CRWR Online Report 06-12

WEAP Hydrology Model Applied: The Rio Conchos Basin

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December 2006

CENTER FOR RESEARCH IN WATER RESOURCES

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1 Introduction

1.1 Background

The Rio Grande headwaters in Colorado and flows south through New Mexico to Paso del Norte, the point where New Mexico, Texas and the Mexican state of Chihuahua meet. Paso del Norte is an exceptionally large bi-national metropolitan area with three large and rapidly growing cities: Las Cruces, New Mexico, El Paso, Texas and Ciudad Juarez, Chihuahua. Flowing southeast from Paso del Norte the Rio Grande, known as the Rio Bravo in Mexico, forms the Texas-Mexico border all the way to the Gulf of Mexico. In both the United States and Mexico the Rio Grande/Rio Bravo region is experiencing population growth well above the national average of the respective nations. Due the population growth, this primarily desert river basin is further stressed by an increasing agricultural demand. These factors culminate to make the basin one of the most water stressed basins in the world, with less than 500 cubic meters of water available per capita per year.

The bi-national aspect and water stressed status of the basin make it the subject of many studies, each with the goal of improving resource management and sustainable solutions to meet the increasing water supply demands. The Center for Research in Water Resources (CRWR) is a member of the RioGrande/Bravo Physical Assessment Project consortium of U.S. and Mexican universities, governmental and non-governmental agencies. The consortium is working to create a basin wide hydrologic planning model to provide improvement in water resource management.

The Water Evaluation and Planning (WEAP) system developed by the Stockholm Environmental Institute is a powerful modeling tool. WEAP is river basin simulation software which includes opportunities for scenarios evaluation as well as water balance and allocation calculations. A WEAP model for the Rio Bravo basin has recently been developed (Danner et al., 2006). The missing component is the hydrologic element of the model that allows for predictions of water flows and availability from precipitation sequences.

The objective of this project is to develop a hydrologic model of the Rio Conchos basin using WEAP with the ultimate goal of determining the feasibility and practicality of a WEAP hydrologic model for the entire Rio Bravo basin. The confluence of the Rio Conchos and Rio Bravo is near Ojinaga, Chihuahua and Presidio, Texas and is significant because the Rio Conchos provides approximately two thirds of the total annual water volume to the lower Rio Bravo. The Rio Conchos basin is primarily located in the Mexican state of Chihuahua with the southern edge spilling into Durango. Figure 1 depicts the Rio Conchos basin in beige and the remainder of the Rio Bravo basin in grey.

Figure 1. Rio Bravo Basin

1.2 Objective

As stated above, the objective of this project is to explore the hydrologic capabilities of WEAP through the development of a Rio Conchos basin model with the intent of evaluating the practicality of incorporating a WEAP hydrology model for the entire Rio Bravo basin into the Physical Assessment Project.

In creating the hydrologic model, data from several sources was compiled and pre-processed for use by WEAP. The WEAP model structure, data sources and parameter input techniques employed are discussed in Section 2 of this report. The most significant sources include:

- Mexican Institute of Water Technology (IMTA) (Martinez et al., 2005)
- Soil Water Assessment Tool (World Bank, 2006)

The hydrologic capabilities of WEAP are evaluated by comparing the flows simulated by WEAP with the flows simulated by the HEC-HMS model prepared by IMTA (Martinez et al., 2005). Flow results for six locations within the Rio Conchos basin are compared in Section 4.

The practical utilization of WEAP as a large, basin scale hydrologic model to assist in water resources planning and management will be evaluated by comparing the general performance of the WEAP model with HEC-HMS model.

2 WEAP Model Preparation

2.1 Model Structure

WEAP supports the use of three hydrologic modeling methods: the Rainfall Runoff Method FAO (Food and Agriculture Organization of the United Nations), the Irrigation Demands Only of the FAO, and the Rainfall Runoff Soil Moisture Method. The goal of this project is to create a hydrologic model that can be calibrated in the future, therefore the Rainfall Runoff Soil Moisture Method was chosen because it offers the most comprehensive analysis by allowing for the characterization of land use and/or soil type impacts to hydrological processes (Sieber, 2005).

The Rainfall Runoff Soil Moisture Method, or Soil Moisture Method, is a one-dimensional, two soil layer algorithm for calculating evapotranspiration, surface runoff, sub-surface runoff and deep percolation for a defined land area unit. A conceptual diagram of the equations incorporated into the Soil Moisture Method water balance calculations are shown in Figure 2.

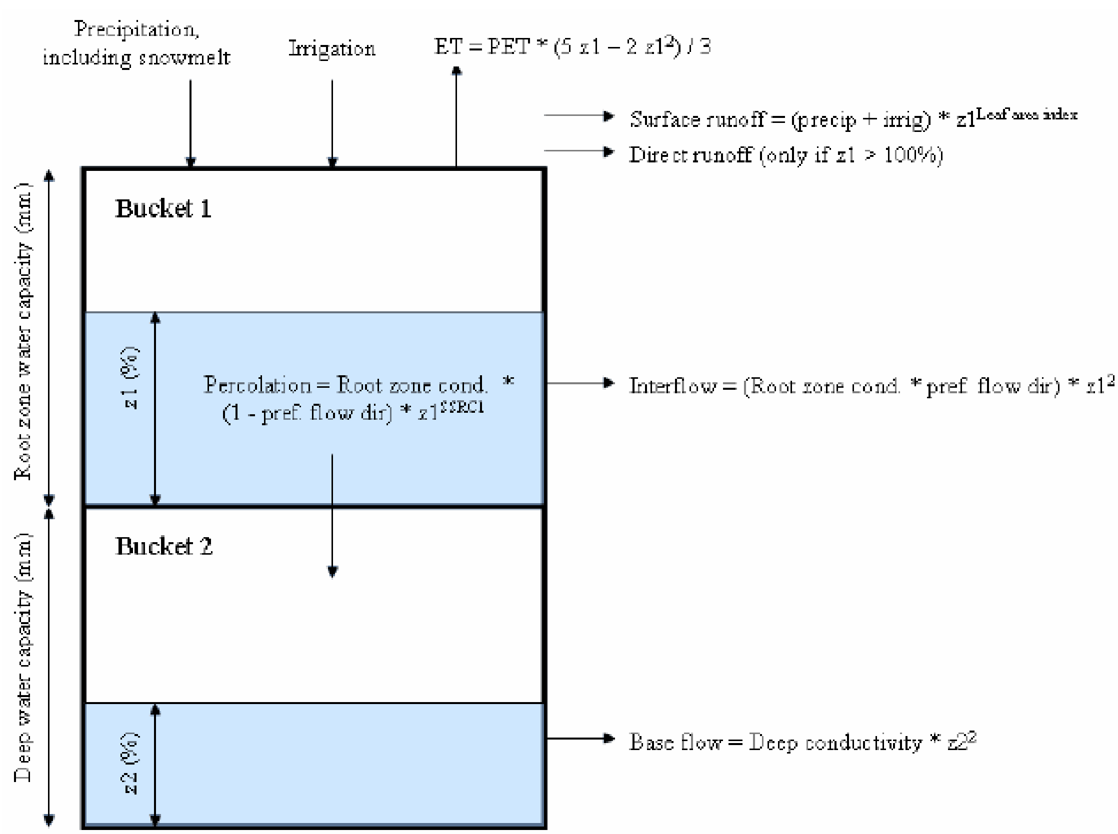


Figure 2. Soil Moisture Method Model (Source: Sieber, 2005)

Using the Soil Moisture Method to more accurately describe the hydrologic response of the basin has the implication that more detailed hydrologic and climatic parameters are required for the model. Consequently, the parameters and data are often difficult to define with certainty. The basic input parameters are listed in Table 1 along with the sensitivities identified for each parameter which are a result of the work of Jantzen et al. (2006). WEAP imposes a model structure in terms input parameter resolution, meaning WEAP forces certain parameters to describe the entire catchment and others to describe smaller land unit areas such as the soil classification or land use category. In the remainder of Section 2 each parameter along with the respective data source and implication of WEAP's model structure is discussed in greater detail.

Table 1. Input Parameters and Sensitivity

Parameter	Units	Resolution	Sensitivity
Land Use			
Area	sq km	Catchment	High
Deep Water Capacity	mm	Catchment	High
Deep Conductivity	mm/day	Catchment	Moderate
Initial Z2	no unit	Catchment	No Influence
Soil Water Capacity	mm	Soil	Moderate
Root Zone Conductivity	mm/day	Soil	Moderate
Prefered Flow Direction	no unit	Soil	Moderate
Initial Z1	no unit	Soil	No Influence
Crop Coefficient, Kc	no unit	Land Use	High
Leaf Area Index	no unit	Land Use	High
Climate			
Precipitation	mm/day	Catchment	High
Temperature	C	Catchment	Moderate
Wind	m/s	Catchment	Low
Humidity	%	Catchment	Low
Melting Point	C	Catchment	Not evaluated
Freezing Point	C	Catchment	Not evaluated
Latitude	degree	Catchment	Not evaluated
Initial Snow	mm	Catchment	Not evaluated

2.2 Catchment Area

A fundamental parameter of any hydrologic model is the catchment area. The Bi-National Rio Grande/Bravo Geodatabase contains delineated sub-basins for all of the Rio Bravo basins including the Rio Conchos (Patiño-Gomez and McKinney, 2005). Thirty-eight sub-basins were delineated for the Rio Conchos; these are illustrated in Figure 3.

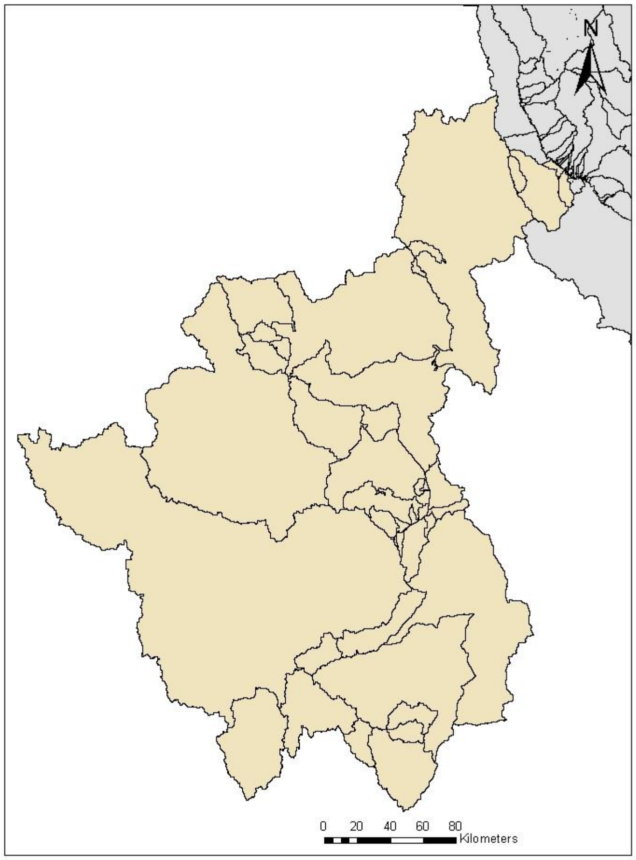


Figure 3. Bi-National Rio Grande/Bravo Geodatabase Rio Conchos Sub-basins

Using different control points 20 sub-basins were delineated by IMTA for use in their HEC-HMS model (Martinez, 2005). One of the tasks of this project is to compare the WEAP model results to the results of IMTA's HEC-HMS model; hence, it is desirable to use the IMTA sub-basin configuration. Sub-basin areas shown in the IMTA report, however, do not appear to be delineated consistently with the divides of the river systems observed in the hydro-edge shapefile. Figure 4 shows the Rio Conchos sub-basins as they appear in the IMTA report. Using the WRAPHydro process (Patiño-Gomez and McKinney, 2005) the sub-basin areas of the Rio Conchos basin were re-delineated using IMTA's basin outlet control points, yielding the results shown in Figure 5. Significant differences occur only between the La Boquilla (sub-basin 19) and Llanitos (12) sub-basins, highlighted by the red boxes. Table 2 summarizes the area for each of the twenty sub-basins as determined by IMTA and the CRWR.

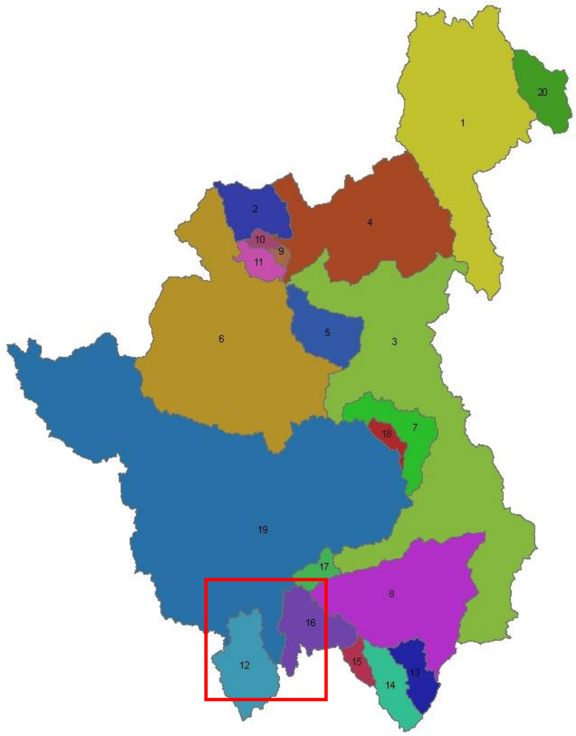


Figure 4. IMTA (Martinez, 2005) Rio Conchos Sub-basins

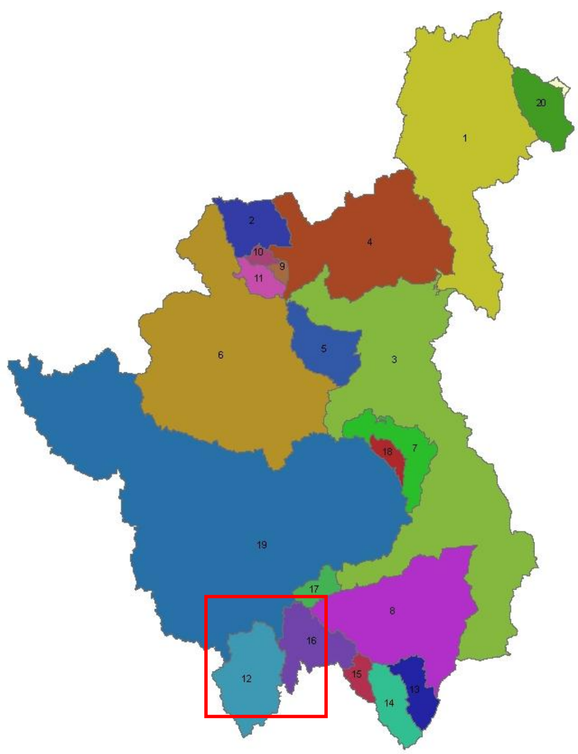


Figure 5. CRWR Rio Conchos Sub-basins

Table 2. Comparison of IMTA and CRWR Sub-basins

Basin Name	IMTA ID	IMTA Area sq km	CRWR Area sq km
Peguis	1	7544.99	7999.30
Sacramento	2	1067.03	1042.61
Las Burras	3	11090.21	11309.47
Luis L. Leon	4	5059.43	5085.51
FCO. Madero	5	1209.10	1211.35
Villalba	6	9327.44	9556.86
Conchos	7	1137.42	1114.39
Jimenez	8	4392.87	4422.96
Chuviscar	9	98.26	106.09
El Rejon	10	154.53	146.85
Chihuahua	11	401.77	399.99
Llanitos	12	1483.88	1829.93
Pico del Aguila	13	658.33	647.61
San Antonio	14	843.80	821.16
San Gabriel	15	267.95	305.85
Puente FFCC	16	1251.12	1270.66
Parral	17	347.95	363.79
Colina	18	244.97	259.06
La Boquilla	19	19054.13	18931.98
Ojinaga	20	1004.28	983.47
Conchos Basin Area		**66639.45**	**67808.88**

WEAP does not support a geo-referenced map within the program but will allow shapefiles to be imported as a background map for the WEAP schematic. The sub-basin shapefile shown in Figure 5 was imported into WEAP as a vector layer so that the WEAP sub-basins created could be placed in a manner that is visually consistent with the geography of the Rio Conchos basin. The actual placement of the catchments is arbitrary.

