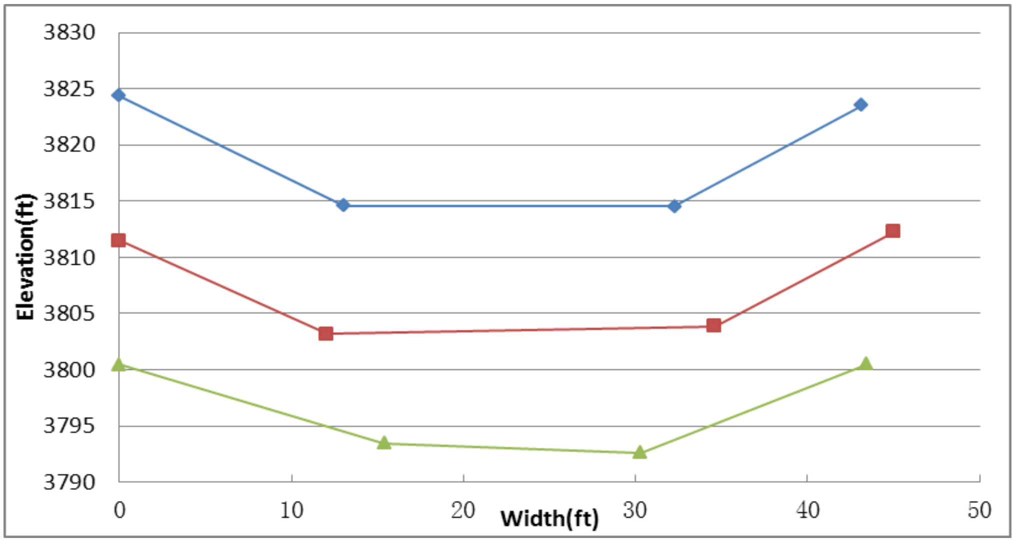


Figure I-A 13 East Drain Reach4 Cross-Sections.

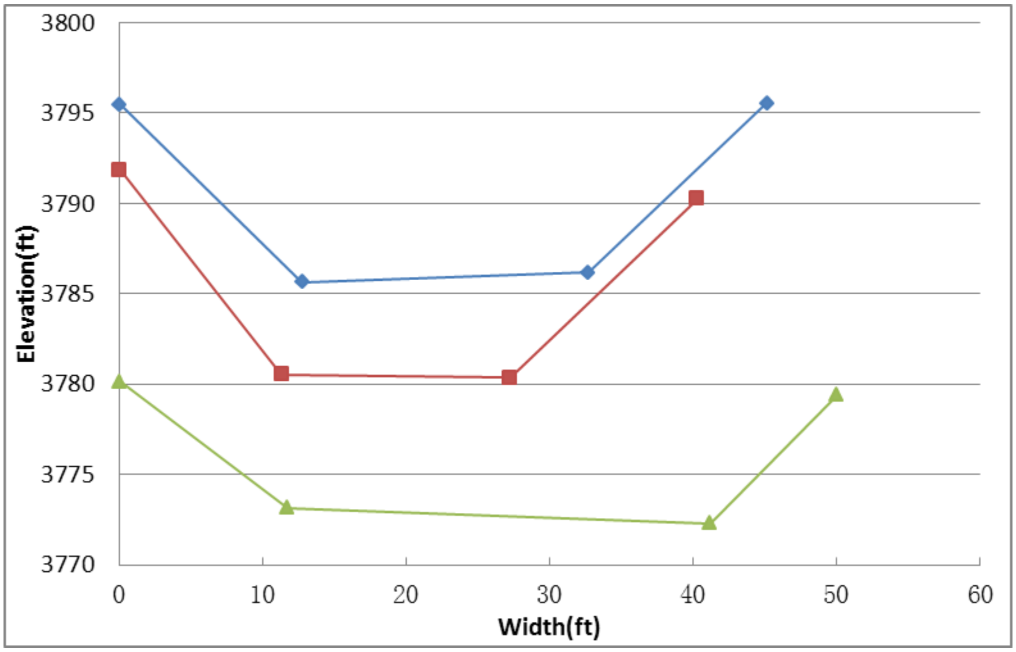


Figure I-A 14 East Drain Reach5 Cross-Sections.

Montoya Drain

Cross-section data for the Montoya Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 15. The blue line shows upstream cross section, red line shows the middle cross section, and green line shows downstream cross section.

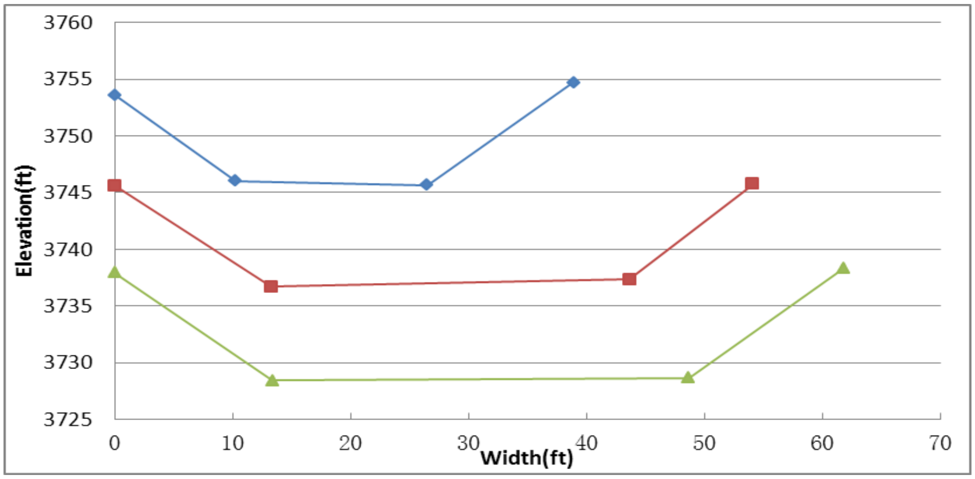


Figure I-A 15 Montoya Drain Cross-Sections.

Picacho Drain

Cross-section data for the Picacho Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 16. The blue line shows upstream cross section, and red, green, purple and light blue lines show cross sections downstream sequentially.

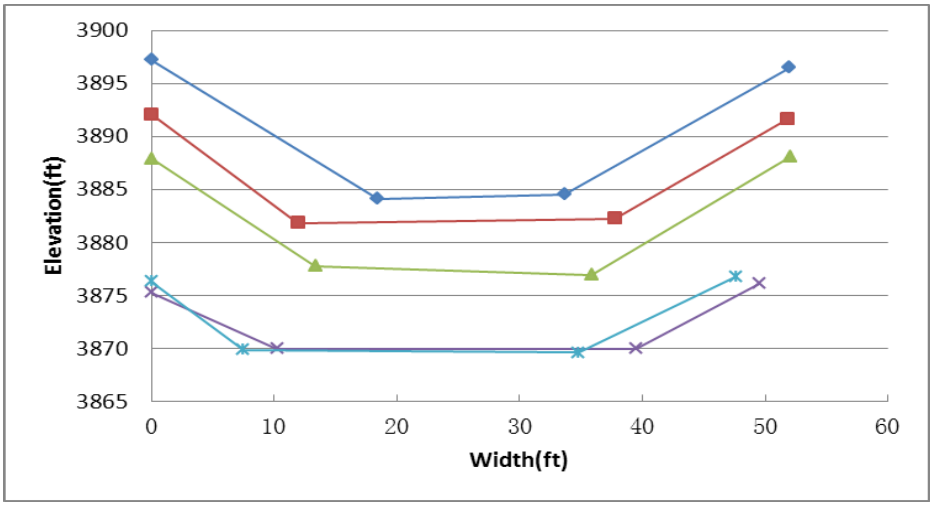


Figure I-A 16 Picacho Drain Cross-Sections.

West Drain

Cross-section data for the West Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 17 and Figure I-A 18. The blue line shows upstream cross section, and red, green, purple and light blue lines show cross sections downstream sequentially.

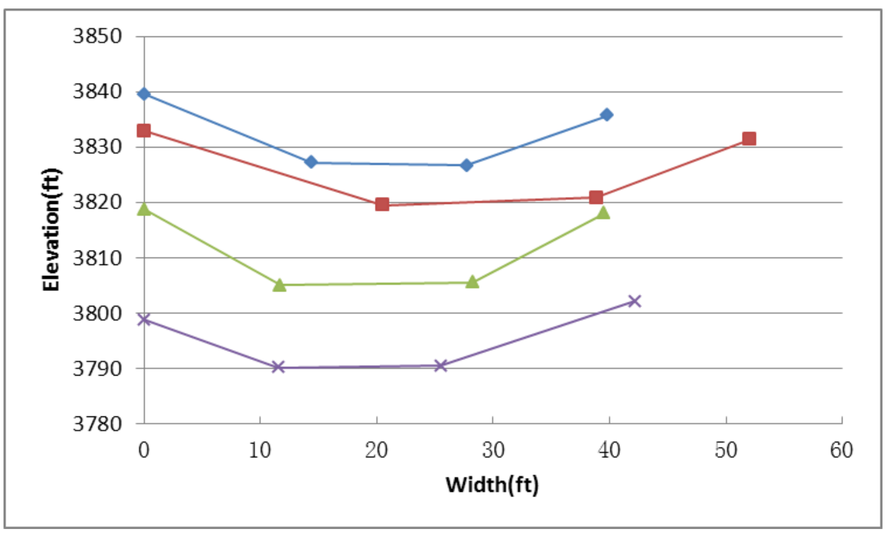


Figure I-A 17 West Drain Reach4 Cross-Sections.

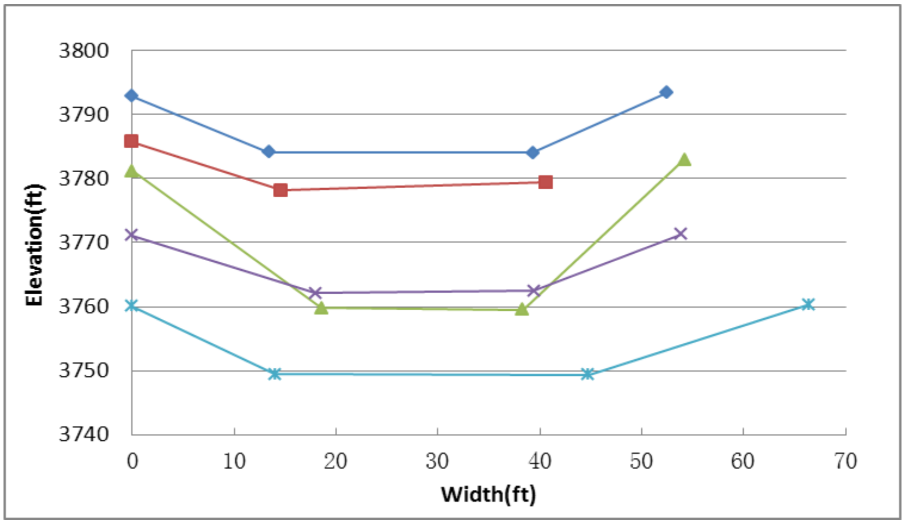


Figure I-A 18 West Drain Reach5 Cross-Sections.

Nemexas Drain

Cross-section data for the Nemexas Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 19 and Figure I-A 20. The blue line shows upstream cross section, and red, green, and purple lines show cross sections downstream sequentially.

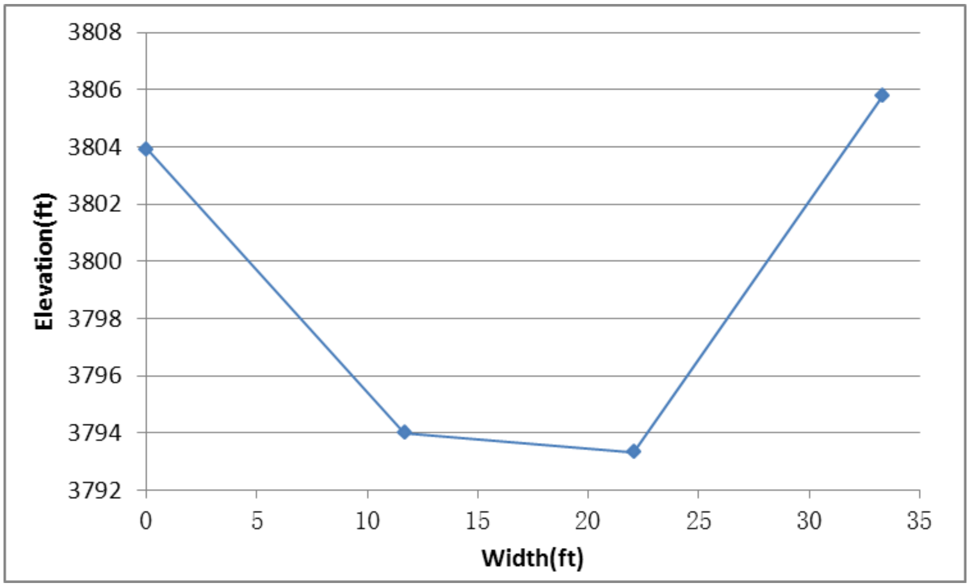


Figure I-A 19 Nemexas Drain Reach4 Cross-Sections.

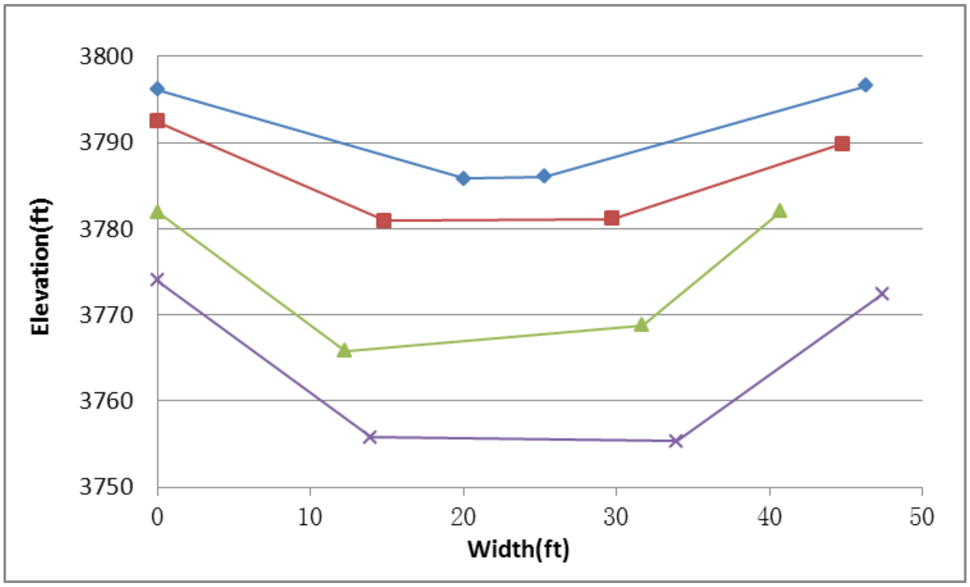


Figure I-A 20 Nemexas Drain Reach5 Cross-Sections.

LaMesa Drain

Cross-section data for the LaMesa Drain was taken from the NMISC (2007) cross-section survey data, with cross-sections of this drain for corresponding groundwater objects and reaches shown in Figure I-A 21 and Figure I-A 22. The blue line shows upstream cross section, and red, green, purple and light blue lines show cross sections downstream sequentially.

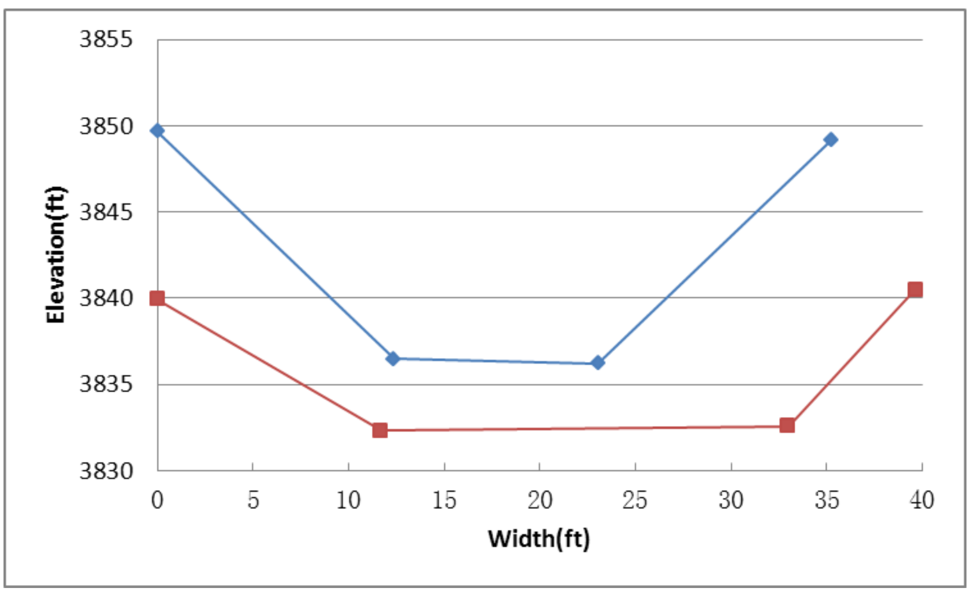


Figure I-A 21 LaMesa Drain Reach3 Cross-Sections.

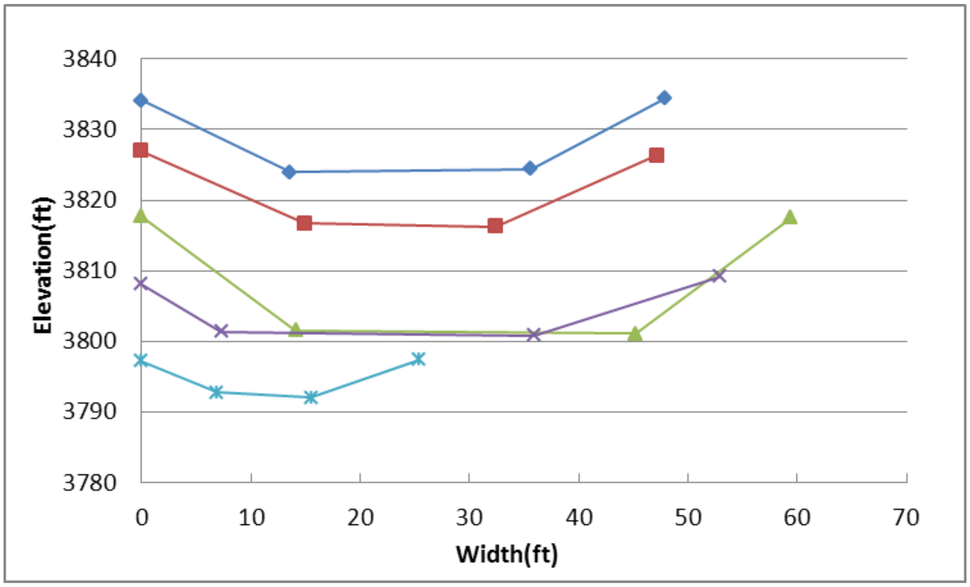


Figure I-A 22 LaMesa Drain Reach4 Cross-Sections.

Part II. El Paso-Juarez Valley RiverWare Model

Zhuping Sheng, Ricardo Marmolejo, Ari Michelsen, and Binayak Mohanty

Introduction

The Rio Grande Project delivers water into southern New Mexico and El Paso County Texas for agricultural production and municipal water supplies. With prolonged drought and continued population growth, the regional water planners and managers are facing greater challenges in securing water supplies. Timely access to and sharing of flow and water quality data as well as modeling tools is of critical importance in making decisions in water operations and management. Since 2002, on behalf of Paso del Norte Watershed Council, TAMU and NMSU researchers have worked on development of Coordinated Water Resources Database and GIS website (Brown *et al.* 2004; Brown *et al.* 2007; Granados *et al.* 2009; Sheng *et al.* 2007; Tillery *et al.* 2009a) and development of RiverWare® for flood control planning and water operations planning (Tillery *et al.* 2006; Tillery *et al.* 2009b). This project is part of the Upper Rio Grande Water Operations Model (URGWOM) (USACE 2011) developed by the U.S. Army Corps of Engineers (Corps) in collaboration with the New Mexico Interstate Stream Commission (NMISC), U.S. Bureau of Reclamation (Reclamation), U. S. Geological Survey (USGS), and U.S. Bureau of Indian Affairs (BIA), with cooperation from numerous other Federal, states, Native American Tribes, local and other agencies. The URGWOM is based on RiverWare® software designed to simulate the river flow and water operations in the Rio Grande basin from the Colorado–New Mexico state-line to just above Fort Quitman, Texas. The development of URGWOM is useful for making management decisions to maintain optimal river ecosystem health while meeting downstream water delivery requirements.

This part of report covers the following tasks: collect and compile necessary data and analyses to expand the URGWOM RiverWare® Model to simulate flows and water operations planning for the El Paso-Juarez Valley in consideration of the new operational agreement among Elephant Butte Irrigation District (EBID), El Paso County Water Improvement District No. 1 (EPCWID#1 or EP#1) and the Bureau of Reclamation for the Rio Grande Project. The model covers the reaches between El Paso and Fort Quitman and includes the physical layout of diversions, reaches, crop and riparian depletions, canals and drains, etc. The report covers site characterization, conceptual model layout, numerical model configuration, and preliminary results and analysis of the numerical model.

Characterization of the Study Area

The study site covers majority of EPCWID#1, Hudspeth County Conservation and Reclamation District No. 1 (HCCRD#1) in United States, and Irrigation District 009 in Juarez Valley of Mexico (Figure II-1). It starts from the Rio Grande gaging station at El Paso (Courchesne Bridge) and extends to Fort Quitman gaging station (Figure II-1). As shown in the Table II-1, a total of 260 miles of river reach and main canals (acequia in Mexico) are included in the study area. The canals account for 183 miles, while the Rio Grande reach accounts for 77 miles. In the Rio Grande Project area, the river delivers the water released from the Elephant Butte reservoir. The river collects return flows from farm fields and runoffs from arroyos in the Rincon Valley and Mesilla Basin as indicated in Part I. Below the Rio Grande gaging station at El Paso, the river also collects wastewater discharge from the municipal wastewater treatment plants in El Paso and Juarez.