The WEAP schematic displays in GCS_WGS_1984 coordinates with a degree bound frame while the CRWR geodatabase is in GCS_North_American_1983 coordinates, NAD_1983_Albers projection (Patiño-Gomez and McKinney, 2005). The shapefile was reprojected from the CRWR geodatabase to the coordinate system used by WEAP. Figure 6 shows the CRWR sub-basins as they are displayed as a background map layer in WEAP with the catchments added.

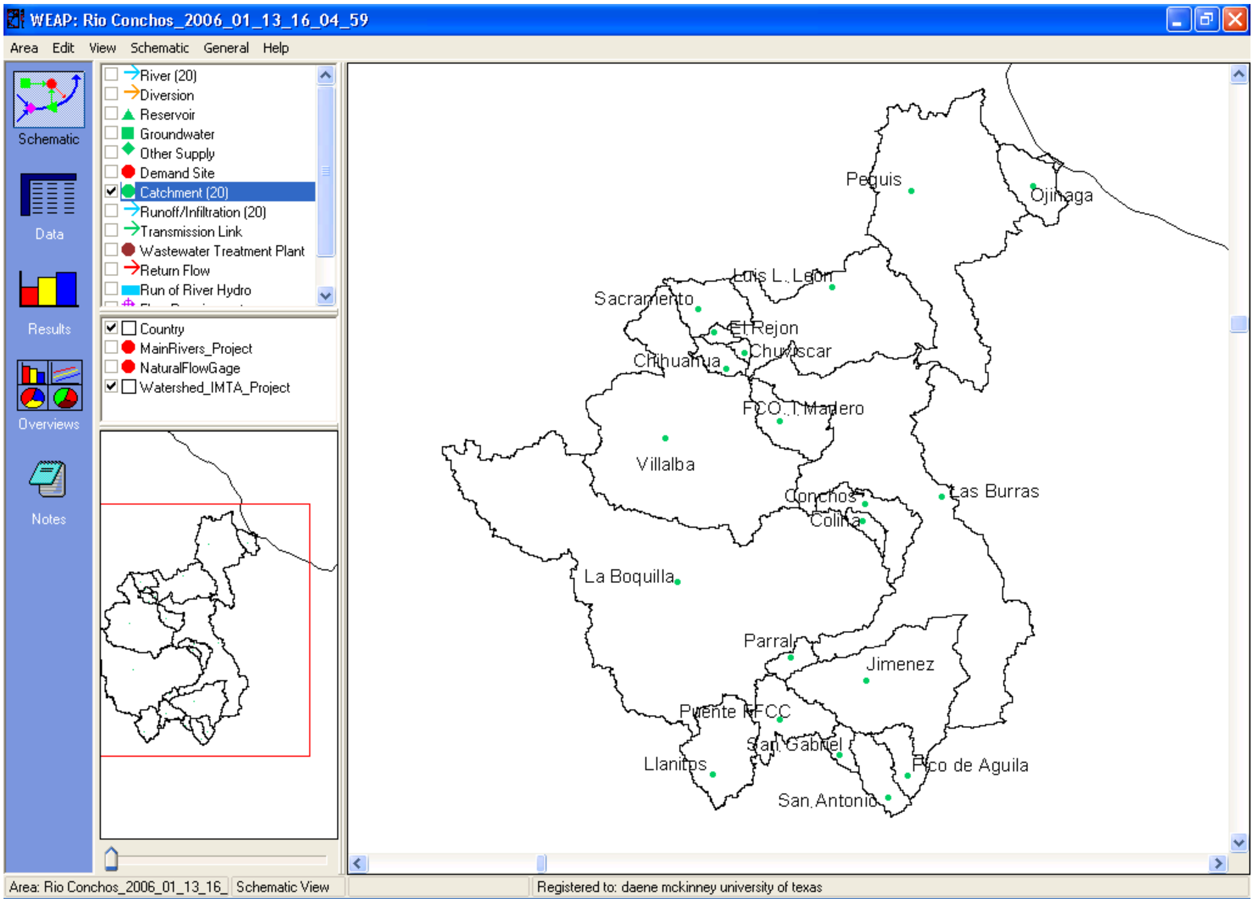


Figure 6. CRWR Rio Conchos Sub-basins Displayed in WEAP

2.3 Soil and Land Use Groups

The twenty sub-basins were sub-divided again by soil groups and land use categories. The land use and soil coverages employed by IMTA (Martinez 2005) are applied in the WEAP model rather than those available from the SWAT model (World Bank, 2006). Again, this relates to the task of evaluating the flows simulated by WEAP by comparing results with IMTA's HEC-HMS model.

Figure 7a and b compare the soil coverages from the SWAT and IMTA data sets, respectively. The SWAT soil classification and land use categories are per the Food and Agricultural Organization (FAO) guidelines. A future model version may find it helpful to work under an internationally referenced system like that provided by the FAO. No work was done to investigate and compare the accuracy or quality of the two datasets.

In receiving the soil coverage from IMTA an error occurred in that data for the Ojinaga sub-basin (No. 20) was omitted. For this reason soil areas were approximated from what overlapping data was received for the basin. Figure 7c shows the soil coverage that was received from IMTA in October of 2006.

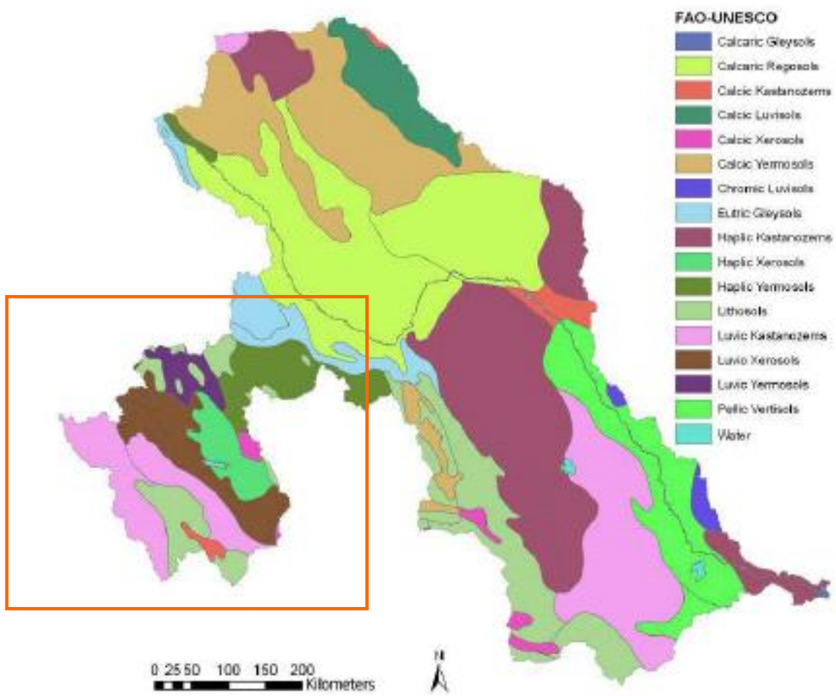


Figure 7a. SWAT Soil Coverage (World Bank 2006)

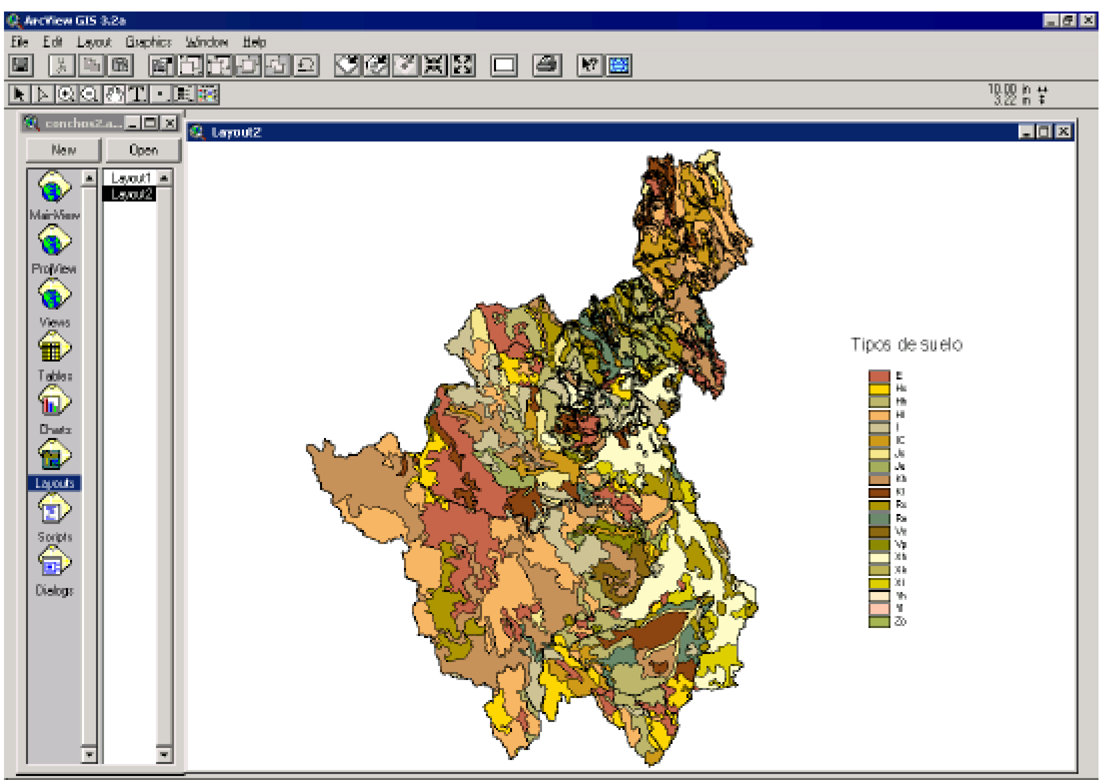


Figure 7b. IMTA Soil Coverage (Martinez, 2005)

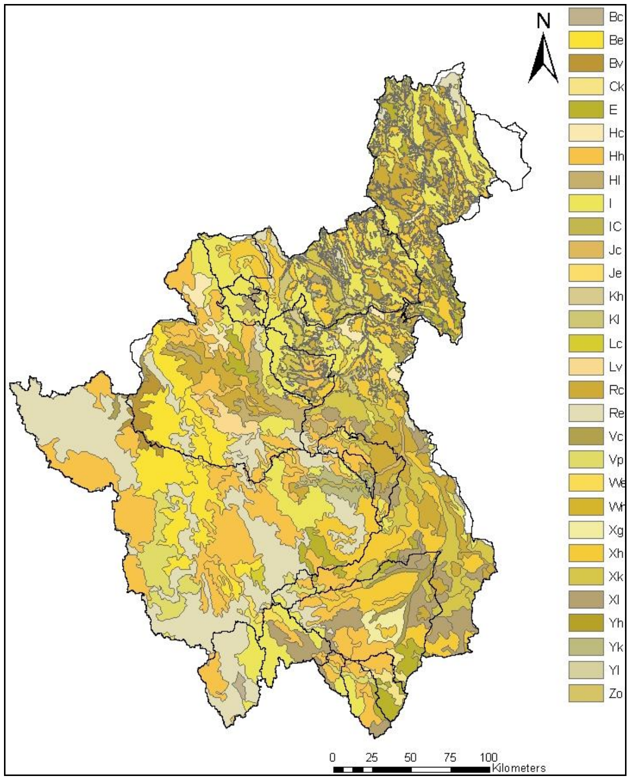


Figure 7c. IMTA Soil Coverage Applied to WEAP

Figure 7. Soil Coverage Datasets

To reduce the number of soil categories applied to each sub-basin, with the intent of thereby reducing computation time, four hydrologic soil group classification, e.g. A, B, C, or D, were used instead of the soil series classification. Normally this would decrease the resolution of parameter inputs such as hydraulic conductivity and soil capacities. However, most of the data applied in the WEAP model is extracted from IMTA's HEC-HMS report, which reports hydraulic parameters calibrated on a sub-basin scale rather than a soil group scale. For this reason the consolidation of soil areas will not affect the results of the model because the limitation is inherent with the resolution of the input parameter data.

Figure 8a and b compare the land use coverages from the SWAT and IMTA data sets, respectively. The IMTA shapefile data set was applied to the WEAP model to determine percentages of land use areas per basin. HEC-HMS however, does not utilize parameters such as crop coefficient and leaf area index which apply to land use categories and these are required in WEAP's Soil Moisture Method. These parameter values were taken from the SWAT dataset and from literature, respectively. The significant difference between the two land use coverages is the number of categories and type of categories defined. Table 3 defines the relationship between the categories as applied to the WEAP model. In cases where multiple SWAT land use categories are shown to correlate to one IMTA land use category, the multiple values from the SWAT data set were averaged and applied to the single IMTA category in WEAP. Values were estimated for categories with no correlation.

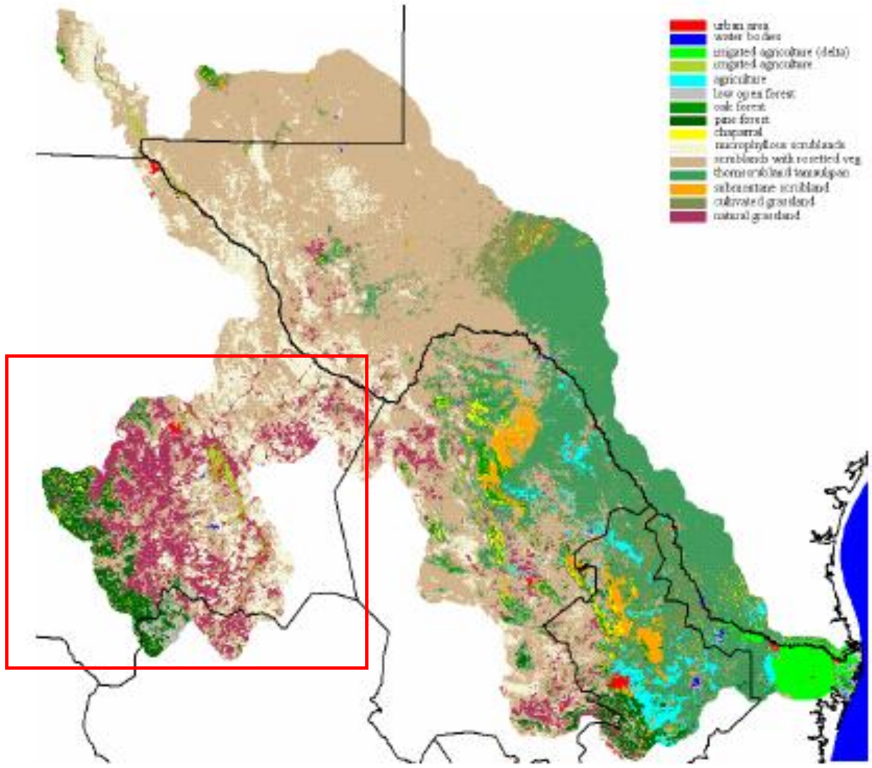


Figure 8a. SWAT Land Use Coverage (World Bank 2006)

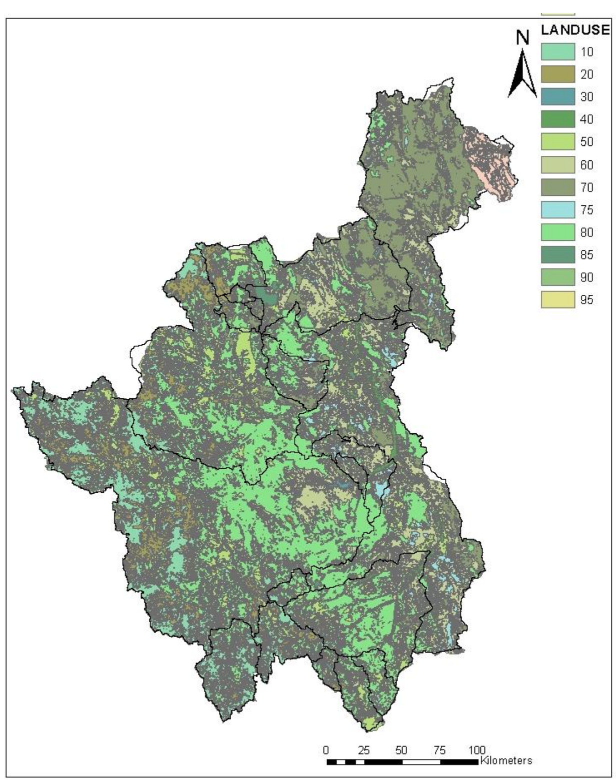


Figure 8b. IMTA Soil Coverage Applied to WEAP
Figure 8. Land Use Coverage Datasets

Table 3. SWAT-IMTA Land Use Category Relationship as Applied in WEAP

IMTA Land Use Code	IMTA Land Use Category	SWAT Land Use Category
85	Urban Areas	Urban Area
30	Water Bodies	Water Bodies
40	Irrigated Areas	Irrigated Agriculture (delta)
		Irrigated Agriculture (valley)
50	Naturally Irrigated Areas	Supplemental Irrigation
20	Forrest Grasses	Low Open Forrest
10	Forrest	Oak Forest
		Pine Forrest
70	High Grasses and Small Brush	Chaparral
75	Other Vegetation	Microphyllous Scrublands
		Scrubland with Rosetted Vegetation
		Thornscrubland Tamaulipan
		Submontane Scrubland
80	Grazing Pastures	Cultivated Grassland
60	Small Pasture Grasses	Natural Grassland
90	Wetland Vegetation	-
95	Without Apparent Vegetation	-

The area of intersection, or overlap, of each land use category and soil hydrologic group within each sub-basin was determined as a percentage of the total sub-basin area using Arc Toolbox. In Arc Toolbox the Analysis/Intersect tool was used to intersect the land use map shapefile and the soil map shapefile. Then the tool was used again to intersect the land use-soil group intersection with the sub-basin shapefile. This final shapefile intersect allowed the area of all of the land use-soil group categories to be determined as shown below in Table 4 for the Peguis sub-basin. Appendix 1. Soil Land Use Intersects by Sub-basin
contains a similar table for each of the twenty sub-basins.

Table 4. Peguis Sub-basin Soil- Land Use Intersect

Peguis Subbasin No. 1 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	10809	0.01	0.02
	20	0	0.00	0.00
	30	38164	0.04	0.05
	40	6380071	6.38	8.91
	50	6502437	6.50	9.08
	60	20395521	20.40	28.49
	70	27555676	27.56	38.49
	75	5846984	5.85	8.17
	80	2563815	2.56	3.58
	85	576152	0.58	0.80
	90	1721146	1.72	2.40
	95	0	0.00	0.00
Total Soil Area (sq km)			71.59	
% of Total Basin Area			0.93	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	28325	0.03	0.00
	20	1509	0.00	0.00
	30	210334	0.21	0.01
	40	718386	0.72	0.03
	50	5966293	5.97	0.28
	60	379643859	379.64	17.51
	70	1699345239	1699.35	78.36
	75	8675007	8.68	0.40
	80	63771996	63.77	2.94
	85	83173	0.08	0.00
	90	4760341	4.76	0.22
	95	5466388	5.47	0.25
Total Soil Area (sq km)			2168.67	
% of Total Basin Area			28.16	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	497	0.00	0.00
	20	30915	0.03	0.00
	30	61411	0.06	0.00
	40	1953737	1.95	0.06
	50	18742950	18.74	0.59
	60	1081764821	1081.76	33.82
	70	1677846763	1677.85	52.45
	75	117288454	117.29	3.67
	80	287986809	287.99	9.00
	85	935075	0.94	0.03
	90	3920024	3.92	0.12
	95	8285730	8.29	0.26
Total Soil Area (sq km)			3198.82	
% of Total Basin Area			41.53	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	784935	0.78	0.03
	20	0	0.00	0.00
	30	779358	0.78	0.03
	40	268422	0.27	0.01
	50	1145767	1.15	0.05
	60	196367414	196.37	8.68
	70	1896450935	1896.45	83.81
	75	43258657	43.26	1.91
	80	119299233	119.30	5.27
	85	152992	0.15	0.01
	90	348263	0.35	0.02
	95	3877069	3.88	0.17
Total Soil Area (sq km)			2262.73	
% of Total Basin Area			29.38	

2.4 River Reaches

River reaches cannot be input directly to WEAP from the geodatabase because the WEAP map serves only as a conceptual schematic. The most significant rivers were added to the WEAP schematic by first exporting and projecting the rivers from the CRWR geodatabase to the WEAP display coordinate system and then adding the projected shapefile to WEAP as a vector layer. The rivers were then drawn in WEAP by tracing over the vector layer. Figure 9a shows the main rivers in the Rio Conchos basin that were imported as a background vector layer and Figure 9b shows the selected river reach segments that were drawn in WEAP.

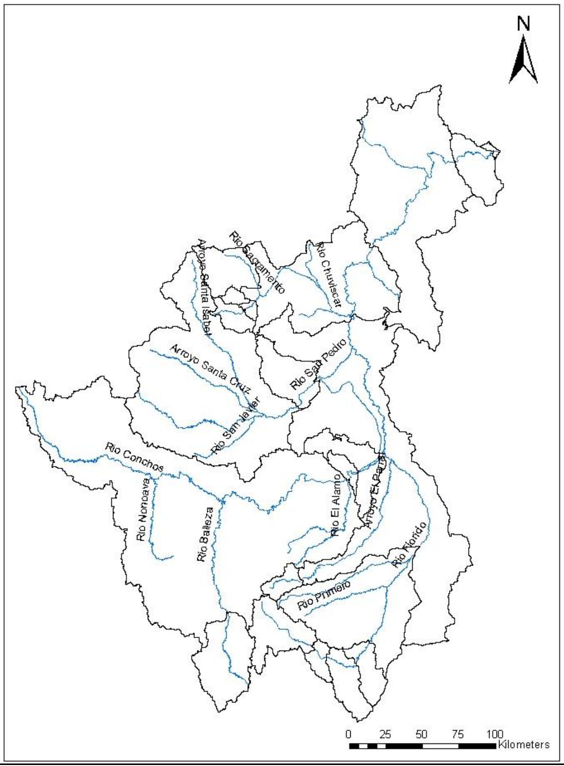


Figure 9a. Geodatabase Main Rivers

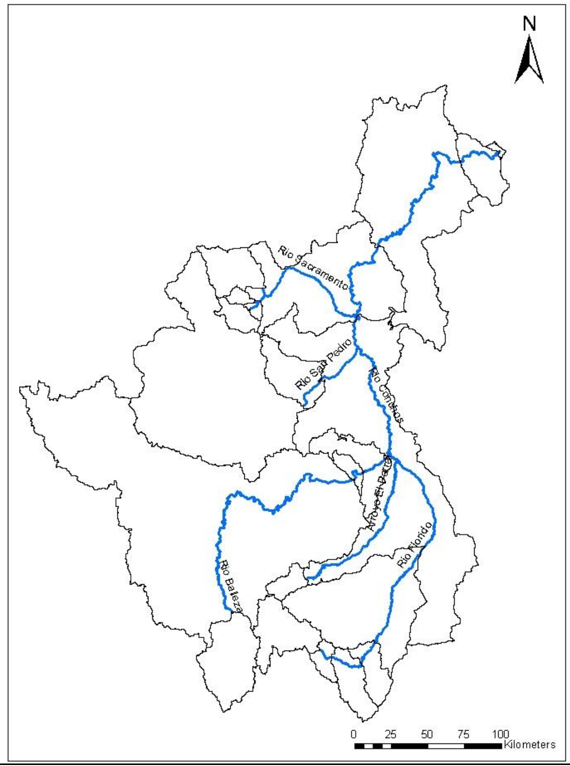


Figure 9b. WEAP River Reaches

Figure 9. Rio Conchos CRWR Bi-National Geodatabase Hydroedges

Figure 10 compares the river reaches from the CRWR geodatabase with those drawn in WEAP; the geodatabase reaches are shown in red and the WEAP reaches are in blue. Inaccuracies of the required tracing are evident by the red lines visible adjacent to the blue lines. The river reaches drawn in WEAP can be edited to more precise river reach lengths as measured from the CRWR geodatabase by right clicking on the river reach and selecting Edit Data and then Reach Length. WEAP uses reach length data when modeling the groundwater and surface water interactions. Groundwater was not modeled in this project so the reach lengths were not adjusted in this model. Although the reach length data was not used for this project, the values were determined and appear in Appendix 2 for use in future work.

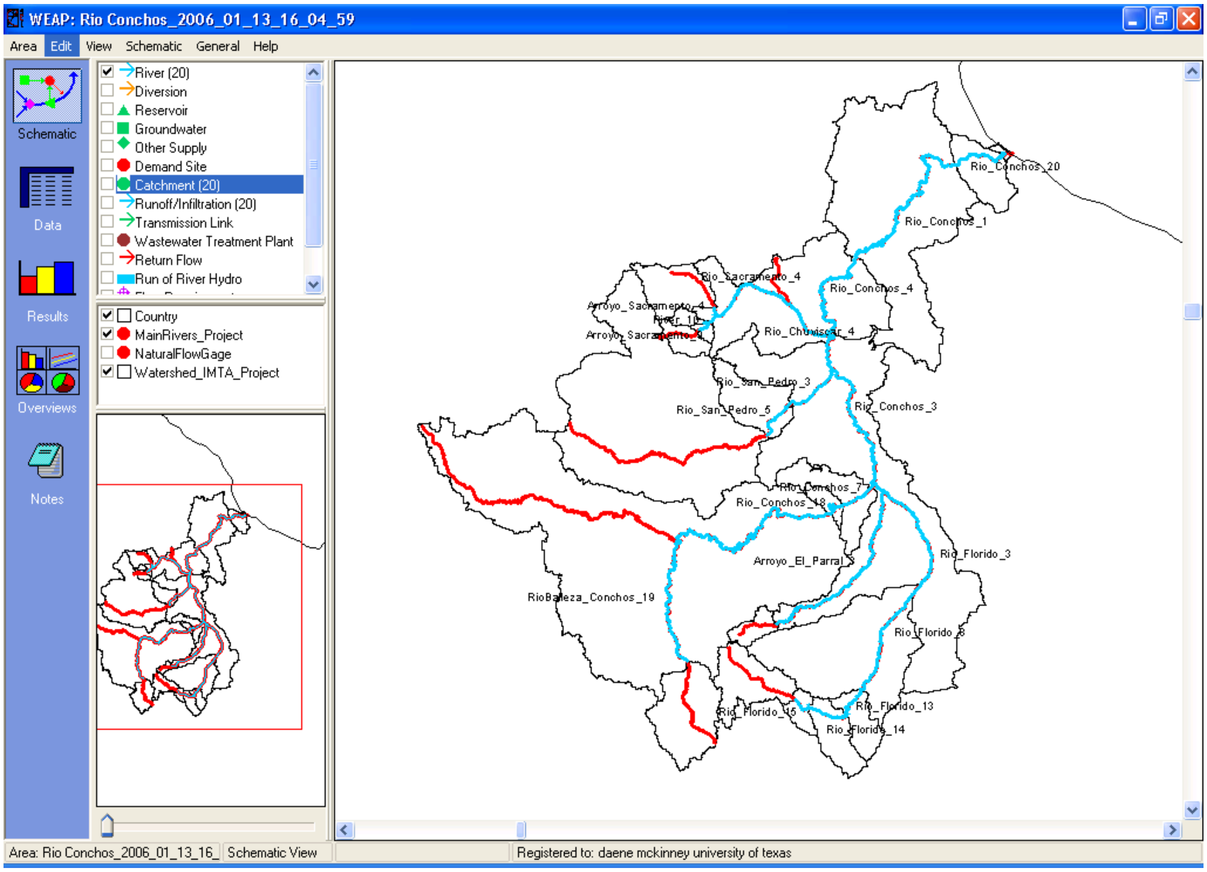


Figure 10. WEAP River Reaches

The river reaches were drawn into WEAP in segments relating to the sub-basin boundaries for reasons related to catchment connectivity. Relating reach lengths to the sub-basin boundaries allows for the runoff from a catchment to link to the river system in a physically appropriate location. For example the Rio Conchos was traced as one segment in each sub-basin and named accordingly, e.g. Rio_Conchos_20 represents the Rio Conchos through the Ojinaga sub-basin which is identified as sub-basin number 20. The reach names are also shown in Figure 10.

There are two exceptions to the naming convention. The first exception is River_10, which drains the El_Rejon sub-basin, sub-basin 10, through the Chuviscar sub-basin, sub-basin 9, to the confluence with the Arroyo_Sacramento_9. This reach is generically named because it did not have a name field in the CRWR geodatabase. The second exception is the WEAP river reach in the La Boquilla sub-basin, sub-basin 19, which is named the RioBalleza_Conchos_19, because it represents the Rio Balleza to the confluence with the Rio Conchos and the Rio Conchos from the confluence to the sub-basin outlet. The river was traced in such a manner so that the Llanitos sub-basin, sub-basin 12, could be entered as headwater to the river reach segment and so that the La Boquilla sub-basin could be connected to the river in a more physically appropriate location, this is further discussed subsequently.

2.5 Catchment Runoff to River Connectivity

Once the river system is traced and named the catchment data is edited to direct the runoff from the sub-basin to the appropriate river reach. For example the Rio Florido headwaters are in the Puente FFC sub-basin, sub-basin 16, and flows through the San Gabriel sub-basin, sub-basin 15, the San Antonio sub-basin, sub-basin 14, the Pico de Aquila sub-basin, sub-basin 13, the Jimenez sub-basin, sub-basin 18, and part of the Las Burras sub-basin, sub-basin 3, to the confluence with the Rio Conchos. Figure 11 shows the upper Rio Florido portion of the WEAP schematic. The solid blue lines are rivers and the dashed blue lines are the conceptual connection of the catchment to the river reach.

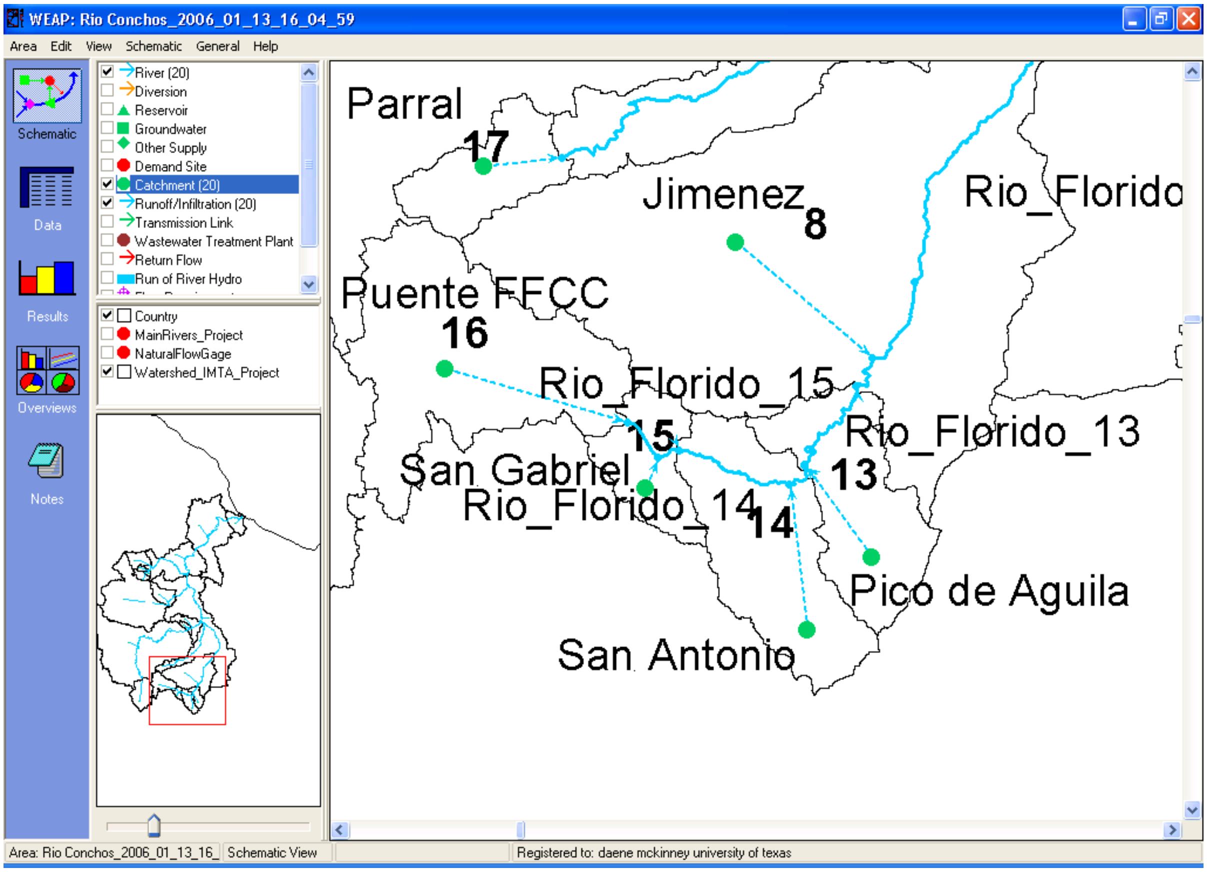


Figure 11. WEAP Schematic of the Rio Florido Connectivity

The schematic shows the connectivity either connecting directly to the head of a reach or as a perpendicular line to the closest point on the identified river reach. The actual surface flow contribution, however, connects to the center of the selected river reach. For example there is no river reach in the Puente FFC sub-basin, because runoff from the sub-basin is entered as head flow for the segment through the downstream San Gabriel sub-basin, Rio_Florido_15. Runoff from the San Gabriel sub-basin enters the Rio_Florido_15 at the center of the river segment. The runoff contribution point is dictated by right clicking on the catchment, selecting General Info, and then selecting the river reach from the pull down menu and selecting the head flow option if desired. Figure 12 shows the WEAP window settings for the above example.