The river water below El Paso gaging station is first diverted into the American Canal for United States (U.S.) water users above the American Dam, and the rest of the water or Mexican allocation is diverted into the Acequia Madre above the International Dam. The Rio Grande below International Dam almost ceases to flow except during floods or operational spills. The river below the Riverside Canal heading or the Riverside Dam (failed on June 9, 1987) collects operations spills from the canals and seepage from the shallow aquifer and eventually collects return flows from the drainage systems within three districts. The river continues further downstream at the Rio Grande gaging station at Fort Quitman (Figure II-1). During a normal flow year, Mexico receives 60,000 acre-feet of water through International Treaty (1906), while EPCWID#1 is allocated 314,000 acre-feet (43% of the release from Caballo with Mexico’s 60,000 acre-feet subtracted out) by the U.S. Department of Interior Executive Order. The City of El Paso diverts their allocated water from the EPCWID#1 and treats it for potable water supplies of approximately 60,000 to 70,000 acre-feet annually for a normal year. The HCCRD#1 receives no water allocation from the Rio Grande Project and relies on the return

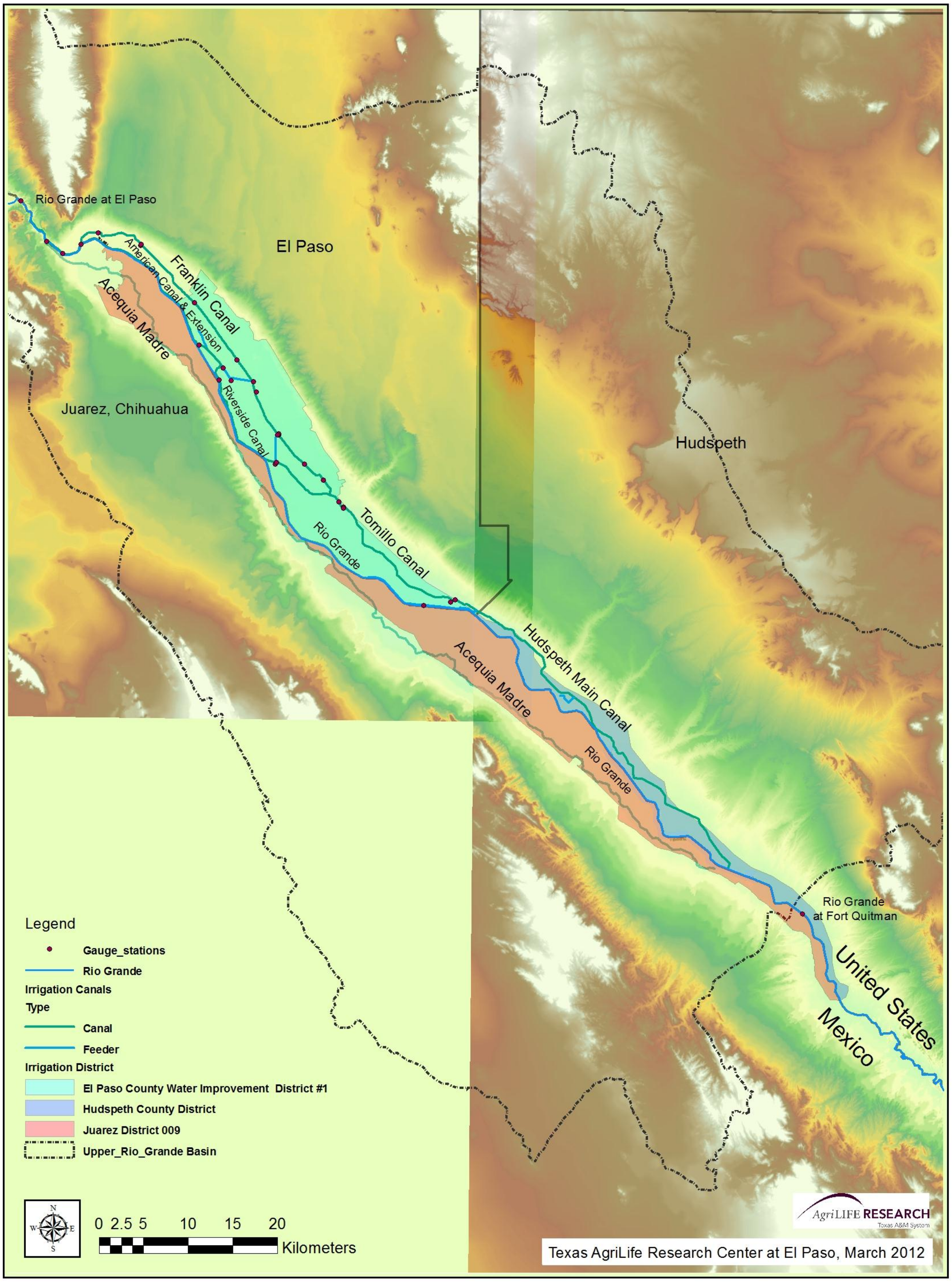


Figure II-1 The river and main irrigation canals network in the study area.

Table II-1 The river reach and main irrigation canals in the study area

Irrigation District	Canal and River Name	Length (mi)
EP#1	American Canal and Extension	13.47
EP#1	Franklin	30.47
EP#1	Riverside Canal	21.22
EP#1	Tornillo	11.97
EP#1	Franklin Feeder	2.68
EP#1	Island Feeder	2.02
HCR#1	Hudspeth Main Canal	28.50
District 009	Acequia Madre	72.70
	Rio Grande	76.89
	Total	259.92

Flows, storm water, and operation spills from the EPCWID#1. The Mexico farmers use the diverted surface water from the Rio Grande, wastewater from the Ciudad Juarez, and groundwater from the Rio Grande Alluvium and Hueco Bolson aquifers for agricultural irrigation. The EPCWID#1 and HCCRD#1 only use groundwater from the shallow Rio Grande Alluvium aquifer to supplement water supplies during drought periods.

The EPCWID#1 has 69,010 acres of land with water rights, of which 57,831 acres is located in the Lower El Paso Valley and 11,179 acres in the Upper El Paso (Mesilla) Valley (EPCWID#1, 2000). The HCCRD#1 has a total of 14,750 acres of crop land (Michelsen *et al.* 2009). The District 009 covers a total of 52,436 acres of crop land (Granados *et al.* 2009). The agricultural acreage has declined and is projected to decline as the urbanization continues. The majority of surface water diverted is used for agricultural production. The main crops in the study area include alfalfa, cotton, and pecan. Common irrigation techniques used in the area are flood irrigation with borders for pecans and alfalfa, and furrow irrigation for all other row crops including cotton and most vegetables.

Methodology

The irrigation network in the study area is a very complex system. First the authors developed a conceptual node-link model to characterize the relationships between the river, canals, laterals, and drains as well as diversion points. Based on the conceptual model, the authors will then develop the RiverWare model to simulate water flows within the study area.

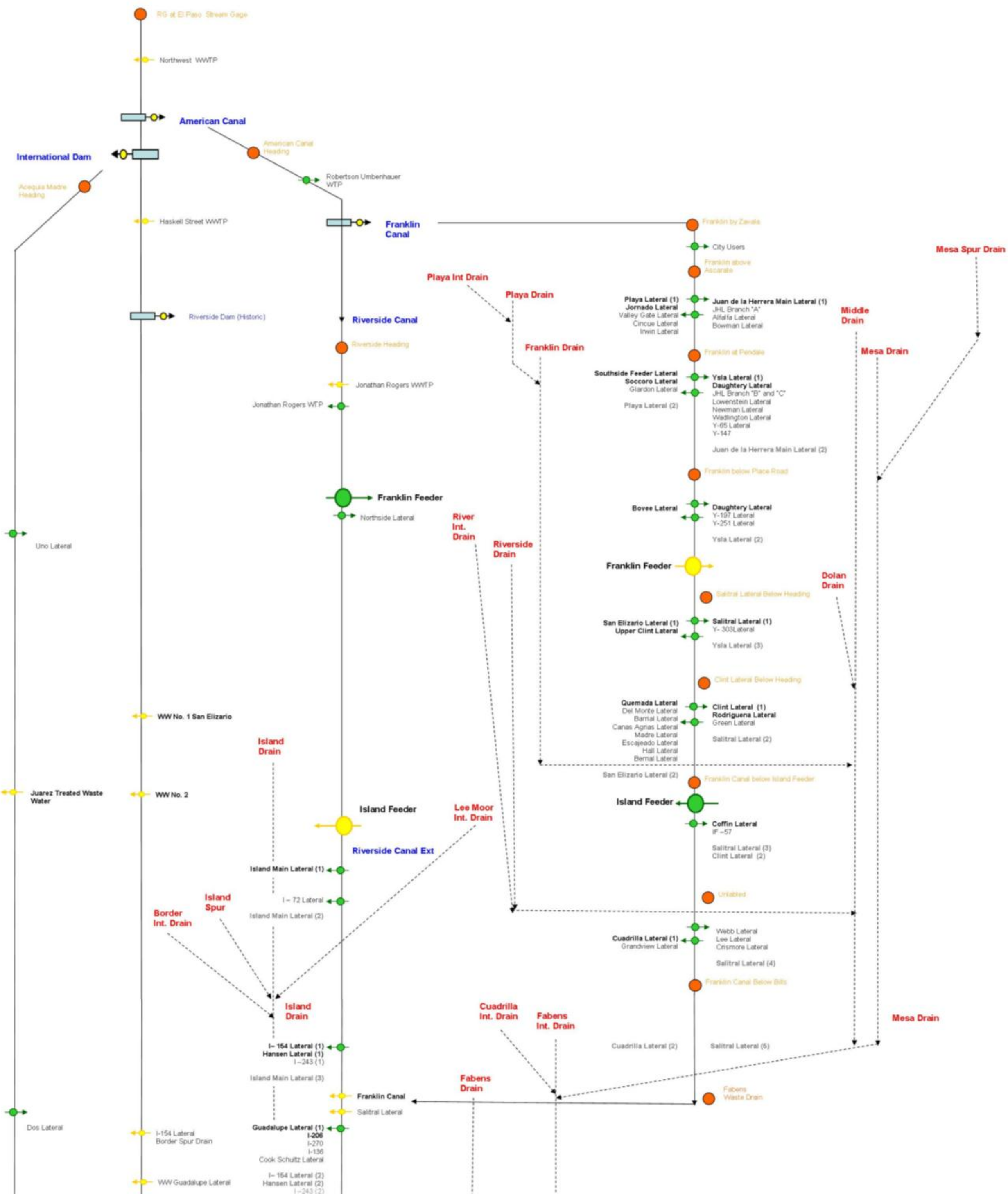
Conceptual model layout

The overall layout of the conceptual model of irrigation network within three irrigation districts is shown in Figure II- 2. A large layout map is included in the deliverable. The water from the Rio Grande below the El Paso gaging station is diverted into two irrigation network systems, one on the US side (EPCWID#1 and HCCRD#1) and the other on the Mexican side (District 009). The water is carried by main canals (design capacity greater than 125 cfs), namely American Canal Extension, Franklin Canal, Franklin Feeder, Riverside Canal, and Tornillo Canal in the EPCWID#1 and Hudspeth Main Canal in the HCCRD#1 on the US side and Acequia Madre on the Mexico side. The water from the main canals is then diverted through laterals (capacity less than 125 cfs) and irrigation ditches to farm fields for irrigation or diverted for urban water uses (landscaping or potable water supplies). The drainage system collects the return flow from the farm fields, discharges it downstream, and eventually returns it to the river.

The conceptual model includes following water budget/hydrological flow components: inflows, diversions, water uses (users), return flows from drains, and outflows.

Inflows: At the El Paso gaging station, the Rio Grande receives water released from the upstream reservoirs as well as return flows collected by drainage system in the RV&MB. The river collects the treated wastewater discharged from three wastewater treatment plants in El Paso, i.e., Northwest Wastewater Treatment Plant, Haskell Street Wastewater Treatment Plant and Roberto R. Bustamante Wastewater Treatment Plant, and one from Ciudad Juarez. The river also collects runoffs from arroyos during rainstorms, which usually discharge into the river through drainage system in the rural area or storm water system in the urban area.

Diversions: The river water is diverted to main canals, including American Canal Extension, Franklin Canal, Franklin Feeder, Riverside Canal, Island Feeder, and Tornillo Canal in the EPCWID#1 and Hudspeth Main Canal in the HCCRD#1 on the US side, and Acequia Madre on the Mexican side (Figure II-1, Figure II- 2). It should be noted that feeders transfer water from one canal to another. There are three major feeders, namely Franklin Feeder, Island Feeder and Hudspeth Feeder. The water from the canal is further diverted through laterals and irrigation ditches, reaching farm fields or through community ditches for urban landscaping. The Rio Grande water is diverted into two water treatment plants, Robertson Umbenhauer Plant (also called Canal Street Plant) and Jonathan Rogers Plant in El Paso to produce potable water supplies. Detail information about canals and laterals in EPCWID#1 (2000) is provided in Appendix Table II-A 1 through Table II-A 6.



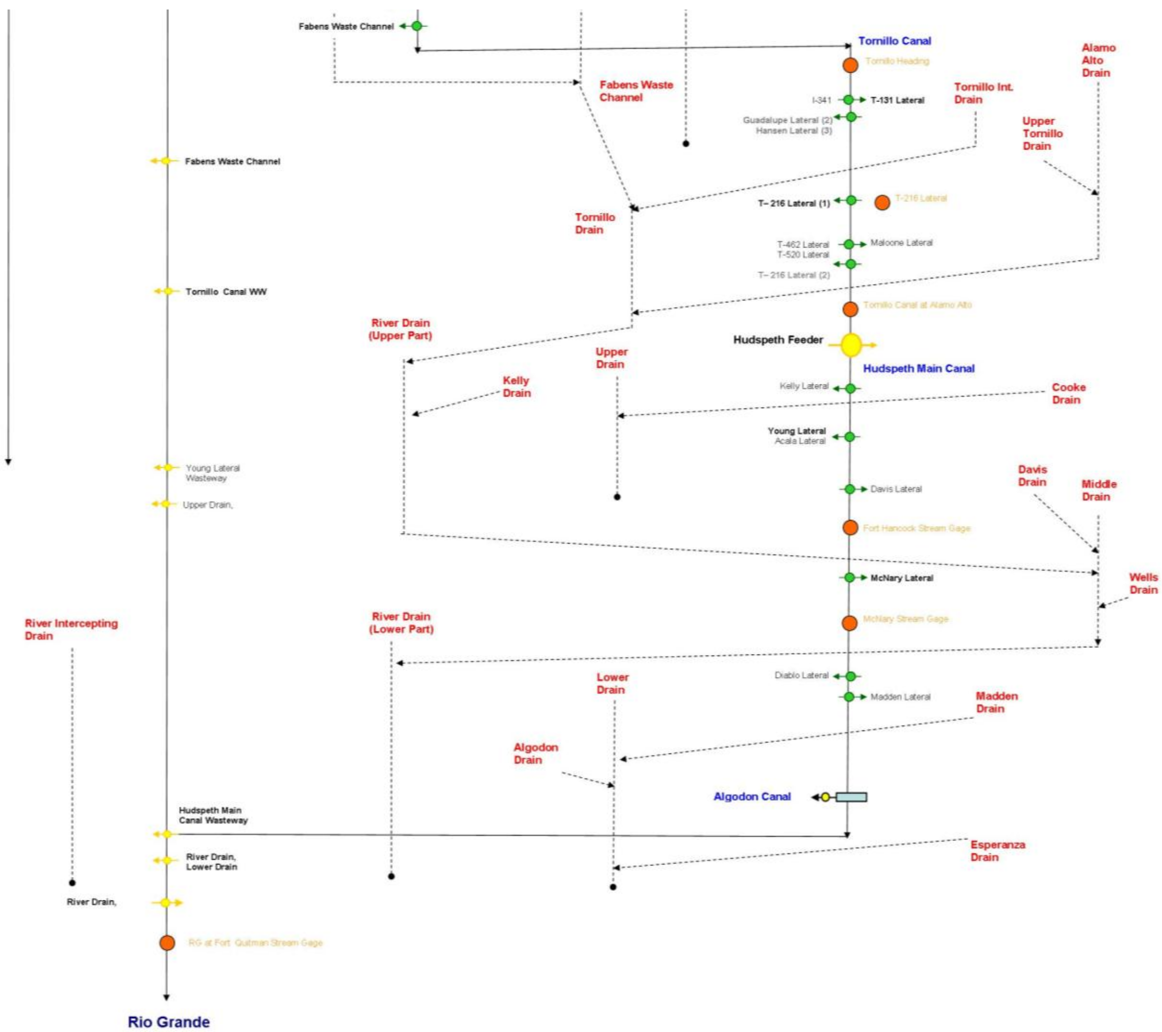


Figure II- 2 Conceptual model layout of the irrigation network and water delivery system.

Water uses (urban and agricultural): Surface water is delivered to urban water users for landscaping (limited, most water rights have been transferred to the city for potable water use) and potable water supplies. The majority of surface water is used for agricultural irrigation. The main crops include alfalfa, cotton, and pecan. Farmers also produce onion, chile, and grains with irrigation water (EPCWID#1, 2000; Michelsen *et al.* 2009).

Return flows: The drainage systems on both US and Mexican side of the river collect return flows from the farm fields (Figure II-1 and Figure II- 2). Almost all the return flows eventually discharge back to the river above the gage at Fort Quitman, Texas. Part of the drain water from the EPCWID#1 is pumped into the storage reservoirs to mix with diverted water and pumped groundwater for irrigation in HCCRD#1.

Outflows: Between El Paso and Fort Quitman gaging stations, the river also collects operational spills from several wasteways. The canals and laterals also lose water to the shallow aquifer through seepage losses (Sheng *et al.* 2003). The consumptive use of water by crops constitutes a significant portion of the water depletion or outflow in the water budget of the irrigation system.

RiverWare model configuration

Based on the conceptual model, a RiverWare model was constructed to simulate flows in the river and irrigation network within the El Paso-Juarez valley. The RiverWare model includes the river reach from the El Paso to Fort Quitman gages and its associated diversion points and gaging stations, main canals and associated gaging stations as well as their diversions into laterals, and drains that collect return flows. The RiverWare model also incorporates both urban and agricultural water users as well as discharges from wastewater treatment plants.

RiverWare model layout

The overall layout of RiverWare model for the El Paso-Juarez Valley is shown in Figure II-3. The figure is a direct image capture from the program, and unfortunately too large to allow for proper viewing of each object and object name. Expanded images will be discussed shortly. Linkages between objects in the model are color coded to distinguish types of those reaches. The dark blue lines connect objects along the Rio Grande. Yellow lines connect objects along various canals. The light blue lines connect objects that represent laterals that feed to various water use objects. The orange lines connect objects that represent feeder lines that transfer water from one canal to another and wasteways. Purple lines connect treated wastewater sources to accepting canals or the river. Green lines connect the objects representing the canal diversions and distribution of water in the Irrigation District 009 irrigation system. The red lines connect the objects representing the drains in the irrigation system.

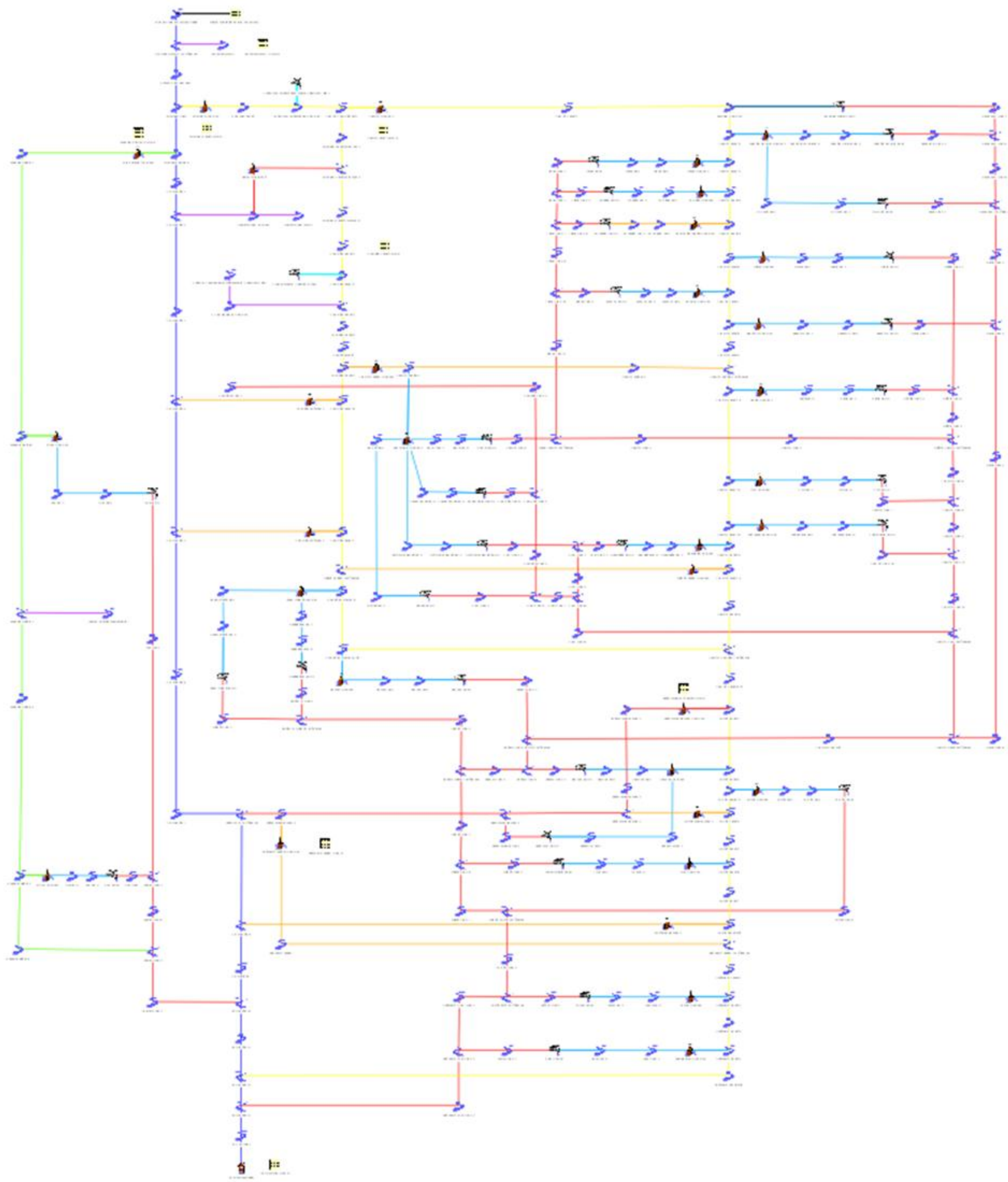


Figure II-3 El Paso RiverWare Model Configuration.

Model specification

Time range: In this phase we chose the data for 2006 and 2007 to test RiverWare model configuration because these years represented the most complete grouping of continuous multi-year historic data. The model is run on a daily time step.

Objects: Several RiverWare objects were used to simulate the El Paso-Juarez Valley irrigation system; including reach, diversion, water user, and gaging station (Figure II-4, Figure II-5, and Figure II-6).

The Reach objects simulate the Rio Grande, canals, laterals, and drains (Figure II-4 and Figure II-5). Under “Methods” icon in the RiverWare model construction, each Reach is set to a routing method of either lag time or no routing. Most of those were set with a lag time for routing. For some of lagged Reach objects the percent loss method is also selected to account for seepage losses. A 7% value is used as the seepage losses based on the seepage losses study and historic records of the irrigation district (Sheng *et al.* 2003).

Diversion objects were used to account for the diversions from the river to canals and the canals to the laterals. The Diversion objects (Figure II-4 and Figure II-5) make a summation of inflows and outflows on each time step to determine the needed diversion from upstream. This flow rate then compounds as it migrates from the bottom of the model to the top, eventually resulting in the total required inflow for each time step. The Diversion objects do this through use of the multi-outflow slot from the known outflow method.

The Water User objects (Figure II-5) are used to define the water demand, consumptive use, and return flow into the drains. Demand is set by the user. Consumptive use is currently set at 75% of demand based on estimate of historical data in EPCWID#1 and HCCRD#1. This estimation is based on analysis of historic flow data. Detailed crop acreage data was not available at time of model configuration. In the next phase of the project, crop consumptive uses and crop acreage can be used to better estimate water demands. The calculated return flows feed into the drain with a time lag of 336 hours, a typical time lag between the starting irrigation and return flow appearing in the drains in the valley. Detail information for some RiverWare reach objects within the El Paso - Juarez system is provided in the Appendix (Table II-A 7 and Table II-A 8) and the RiverWare model package which is included as a deliverable with the report.

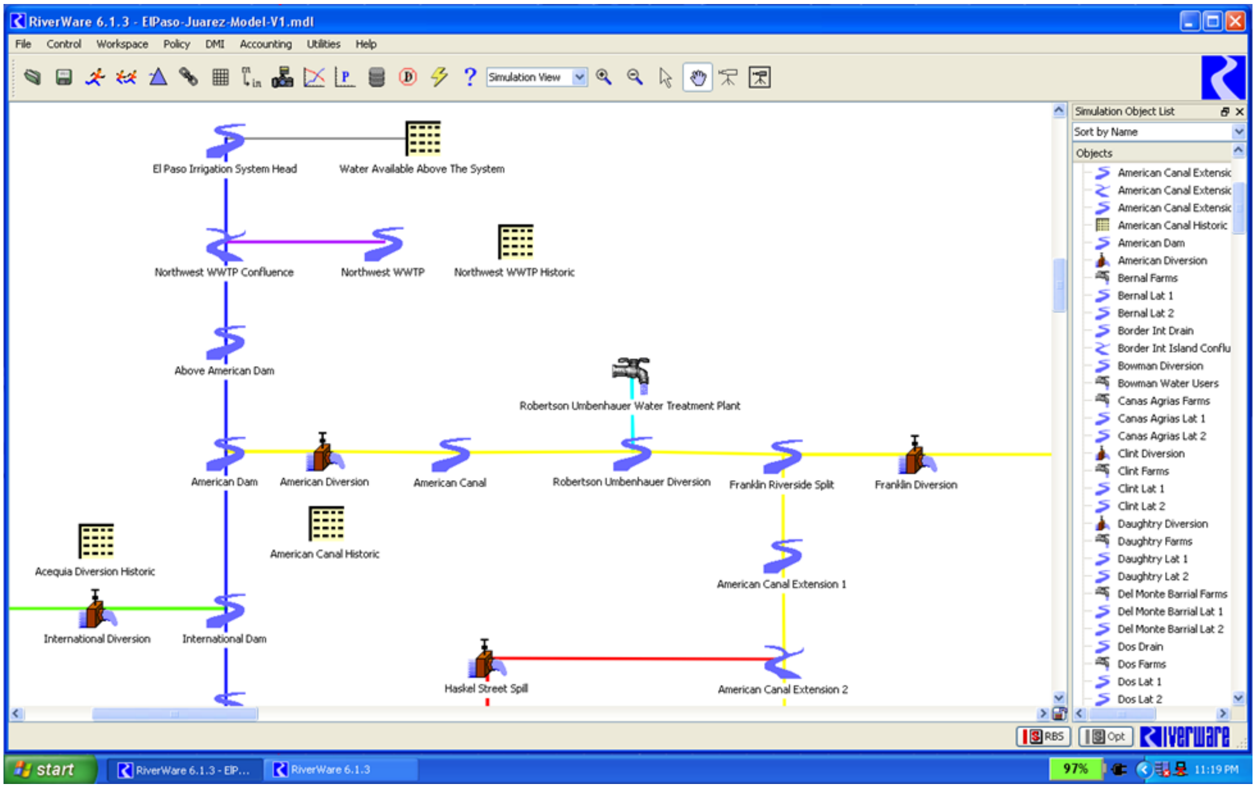


Figure II-4 RiverWare objects at system heading, urban water user and wastewater discharge.

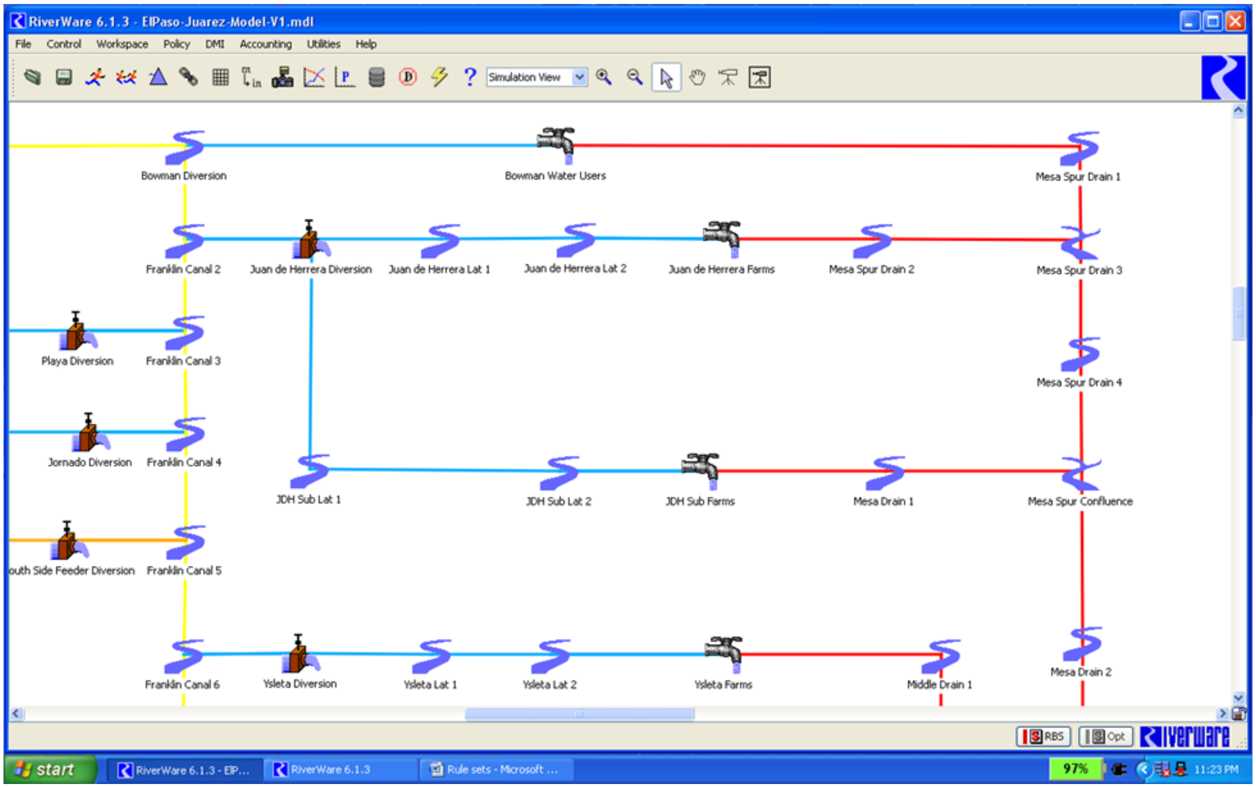


Figure II-5 RiverWare objects for agricultural water users, diversion, and drains.

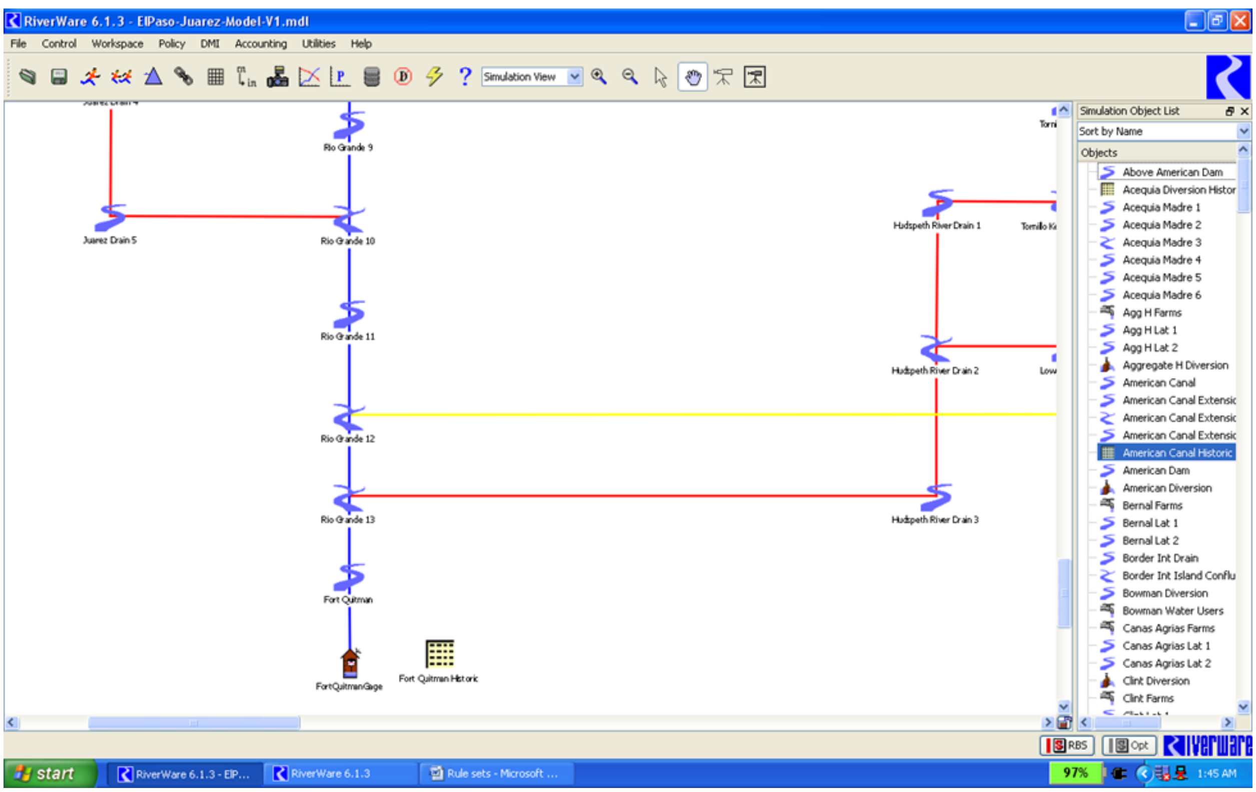


Figure II-6 RiverWare objects at the system tail, wasteway, return flows and gaging stations.

Rule based simulation: In this RiverWare model the Rule Based Simulation was carried out to simulate the flow in the irrigation system using the historic water budget balancing policy. RiverWare refers to all rule sets as "policy." This is because the rule set actively governs the application of distribution of flows. The RiverWare rule set and its application will hence be referred to as policy in this report. It should be noted that it does not fully represent operational procedures of the irrigation districts, but only incorporates physical constraints of flow in the El Paso-Hudspeth irrigation system. The rule set constructed for the EP-JV model primarily seeks to replicate historical flows with accuracy and simultaneously optimize diversions through the various interchanges in the system. This includes procedurally generated reproduction of historical data at the various gage stations for all time steps, which were then analyzed for accuracy. Rule Based Simulation uses a logical instruction writing tool to give individual directions to the model regarding the generation and setting of values in specific objects across specific linkages. RiverWare's iterative method of setting slot values requires that circular linkages have only one direction left open for solution, otherwise the slots never dispatch and no value is ever set. Writing rules to govern the setting of these values under individualized circumstances allows the slots to remain open to variable quantities instead of being permanently set at specific values. The rule sets created for the El Paso-Hudspeth system govern transfer of water from the Riverside Canal into the Franklin Canal through Franklin Feeder, diversion of water from the Fabens Wasteway Channel into the Hudspeth Feeder, and the generation of supplemental water from wells along the Riverside Canal and Franklin Feeder. The rule sets also calculate the system consumptive use values at each time step and system supply deficit data, as defined by the execution of functions within the rule set, for each time step, and store them in a data object associated with the reach object, titled El Paso Irrigation System Head.

The rule set for Hudspeth Feeder Canal is shown as an example in Figure II-7. All the other rule sets are included in the Appendices (Table II-A 9).

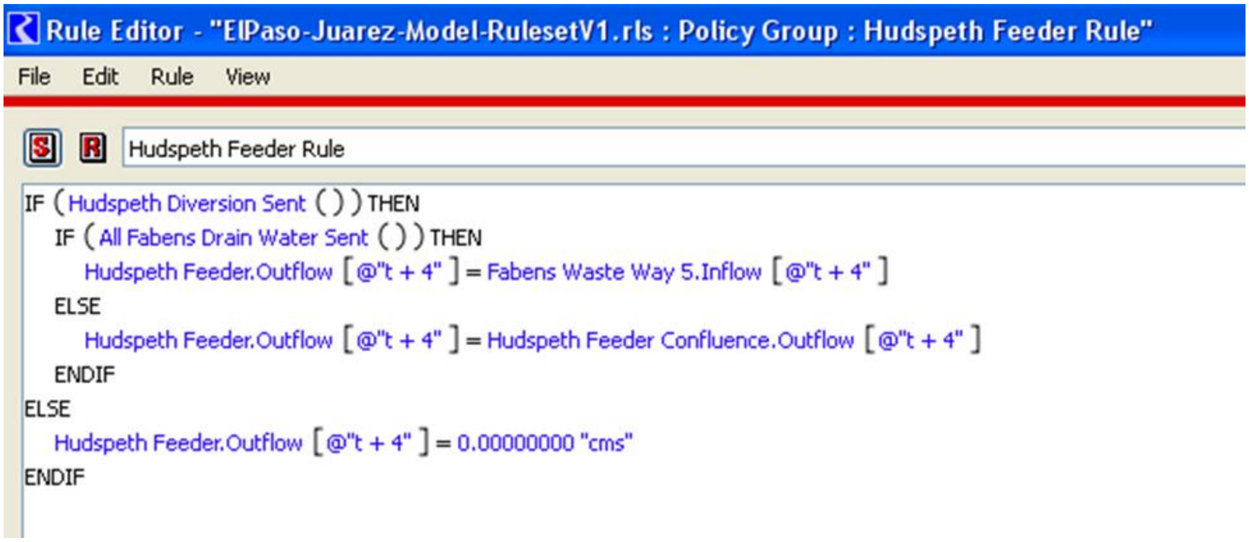


Figure II-7 Rule set for the Hudspeth Feeder Canal.

Data: input and output

Flow data at different gaging stations were compiled from different sources; U.S. Geological Survey, U.S. Bureau of Reclamation, International Boundary and Water Commission, and irrigation districts, and the Universidad Autónoma de Ciudad Juárez, México. The data availability is summarized in a technical report (Tillery *et al.* 2009b). Data used in the model include historical flow data at gaging stations, canal diversions, estimated water demands based on historic data, estimated seepage losses along the canals and river reaches, historical data of wastewater discharges from El Paso Water Utilities and estimated discharge from the Juarez wastewater treatment plant as inflows, and time lag estimated from water operations procedure of the irrigation districts. Efforts were made to acquire data on crop acreage and historic diversions from the EPCWID#1 and HCCRD#1; however, data was not available for model construction in this phase. Other data gaps such as canal and drains cross-sections and curve tables, historic drain flows, arroyos runoffs, and others have been identified and will be completed in future phases of this project for further calibrating and verifying the model.

Known system inflows were set for the simulation period (2006-2007) on a daily time step. Then the model was run to produce outputs as flows. The resulting simulation outputs were compared to known historical flows within the system to verify its accuracy. Analysis of the historical flows was also used to determine policy for flow determination in the construction of functions and rules in the rule based simulation method for the model. This was involved in splitting flow volumes where the feeders transfer water from one canal to another or local flows are generated or diverted.

Various seepage loss calculations were made at points along the Rio Grande, Franklin Canal, Riverside Canal, Tornillo Canal, and Hudspeth Canal. The mass balance calculations were made to determine losses and then averaged to determine a uniform seepage loss constant to apply within the model. This value was then compared with seepage loss measurements conducted in EPCWID#1 (Sheng et al, 2003). In the RiverWare model, the percentage of the inflow was used to account for the seepage losses within the reach. Based on overall seepage losses versus inflows within the system, the value determined was 7% of inflows on average.

Historic data at American Canal heading, Franklin Canal heading, Rio Grande at Fort Quitman, and Acequia Madre was also used for preliminary calibration of the model.

Results and Discussions

The RiverWare model was developed to simulate flows in the irrigation systems and diversions at different locations within three irrigation districts as well as the flow in the Rio Grande. Due to lack of crop acreage, the researchers generated water demands based on historical data during the irrigation season. In general, the model construction is very promising by capturing major features in the system and producing good simulated flow at key diversion features. It should be noted that the model only covered a two-year period of water operations within the system as a pilot test. Therefore the calibration of the model is preliminary and primarily for verifying configuration of the RiverWare model. Improvement to the RiverWare model, especially with emphasis on groundwater and surface water interaction, has been identified and will be implemented in the next phase.

Preliminary calibration

The preliminary calibration was made by comparing the simulated flow with the historic observations at the selected diversion sites, American Canal heading, Franklin Canal heading, Rio Grande at Fort Quitman, and Acequia Madre. Both hydrographs and scatter plots were generated to show the comparison of simulated flow vs. historic observations.

American Canal

Hydrographs of simulated diversions (dashed line) and historic observations (solid line) at American Canal are shown in Figure II- 8. Overall trends match reasonably well, although differences between the two data sets exist, probably resulting from inaccuracy of water demand definition.

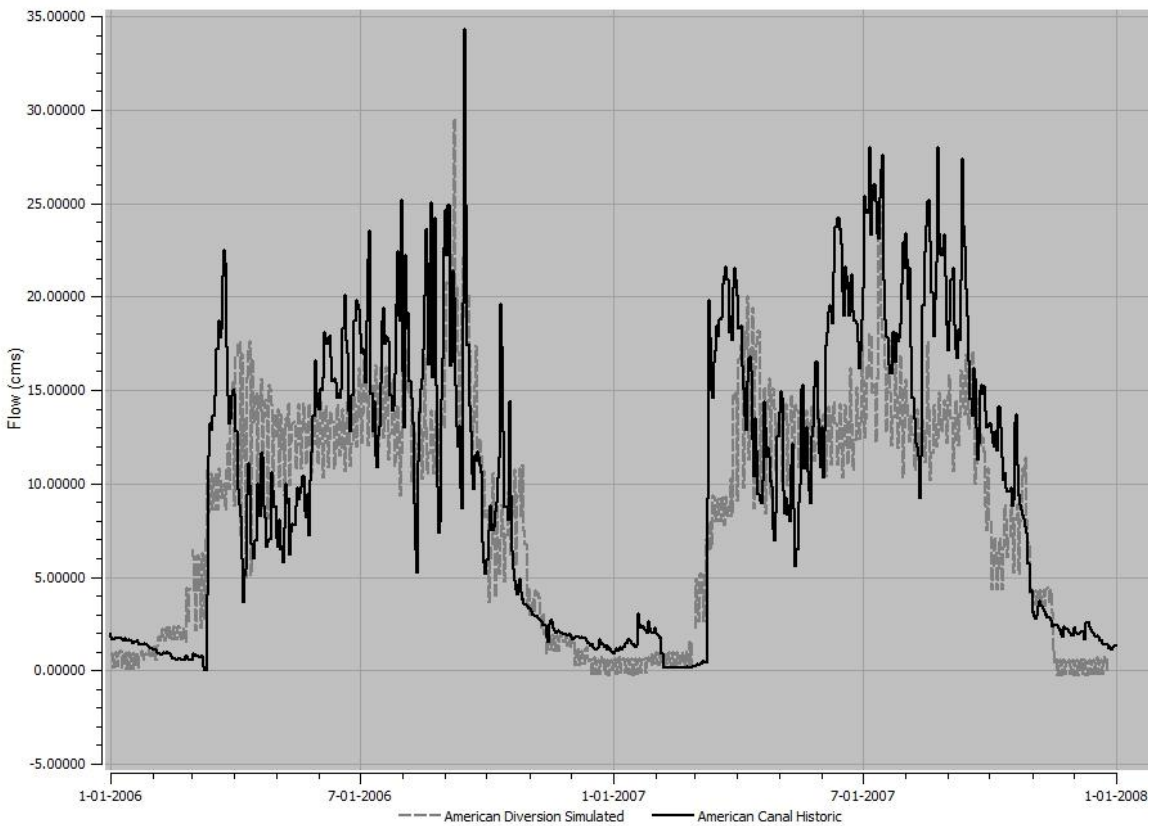


Figure II- 8 Hydrographs of simulated diversion and historic observation at American Canal.

The scatter plot (Figure II- 9) shows how close the simulated results in comparison with the historic measurements. Overall the simulated results underestimate the flow at American Canal with a R^2 of 0.6445. If one forces the trend line to intercept at 0.0, the relationship is y=1.1218x (R^2=0.6356).

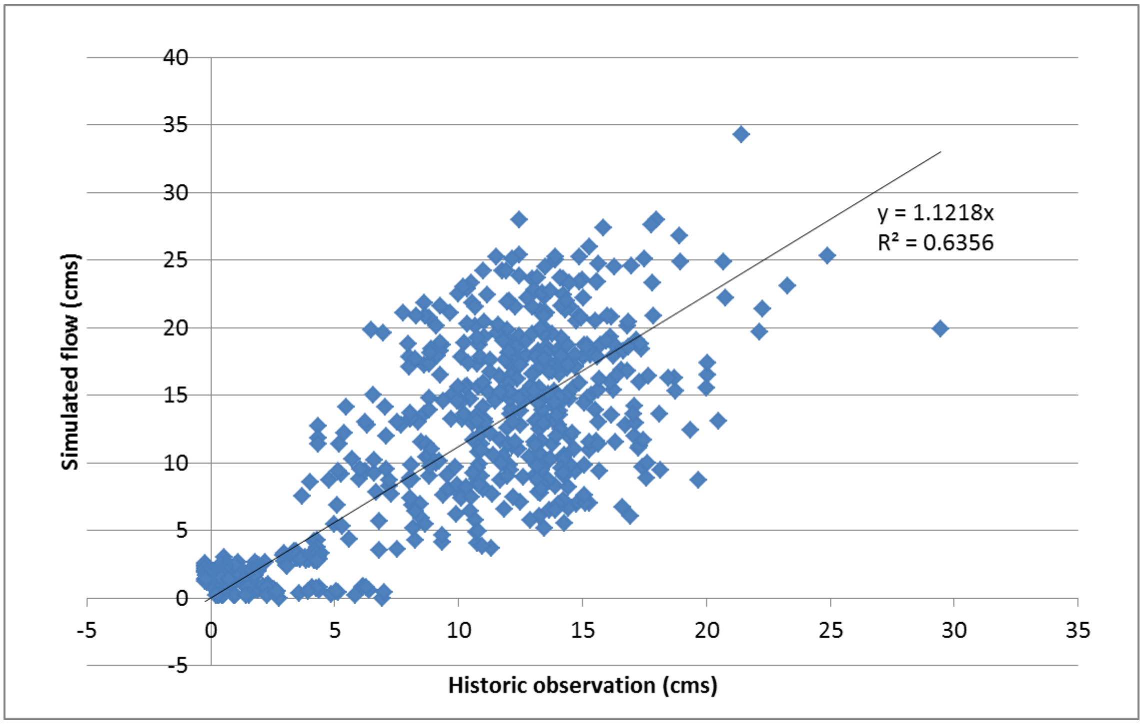


Figure II- 9 Comparison of simulated diversion vs. historic observations at American Canal.

Acequia Madre Heading

Hydrographs of simulated diversions (dashed line) and historic observations (solid line) at Acequia Madre are shown in Figure II- 10. In general the simulated flow matches well with the historic observations except a few low flows simulated at the beginning of 2006 irrigation season. The scatter plot (Figure II- 11) also shows a very good match between the simulated results and the historic measurements at Acequia Madre. It should be noted that only limited water users were included on the Mexican side. More water users will be added to better simulate water distributions within the District 009 in Mexico.

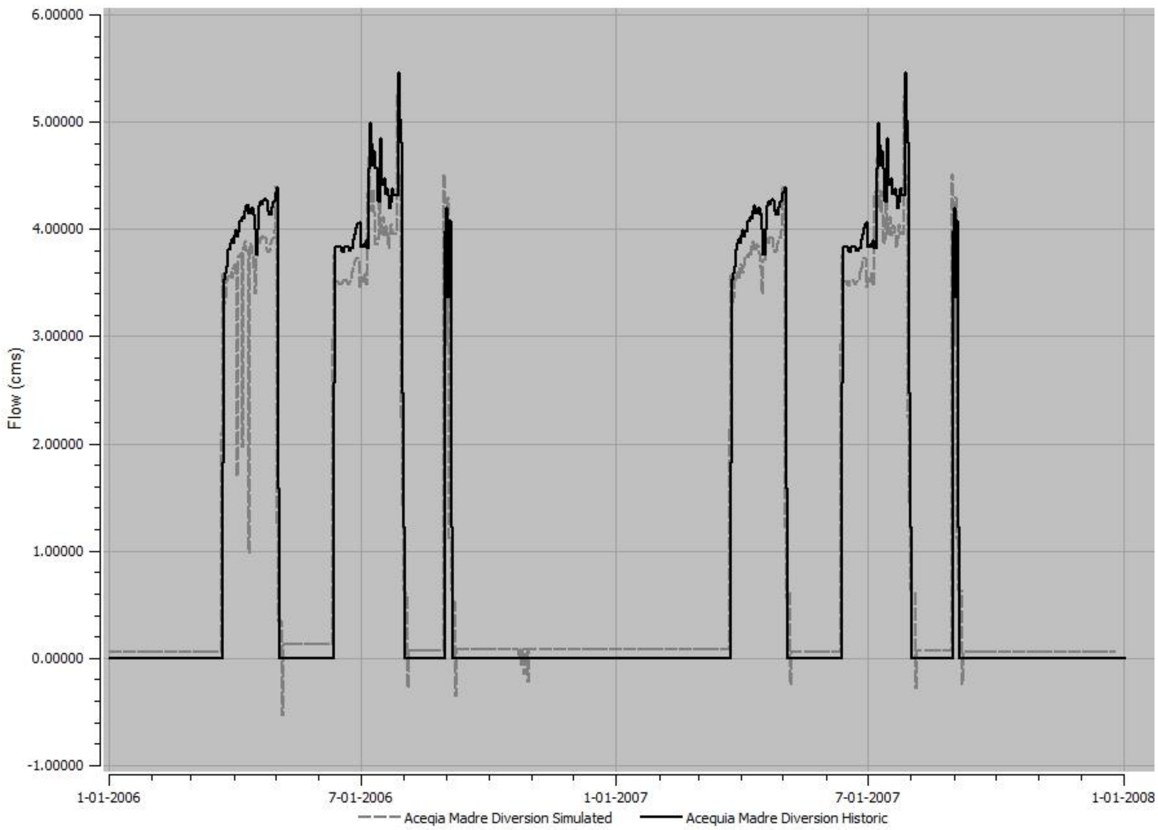


Figure II- 10 Hydrographs of simulated diversion and historic observation at Acequia Madre.