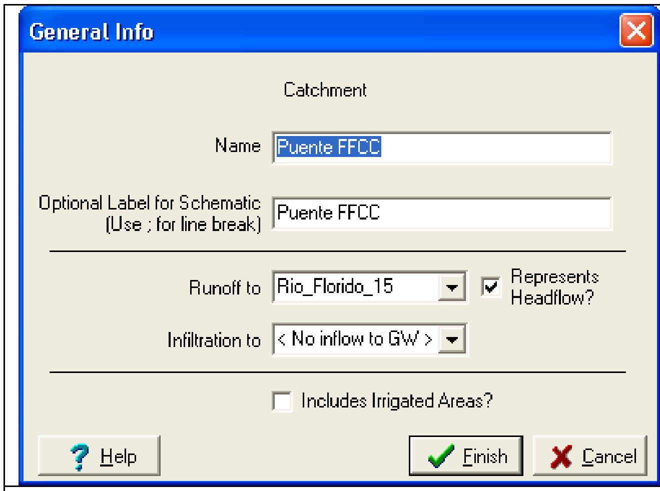


Figure 12a. Sub-basin 16 Runoff Settings

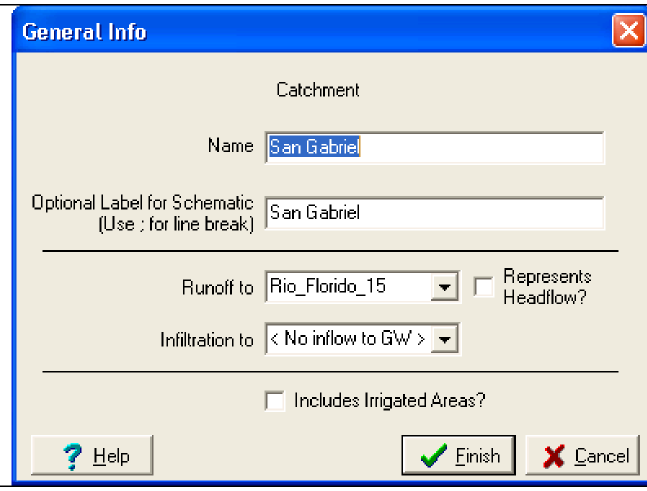


Figure 12b. Sub-basin 15 Runoff Settings

Figure 12. Runoff Settings

2.6 Deep Water Capacity

Deep Water Capacity is the effective water holding capacity, in millimeters, of the deep soil layer, or the second bucket in the Soil Moisture Method. WEAP applies this parameter to an entire catchment so that the parameter cannot be characterized by land use or soil area. IMTA (Martinez, 2005) determined the storage capacity and percolation rate for each sub-basin for a three-soil layer, or three-bucket model. Figure 13 is a conceptual diagram of the soil moisture method applied to HEC-HMS by IMTA.

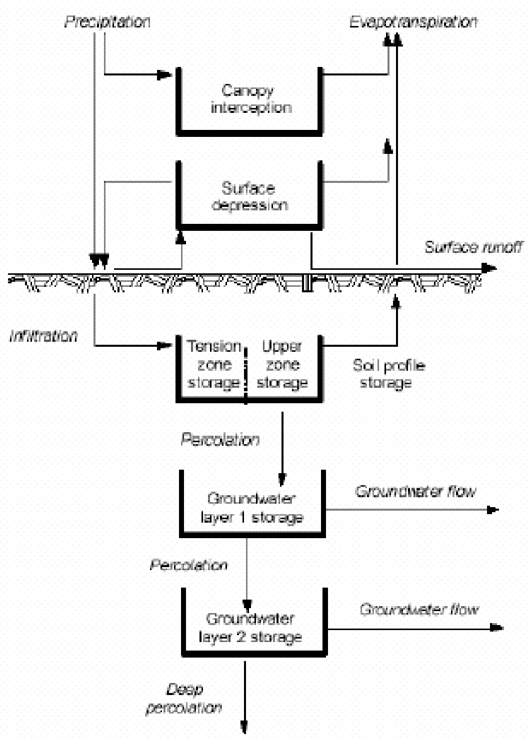


Figure 13. IMTA Soil Moisture Method (Martinez, 2005)

The first bucket in the WEAP Soil Moisture Method relates to the "Soil Profile" layer in IMTA's model. "Ground Water 1" is the second layer in IMTA's model that relates to the second bucket in the WEAP Soil Moisture Method. Data for the third bucket of IMTA's model was not utilized because the Soil Moisture Method in WEAP only supports two layers. Table 5 lists the values for Deep Water Capacity found in the IMTA report and those applied in the WEAP model.

Table 5. Deep Water Capacity Values

Basin Name	IMTA ID	IMTA Ground Water 1 Storage Capacity (mm)	WEAP Deep Water Capacity (mm)
Peguis	1	4	4
Sacramento	2	5	5
Las Burras	3	1	1
Luis L. Leon	4	25	25
FCO. Madero	5	10	10
Villalba	6	8	8
Conchos	7	3	3
Jiminez	8	3	3
Chuviscar	9	3	3
El Rejon	10	10	10
Chihuahua	11	5	5
Llanitos	12	1	1
Pico del Aguila	13	5	5
San Antonio	14	20	20
San Gabriel	15	25	25
Puente FFCC	16	25	25
Parral	17	8	8
Colina	18	15	15
La Boquilla	19	15	15
Ojinaga	20	4	4

2.7 Deep Conductivity

The Deep Conductivity parameter represents the conductivity rate of the second bucket, in millimeters per day. As Figure 2 shows, Deep Conductivity controls the transmission of base flow. WEAP applies a single value of Deep Conductivity to the entire catchment. IMTA determined percolation rates for each sub-basin, which are applied as conductivity values by setting the Preferred Flow Direction Values to 0, which indicates 100% vertical flow as percolation implies. The Preferred Flow Direction is discussed in a subsequent section. Table 6 lists the values IMTA determined for percolation rates and those applied to Deep Conductivity in the WEAP model.

Table 6. Deep Conductivity Values

Basin Name	IMTA ID	IMTA Ground Water 1 Percolation Max Rate (mm/h)	WEAP Deep Conductivity (mm/d)
Peguis	1	4	96
Sacramento	2	20	480
Las Burras	3	5	120
Luis L. Leon	4	15	360
FCO. Madero	5	25	600
Villalba	6	25	600
Conchos	7	13	312
Jiminez	8	5	120
Chuviscar	9	13	312
El Rejon	10	20	480
Chihuahua	11	20	480
Llanitos	12	8	192
Pico del Aguila	13	22	528
San Antonio	14	35	840
San Gabriel	15	10	240
Puente FFCC	16	10	240
Parral	17	30	720
Colina	18	10	240
La Boquilla	19	45	1080
Ojinaga	20	4	96

2.8 Initial Z2

The "Initial Z2" parameter is the relative storage given as a percentage of the total effective storage of the Deep Water Capacity at the beginning of a simulation. WEAP, like Deep Water Capacity, forces Initial Z2 to be constant for each basin. A value of 50 percent was assigned to every sub-basin. Refinement of these three deep soil layer parameters would require finer catchment delineation, referring to Table 1, calibration was determined to be sensitive to Deep Capacity and Conductivity but not Initial Z2 (Jantzen, 2006). Future work may investigate potential value, if any, of such a course.

2.9 Soil Water (Root Zone) Capacity

Soil Water or Root Zone Capacity is the effective water holding capacity, in millimeters, of the first bucket in the Soil Moisture Method. The WEAP model structure allows this parameter to characterize the soils groups within a sub-basin. Typically in WEAP, values of Soil Water Capacity are applied to the land use groups delineated within each sub-basin. However, as previously stated IMTA (Martinez, 2005) determined storage capacity and percolation rate on a sub-basin scale so the value for each sub-basin was entered multiple times for each land use category in the sub-basin. Table 7 lists the storage capacity values determined by IMTA and those applied in WEAP.

Table 7. Soil Capacity Values

Basin Name	IMTA ID	IMTA Soil Profile Storage Capacity (mm)	WEAP Root Zone Capacity (mm)
Peguis	1	20	20
Sacramento	2	20	20
Las Burras	3	10	10
Luis L. Leon	4	15	15
FCO. Madero	5	15	15
Villalba	6	9	9
Conchos	7	10	10
Jiminez	8	25	25
Chuviscar	9	10	10
El Rejon	10	5	5
Chihuahua	11	10	10
Llanitos	12	6	6
Pico del Aguila	13	10	10
San Antonio	14	10	10
San Gabriel	15	8	8
Puente FFCC	16	8	8
Parral	17	15	15
Colina	18	10	10
La Boquilla	19	5	5
Ojinaga	20	20	20

WEAP employs a method known as "Key Assumption", which allows parameter values that will be applied frequently to be coded in once as a Key Assumption and then referenced throughout the model. The Soil Water Capacity values were coded using the Key Assumption function to assign the sub-basin value to each land use within each soil group. The Root Zone Capacity Key Assumption setup and application are shown in Figure 14 and Figure 15.

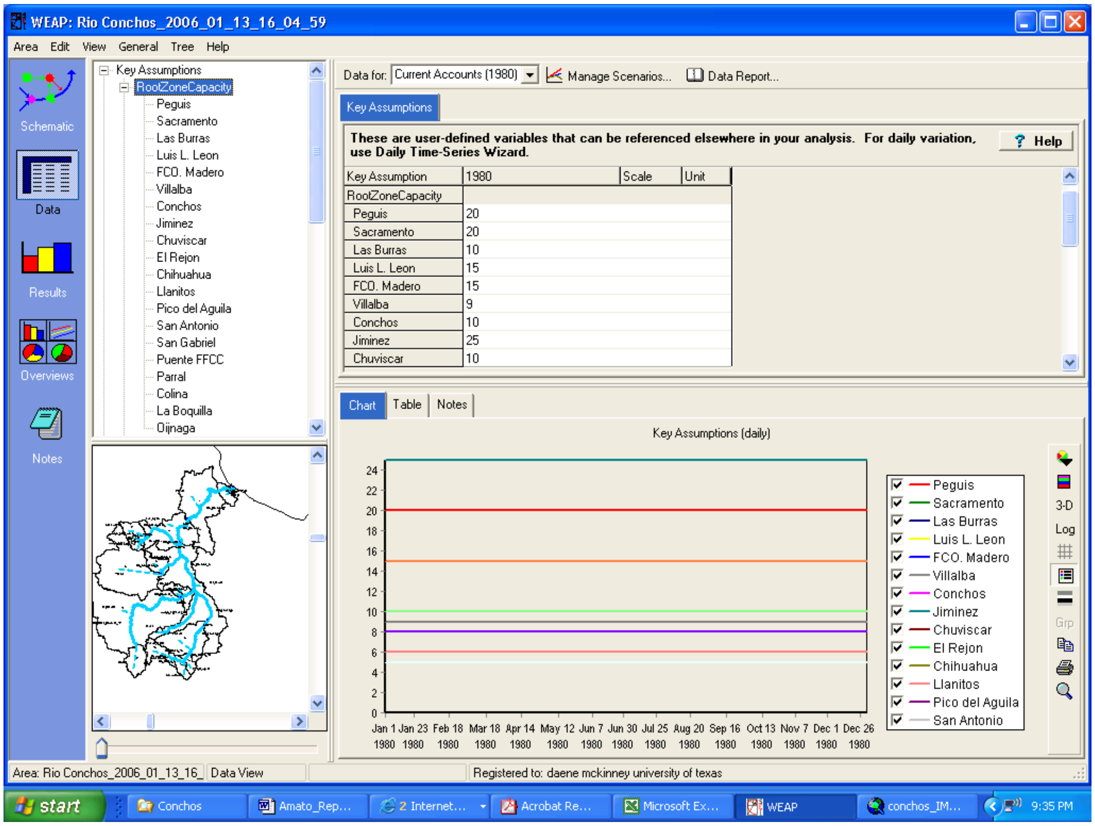


Figure 14. Root Zone Capacity Key Assumptions Setup

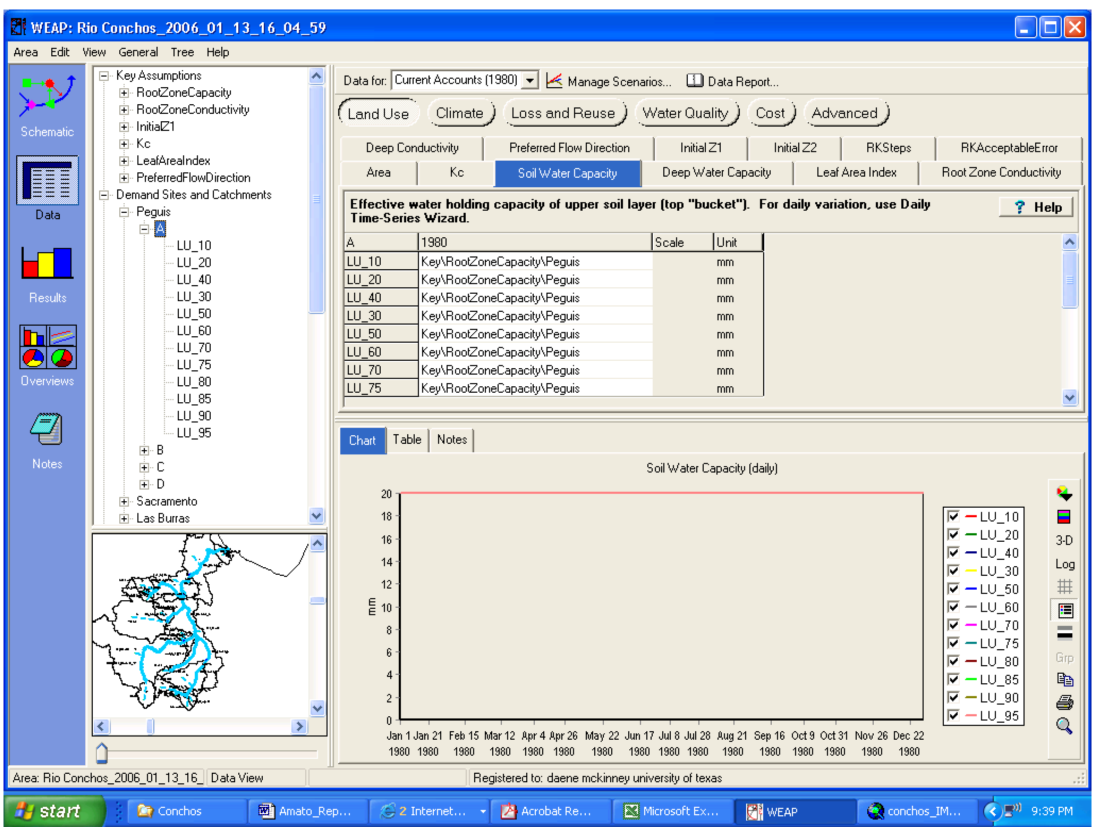


Figure 15. Root Zone Capacity Key Assumptions Applied

2.10 Root Zone Conductivity

Root Zone Conductivity or soil conductivity is the conductivity in the first bucket. Conductivity rate typically varies among soil and land use classifications. As with the second bucket IMTA determined percolation rates for the first bucket for each sub-basin. Again the percolation values are applied as conductivity values by setting the Preferred Flow Direction Values to 0.

Table 8 lists the values for percolation in the first bucket determined by IMTA and those applied to Root Zone Conductivity in the WEAP model. A Key Assumption for the Root Zone Conductivity of each basin was created. The land use branches within each sub-basin and soil group then referenced the Key Assumption.

Table 8. Root Zone Conductivity Basin Values

Basin Name	IMTA ID	IMTA Soil Profile Percolation Max Rate (mm/h)	WEAP Soil Conductivity (mm/d)
Peguis	1	6.00	144
Sacramento	2	25.00	600
Las Burras	3	2.00	48
Luis L. Leon	4	8.00	192
FCO. Madero	5	25.00	600
Villalba	6	23.00	552
Conchos	7	1.25	30
Jiminez	8	26.00	624
Chuviscar	9	1.25	30
El Rejon	10	10.00	240
Chihuahua	11	1.00	24
Llanitos	12	2.00	48
Pico del Aguila	13	5.00	120
San Antonio	14	25.00	600
San Gabriel	15	0.28	7
Puente FFCC	16	0.28	7
Parral	17	15.00	360
Colina	18	15.00	360
La Boquilla	19	5.00	120
Ojinaga	20	6.00	144

2.11 Preferred Flow Direction

The Preferred Flow Direction parameter is used to partition flow out of the root zone layer to the lower soil layer or groundwater. Preferred flow direction can vary by land use classification and ranges from 0 to 1. A preferred flow direction of 1 indicates 100% horizontal flow direction while 0 indicates 100% vertical flow direction. A Key Assumption for the Preferred Flow Direction of each land use category was created with a value equal to zero to effectively apply the available percolation data from IMTA to hydraulic conductivity input, refer to Figure 2. Again, each land use category branch then references the Key Assumption for Preferred Flow Direction.

2.12 Initial Z1

The Initial Z1 parameter is the relative storage given as a percentage of the total effective storage of the Root Zone Water Capacity at the beginning of a simulation. Therefore, like Root Zone Water Capacity this parameter typically varies with the land use, however, because the Root Zone Capacity parameter is coded by basin Initial Z1 was done in the same way. A Key Assumption for the Initial Z1 value of each sub-basin was created with a value equal to 20 percent. Each land use category within the sub-basins then references the Key Assumption.

2.13 Crop Coefficient, Kc

The crop coefficient, Kc, parameter represents the effects of vegetative evapotranspiration and soil evaporation, for this reason the parameter varies by land class type. The parameter was created to study the required soil moisture to maximize crop biomass production; hence, Kc is typically used to calculate the required evapotranspiration using the equation:

$$(\text{Evapotranspiration})_{\text{required}} = Kc * (\text{Evapotranspiration})_{\text{reference}}$$

The Rio Bravo study (World Bank, 2006) determined actual and potential evapotranspiration, which relates to the required and potential evapotranspiration, respectively. These values were determined for fifteen land use categories which differ from the land use categories determined by IMTA and used in the WEAP model. Section 2.3 discusses these differences. Table 9 lists World Banks data and the crop coefficient values applied in WEAP. A Key Assumption for the Kc value of each land use category was created and the land use branches within each sub-basin reference the Key Assumptions.

Table 9. Crop Coefficient Values

<table>
<tr><th>Land Use</th><th>ET_{act} (mm)</th><th>ET_{pot} (mm)</th><th>Kc</th><th>IMTA Land Use Code</th><th>IMTA Land Use Category</th><th>Kc Used in Weap</th></tr>
<tr><td>Urban Area</td><td>803</td><td>1048</td><td>0.77</td><td>85</td><td>Urban Areas</td><td>0.77</td></tr>
<tr><td>Water Bodies</td><td>1578</td><td>1578</td><td>1.00</td><td>30</td><td>Water Bodies</td><td>1.00</td></tr>
<tr><td>Irrigated Agriculture (delta)</td><td>1202</td><td>1346</td><td>0.89</td><td rowspan="2">40</td><td rowspan="2">Irrigated Areas</td><td rowspan="2">0.88</td></tr>
<tr><td>Irrigated Agriculture (valley)</td><td>898</td><td>1040</td><td>0.86</td></tr>
<tr><td>Supplemental Irrigation</td><td>1242</td><td>1298</td><td>0.96</td><td>50</td><td>Naturrally Irrigated Areas</td><td>0.96</td></tr>
<tr><td>Low Open Forrest</td><td>483</td><td>1272</td><td>0.38</td><td>20</td><td>Forrest Grasses</td><td>0.38</td></tr>
<tr><td>Oak Forest</td><td>538</td><td>1747</td><td>0.31</td><td rowspan="2">10</td><td rowspan="2">Forrest</td><td rowspan="2">0.35</td></tr>
<tr><td>Pine Forrest</td><td>487</td><td>1272</td><td>0.38</td></tr>
<tr><td>Chapparral</td><td>481</td><td>1424</td><td>0.34</td><td>70</td><td>High Grasses and Small Brush</td><td>0.34</td></tr>
<tr><td>Microphyllous Scrublands</td><td>237</td><td>501</td><td>0.47</td><td rowspan="4">75</td><td rowspan="4">Other Vegetation</td><td rowspan="4">0.45</td></tr>
<tr><td>Scrubland with Rosetted Vegetation</td><td>263</td><td>616</td><td>0.43</td></tr>
<tr><td>Thornscrubland Tamaulipan</td><td>583</td><td>1254</td><td>0.46</td></tr>
<tr><td>Submontane Scrubland</td><td>711</td><td>1605</td><td>0.44</td></tr>
<tr><td>Cultivated Grassland</td><td>516</td><td>1129</td><td>0.46</td><td>80</td><td>Grazing Pastures</td><td>0.46</td></tr>
<tr><td>Natural Grassland</td><td>342</td><td>642</td><td>0.53</td><td>60</td><td>Small Pasture Grasses</td><td>0.53</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>90</td><td>Wetland Vegetation</td><td>0.9</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>-</td><td>95</td><td>Without Apparent Vegetation</td><td>0.3</td></tr>
</table>

2.14 Leaf Area Index

Leaf Area Index (LAI) is a parameter that varies by land use and is used to control the surface runoff response. Runoff tends to decrease with higher values of LAI. LAI is not an easily determined parameter and there are many discrepancies in definitions and values, which apply to the same land use. Scurlock et al. (2001) compiled estimates of LAI published between 1932 and 2000 and produced a table of LAI values for fifteen categories of vegetative land use. The LAI values produced by Scurlock et al. are shown in Table 10. The values as applied to the WEAP model are listed in Table 11.

Referring to Table 1, simulated flow results from WEAP are highly sensitive to Kc and LAI parameters. Future work should include an investigation into the importance of these values and the cost benefit for applying site specific LAI versus literature values and importance of seasonal Kc and LAI values

Table 10. LAI Values Scurlock et al. , 2001

Table: Statistical distribution of leaf area index by biome, for the data set "Global Leaf Area Index Data from Field Measurements, 1932-2000", and after removal of outliers following Inter-Quartile Range (IQR) statistical analysis. Of the original total of 1008 records, 77 were excluded from this analysis (e.g., because biome was not available). See the accompanying Technical Memorandum (Scurlock et al., 2001) for biome acronyms.

	Original data					Data after IQR analysis				
Biome	Number of observations	Mean	Standard deviation	Min	Max	Number of outliers removed	Mean	Standard deviation	Min	Max
All	931	5.23	4.08	0.002	47.0	53	4.51	2.52	0.002	12.1
Forest / BoDBL	58	2.64	1.03	0.28	6.0	5	2.58	0.73	0.6	4.0
Forest / BoENL	94	3.50	3.34	0.48	21.6	8	2.65	1.31	0.48	6.21
Crops	88	4.22	3.29	0.2	20.3	5	3.62	2.06	0.2	8.7
Desert	6	1.31	0.85	0.59	2.84	0	1.31	0.85	0.59	2.84
Grassland	28	2.50	2.98	0.29	15.4	3	1.71	1.19	0.29	5.0
Plantation	77	8.72	4.32	1.55	18.0	0	8.72	4.32	1.55	18.0
Shrub	5	2.08	1.58	0.4	4.5	0	2.08	1.58	0.4	4.5
Forest / BoTeDNL	17	4.63	2.37	0.5	8.5	0	4.63	2.37	0.5	8.5
Forest / TeDBL	187	5.12	1.84	0.4	16.0	3	5.06	1.60	1.1	8.8
Forest / TeEBL	58	5.82	2.57	0.8	12.5	1	5.70	2.43	0.8	11.6
Forest / TeENL	215	6.70	5.95	0.002	47.0	16	5.47	3.37	0.002	15.0
Forest / TrDBL	18	3.92	2.53	0.6	8.9	0	3.92	2.53	0.6	8.9
Forest / TrEBL	61	4.90	1.95	1.48	12.3	1	4.78	1.70	1.48	8.0
Tundra	13	2.69	2.39	0.18	7.2	2	1.88	1.47	0.18	5.3
Wetlands	6	6.34	2.29	2.50	8.4	0	6.34	2.29	2.5	8.4

Table 11. LAI Values

Scurlock et al., 2001 Land Use Category	IMTA Land Use Code	IMTA Land Use Category	LAI Used in Weap
Forest Average	10	Forrest	5.18
Forest Average (BoDBL and BOENL)	20	Forrest Grasses	3.07
	30	Water Bodies	0.10
Crops	40	Irrigated Areas	4.22
Crops	50	Naturally Irrigated Areas	4.22
Grassland	60	Small Pasture Grasses	2.50
Shrub	70	High Grasses and Small Brush	2.08
Shrub	75	Other Vegetation	2.08
Grassland	80	Grazing Pastures	2.50
	85	Urban Areas	8.00
Wetlands	90	Wetland Vegetation	6.34
Desert	95	Without Apparent Vegetation	1.31

2.15 Precipitation

Precipitation data was obtained from the IMTA DSS file as spatially weighted daily values for each sub-basin. IMTA (Martinez, 2005) applied the Theissen polygon method to sixty-five climate stations, shown in Figure 16, to determine the incremental precipitation per day for each sub-basin for the period of 1980 to 1999. The differences between the sub-basins as IMTA delineated them and as they were delineated for this study (Figure 5) transfer to the application of the spatially weighted data obtained from IMTA, however, the effect is expected to be minor is not investigated or addressed in this report.

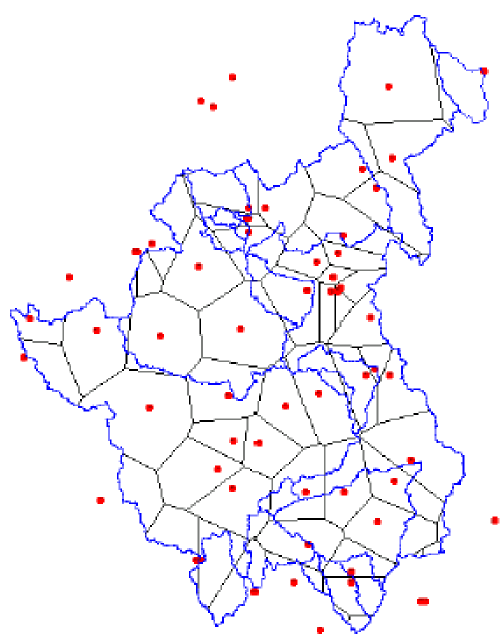


Figure 16. IMTA Precipitation Stations (Martinez, 2005)

The precipitation data extracted from the DSS file was formatted in Excel and saved as a CSV file, which can be read by WEAP as a daily time series expression. An excerpt of the Excel file is shown in Figure 17 and Figure 18 shows how the time series for each sub-basin are entered in WEAP.

# WEAP COLUMN NUMBER				3	4	5
#		IMTA BASIN NUMBER		1	2	3
#		REPORT BASIN NAME		PEGUIS	SACRAMENTO	LAS BURRAS
#		HMS BASIN NAME		PEGUIS	SACRAMENTO	BURRAS
#				GAGE	GAGE	GAGE
#				MM	MM	MM
# Year	Day Count	Month	Day	PER-CUM	PER-CUM	PER-CUM
1980	1	1	1	0.000	0.000	0.000
1980	2	1	2	0.000	0.000	0.000
1980	3	1	3	0.000	0.000	0.000
1980	4	1	4	0.000	0.000	0.000
1980	5	1	5	0.000	0.000	0.000
1980	6	1	6	0.000	0.000	0.000
1980	7	1	7	0.000	0.000	0.000
1980	8	1	8	0.000	0.000	0.000
1980	9	1	9	0.000	0.000	0.000
1980	10	1	10	0.000	0.000	0.000
1980	11	1	11	0.000	0.000	0.000
1980	12	1	12	0.500	0.000	0.200
1980	13	1	13	0.000	0.000	0.000
1980	14	1	14	0.000	0.000	0.000
1980	15	1	15	0.000	0.000	0.000
1980	16	1	16	0.000	0.000	0.000
1980	17	1	17	0.000	0.000	0.000
1980	18	1	18	0.000	0.000	0.000
1980	19	1	19	0.000	0.000	0.000

Figure 17. Excerpt of Precipitation Data CSV File

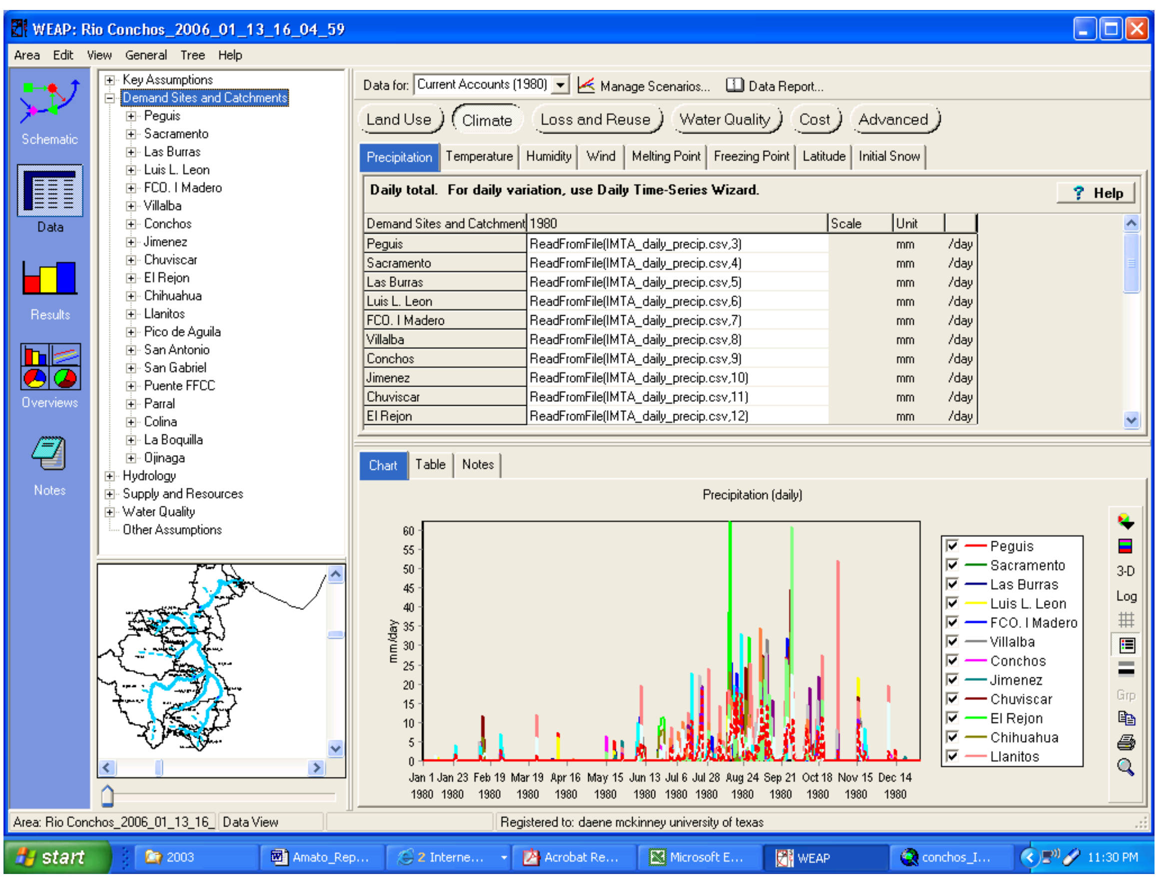


Figure 18. WEAP Precipitation Time Series Expression

2.16 Temperature, Wind and Humidity

Temperature data is entered in degrees Celsius. Humidity is the relative humidity entered as a percentage and Wind values are entered in meters per second. Ideally, each of the parameters should be entered as time series data following the chosen time step of the model, days in this case. However, only averaged monthly data in raster format was available for the Rio Bravo basin from the SWAT data set. The Zonal Statistics tool in Arc Toolbox was used to determine a single average monthly value for each sub-basin for each of the three parameters. The monthly values were repeated for every day of the corresponding month and read into WEAP as a time series expression from a CSV file.