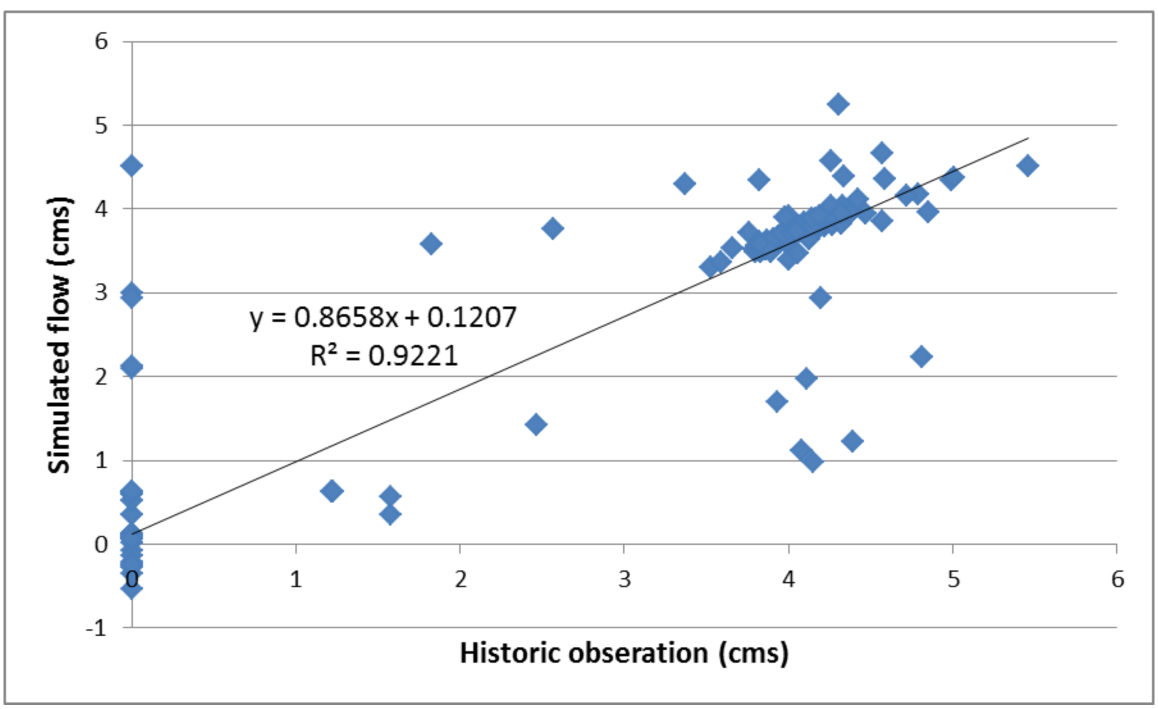


Figure II- 11 Comparison of simulated diversion vs. historic observations at Acequia Madre.

Franklin Canal Heading

Hydrographs of simulated diversions (dashed line) and historic observations (solid line) at Franklin Canal heading is shown in Figure II- 12. The historic low and no flow conditions during the 2006 irrigation season were not well simulated by the RiverWare model. The scatter plot (Figure II- 13) also shows a poor match between the simulated results and the historic measurements at

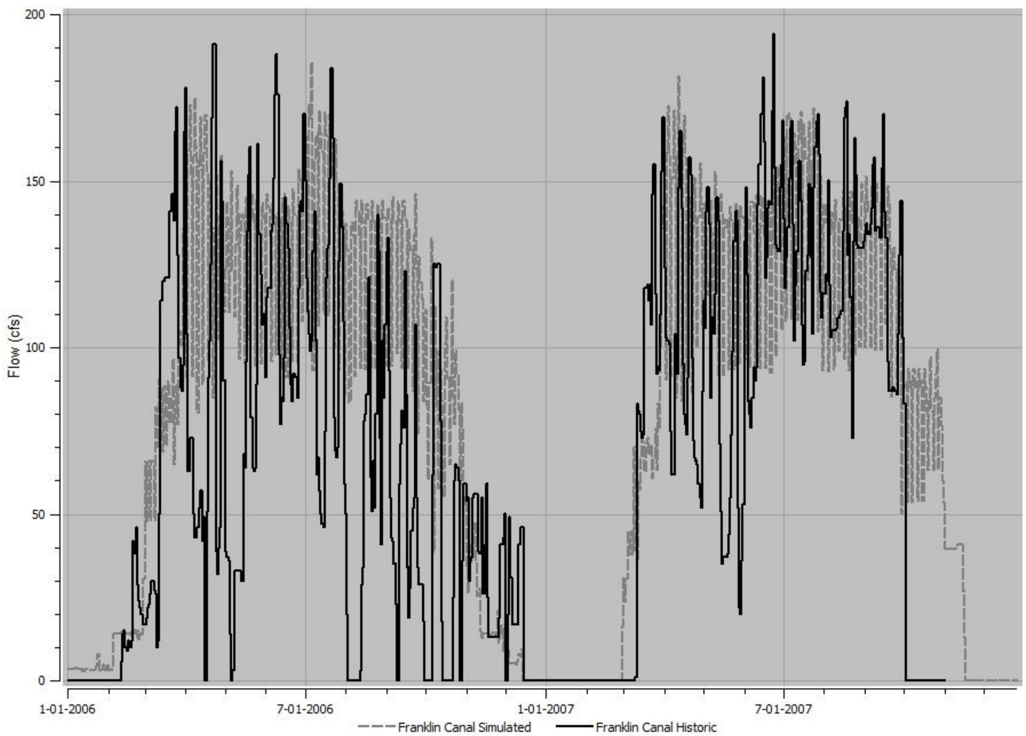


Figure II- 12 Hydrographs of simulated diversion and historic observation at Franklin Canal Heading.

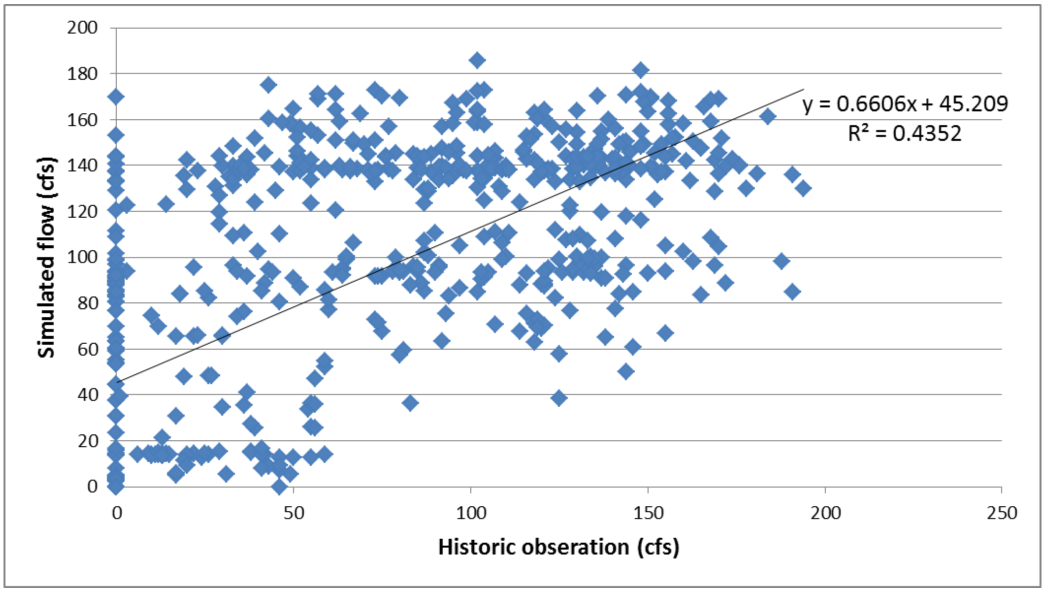


Figure II- 13 Comparison of simulated diversion vs. historic observations at Franklin Canal Heading.

Franklin Canal heading. Matching the specific magnitudes of the historic values is exceedingly difficult because accurate farm diversion data and crop acreages were not available. Better characterization of water demand distributions is expected to improve the performance of the RiverWare model.

Riverside Canal

Hydrographs of simulated diversions (blue line) and historic observations (red line) at Riverside Canal are shown in Figure II-14. In general the RiverWare model simulated flows are higher than the historic observations. It should be noted that a high flow occurred during the rainstorm in August 2006. The large variations of historic diversion in 2007 were not well captured by the RiverWare model. The scatter plot (Figure II-15) also shows a poor match between the simulated results and the historic measurements. It is most likely that this result is related to a lack of historical water demand data.

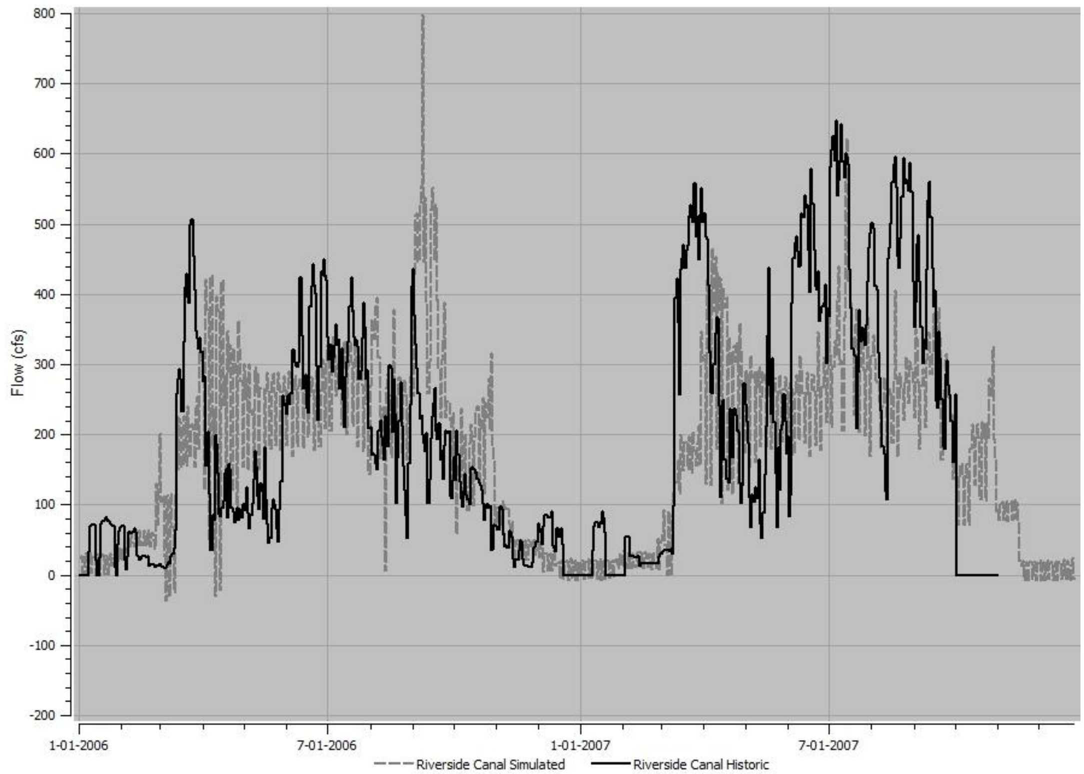


Figure II-14 Hydrographs of simulated diversion and historic observation at Riverside Canal Gaging Station.

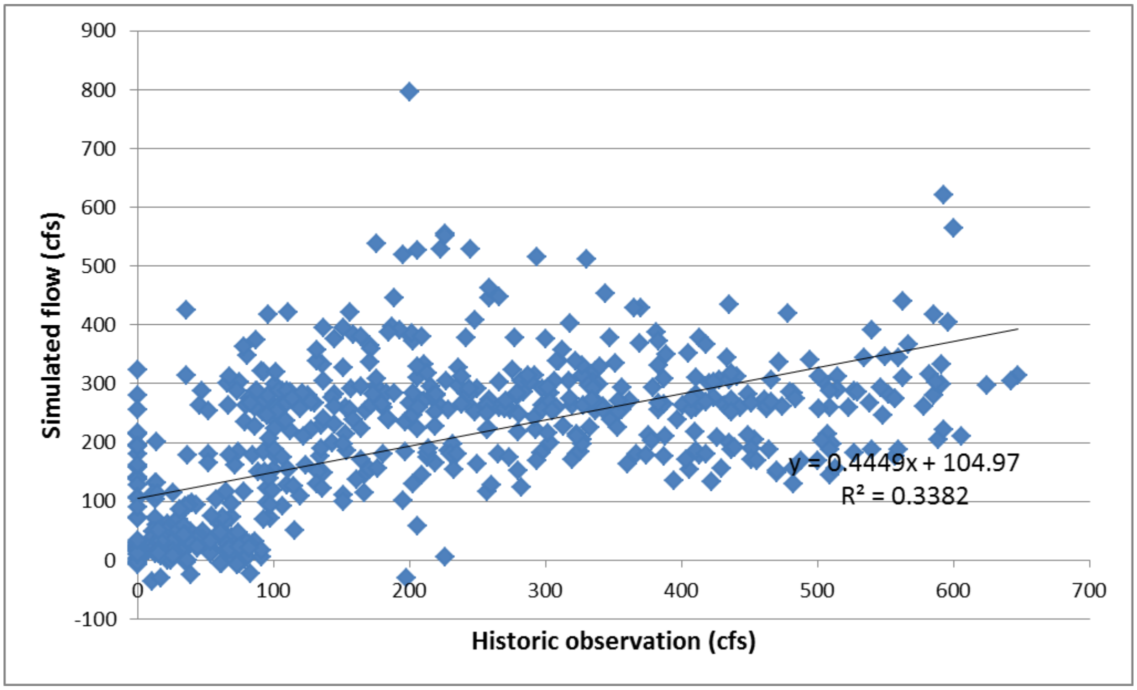


Figure II-15 Comparison of simulated diversion vs. historic observations at Riverside Canal Gaging Station.

Rio Grande at Fort Quitman

Hydrographs of simulated diversions (dashed line) and historic observations (solid line) at Rio Grande Fort Quitman gaging station are shown in Figure II- 16. In general, the RiverWare model simulated flows are higher than the historic observations. The model did estimate high flows during the rainstorm as these flows, obviously, affected flow volumes at gage stations across the system. The simulated river flow discharges at the tail of the irrigation system were affected by the river hydrology, water uses in three districts and return flows from the irrigation fields. The scatter plot (Figure II-17) also shows a poor match between the simulated results and the historic measurements with a R^2 of 0.2407.

Preliminary calibration of such a complex model is time consuming, and in this case we are also lacking historic data. Overall results indicate that the RiverWare model captured key features and showed an encouraging correlation between the simulated flow and historic observations. In large part, the accuracy and functionality of the model is the result of policy generated by rule based simulation modeling. The flows and their distributions generated by the rules and functions loaded into the model produced results that are much better estimates of historical flow data than what would otherwise be possible in simple physical simulation with no operating rules. The model simulated the physical constraints of the irrigation system as well as simple water operations policy, which build a solid foundation for the simulation of more complex water operations policy.

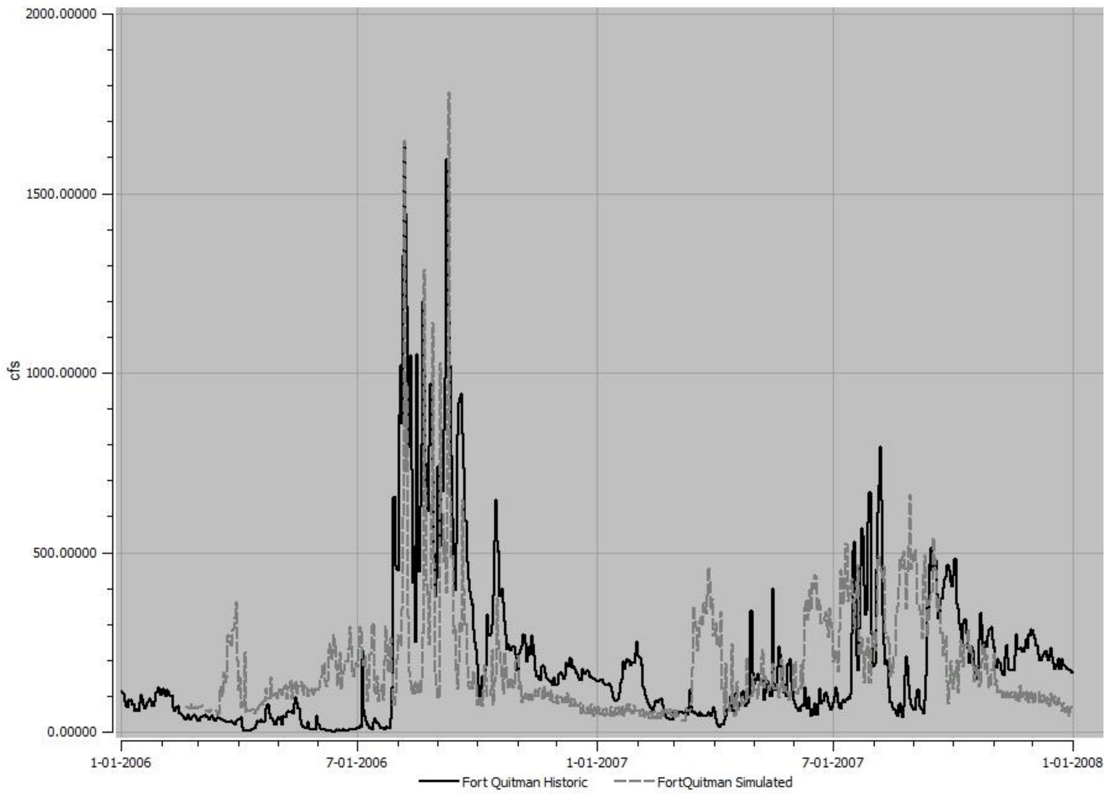


Figure II- 16 Hydrographs of simulated flows and historic observation at the Rio Grande at Fort Quitman Gaging Station.

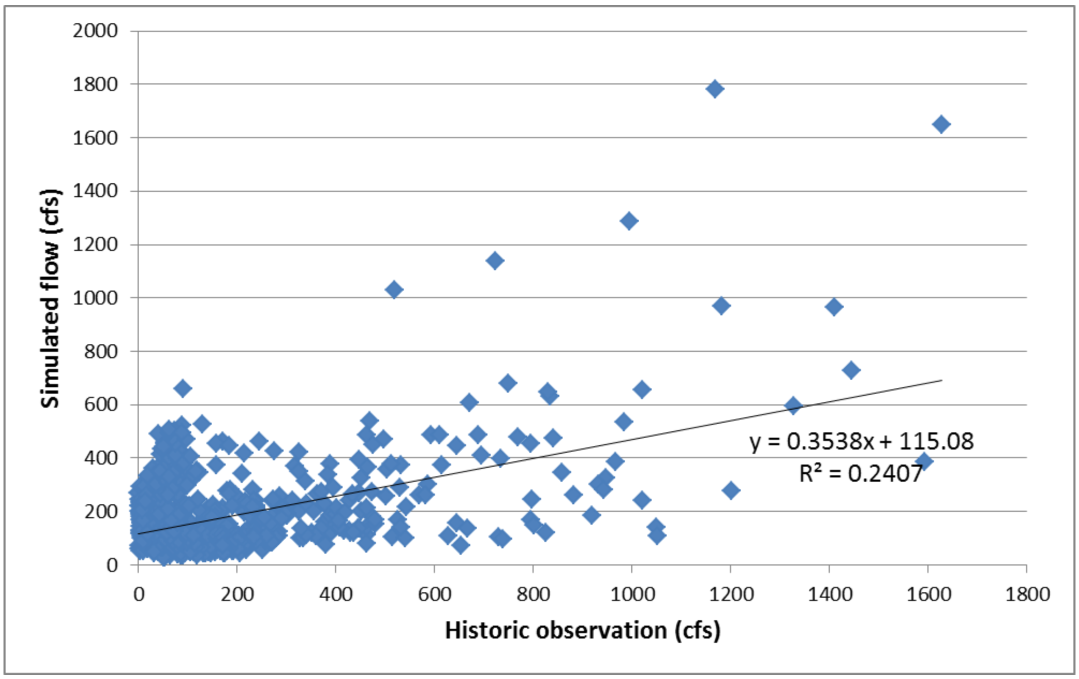


Figure II-17 Comparison of simulated flows vs. historic observations at the Rio Grande at Fort Quitman Gaging Station.

Discussion

To further test the model and identify factors that affected accuracy of the model, we compared simulated flows with historic observations at Faben Wasteway Channel. First we compared the original simulation results versus historic observations as shown in Figure II- 18. It shows a very low correlation with a R^2 of 0.1558. We further evaluated the data set by removing 35 data points with high historic flow measurements poorly matched by the RiverWare model simulation. The comparison shows a much better correlation with a R^2 of 0.6686 as shown in Figure II-19. The results indicated that the current model did not simulate those high flows very well because the current model did not include components that could handle the storage reservoir operations in the Hudspeth County as well as storm water management.

The R^2 values are somewhat misleading. Matching the trends of the historical data through simulation was the larger goal in regards to direct replication of historic data, and this goal was soundly achieved. As there are no databases that compile a direct daily value of consumption and diversion for every water user (i.e. diversion into every lateral and sub-lateral, or a compilation of local inflows that result from runoff, for every day of the simulation period) it will be impossible to replicate every 24 hour fluctuation in gage flows. This causes a significant degree of variation in direct statistical analysis (R^2), but does not account for the accuracy demonstrated in simulating a system that requires an average of 6 days flow time from start to finish, across 720 hours of simulation.

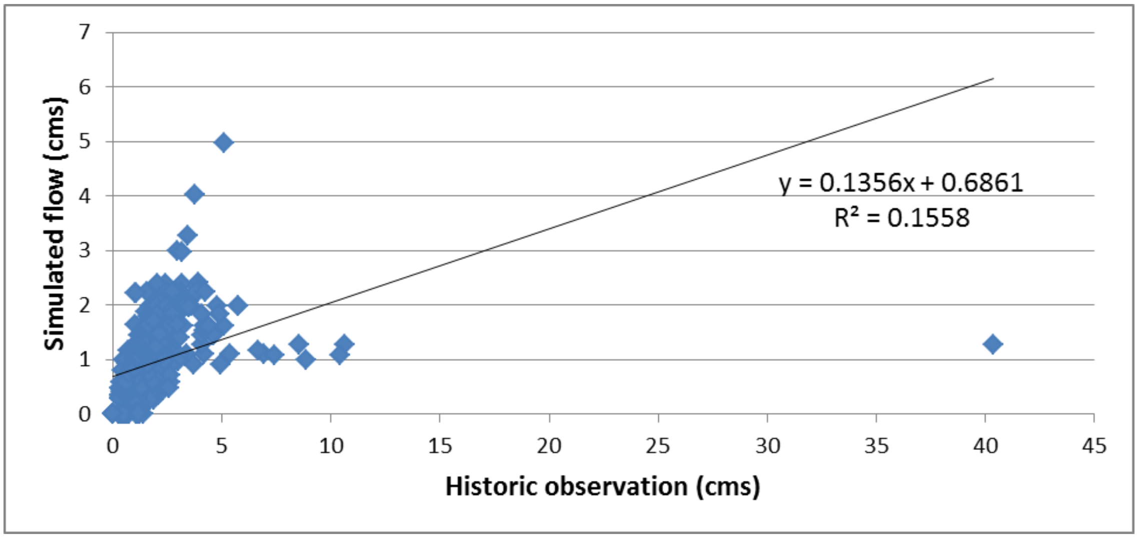


Figure II- 18 Comparison of simulated flows vs. historic observation at Fabens Waste Channel.