# WEAP Column				3	4	5
# SWAT DATA						
#		IMTA BASIN NUMB		1	2	3
#		BASIN NAME		PEGUIS	SACRAMENTO	LAS BURRAS
# Year		Month		Temp	Temp	Temp
#		1		9.37	8.8	10
#		2		11.57	10.46	12.24
#		3		14.9	13.52	15.63
#		4		19.87	17.56	20.35
#		5		24.22	21.3	23.84
#		6		28.16	24.88	26.87
#		7		28.32	24.42	25.95
#		8		27.4	23.5	25.29
#		9		25	21.38	23.06
#		10		20.33	17.46	19.32
#		11		13.92	12.4	13.98
#		12		9.86	9	10.51
# Year	Day Count	Month	Day	Flow (Mm	Flow (Mm^3)	Flow (Mm^3)
1980	1	1	1	9.37	8.8	10
1980	2	1	2	9.37	8.8	10
1980	3	1	3	9.37	8.8	10
1980	4	1	4	9.37	8.8	10
1980	5	1	5	9.37	8.8	10
1980	6	1	6	9.37	8.8	10
1980	7	1	7	9.37	8.8	10

Figure 19. Excerpt of Temperature Data CSV File

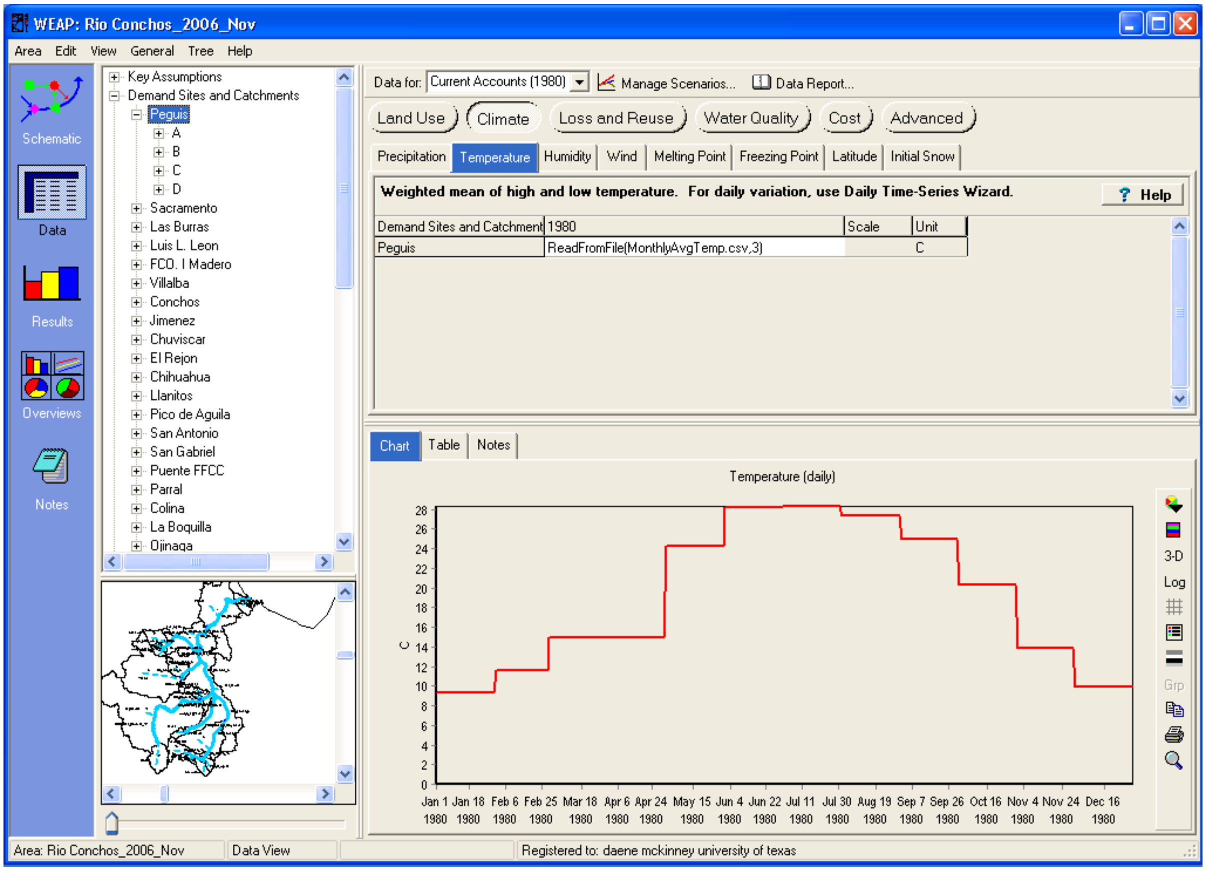


Figure 20. WEAP Temperature Data for the Peguis Sub-basin

2.17 Latitude

WEAP uses latitude in calculating water temperature in water quality models and losses in the Soil Moisture Method. The latitude at the centroid of each catchment was estimated from Figure 21. The estimated values are summarized in Table 12.

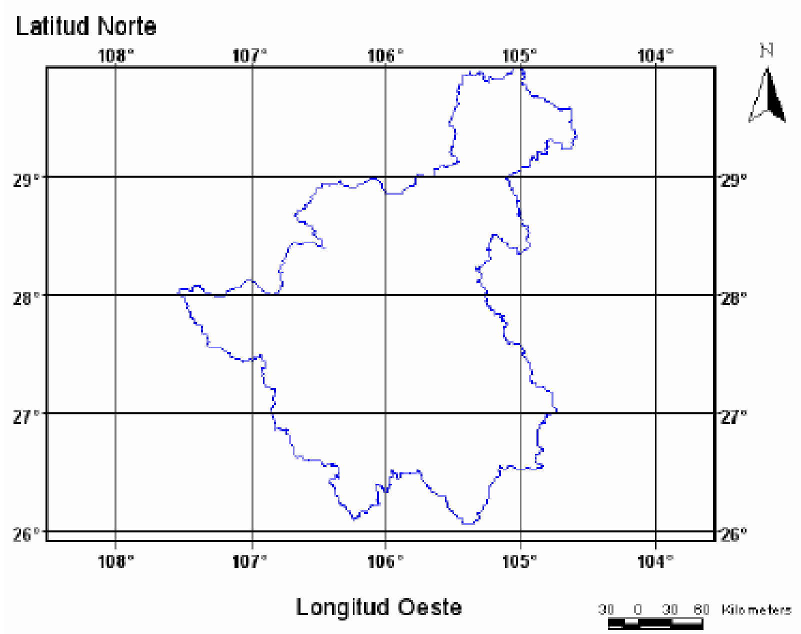


Figure 21. Latitude and Longitude (Martinez 2005)

Table 12. Sub-basin Latitude Values

Basin Name	IMTA ID	Latitude DD
Peguis	1	29.50
Sacramento	2	29.00
Las Burras	3	28.00
Luis L. Leon	4	29.00
FCO. Madero	5	28.50
Villalba	6	28.00
Conchos	7	28.00
Jimenez	8	27.50
Chuviscar	9	27.00
El Rejon	10	28.50
Chihuahua	11	28.50
Llanitos	12	26.50
Pico del Aguila	13	26.50
San Antonio	14	26.50
San Gabriel	15	26.50
Puente FFCC	16	26.50
Parral	17	26.50
Colina	18	27.00
La Boquilla	19	29.50
Ojinaga	20	29.50

2.18 Melting Point, Freezing Point and Initial Snow

The remaining three climatic parameters are Melting Point, Freezing Point and Initial Snow value. Melting Point is the threshold for snow melt in degrees Celsius. A value of 0 was used for all basins. Freezing Point is the threshold for snow accumulation in degrees Celsius. A value of 0 was used for all basins. The Initial Snow value is the snow accumulation at the beginning of the first month of the simulation. Zero was chosen as the initial value for each of the twenty catchments.

3 HEC-HMS Data

The HEC-HMS model created by IMTA is a tool against which to compare and evaluate the results of the WEAP model. Six locations were selected as comparison points between the WEAP and HEC-HMS simulated flows. These particular points were selected because they are also naturalized and historical flow gage locations. Although, these flow data are not addressed in this project, the points chosen for comparison are significant to future work to allow for congruency in locations at which to evaluate and assess the model. Physical locations of the gages are shown in Figure 22. The virtual location of the gages within the WEAP model structure are listed in Table 13.

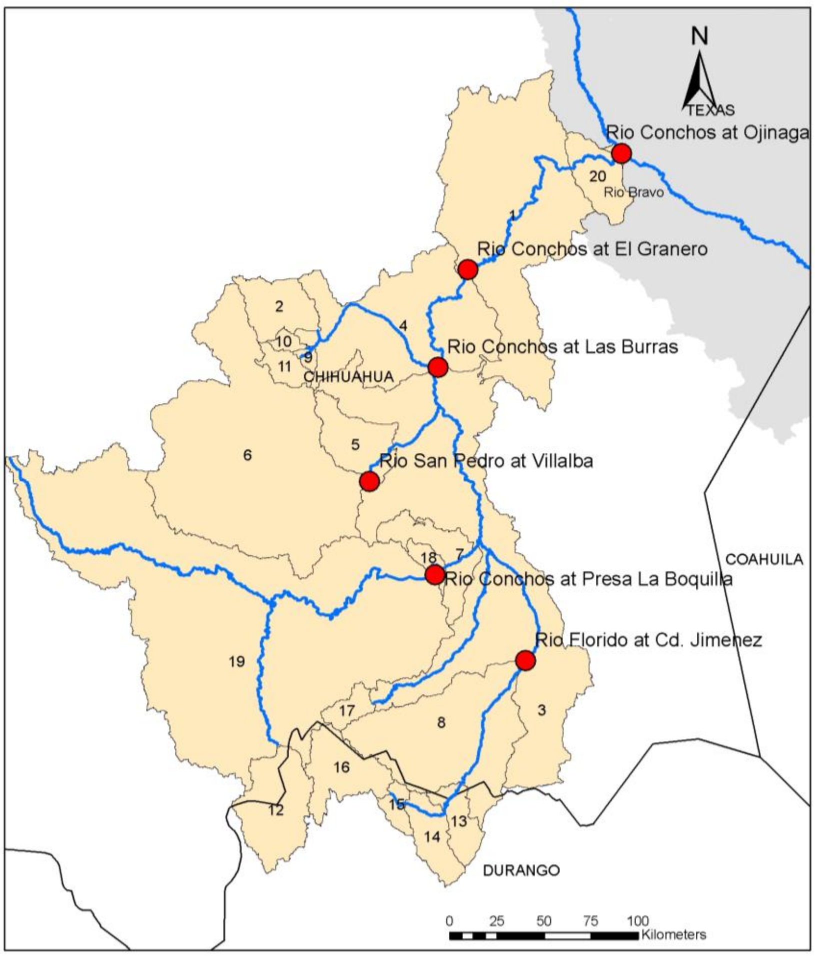


Figure 22. Gauges Locations

Table 13. Rio Conchos Gages

Gage Name	Gage Location	HydroID
Rio Conchos at Ojinaga	Bottom of Reach Rio_Conchos_20	2020200051
Rio Conchos at El Granero	Top of Reach Rio_Conchos_1	2020200004
Rio Conchos at Las Burras	Bottom of Reach Rio_Conchos_3	2020200003
Rio San Pedro at Villalba	Top of Reach Rio_San_Pedro_5	2020200001
Rio Conchos at Presa La Boquilla	Top of Reach Rio_Conchos_18	2020200005
Rio Florido at Cd. Jimenez	Top of Reach Rio_Florido_3	2020200002

Many problems were encountered while using the HEC-HMS model received from IMTA including errors for missing input data and incomplete run configurations to correlate to the gage locations. Model runs for La Boquilla, Jimenez and Villalba were completed but with uncertainty. Run configurations for the remaining three gage locations were not completed due to either parameter errors or seemingly missing model components. For these reasons a request was made to IMTA for the direct results of the model; subsequently IMTA provided a DSS file with the hourly computed flow rate for all run configurations for the year 1980. Table 15 contains the run configuration names within the DSS file and the correlation to the gage locations.

There were large discrepancies between the computed volumes determined from the model for La Boquilla, Jimenez and Villalba and the values from the DSS file. The source of this discrepancy is unknown at this time possible causes are user error or the use of an incomplete model. The values obtained from each source are listed below:

Table 14. Comparison of HEC-HMS Model and DSS Flow Values

Gage Name	HEC-HMS Flow (Mm^3)	DSS Flow from IMTA (Mm3)
Rio Conchos at Ojinaga	-	2,740
Rio Conchos at El Granero	-	2,620
Rio Conchos at Las Burras	-	2,409
Rio San Pedro at Villalba	4,171	864
Rio Florido at Cd. Jimenez	2,064	262
Rio Conchos at Presa La Boquilla	2,064	923

Table 15. Sub-basins Contributing to Gages

Gage Name	Contributing Sub-basins
Rio Conchos at Ojinaga	All 23 runs
Rio Conchos at El Granero	All Runs Except C-PEGUIS OJINAGA
Rio Conchos at Las Burras	BURRAS ALTA C-LAS BURRAS C-FCO I MAD C-VILLALBA C-CONCHOS C- JIMENEZ C-LLANITOS C- PICO DE AGUILA C- SAN ANTONIO C- SAN GABRIEL C-PUENTE FFC C- PARRAL C.-COLINA C. BOQUILLA BOQUILLA1 BOQUILLA2
Rio San Pedro at Villalba	C-VILLALBA
Rio Florido at Cd. Jimenez	C- JIMENEZ C- PICO DE AGUILA C- SAN ANTONIO C- SAN GABRIEL C-PUENTE FFC
Rio Conchos at Presa La Boquilla	C-LLANITOS C. BOQUILLA BOQUILLA1 BOQUILLA2

4. Calibration Process for 1980

For this initial calibration, naturalized flows from TCEQ (Brandes, 2003) for the period from January to December 1980 were used to calibrate the WEAP model. The calibration involved both quantitative and qualitative evaluation of the hydrologic response of each tributary in each sub-basin. After that, parameters were adjusted to reproduce the naturalized monthly and annual stream flow. To this end, the soil moisture method in WEAP model was used and the relevant parameters are described below.

4.1. Root Zone Water Capacity

Initially, values of Root Zone Capacity above 1000 mm were assumed according to the land use; however, the results did not reproduce the trend of naturalized monthly flows in each stream gage considered for the analysis. For this reason, the values of root zone water capacity were reduced; from 160 mm to 400 mm in the Puente FFC, Ojinaga, and Peguis sub-basins, respectively. Values found for each sub-basin can be seen Table 24.

4.2. Root Zone Conductivity

Root Zone Conductivity is a very important parameter in the calibration process which controls the transmission of flow to the lower soil layer and the interflow. The inter flow depends of the preferred flow direction; for our study case, we have assumed it is equal cero or vertical flow which means that there is not inter flow. The flow volume of each catchment from the upper layer to the lower layer is estimated with a simple expression of its relative storage.

$$V_p(t) = \sum_{i=1}^{N} A_i k_1 * (1 - pref.flowdir) * z_1^2$$

According to the values found for the Villalba sub-basin (see table 24), and substituting in the expression above, we have an average volume of percolation of 9.057 Mm3/day. If this parameter is reduced, the stream flow is increased; therefore, the transmission of flow volume toward the lower layer is also reduced.

4.3. Initial Root Zone Water Capacity

An Initial Root Zone Water Capacity at the beginning of a simulation was assumed for each sub-basin. This parameter varies from 5 to 30 % in some sub-basins. Surface runoff is directly correlated with the initial storage, z_1; if z_1 is increased, the runoff as well. The values for this parameter are shown in Table 16.

Table 16. WEAP Upper Layer Soil Parameters Calibrated for the Conchos River Basin

Sub-basin	Drainage Area Km2	Bucket 1		
		Root Zone Capacity Mm	Root Zone Conductivity mm/day	Initial Z1 %
Peguis	7999.2972	400	120	10
Sacramento	1042.6059	250	70	10
Las Burras	11309.4666	350	80	10
Luis L. Leon	5085.5131	350	120	5
FCO. I Madero	1211.3488	260	24	20
Villalba	9556.8624	253	13	27
Conchos	1114.3944	280	14	30
Jimenez	4422.9591	257	28	10
Chuviscar	106.0884	250	75	10
El Rejon	146.8494	250	70	10
Chihuahua	399.9897	250	80	10
Llanitos	1829.9295	270	4	30
Pico de Aguila	647.6067	250	45	5
San Antonio	821.1609	210	24	10
San Gabriel	305.8525	210	24	10
Puente FFCC	1270.6609	160	14	10
Parral	363.7890	250	12	10
Colina	259.0569	280	28	30
La Boquilla	18931.9788	315	4	30
Ojinaga	983.4705	400	100	10

4.4. Lower Deep Water Capacity

Values assumed for the Lower Deep Water Capacity are shown in Table 17. It is likely the high values found in some sub-basins shows the existence of deep aquifers. Initially, values between 100 mm to 300 mm as deep water capacity were proposed for the sub-basins. This range of values gave a high stream flow per year (relative to the naturalized flows), and a great amount of base flow was generated from September to December. For this reason, upper values 2800 mm were assumed and evaluated.