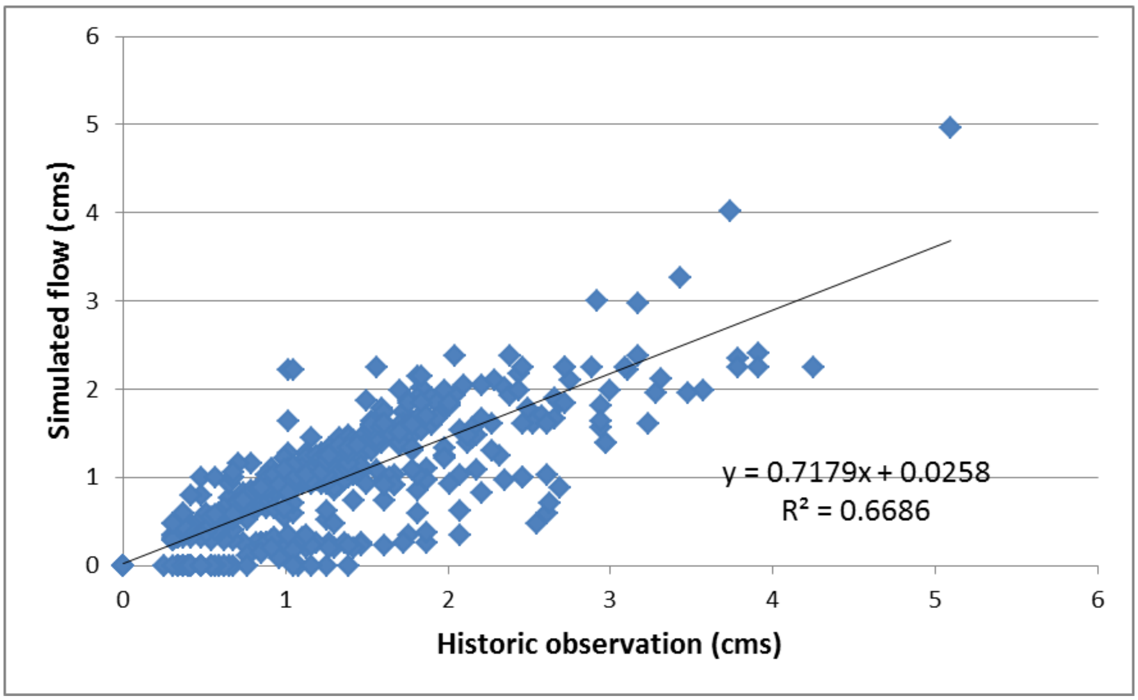


Figure II-19 Comparison of simulated flows vs. historic observation at Fabens Waste Channel after removing high flows in the historic data.

The design and configuration of the RiverWare model are based on availability of representative data of the relevant physical features of the irrigation system. Lack of crop acreage and crop patterns reduced the accuracy of water demand estimates. Although there are a lot of historical flow and various survey data available, some data gaps at diversion points further impacted the calibration of the RiverWare model.

Even though time lag routing is included in the model, inaccurate estimate of lag time within a daily time step model could potentially impact performance of the model. The total time for water to flow unhindered from the top of the system to the bottom of the system is assumed to be approximately six days. Currently the lag time was set to a similar fashion for flows through the river or through the canals. This constraint may marginally decrease the degree of certainty for short term water delivery, but should not impact the accuracy of seasonal water release planning. Other routing methods can be further explored in the next phase.

Recommendations

Water demand estimates for crop consumptive uses was hindered by lack of crop acreage and crop patterns. An effort is ongoing to acquire data on crop acreage and crop patterns from the irrigation districts. By incorporating crop data as well as crop ET coefficients, it is anticipated to generate better water demand patterns and simulate diversion requests and diversions more accurately.

In this model, drain flows were estimated using percentage of return flows based on estimate provided by the districts (EPCWID#1, 2000). A better method will be explored to simulate groundwater and surface water interaction, including correlation between diversions and return flows and using groundwater objects to calculate drain flows and other empirical methods, as was done in the Rincon and Mesilla Valleys. In addition, three storage reservoirs operated by the HCCRD#1 will be added into the model to better simulate the water operations in the district. Previously, operational data for these reservoirs was not available, and known historic flows were directly estimated as demand. Additional diversion points from the main canal and drains will also be added into the District 009 irrigation network as data become available. Current diversion points were intended to better characterize the overall flow distribution within the EPCWID#1. Aggregate diversion objects will be used to integrate multiple diversions along a segment of canal reach to further simplify model configuration in next phase.

The model generally simulates higher flows in the river system than were observed. However, runoffs from local arroyos are not incorporated in the simulations, as there is no runoff data available. To better simulate impacts of local storm events on the river flow as well as potential release of flood flow using irrigation networks, it is recommend that the urban storm system be evaluated and its runoff events be considered in enhancement of the model configuration. This would include assessing intensity of storm water and associated discharge based on historic records, and identifying where the irrigation system collects the storm water and how much it collects. The Local Inflow method in the Reach objects would be applied to account for runoff discharge into the drainage system.

To better facilitate data transfer between the source data and the modeling input, Data Management Interfaces (DMI) will be developed. To assist analysis of modeling output, Spreadsheet Control Table (SCT) will be developed to generate data sets for additional analysis of modeling results and produce graphs for model calibration and verification.

Current rule sets primarily focus on the physical constraints of the irrigation network for delivery of water. Additional rule sets will be incorporated to simulate the policy constraints in terms of scheduling water delivery, calling for supplement groundwater, and other operational planning strategies.

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Appendices

Information of canals and laterals in El Paso County

Table II-A 1 Canal and Laterals in EPCWID#1 (Unit 7A)

Unit 7A				Capacity		
Lateral code	Canal/lateral name	Type of waterway	Length (Mi)	Built for (CFS)	Actual (CFS)	Channel type
713	Bovee	lateral	0.95	25	25	Cement*
714	Daugherty	lateral	3.17	25	25	Dirt*
400	Franklin	canal	5.5	300	225	Dirt
703	Glardon	lateral	0.36	20	20	Dirt
702	Lowenstein	lateral	0.69	25	25	Dirt
704	Socorro	lateral	3.29	35	35	Cement
701	Southside	lateral	2.85	65	65	Dirt/Cement
712	Wadlington	lateral	0.81	70	70	Dirt
705	Ysla	lateral	7.29	50	50	Dirt/Cement
711	Ext Ysla	sub-lat	0.19	25	25	Cement
706	Y-65	sub-lat	1.04	25	25	Dirt
707	Y-147	sub-lat	1.69	30	30	Dirt
708	Y-197	sub-lat	1.02	25	25	Cement
709	Y-251	sub-lat	0.47	30	15	Cement
710	Y-303	sub-lat	1.13	25	25	Cement
	Totals		30.45			

- Information is provided by EPCWID#1. Cement = Concrete, Dirt = Earth

Table II-A 2 Canal and Laterals in EPCWID#1 (Unit 7B)

Unit 7B				Capacity		
Lateral code	Canal/lateral name	Type of waterway	Length (Mi)	Built for (CFS)	Actual (CFS)	Channel type
725	Alfalfa	lateral	0.4	15	15	Dirt
716	Bowman	lateral	1.07	20	20	Dirt/pipe
722	Cinecue	lateral	0.47	20	20	Dirt
400	Franklin	canal	14.69	300	225	Dirt
723	Irwin	lateral	0.45	15	15	Dirt/pipe
717	JDH Main	lateral	7.01	80	80	Dirt
718	JDH A	sub-lat	3.21	35	35	Dirt
719	JDH B	sub-lat	3.39	30	30	Dirt
720	JDH C	sub-lat	1.23	25	25	Dirt
724	Jornado	lateral	2.84	30	30	Dirt
721	Playa	lateral	6.48	30	30	Dirt
100	Ascarate WW	canal	1.16	0	0	Dirt
725	Valley Gate	lateral	does not exist	0	0	Dirt
	Totals		42.4			

Table II-A 3 Canal and Laterals in EPCWID#1 (Unit 8A)

Unit 8A				Capacity		
Lateral code	Canal/lateral name	Type of waterway	Length (Mi)	Built for (CFS)	Actual (CFS)	Channel type
803	Clint	lateral	7.21	75	75	Cement
806	Coffin	lateral	0.68	20	20	Cement
802	Crismore	sub-lat	1.64	20	20	Cement
808	Cuadrilla	lateral	1.89	25	25	Cement
400	Franklin	canal	10.28	300	300	Dirt
810	Grandview	lateral	0.57	20	20	Cement
804	Green	sub-lat	1.27	25	25	Dirt
809	Lee	lateral	0.46	20	20	Cement
805	Rodriquena	lateral	2.53	25	25	Cement
801	Salitral	lateral	11.51	75	75	Dirt/cem
807	Webb	lateral	0.49	20	20	Cement
800	Ext Clint	sub-lat	0.63	20	20	Cement
	Totals		39.16			

Table II-A 4 Canal and Laterals in EPCWID#1 (Unit 8B)

Unit 8B				Capacity		
Lateral code	Canal/lateral name	Type of waterway	Length (Mi)	Built for (CFS)	Actual (CFS)	Channel type
817	Barrial	sub-lat	1.34	15	15	Dirt
821	Bernal	cement	1.39	20	20	Cement
818	Canas Agrias	sub-lat	1.57	25	25	Dirt
815	Del Monte	sub-lat	0.64	20	20	Cement
820	Escajeda	sub-lat	0.23	10	10	Dirt
400	Franklin	canal	4.82	300	300	Dirt
825	Frk Feeder	canal	2.68	400	300	Dirt
822	Hall	lateral	0.41	25	25	Cement
823	Island Feeder	lateral	2.02	80	80	Dirt
824	IF 57	sub-lat	2.06	30	30	Cement
819	Madre	sub-lat	0.2	10	10	Dirt
811	Northside	lateral	0.59	10	10	Dirt
814	Quemada	sub-lat	0.98	20	20	Cement
500	Riverside	canal	10.01	700	700	Dirt
812	San Eli Main	lateral	7.8	120	100	Dirt/Cem
816	San Eli WW#1	sub-lat	0.79	75	75	Dirt
813	Upper Clint	sub-lat	2.11	25	25	Cement
	Totals		39.64			

Table II-A 5 Canal and Laterals in EPCWID#1 (Unit 9A)

Unit 9A				Capacity		
Lateral code	Canal/lateral name	Type of waterway	Length (Mi)	Built for (CFS)	Actual (CFS)	Channel type
916	I-243	lateral	3.01	35	35	Cement
918	I-341	lateral	4.05	50	50	Cement
917	Cook&Schultz	sub-lat	0.24	20	20	Dirt
904	Malone	lateral	1.09	35	35	Dirt
901	Tornillo	canal	11.97	350	350	Dirt
902	T-131	lateral	2.9	40	40	Dirt
903	T-216	lateral	5.37	80	80	Dirt
905	T-462	lateral	0.34	20	20	Dirt
906	T-520	lateral	1.48	30	30	Dirt
	Totals		30.45			

Table II-A 6 Canal and Laterals in EPCWID#1 (Unit 9B)

Unit 9B				Capacity		
Lateral code	Canal/lateral name	Type of waterway	Length (Mi)	Built for (CFS)	Actual (CFS)	Channel type
912	Guadalupe	lateral	5.62	60	60	Cenment
913	Guad Ext	sub-lat	0.53	20	20	Cenment
915	Hansen	lateral	5.14	120	120	Dirt
907	I-Zero	lateral	0.79	25	25	Cement
908	Island Main	lateral	3.94	120	120	Dirt
909	I-72	sub-lat	0.66	20	20	Cement
910	I-154	sub-lat	4.36	45	45	Dirt
911	I-136	sub-lat	0.97	20	20	Dirt
914	I-206	sub-lat	2.61	30	30	Cement
919	I-270	sub-lat	1.09	30	30	Cement
500	Riverside	canal	11.21	700	700	Dirt
	Totals	36.92				

<u>Location information for some RiverWare Objects</u>

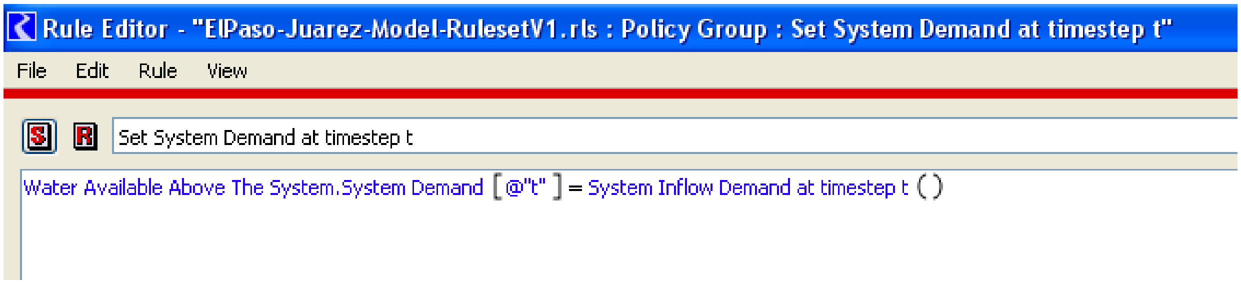
Table II-A 7 RiverWare Reach Objects within the El Paso-Hudspeth irrigation system

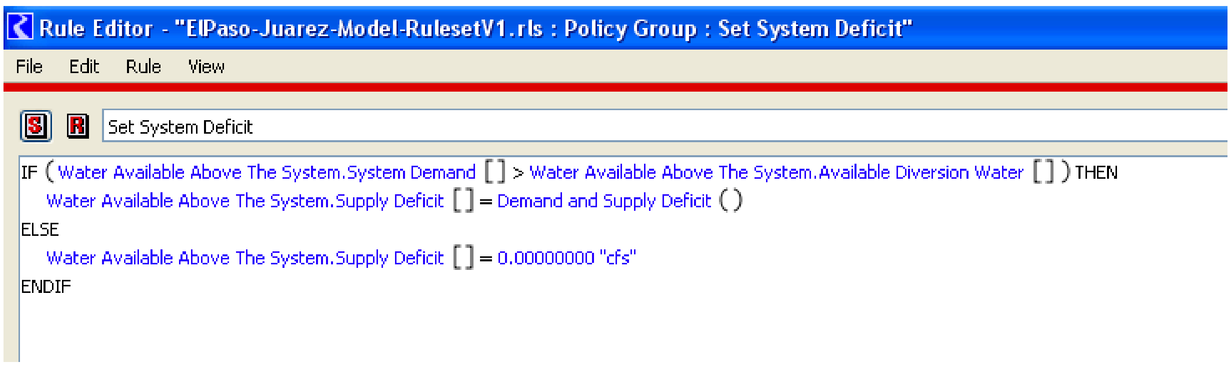
Unit	Reach Hydraulically Determinate	Length (ft)	Heading Latitude	Heading Longitude	Ending Latitude	Ending Longitude
	American Canal	27407	31^{0}47'3.11"N	106^{0}31'38.87W	31^{0}45'33.02"N	106^{0}28'5.79"W
7B	Franklin Canal 1	77563	31^{0}45'33.02"N	106^{0}28'5.79"W	31^{0}39'28.895"N	106^{0}17'35.397"
7A, 8A, 8B	Franklin Canal 8	83318	31^{0}39'25.944"N	106^{0}17'35.399"W	31^{0}30'29.501" N	106^{0}10'13.618"W
	American Canal Extension 1	75410	31^{0}45'33.02"N	106^{0}28'5.79"W	31^{0}38'18.20"N	106^{0}18'2.14"W
8A, 8B, 9B	Riverside Canal 4	71711	31^{0}38'18.20"N	106^{0}18'2.14"W	31^{0}29'44.328" N	106^{0}9'17.749" W
9A	Franklin Canal End (Tornillo)	35922	31^{0}29'44.328" N	106^{0}9'17.749" W	31^{0}26'28.72"N	106^{0}5'54.24"W
	Tornillo Canal 4	35922	31^{0}26'28.72"N	106^{0}5'54.24"W	31^{0}26'38.91"N	106^{0}0'29.22"W
	Hudspeth Canal 1	57729	31^{0}26'38.91"N	106^{0}0'29.22"W	31^{0}26'38.91"N	106^{0}0'29.22"W
	Hudspeth Canal 4	92769	31^{0}18'17.32"N	105^{0}52'47.47"W	31^{0}7'55.556"N	105^{0}41'49.825"W
	Rio Grande 1	92769	31^{0}47'18.442"N	106^{0}31'36.933"W	31^{0}39'30.604"N	106^{0}19'47.182"W
	Rio Grande 3	51347	31^{0}39'30.604"N	106^{0}19'47.182"W	31^{0}32'34.618"N	106^{0}14'51.970"W
	Rio Grande 6	62494	31^{0}32'34.618"N	106^{0}14'51.970"W	31^{0}25'26.391"N	106^{0}07'25.691"W
	Rio Grande 7	39870	31^{0}25'26.391"N	106^{0}07'25.691"W	31^{0}23'34.394"N	106^{0}0'30.389"W
	Rio Grande 9	62907	31^{0}23'34.394"N	106^{0}0'30.389"W	31^{0}17'28.767"N	105^{0}52'49.694"W
	Rio Grande 11	96595	31^{0}17'28.767"N	105^{0}52'49.694"W	31^{0}7'24.758"N	105^{0}40'14.73"W

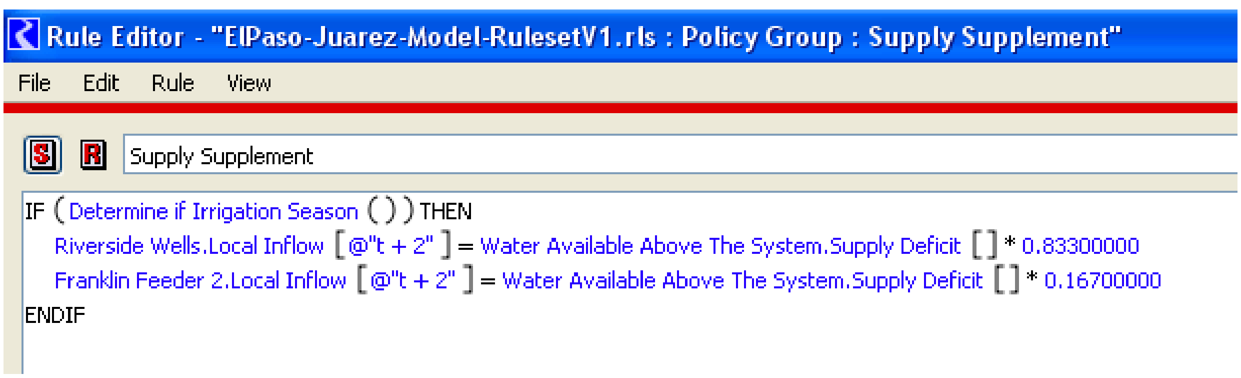
Table II-A 8 Location of Some Key RiverWare Objects

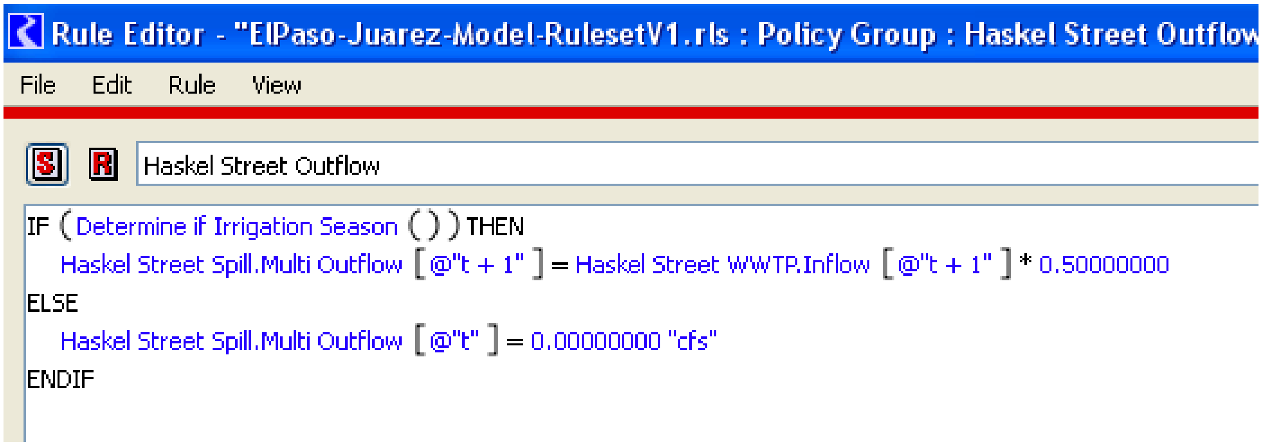
Objects	Location		Objects	Location	
	Latitude	Longitude		Latitude	Longitude
Northwest WWTP Confluence	31^{0}47'18.442"N	106^{0}31'36.933"W	Franklin Feeder 1 (San Elizario)	31^{0}37'32.007"N	106^{0}17'24.331"W
Above American Dam	31^{0}47'18.442"N	106^{0}31'36.933"W	Del Monte/Barrial Lat 1	31^{0}35'51.717"N	106^{0}16'21.645"W
American Dam	31^{0}47'3.39"N	106^{0}31'40.94"W	Canas Agrias Lat 1	31^{0}35'7.697"N	106^{0}16'30.992"W
International Dam	31^{0}45'39.823"N	106^{0}30'35.048W	Bernal Lat 1	31^{0}33'52.803"N	106^{0}15'45.493"W
Franklin Riverside Split	31^{0}45'33.099"N	106^{0}28'5.757"W	Franklin Canal 9 (Daugherty)	31^{0}38'40.818"N	106^{0}16'54.591"W
American Canal Extension 2	31^{0}45'32.992"N	106^{0}26'29.236"W	Franklin Feeder Confluence	31^{0}37'19.838"N	106^{0}15'47.656"W
Rio Grande 2 (Haskel St WWTP)	31^{0}45'32.105"N	106^{0}26'30.424"W	Franklin Canal 12 (Salita)	31^{0}37'19.657"N	106^{0}15'44.923"W
Rio Grande 4 (Riverside WW #1)	31^{0}37'44.192"N	106^{0}18'27.269"W	Franklin Canal 13(Clint)	31^{0}36'38.856"N	106^{0}15'35.132"W
Rio Grande 5 (Riverside WW #2)	31^{0}32'34.618"N	106^{0}14'51.970"W	Franklin Canal 14 (Rodrguena)	31^{0}36'33.371"N	106^{0}15'30.594"W
Fabens Rio Confluence	31^{0}25'26.391"N	106^{0}07'25.691"W	Franklin Canal 15 (Quemada)	31^{0}36'26.652"N	106^{0}15'30.835"W
Rio Grande 8 (Tornillo WW #2)	31^{0}23'34.394N	106^{0}0'30.389"W	Franklin Canal 16 (Island Feeder)	31^{0}34'7.604"N	106^{0}13'55.473"W
Rio Grande 10 (Juarez Drain)	31^{0}7'55.556"N	105^{0}41'49.825"W	Riverside Franklin Confluence	31^{0}30'29.551"N	106^{0}10'13.541"W
Rio Grande 13 (Lower Drain)	31^{0}7'24.758"N	105^{0}40'14.73"W	Riverside Canal 2 (J Rodgers)	31^{0}39'27.917"N	106^{0}19'39.553"W
Bowman Diversion	31^{0}44'26.401"N	106^{0}22'24.979"W	Riverside Canal 3 (RRB)	31^{0}38'11.437"N	106^{0}18'6.605"W
Franklin Canal 2 (JDH)	31^{0}44'5.575"N	106^{0}22'0.125"W	Riverside Canal 5 (Franklin Feeder)	31^{0}38'18.622"N	106^{0}18'2.183"W
JDH Sub Lat 1	31^{0}43'35.262"N	106^{0}21'2.73"W	Riverside Canal 6 (WW #1)	31^{0}37'45.491"N	106^{0}18'23.889"W
Franklin Canal 3 (Playa)	31^{0}44'3.818"N	106^{0}22'1.853"W	Riverside Canal 9 (WW #2)	31^{0}32'38.173"N	106^{0}14'49.662"W
Frainklin Canal 4 (SS Feeder)	31^{0}42'30.562"N	106^{0}20'37.788"W	Island Feeder Confluence	31^{0}32'25.886"N	106^{0}14'6.114"W
Franklin Canal 5 (Jornado)	31^{0}41'34.484"N	106^{0}19'28.41"W	Riverside Extension 1 (Island)	31^{0}32'24.874"N	106^{0}14'6.143"W
Franklin Canal 6 (Socorro)	31^{0}40'22.019"N	106^{0}18'24.614"W	Guadalupe Lat 1	31^{0}30'14.609"N	106^{0}12'29.748"W
Franklin Canal 7 (Ysleta)	31^{0}40'10.81"N	106^{0}18'12.109"W	Riverside Extenion End (Hansen)	31^{0}29'44.204"N	106^{0}9'17.671"W