4.5. Lower Deep Conductivity

The Lower Deep Conductivity controls the transmission of base flow in each sub-basin. This parameter can be estimated with the following expression:

$$B_f(t) = \sum_{i=1}^{N} A_i(k_2 z_2^2)$$

where A_i is the area of the land use cover fraction, *i*, k_2 is the conductivity rate of the lower layer at full saturation ($z_2 = 1.00$) in mm/month, and z_2 is the relative storage given as a percentage of the effective storage of the lower soil layer. From the expression mentioned above, initial hydraulic conductivity was estimated of the following way:

$$k_2 = \frac{(B_f / A_i)}{z_2^2}$$

The baseflow (B_f) can be estimated with different methods depending of hydrologic behavior of basin in study. To this end, considering the limitation of information, it is possible to make rough calculations of the baseflow using the straight line method. For example, for the Villalba sub-basin with a drainage area of 9,557 km2, the baseflow was estimated to be 1.5 Mm3/month for 1980, and the average initial store z_2 was assumed to be 4% for all fractions *i*, the resulting hydraulic conductivity is $k_2 = 98 mm / month$, or equal to 3.2 mm/day. In this case, in order to have more accurate results from the hydrologic simulation, this value was adjusted to 60 mm/month. The k_2 parameter found for each sub-basin can be seen in Table 17.

4.6. Initial Lower Layer Capacity

Different values of Lower Layer Initial Storage were assumed in the hydrologic simulation. At the beginning of the simulation, percentages around 40 – 50 % were assumed; nevertheless, in many cases, the baseflow was more than 50 % with regard to the stream flow. For example, in the Villalba Sub-basin, the baseflow was more than 70%; for this reason, small values of z_2 were assumed varying from 4% to 10%. The initial storage z_2 assumed for each sub-basin is shown in Table 17.

Table 17. WEAP Lower Layer Soil Parameters Calibrated for the Rio Conchos Basin

Sub-basin	Drainage Area km2	Bucket 2			
		Deep Water Capacity Mm	Deep Water Conductivity		Initial Z2 %
			mm/day	mm/month	
Peguis	7999.2972	4500	1.0	30.0	5
Sacramento	1042.6059	3500	2.0	60.0	5
Las Burras	11309.4666	4500	3.0	90.0	10
Luis L. Leon	5085.5131	30000	1.0	30.0	5
FCO. I Madero	1211.3488	3500	2.0	60.0	6
Villalba	9556.8624	2800	2.0	60.0	4
Conchos	1114.3944	3700	3.0	90.0	10
Jimenez	4422.9591	5000	0.5	15.0	4
Chuviscar	106.0884	3500	2.0	60.0	5
El Rejon	146.8494	3500	2.0	60.0	10
Chihuahua	399.9897	3500	2.0	60.0	5
Llanitos	1829.9295	25000	2.0	60.0	10
Pico de Aguila	647.6067	4500	0.5	15.0	5
San Antonio	821.1609	4000	0.5	15.0	5
San Gabriel	305.8525	4000	0.5	15.0	5
Puente FFCC	1270.6609	4000	0.5	15.0	5
Parral	363.7890	4000	3.0	90.0	5
Colina	259.0569	4000	2.0	60.0	10
La Boquilla	18931.9788	30000	3.5	105.0	10
Ojinaga	983.4705	4500	1.0	30.0	5

5 Results

This section compares the simulated flows from the IMTA HEC-HMS model and the WEAP model for the calendar year 1980. This specific year (1980) was selected because it is the first year within in the period of record, 1980 to 1999, for which IMTA utilized climatic data to develop their HEC-HMS model. The year is also within the period of record, 1980 to 1985, against which IMTA calibrated the values of Soil Capacity and Soil Conductivity.

Before comparing the flows of the two models the total annual precipitation was determined for each basin and the average annual precipitation was then determined for each of the gage locations. The average annual precipitation was then multiplied by the drainage area to determine to the maximum possible flow volume at each gage site. This serves as a good reference point to evaluate the rough accuracy or plausibility of the simulated flow output. Table 18 contains the total annual precipitation of each sub-basin.

Table 18. Sub-basin Annual Precipitation for 1980

Basin Name	IMTA ID	1980 Annual Precipitation Total (mm)	Area (sq km)
Peguis	1	350.9	7999.30
Sacramento	2	410.5	1042.61
Las Burras	3	332.4	11309.47
Luis L. Leon	4	388.9	5085.51
FCO. Madero	5	415.8	1211.35
Villalba	6	447.2	9556.86
Conchos	7	357.7	1114.39
Jimenez	8	400.8	4422.96
Chuviscar	9	424.4	106.09
El Rejon	10	441.6	146.85
Chihuahua	11	379.5	399.99
Llanitos	12	705.9	1829.93
Pico del Aguila	13	447.5	647.61
San Antonio	14	451.5	821.16
San Gabriel	15	441.1	305.85
Puente FFCC	16	414.5	1270.66
Parral	17	442.6	363.79
Colina	18	400.5	259.06
La Boquilla	19	514.935	18931.98
Ojinaga	20	419.196	983.47

5.1. Annual Streamflow Comparison

Table 19 shows the annual stream flows simulated by WEAP in each selected station; likewise, the maximum possible flows as resulted to the integration of the drainage area and average precipitation upstream of each gage station. The largest difference between the naturalized flow and WEAP simulated stream flow is at the Ojinaga station where the model tends to overestimate the stream flow by about 16%. Most likely, this behavior is because for the 1980 calibration year, the naturalized flow estimated for the Ojinaga station is smaller than those located upstream of the basin; on the other hand, the model tends to over-estimate the flow at the outlet of the basin.

Table 19. Annual TCEQ Naturalized and WEAP Simulated Flows for the Rio Conchos Basin

Gage Name	Drainage Area (km2)	Ave. Precipitation (mm)	Stream flows (Mm3)			Ratio WEAP/TCEQ	Ratio WEAP/HMS
			TCEQ	WEAP	HMS		
Rio Conchos at Ojinaga	67,809	429	2,029	2,362	2,740	1.16	0.86
Rio Conchos at El Granero	58,826	434	2,192	2,299	2,620	1.05	0.88
Rio Conchos at Las Burras	52,045	444	2,220	2,230	2,409	1.00	0.93
Rio San Pedro at Villalba	9,557	447	341	340	864	1.00	0.39
Rio Florido at Cd. Jiminez	7,468	431	123	123	262	1.00	0.47
Rio Conchos at La Boquilla	20,762	610	1,446	1,439	923	1.00	1.56

Figures Figure 23, Figure 24, Figure 25, Figure 26, Figure 27, and Figure 28 show the TCEQ naturalized flows and the WEAP simulated flows for the selected gage stations. Figure 23 is a plot of the monthly mean observed and simulated stream flow for the Rio San Pedro at Villalba (period from Jan to Dec 1980). In this stream gage, the model simulates less baseflow in the period January to April (33% on average of the naturalized flow). However, the simulated flows are more accurate in the summer and fall seasons; for example, the WEAP flow in August represents 95 % of the naturalized flow and 104% in September; which means that in this month, the model only overestimates the monthly peak flow in 4%. It is possible to increase the base flow in the first months of year, by using a larger z_2 or k_2. However, if z_2 is increased from 4% to 10%, the monthly stream flows in November and December increase to more than 80% and 100 % respectively.

5.2. Monthly Streamflow Comparison

Figure 24 shows the monthly WEAP simulated flow for the Rio Conchos at La Boquilla. The most notable difficulty of the hydrologic simulation is to predict the spring and summer flow (Feb –Jun) when the simulated values are around 45 % of the naturalized flows, except in January when the simulation is almost perfect. However, the simulation is more accurate for the fall and winter flows; even though they are overestimated. For example, from August to October when the most important flows occur the ratio the simulated to naturalized flow is 1.09; which means that the model only overestimated the stream flow by 9% on average during this period.

Figure 25 shows the WEAP simulated and TCEQ naturalized flows for the Rio Florido at Cd. Jimenez. Despite of its perfect approximation of the annual flow, there are important differences in the monthly flows. From January to June, simulated flows are smaller than the naturalized flows, while peak flows are close to the naturalized flows (at least in September). It is possible to improve this performance, increasing the hydraulic conductivity, k_1 of the upper soil layer to reduce the stream flows in August and September as well as z_1 in order to increase the stream flows in April, May, June, and November, in all sub-basin located upstream of the Cd. Jimenez stream gage.

Similar behavior is presented in Las Burras, El Granero, and Ojinaga gage stations whose tendencies can be seen in Figure 26, Figure 27, and Figure 28. However, the differences between observed and simulated flows are more noticeable in the last two stations located downstream of the Rio Conchos at Las Burras, because the natural flows are reduced in those points. The rainfall contributions from the Luis Leon, Peguis, and Ojinaga sub-basins are quite small (< 1%) and most of this water is lost to evaporation and seepage along the river. In general, the model overestimates the peak flows produced in September by around 15 %. Figure 29, Figure 30, Figure 31, Figure 32, Figure 33, and Figure 34 are plots showing the daily stream flows simulated by WEAP in the selected points.

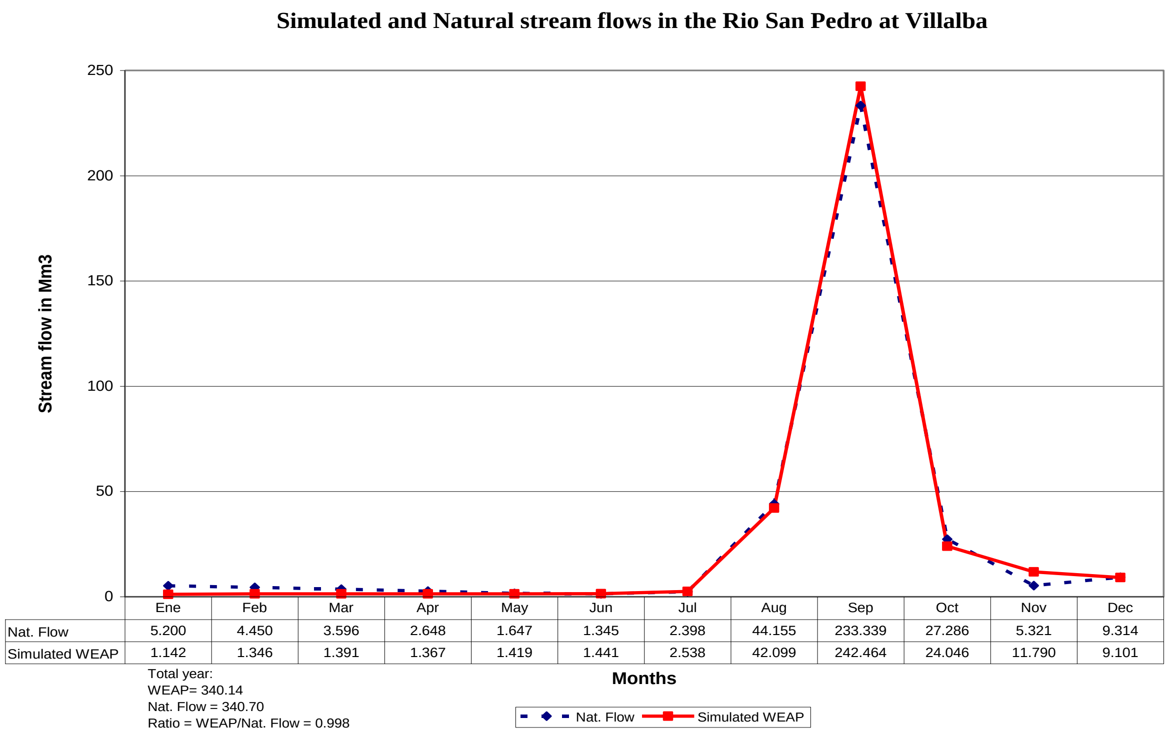
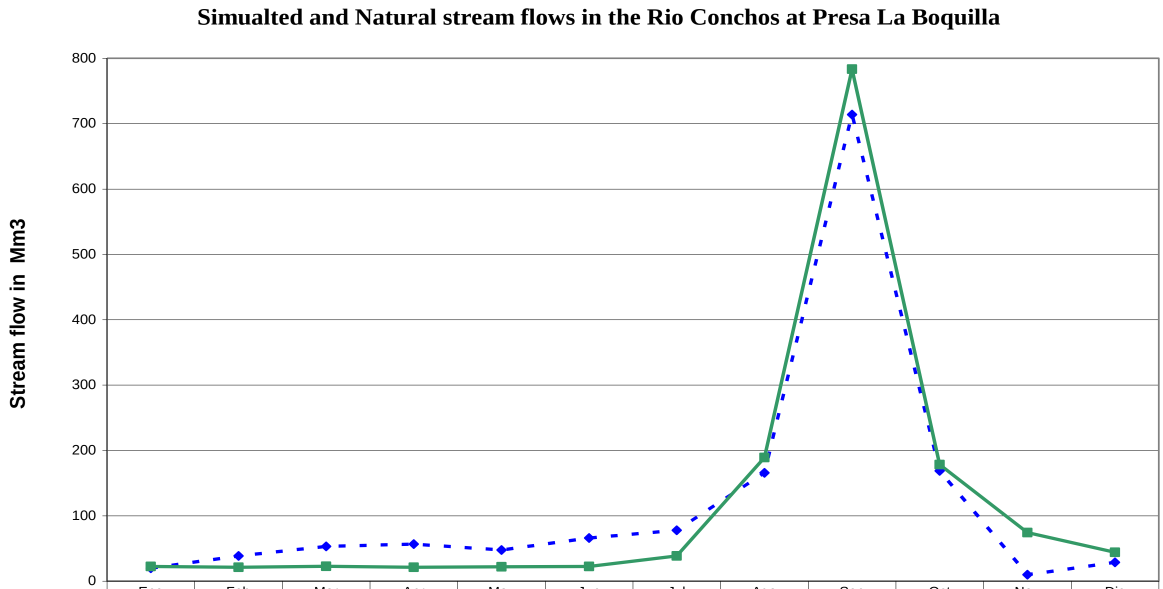


Figure 23. Monthly WEAP simulated and TCEQ naturalized streamflow in the Rio San Pedro at Villalba



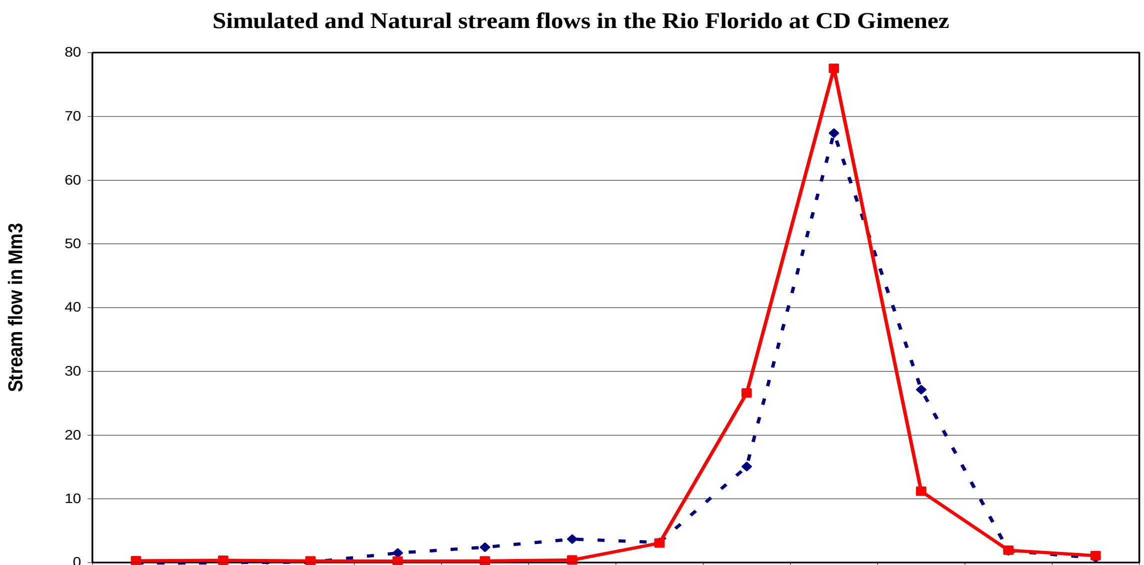
	Ene	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dic
Nat. Flow	19.760	38.430	53.180	56.710	47.580	66.050	77.670	165.540	713.810	168.600	9.930	28.820
Simulated WEAP	22.446	21.057	22.617	21.180	21.891	22.512	38.391	189.019	783.500	178.263	74.214	43.972