Table II-A 9 RiverWare rule sets





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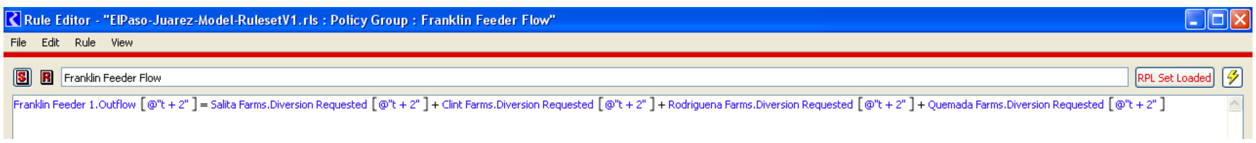
File Edit Rule View
Haskel Street Outflow
IF (Determine if Irrigation Season ( )) THEN
Haskel Street Spill.Multi Outflow [@"t + 1"] = Haskel Street WWTP.Inflow [@"t + 1"] * 0.50000000
ELSE
Haskel Street Spill.Multi Outflow [@"t"] = 0.00000000 "cfs"
ENDIF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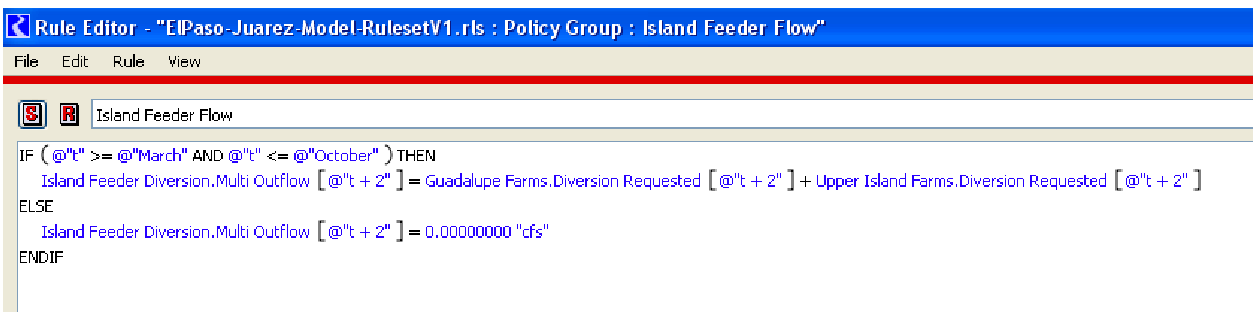
Franklin Feeder Flow
RPL Set Loaded
Franklin Feeder 1.Outflow [@"t + 2"] = Salita Farms.Diversion Requested [@"t + 2"] + Clint Farms.Diversion Requested [@"t + 2"] + Rodriguena Farms.Diversion Requested [@"t + 2"] + Quemada Farms.Diversion Requested [@"t + 2"]


Rule Editor - "ElPaso-Juarez-Model-RulesetV1.rls : Policy Group : Island Feeder Flow"
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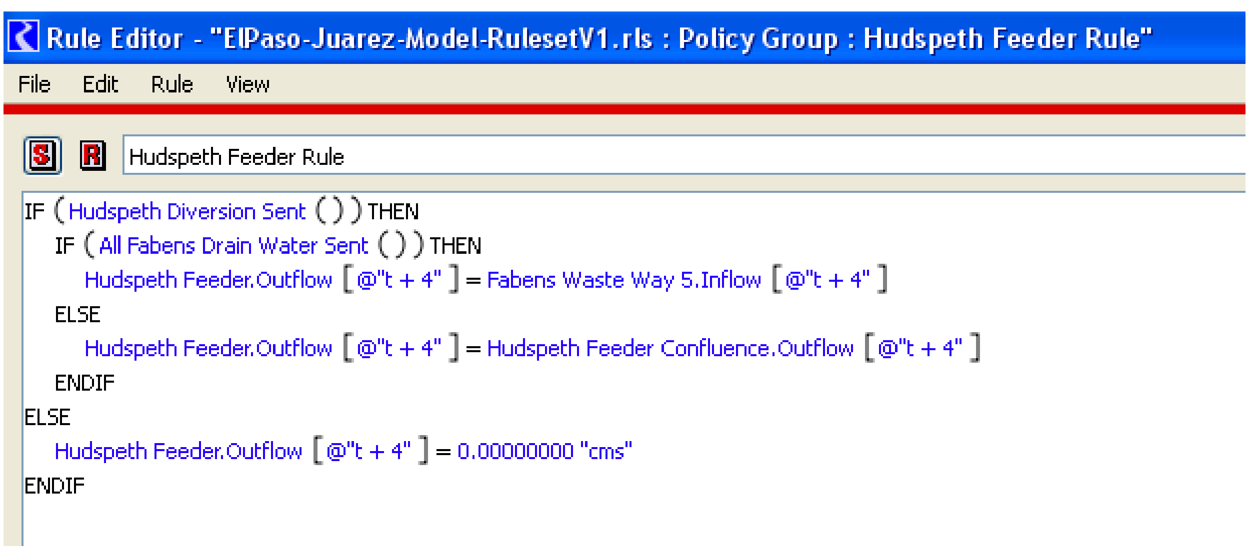
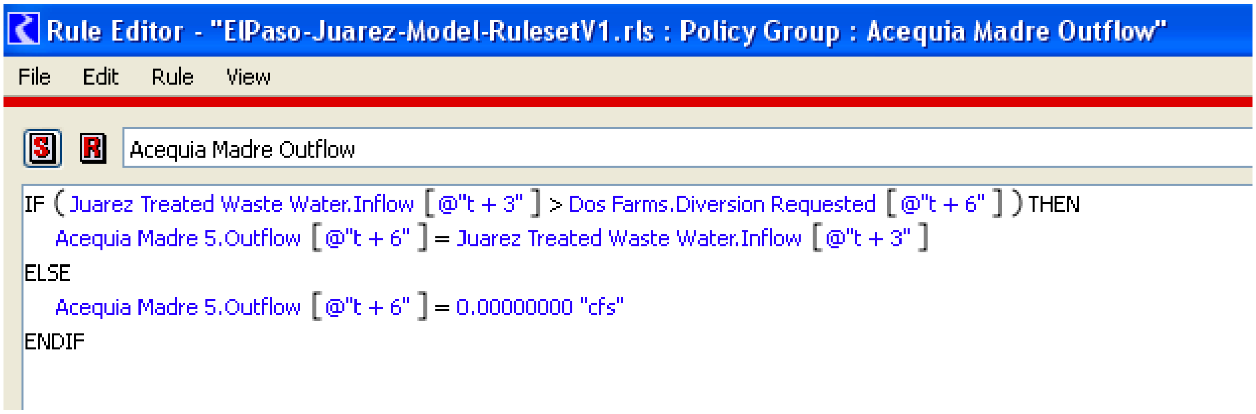
Island Feeder Flow
IF (@"t" >= @"March" AND @"t" <= @"October") THEN
Island Feeder Diversion.Multi Outflow [@"t + 2"] = Guadalupe Farms.Diversion Requested [@"t + 2"] + Upper Island Farms.Diversion Requested [@"t + 2"]
ELSE
Island Feeder Diversion.Multi Outflow [@"t + 2"] = 0.00000000 "cfs"
ENDIF


Rule Editor - "ElPaso-Juarez-Model-RulesetV1.rls : Policy Group : Hudspeth Feeder Rule"
File Edit Rule View
Hudspeth Feeder Rule
IF (Hudspeth Diversion Sent ( )) THEN
IF (All Fabens Drain Water Sent ( )) THEN
Hudspeth Feeder.Outflow [@"t + 4"] = Fabens Waste Way 5.Inflow [@"t + 4"]
ELSE
Hudspeth Feeder.Outflow [@"t + 4"] = Hudspeth Feeder Confluence.Outflow [@"t + 4"]
ENDIF
ELSE
Hudspeth Feeder.Outflow [@"t + 4"] = 0.00000000 "cms"
ENDIF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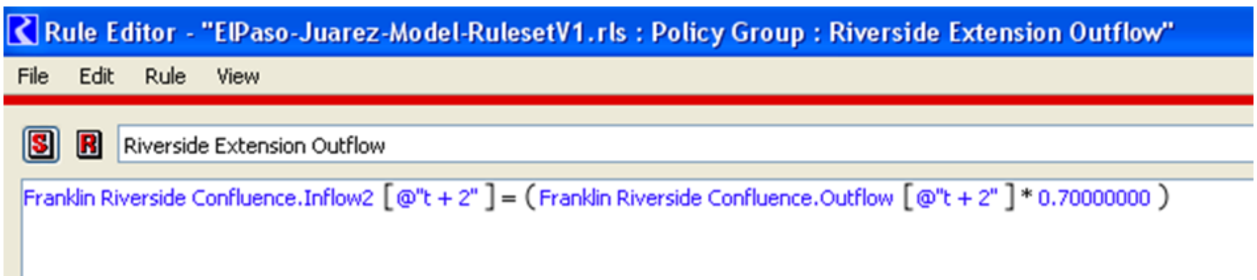
Acequia Madre Outflow
IF (Juarez Treated Waste Water.Inflow [@"t + 3"] > Dos Farms.Diversion Requested [@"t + 6"]) THEN
Acequia Madre 5.Outflow [@"t + 6"] = Juarez Treated Waste Water.Inflow [@"t + 3"]
ELSE
Acequia Madre 5.Outflow [@"t + 6"] = 0.00000000 "cfs"
ENDIF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Riverside Extension Outflow
Franklin Riverside Confluence.Inflow2 [@"t + 2"] = (Franklin Riverside Confluence.Outflow [@"t + 2"] * 0.70000000)

Part III. Hydrologic Modeling of Main Tributaries to Estimate Runoff Potential into the Rio Grande-Rio Bravo at Irrigation District 009 Valle de Juarez

Alfredo Granados-Olivas and Víctor Esquivel-Ceballos

Introduction

Water resources across international borders are an important issue around the world and in the XXI century, the demands on this resource will become a subject for international policy and strategic sustainable development. Mexico and the United States have conducted relevant advances on this subject throughout time. The two countries have accomplished international agreements in regards to management policies of shared water resources along their transboundary watersheds. The Paso del Norte (PdN) Region has special hydrologic characteristics since the surface water and groundwater resources in the region are binational in nature. However, despite the success stories on data sharing and water policy compromise by both nations, there is still a need to gather and analyze basic hydrologic data along the border region. Furthermore, the effect of the "white syndrome" maps along the border region, whereby Mexican maps have no detail north of the border, and US maps have none to the south, is an indication of the lack of transboundary integration of information. Hence, the approach taken by several regional universities within the PdN watershed have enhanced the potential collaboration on data gathering along the border, concentrating on finding possible solutions on water assets for proper management solutions on water issues along the transboundary region (http://www.pdnwc.org) . For example, over the past 12 years, several efforts on data exchange and binational hydrological modeling have taken place embracing the possibility of a holistic approach to water management, (Granados *et al.*, 2012; Eastoe *et al.*, 2010; Granados *et al.* 2009; Hawley *et al.*, 2009; Tillery *et al.* 2006, 2009a and 2009b; Creel *et al.*, 2006; Brown *et al.*, 2005; Hibbs., *et al.*, 2003). Despite these important efforts on water information along the transboundary region between Mexico and the US, there is still a need for further analysis and more detail studies on surface water and groundwater resources. This paper addresses the efforts taken place on the Mexican side of the project while concentrating on hydrologic modeling of adjacent subwatersheds connecting tributaries to the main stream of the Rio Bravo -Rio Grande along the Hydrologic Region 24-Rio Bravo (RH-24) where the agricultural area of northern

Chihuahua, Irrigation District 009 (ID-009)-Valle de Juarez is located. This research is important since no previous work has addressed the potential runoff from these tributaries into the main stem of the Rio Bravo-Rio Grande. Furthermore, the update on geospatial information from the region on the Mexican side of the project will alleviate the “white map” syndrome along this transboundary watershed.

Approach to Hydrologic Modeling of Mexican Tributaries

The rainfall-runoff modeling along the ID009-Valle de Juarez was approached by the Mexican team members while concentrating on the integration of a geodatabase for water resources using Geographic Information Systems (GIS) technology. Digital geospatial information on natural resources were gathered for the region of interest and projected into digital maps where base maps for the hydrologic modeling were incorporated to the project area. Once the main geodatabases were integrated, a Digital Elevation Model (DEM) was created with the topography layer at a 1:50,000 scale to delineate watershed boundaries and model the stream channels connecting as tributaries into the Rio Bravo-Rio Grande (Figure III- 1).

Further steps into the hydrologic modeling required the application of specialized software to model hydrologic parameters of the Mexican tributaries. To accomplish this goal, tools within HEC-HMS™ software were applied and hydrologic parameters estimated. Hydrometeorological data were collected from historical precipitation records selected from two UACJ weather stations located at Cd. Juarez (UACJ-IIT) and at the ID-009-Valle de Juarez (UACJ Agricultural Station at Praxedis G. Guerrero). In order to estimate Curve Numbers (CN) and simulate runoffs along the region of interest, the Land use-Land cover data were acquired from Mexican official sources at scale 1:250,000 (INEGI, 2000). Crop estimates and type of agriculture established along the ID009 were gathered from official sources published by the Mexican Agriculture Minister (SAGARPA, 2000).

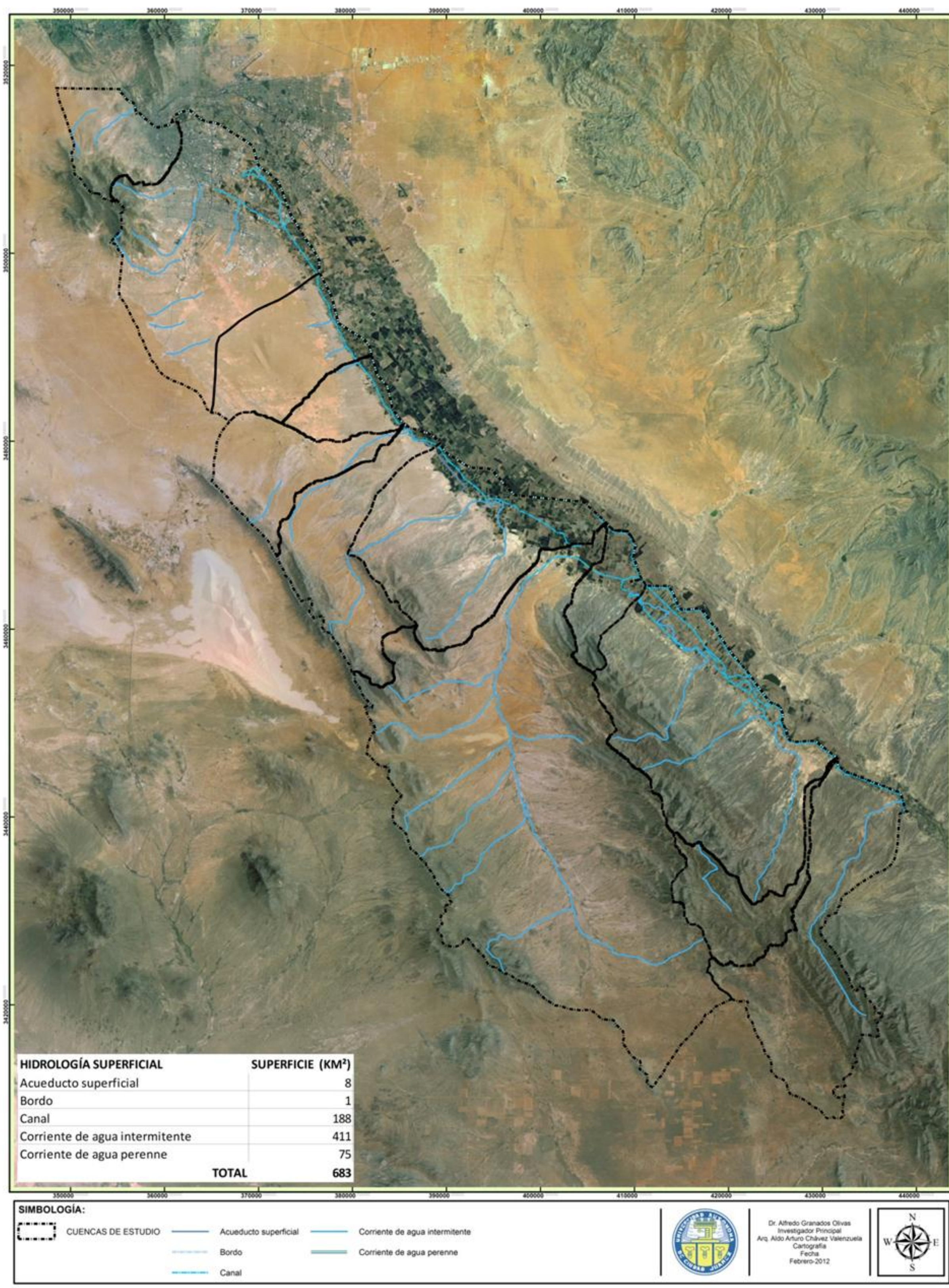
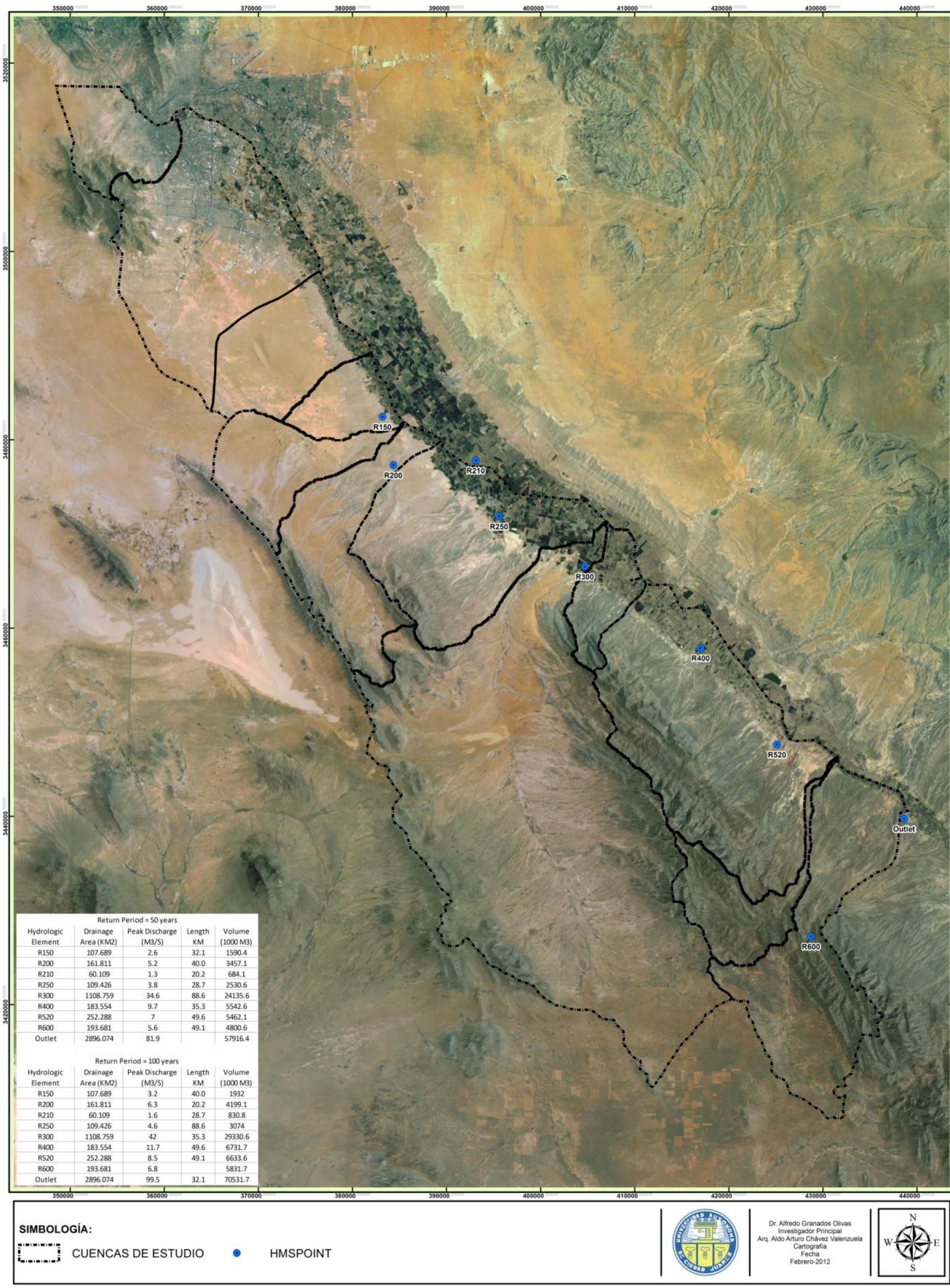


Figure III- 1 Watersheds and main tributaries connecting into the Rio Grande-Rio Bravo.

Products of the Hydrologic Modeling at ID009-Valle de Juarez

The results of the main GIS processes and hydrologic modeling are located in attached Appendices of this report and GIS files in shapefile format were incorporated on the deliverables included with the report. Twelve main subwatersheds were defined in the DEM-based delineation using the topography layer as shown in Figure III- 1. The first three of these upstream subwatersheds were considered as urban subwatersheds since most of the areas were located within the urbanized region of Cd. Juarez, Chihuahua, and their surface hydrology is related to urban hydrologic infrastructure such as small dams that control runoff, and effects of streets and highways that disrupt the potential connection into the main stream of the Rio Bravo-Rio Grande. The other nine subwatershed were taken into consideration to model the main hydrologic parameters for this project and main junctions were selected as outlets into the main stream of the area of interest (Figure III- 2). These junctions played an important role in the model. They were used to estimate upstream conditions of the main subwatersheds along the Mexican side of the project and the definitions of areas on the watersheds and distance of main tributaries were calculated, (Table III- 1; Figure III- 2). The most important Hydrologic Junction R300 represents the region of the Bandejas Subwatershed, which incorporates a total drainage area of 1,109 km^2 and a total of 89 km of streams from headwaters to junction at the ID009 as provided in Table III- 1. Although slope on the Bandejas Subwatershed was estimated at 6%, some of its neighboring areas have a more pronounced topography which increases the flooding risk on the area.

CNs on all subwatersheds were estimated based on a rangeland type of land use, with a value of 62, representative of typical shrub and desert grasslands with scarce vegetation. Return periods for 50 and 100 years (TR50 and TR100) were considered while estimating accumulated rainfall within a period of 24 hrs on the runoff calculations. Again, junction point R300, the representative of the Bandejas Subwatershed was the region with the highest values of estimated runoff with potential peak discharges of 34.6 m^3/s and 42 m^3/s for TR50 and TR100, respectively.



Return Period = 50 years

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Length KM	Volume (1000 M3)
R150	107.689	2.6	32.1	1590.4
R200	161.811	5.2	40.0	3457.1
R210	60.109	1.3	20.2	684.1
R250	109.426	3.8	28.7	2530.6
R300	1108.759	34.6	88.6	24135.6
R400	183.554	9.7	35.3	5542.6
R520	252.288	7	49.6	5462.1
R600	193.681	5.6	49.1	4800.6
Outlet	2896.074	81.9		57916.4

Return Period = 100 years

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Length KM	Volume (1000 M3)
R150	107.689	3.2	40.0	1932
R200	161.811	6.3	20.2	4199.1
R210	60.109	1.6	28.7	830.8
R250	109.426	4.6	88.6	3074
R300	1108.759	42	35.3	29330.6
R400	183.554	11.7	49.6	6731.7
R520	252.288	8.5	49.1	6633.6
R600	193.681	6.8		5831.7
Outlet	2896.074	99.5	32.1	70531.7

Figure III- 2 Junctions along the ID009-Valle de Juarez

Table III- 1 Hydrologic Characterization of Subwatersheds at ID009*

Hydrologic Junction**	Drainage Area (km^2)	Length (Km)	Slope (%)	CN	Peak Discharge TR50 (m^3/s)	Peak Discharge TR100 (m^3/s)
R150	107.7	32.1	9	62	2.6	3.2
R200	161.8	40	11	62	5.2	6.3
R250	109.4	28.7	16	62	3.8	4.6
R300	1108.7	88.6	6	62	34.6	42
R520	252.3	49.6	15	62	7.0	8.5
R600	193.7	49.1	14	62	5.6	6.8
Outlet	1933.5	288.1	2***	62	81.9	99.5

*Urban Subwatersheds not included
**Narrow subwatershed included in neighboring junctions downstream
*** Slope considered along the ID009 from CJ to Outlet

Summary and Recommendations

Ongoing efforts to define hydrologic characteristics at the ID009-Valle de Juarez have been one of the most important strategies within the binational effort to develop a holistic approach to water management and policy in the PdN region. Academic endeavors from regional universities and research centers over the past 20 years focusing on data exchange and watershed characterization have been helpful in gathering important natural resources data along the transboundary watersheds ((http://www.pdnwc.org). Hydrologic modeling of watersheds at these binational hydrologic corridors has advanced over the last 5 years as joint collaboration from regional institutions and research centers specializing on water resources continues. In this phase of the project following information and data were compiled to develop hydrologic model: soil types, land use, surface hydrology, groundwater, geomorphology, topography, and fracture trace analysis, among other GIS coverages from thematic map layers. Furthermore, hydrologic modeling was developed using HEC-HMS, and results from these models demonstrated the importance of these procedures to evaluate tributary contribution from main subwatersheds linked to the principal stream from the Rio Bravo-Rio Grande. Twelve regions were defined on the system, of which three (upstream at the Cd. Juarez) were classified as urban subwatersheds and nine were classified as rural subwatersheds. The most important subwatershed in the region was the Bandejas Subwatershed, which had the largest area and highest estimated flows for the 50 and 100 year events.

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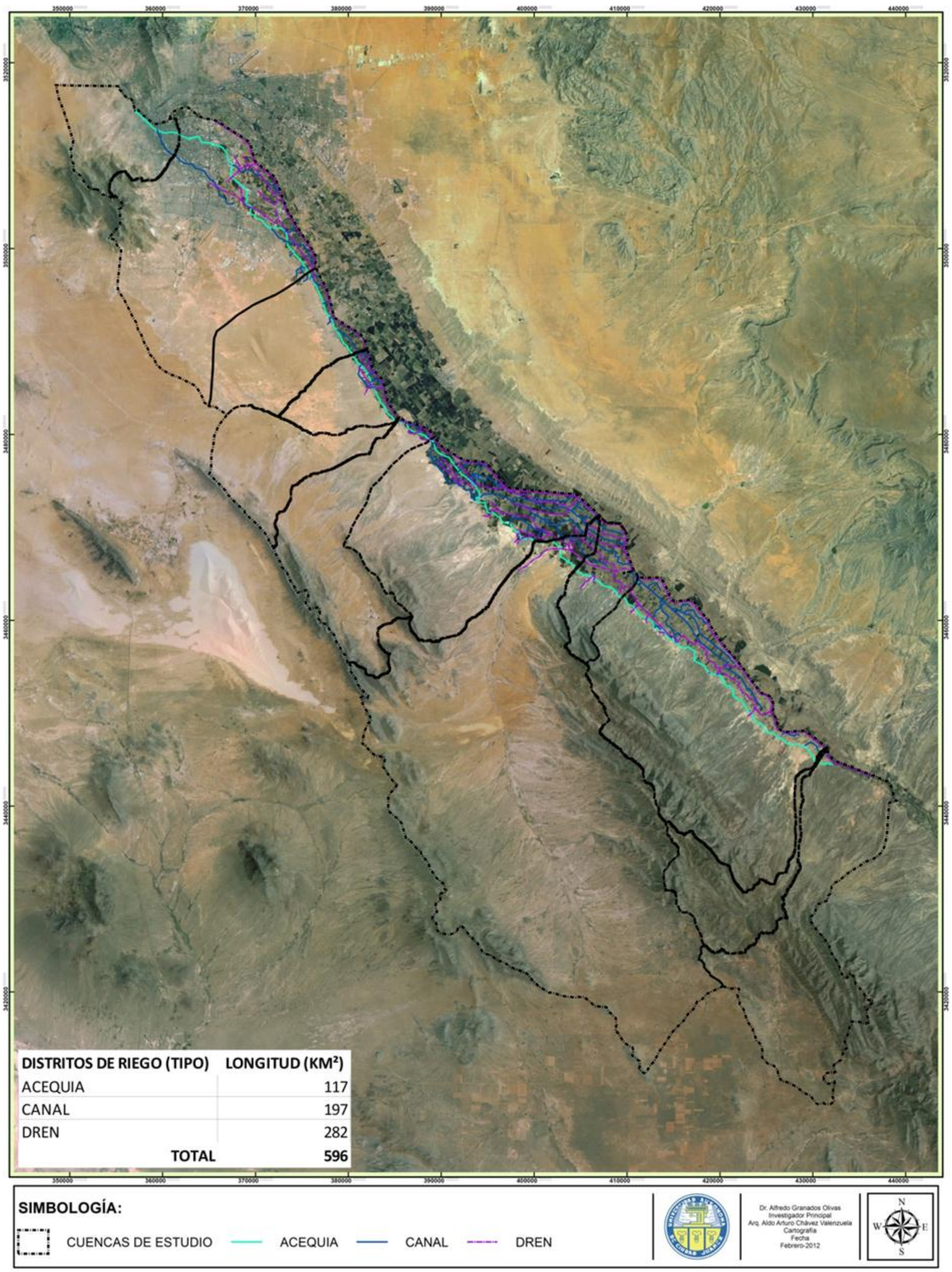
Appendices


DISTRITOS DE RIEGO (TIPO) LONGITUD (KM²)
ACEQUIA 117
CANAL 197
DREN 282
TOTAL 596
SIMBOLOGÍA:
CUENCAS DE ESTUDIO
ACEQUIA
CANAL
DREN
Dr. Alfredo Granados Olivas
Investigador Principal
Arq. Aldo Arturo Chávez Valenzuela
Cartografía
Fecha
Febrero-2012
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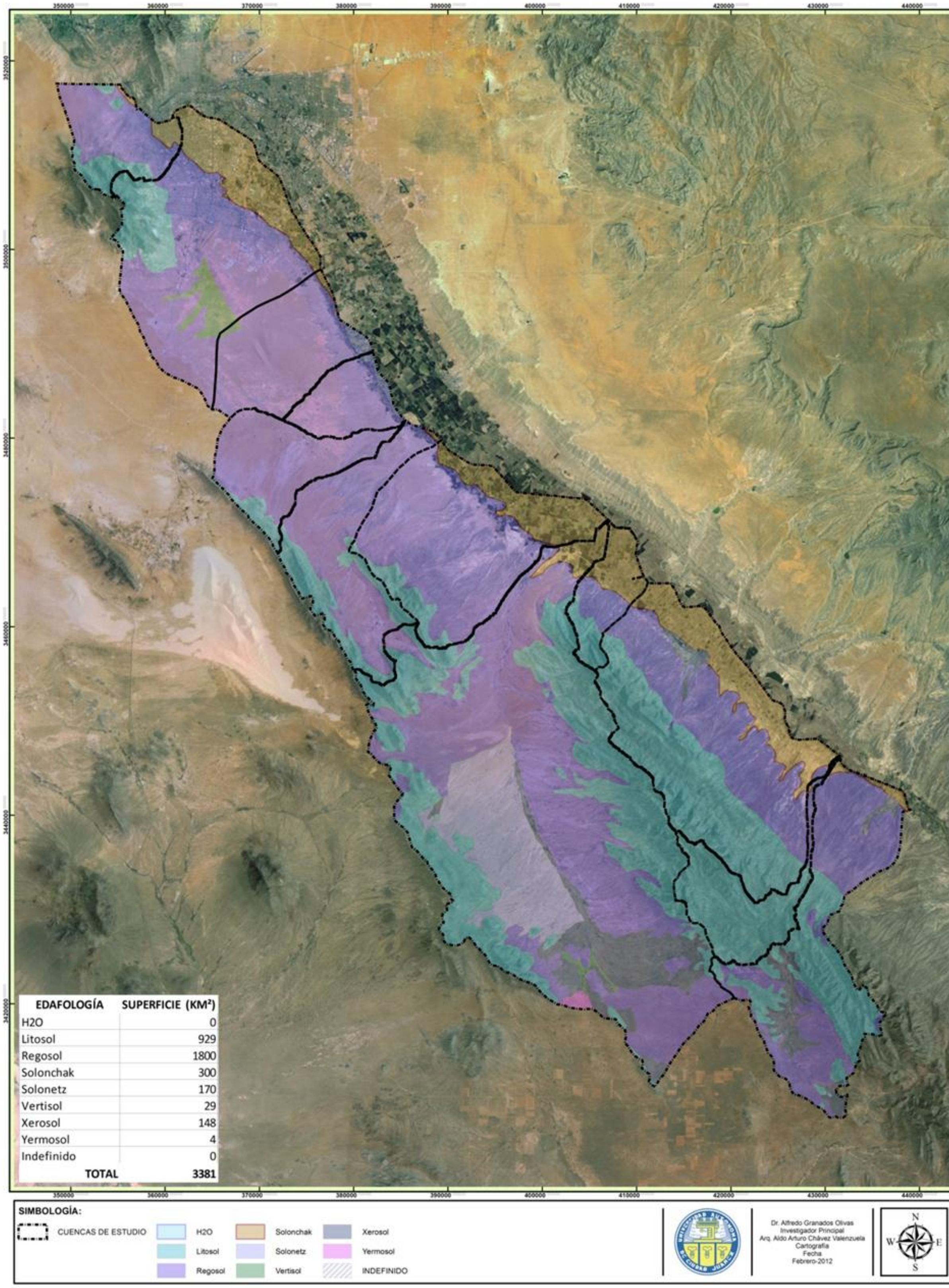
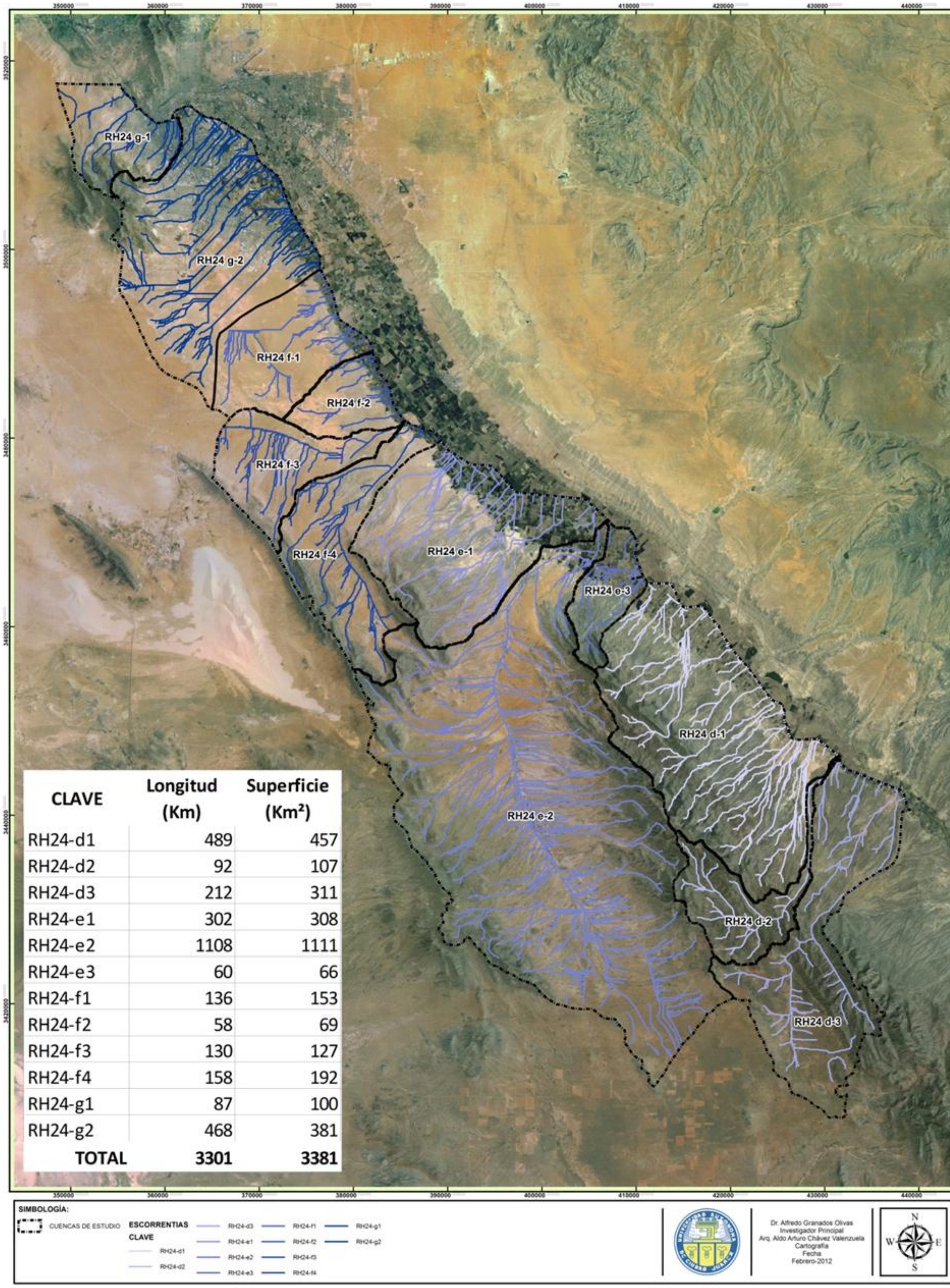
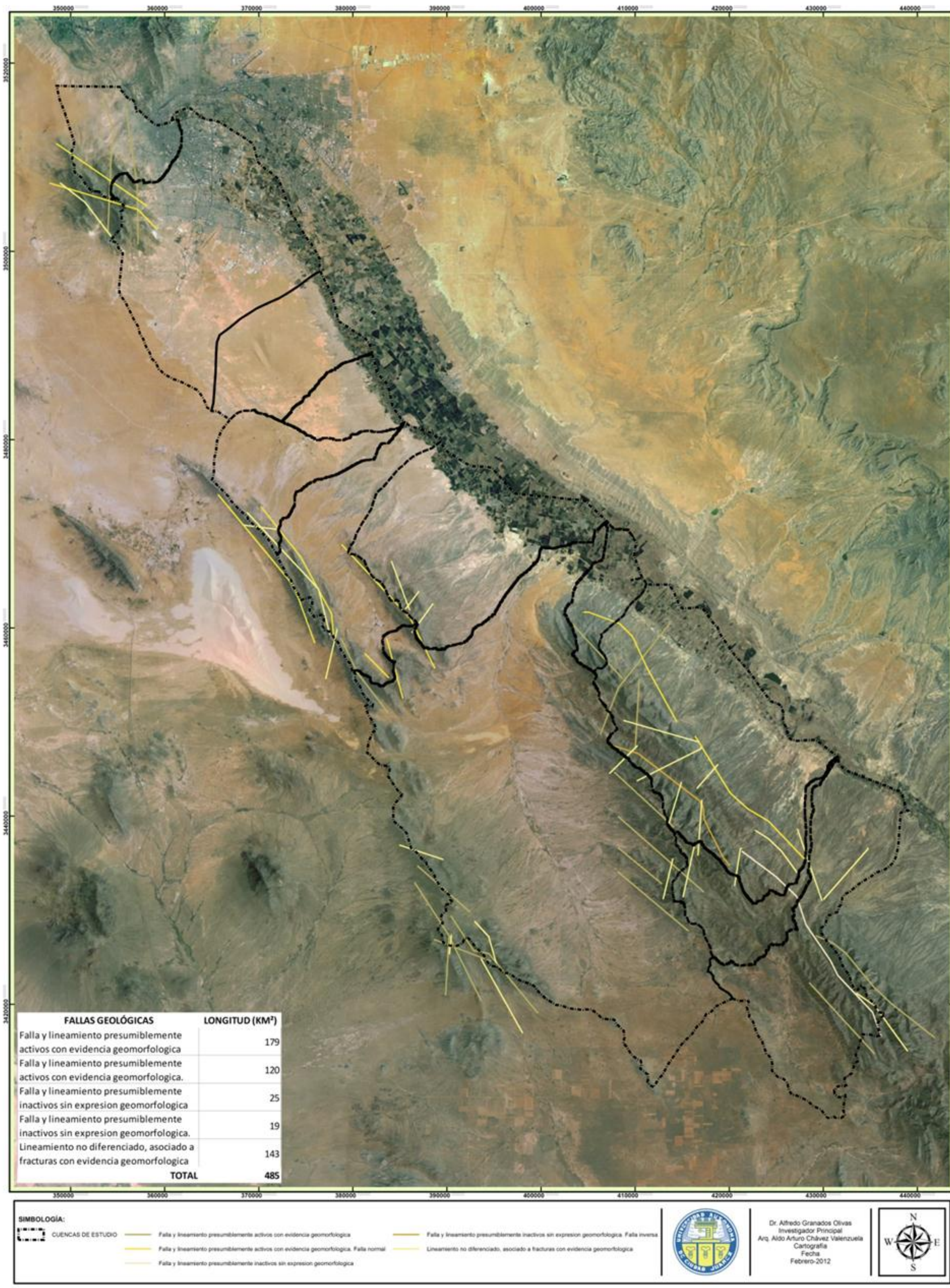


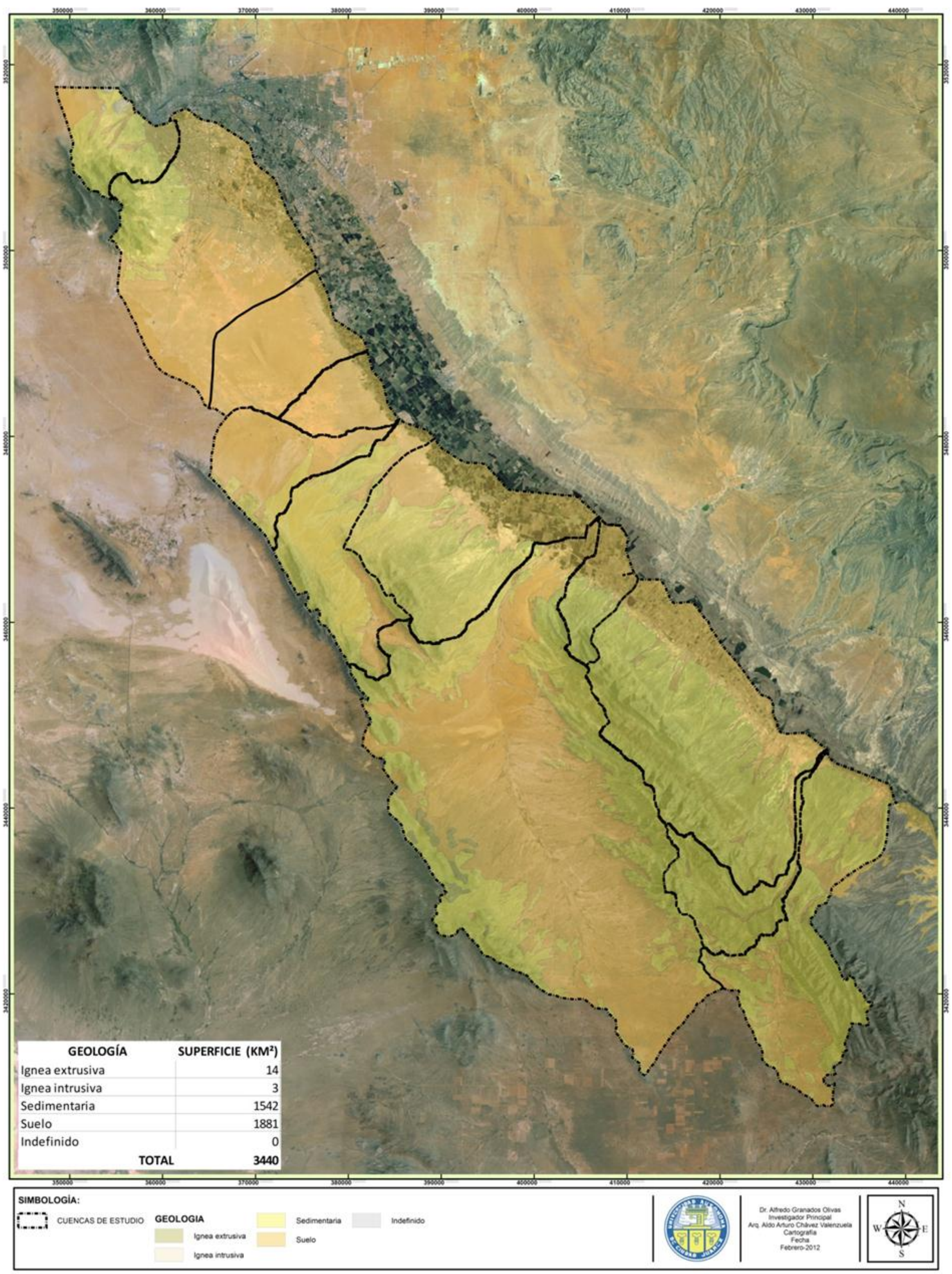
EDAFOLOGÍA	SUPERFICIE (KM²)
H2O	0
Litosol	929
Regosol	1800
Solonchak	300
Solonetz	170
Vertisol	29
Xerosol	148
Yermosol	4
Indefinido	0
TOTAL	3381



CLAVE	Longitud (Km)	Superficie (Km²)
RH24-d1	489	457
RH24-d2	92	107
RH24-d3	212	311
RH24-e1	302	308
RH24-e2	1108	1111
RH24-e3	60	66
RH24-f1	136	153
RH24-f2	58	69
RH24-f3	130	127
RH24-f4	158	192
RH24-g1	87	100
RH24-g2	468	381
TOTAL	**3301**	**3381**



FALLAS GEOLÓGICAS	LONGITUD (KM^2)
Falla y lineamiento presumiblemente activos con evidencia geomorfologica	179
Falla y lineamiento presumiblemente activos con evidencia geomorfologica.	120
Falla y lineamiento presumiblemente inactivos sin expresion geomorfologica	25
Falla y lineamiento presumiblemente inactivos sin expresion geomorfologica.	19
Lineamiento no diferenciado, asociado a fracturas con evidencia geomorfologica	143
TOTAL	485


GEOLOGÍA | SUPERFICIE (KM²)
Ignea extrusiva 14
Ignea intrusiva 3
Sedimentaria 1542
Suelo 1881
Indefinido 0
TOTAL 3440
SIMBOLOGÍA:
CUENCAS DE ESTUDIO
GEOLOGIA
Ignea extrusiva
Ignea intrusiva
Sedimentaria
Suelo
Indefinido
Dr. Alfredo Granados Olivas
Investigador Principal
Arq. Aldo Arturo Chávez Valenzuela
Cartografía
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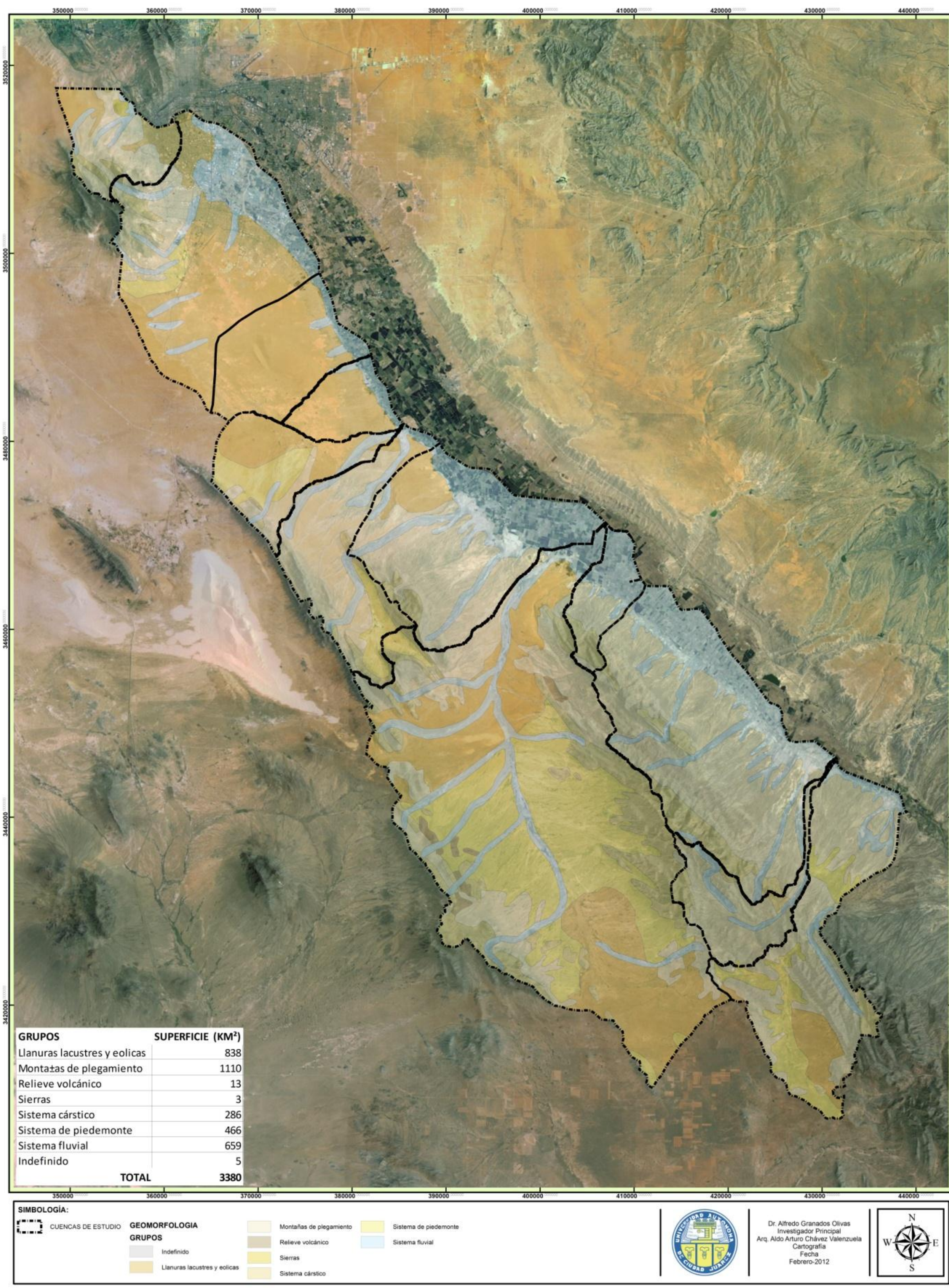
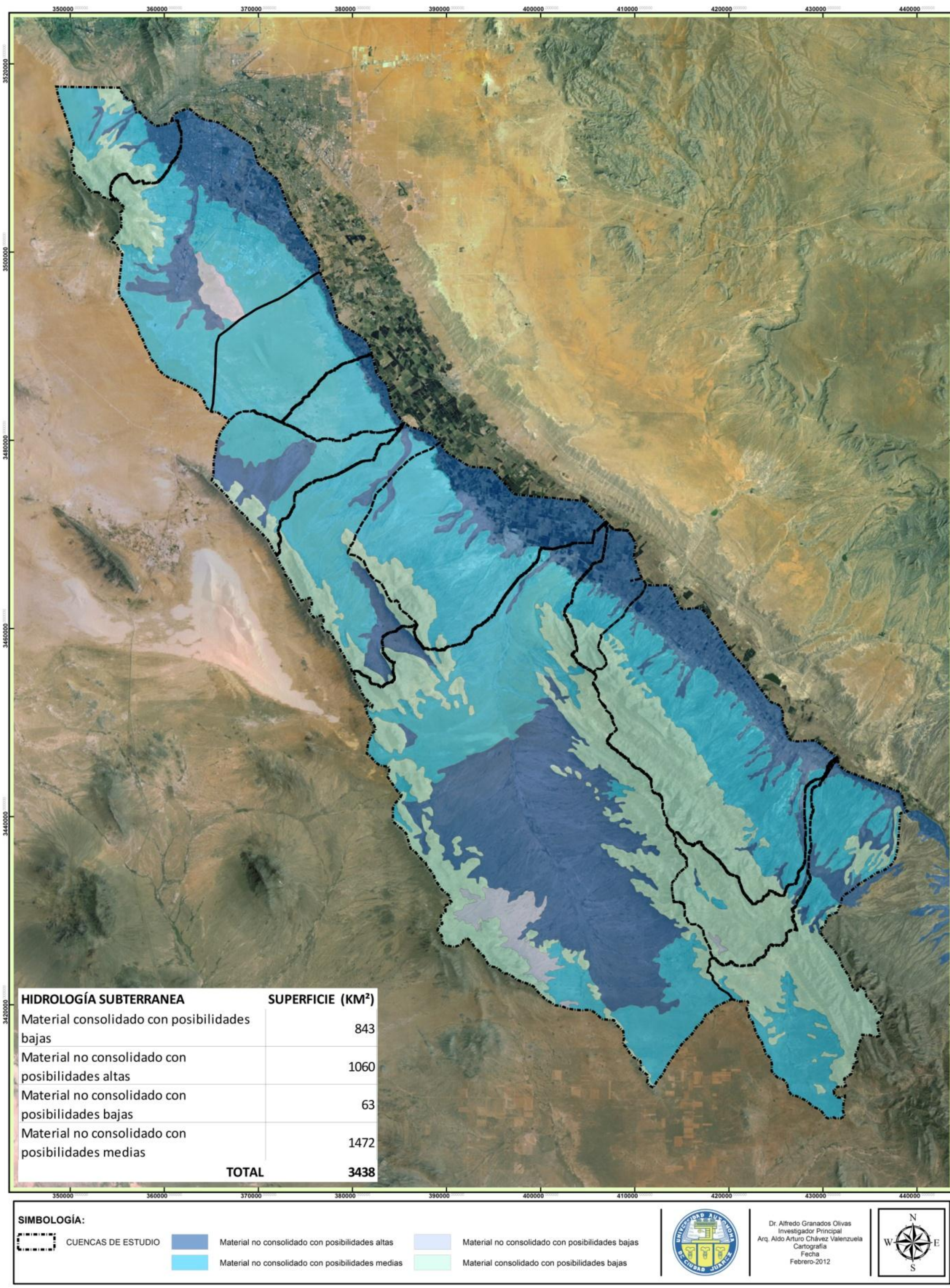
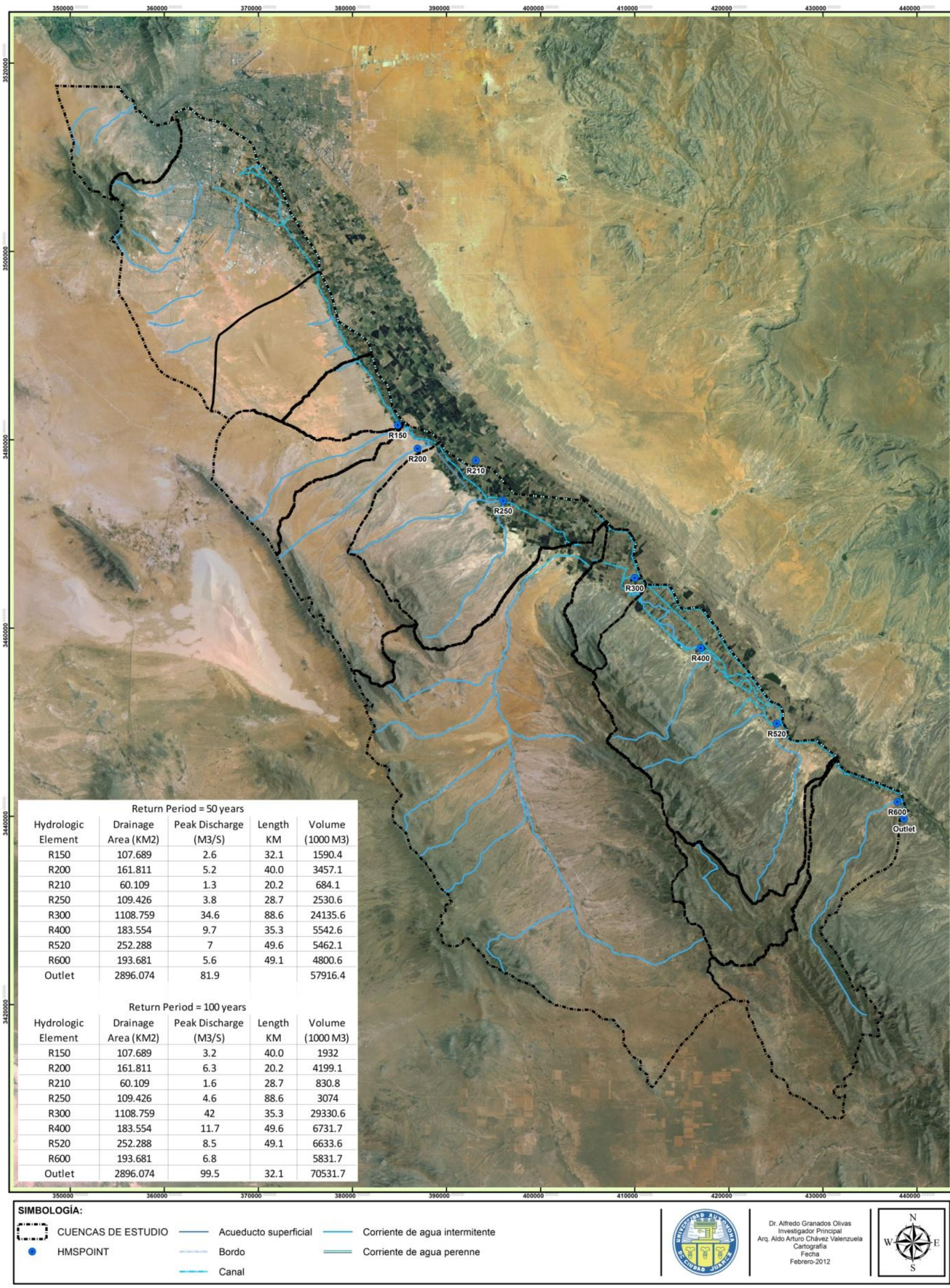


GRUPOS	SUPERFICIE (KM²)
Llanuras lacustres y eolicas	838
Monta±as de plegamiento	1110
Relieve volcánico	13
Sierras	3
Sistema cárstico	286
Sistema de piedemonte	466
Sistema fluvial	659
Indefinido	5
TOTAL	3380



HIDROLOGÍA SUBTERRANEA	SUPERFICIE (KM²)
Material consolidado con posibilidades bajas	843
Material no consolidado con posibilidades altas	1060
Material no consolidado con posibilidades bajas	63
Material no consolidado con posibilidades medias	1472
TOTAL	**3438**



Return Period = 50 years

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Length KM	Volume (1000 M3)
R150	107.689	2.6	32.1	1590.4
R200	161.811	5.2	40.0	3457.1
R210	60.109	1.3	20.2	684.1
R250	109.426	3.8	28.7	2530.6
R300	1108.759	34.6	88.6	24135.6
R400	183.554	9.7	35.3	5542.6
R520	252.288	7	49.6	5462.1
R600	193.681	5.6	49.1	4800.6
Outlet	2896.074	81.9		57916.4

Return Period = 100 years

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Length KM	Volume (1000 M3)
R150	107.689	3.2	40.0	1932
R200	161.811	6.3	20.2	4199.1
R210	60.109	1.6	28.7	830.8
R250	109.426	4.6	88.6	3074
R300	1108.759	42	35.3	29330.6
R400	183.554	11.7	49.6	6731.7
R520	252.288	8.5	49.1	6633.6
R600	193.681	6.8		5831.7
Outlet	2896.074	99.5	32.1	70531.7


Localidades 165
SIMBOLOGÍA:
CUENCAS DE ESTUDIO
LOCALIDADES
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Cartografía
Fecha
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SIMBOLOGÍA:
CUENCAS DE ESTUDIO
POZOS
Pozo
Noria
Manantial
Indefinido
Dr. Alfredo Granados Olivas
Investigador Principal
Arq. Aldo Arturo Chávez Valenzuela
Cartografía
Fecha
Febrero-2012
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NE 87.0
NE 7.5
NE 7.0
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NE 8.0
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N
S
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W


SIMBOLOGÍA:
CUENCAS DE ESTUDIO
TOPOGRAFIA
ELEVACIÓN
1100 - 1350
1351 - 1500
1501 - 1650
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Dr. Alfredo Granados Olivas
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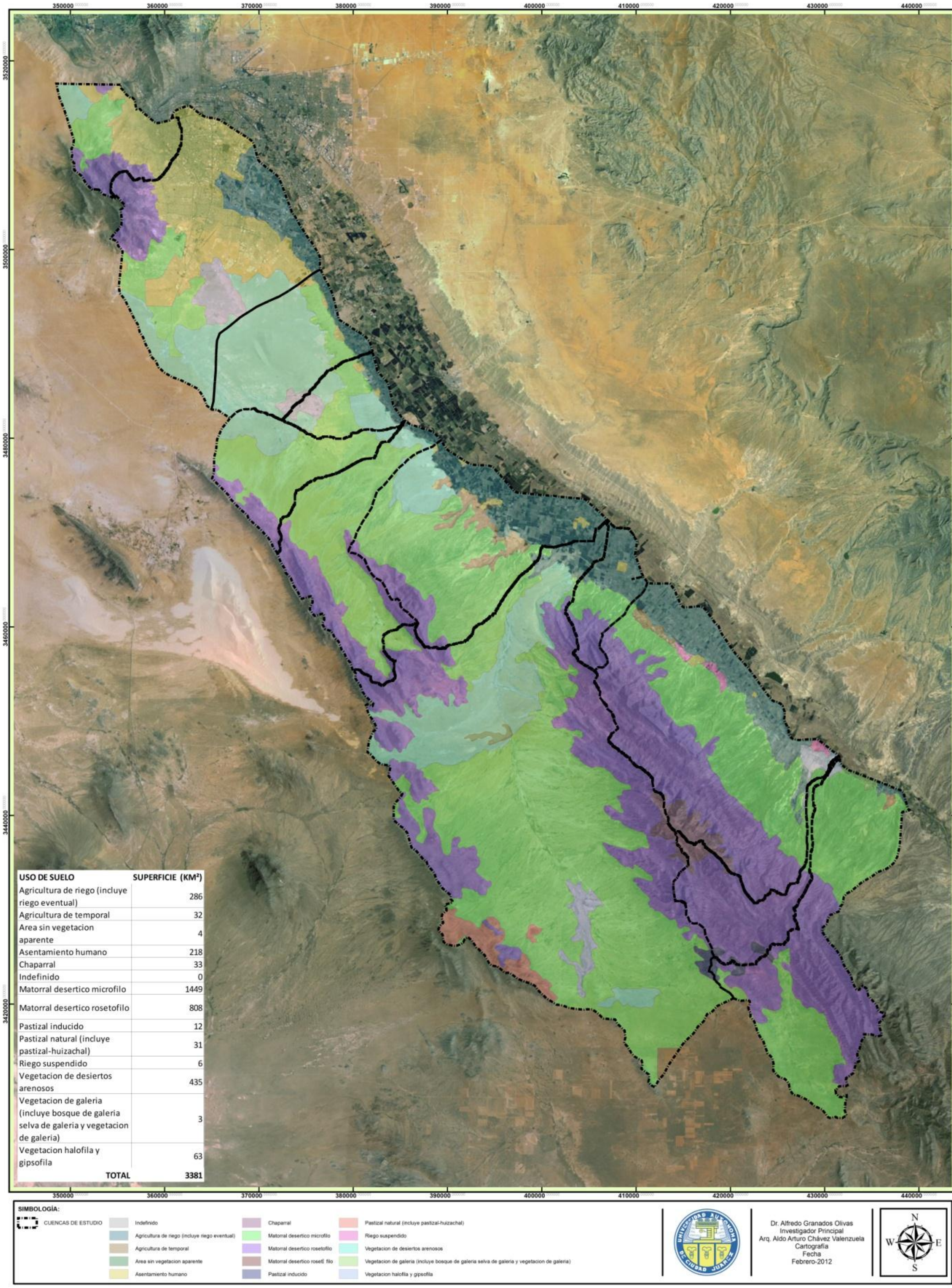
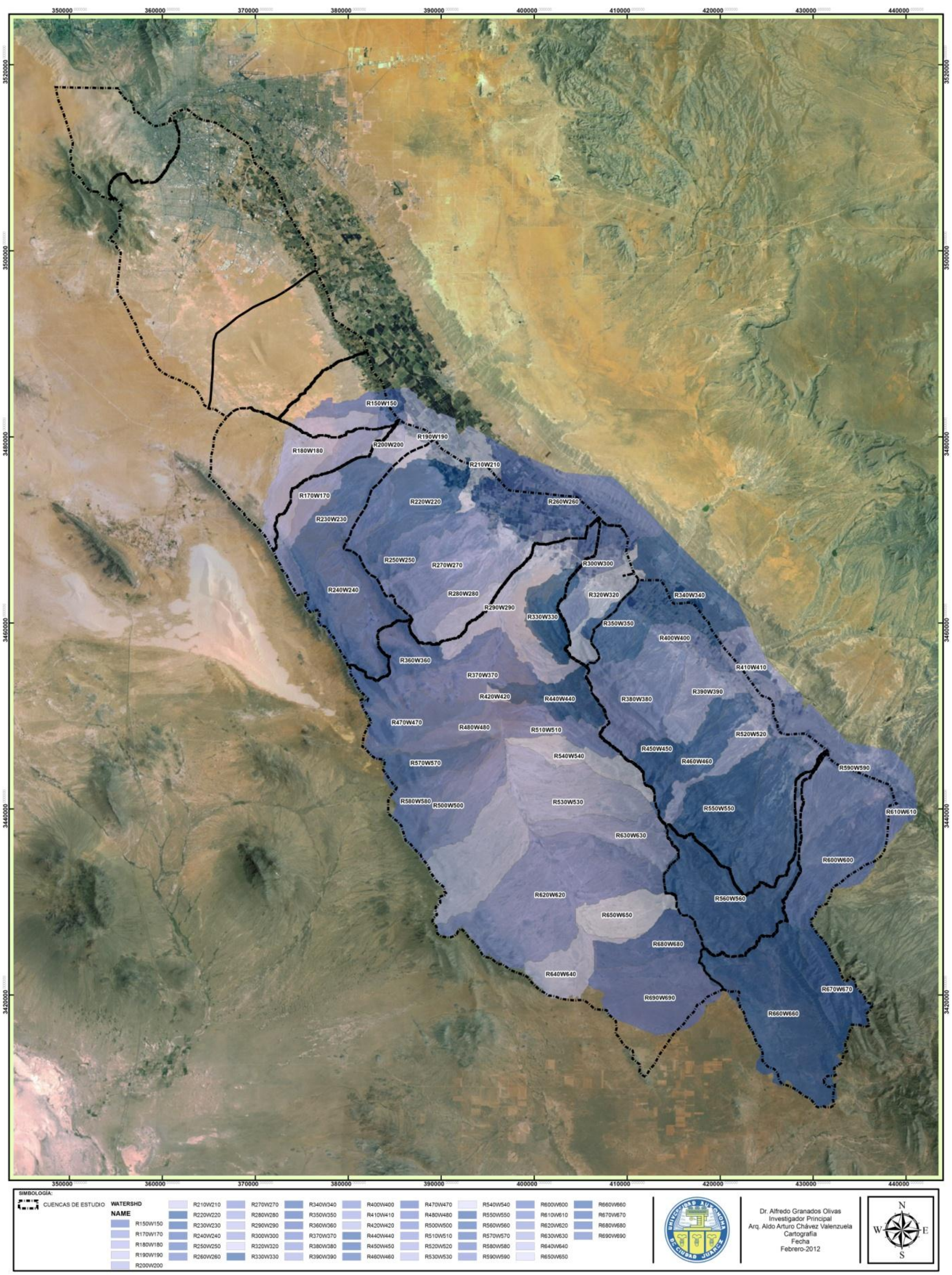


USO DE SUELO	SUPERFICIE (KM²)
Agricultura de riego (incluye riego eventual)	286
Agricultura de temporal	32
Area sin vegetacion aparente	4
Asentamiento humano	218
Chaparral	33
Indefinido	0
Matorral desertico microfilo	1449
Matorral desertico rosetofilo	808
Pastizal inducido	12
Pastizal natural (incluye pastizal-huizachal)	31
Riego suspendido	6
Vegetacion de desiertos arenosos	435
Vegetacion de galeria (incluye bosque de galeria selva de galeria y vegetacion de galeria)	3
Vegetacion halofila y gipsofila	63
TOTAL	3381


SIMBOLOGÍA:
CUENCAS DE ESTUDIO
WATERSHD
NAME
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R170W170
R180W180
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R200W200
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R220W220
R230W230
R240W240
R250W250
R260W260
R270W270
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R290W290
R300W300
R320W320
R330W330
R340W340
R350W350
R360W360
R370W370
R380W380
R390W390
R400W400
R410W410
R420W420
R440W440
R450W450
R460W460
R470W470
R480W480
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List of Data Sets for Numerical Models

Three sets of modeling data were submitted with this report. They cover Rincon Valley- Mesilla Basin RiverWare model, El Paso – Juarez Valley RiverWare model, and Hydrological model (HEC-HMS) for the Juarez Valley Irrigation District 009.

Rincon Valley – Mesilla Basin RiverWare Model

RiverWare model: Rincon Model-v1.gz; Mesilla Model-v1.gz

El Paso – Juarez Valley RiverWare Model

Conceptual model layout: Conceptual model diagram-ElPaso-Juarez.pub and Conceptual model diagram-ElPaso-Juarez.jpg

RiverWare model: ElPaso-Juarez-Model-v1.gz

Rule set: ElPaso-Juarez-Model-Ruleset.rls

Hydrological model (HEC-HMS) for the Juarez Valley Irrigation District 009

HEC-HMS model: (1) Hidrology Valle.zip; (2) tr5,10,25,50.zip; (3) tr100 uniones.zip

All the GIS coverages have been incorporated and will be enhanced in Coordinated Water Resources Database and GIS website of the Paso del Norte Watershed Council (http://www.pdnwc.org).