Total year:
WEAP= 1439. 062
Nat. Flow = 1446.08
Ratio = WEAP/Nat. Flow = 0.995

Months

Nat. Flow — Simulated WEAP

Figure 24. Monthly WEAP simulated and TCEQ naturalized streamflow in the Rio Conchos at La Boquilla



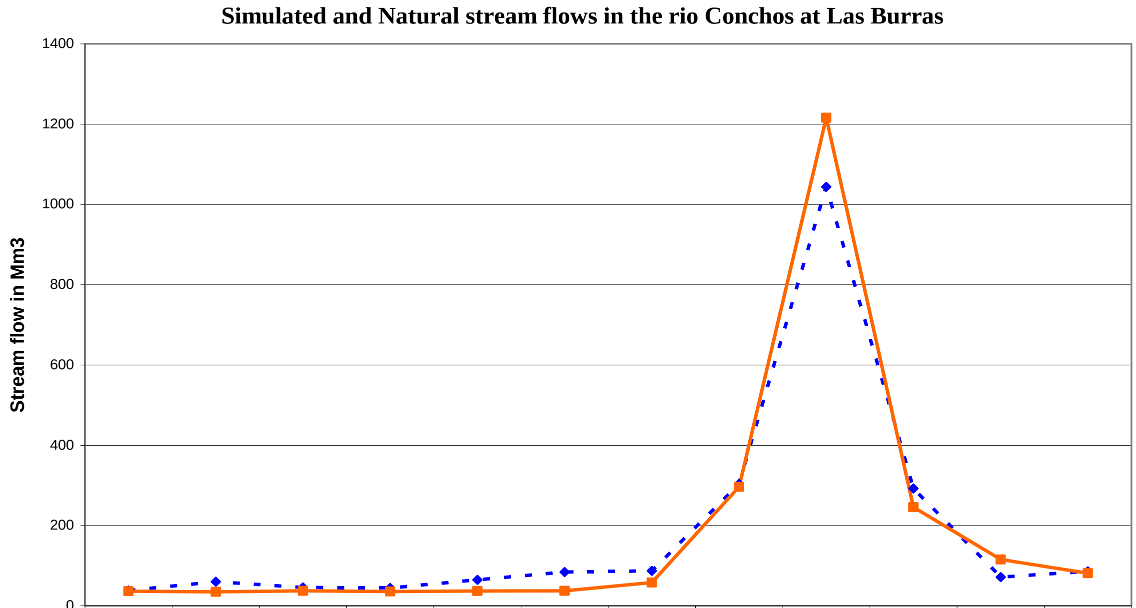
	Ene	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dic
Nat. Flow	0.000	0.000	0.052	1.497	2.396	3.685	3.156	15.067	67.362	27.124	1.821	0.730
Simulated WEAP	0.286	0.345	0.245	0.236	0.260	0.408	3.062	26.600	77.525	11.184	1.917	1.069

Total year:
WEAP= 123.136
Nat. Flow = 122.89
Ratio = WEAP/Nat. Flow =1 . 00

Months

Nat. Flow — Simulated WEAP

Figure 25. Monthly WEAP simulated and TCEQ naturalized streamflow in the Rio Conchos at Jimenez



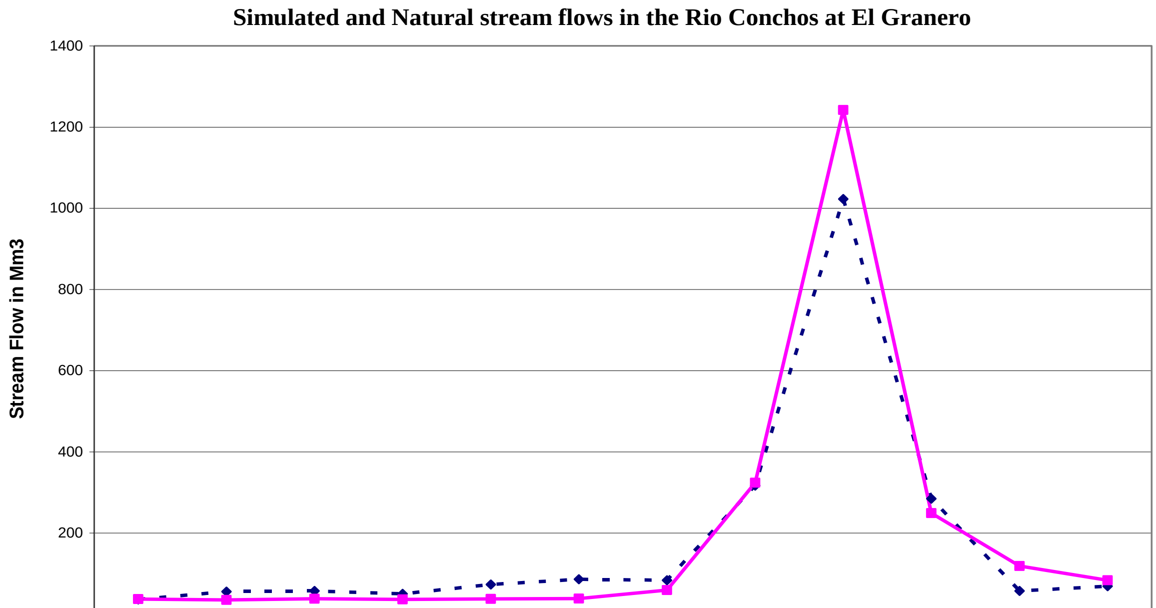
	Ene	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nat. Flow	37.8606	59.9896	45.6388	44.4083	64.5306	84.1077	86.8575	303.3935	1043.73	292.0544	71.485	85.8154
Simulated WEAP	36.4215	34.4743	37.2713	35.3659	36.5933	37.3606	57.9972	296.5854	1215.9141	245.8279	115.1041	81.1253

Months

Total year:
WEAP= 2230. 04
Nat. Flow = 2219.87
Ratio = WEAP/Nat. Flow =1 . 004

Nat. Flow — Simulated WEAP

Figure 26. Monthly WEAP simulated and TCEQ naturalized streamflow in the Rio Conchos at Las Burras



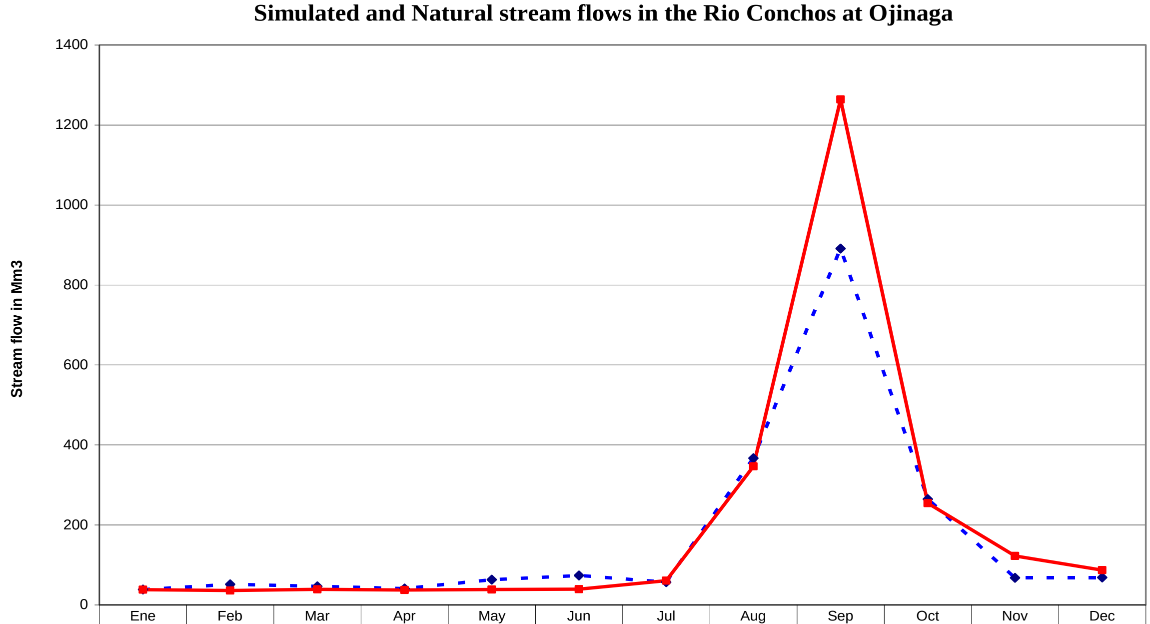
	Ene	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nat. Flow	36.346	55.366	57.240	50.221	73.320	86.116	83.596	316.484	1022.775	284.474	57.434	69.119
Simulated WEAP	37.182	35.220	38.056	36.185	37.397	38.395	59.123	323.800	1241.887	248.974	118.660	83.764

Months

Total year:
WEAP= 2298.64
Nat. Flow = 2192.49
Ratio = WEAP/Nat. Flow = 1.04

Nat. Flow — Simulated WEAP

Figure 27. Monthly WEAP simulated and TCEQ naturalized streamflow in the Rio Conchos at El Granero



	Ene	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nat. Flow	38.437	51.580	46.447	40.870	62.910	73.315	56.817	366.781	891.026	264.565	67.680	68.682
Simulated WEAP	37.981	35.981	38.904	37.032	38.272	39.333	60.723	346.393	1263.838	254.399	122.531	86.837

Total year:
WEAP= 2362.22
Nat. Flow = 2019.108
Ratio = WEAP/Nat. Flow = 1.17

Months

Nat. Flow — Simulated WEAP

Figure 28. Monthly WEAP simulated and TCEQ naturalized streamflow in the Rio Conchos at Ojinaga

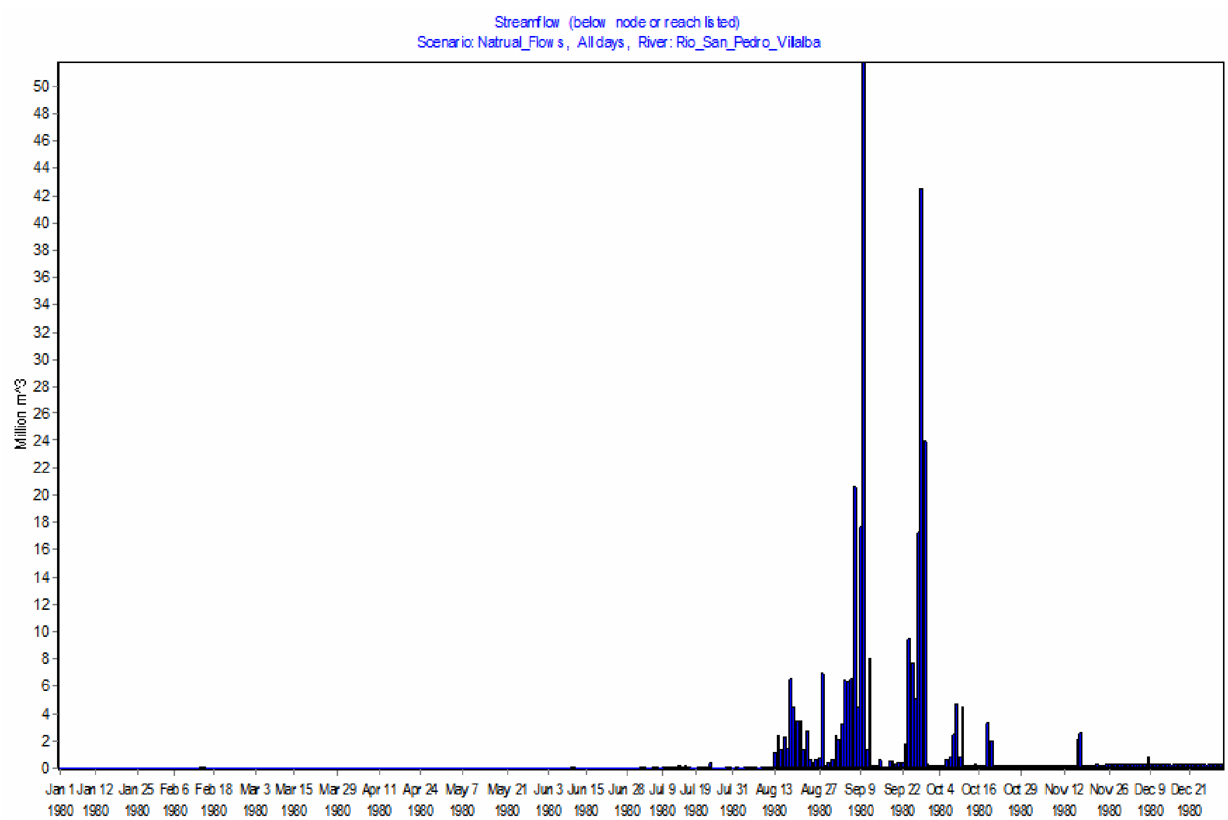


Figure 29. Daily WEAP simulated streamflow in the Rio San Pedro at Villalba

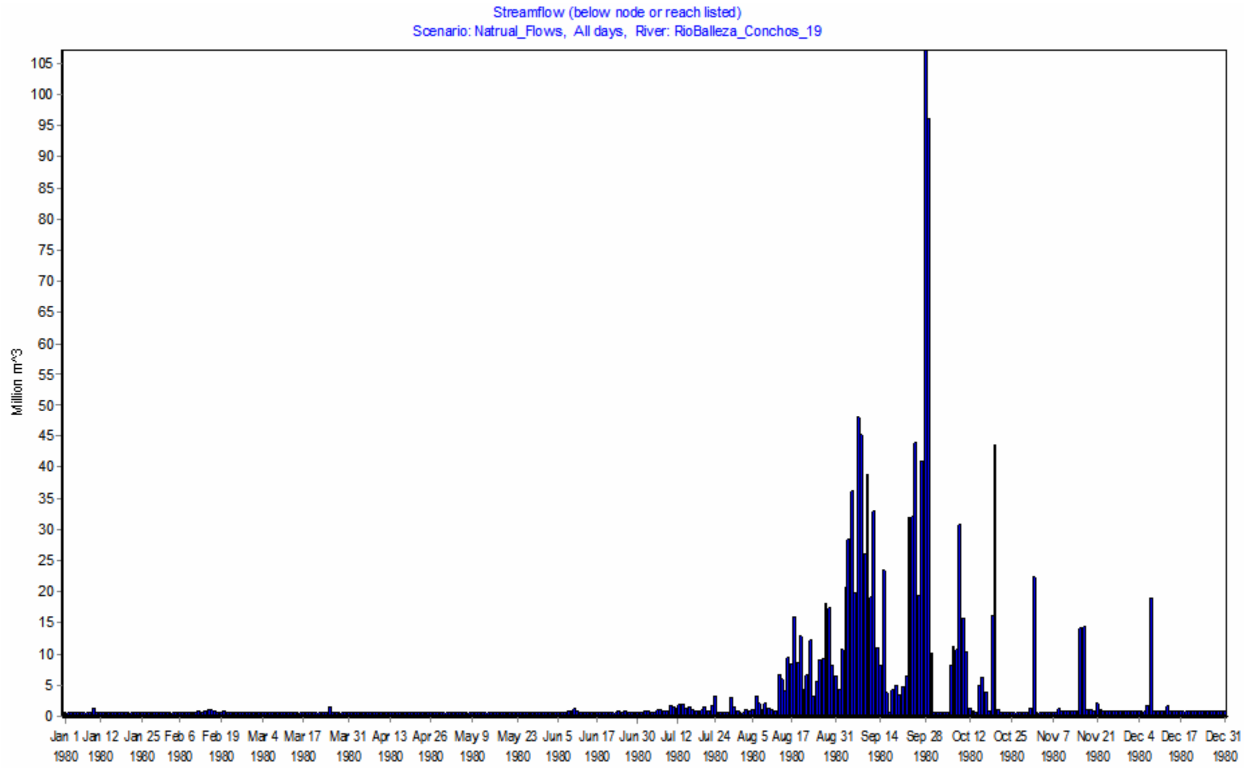


Figure 30. Daily WEAP simulated streamflow in the Rio Conchos at La Boquilla

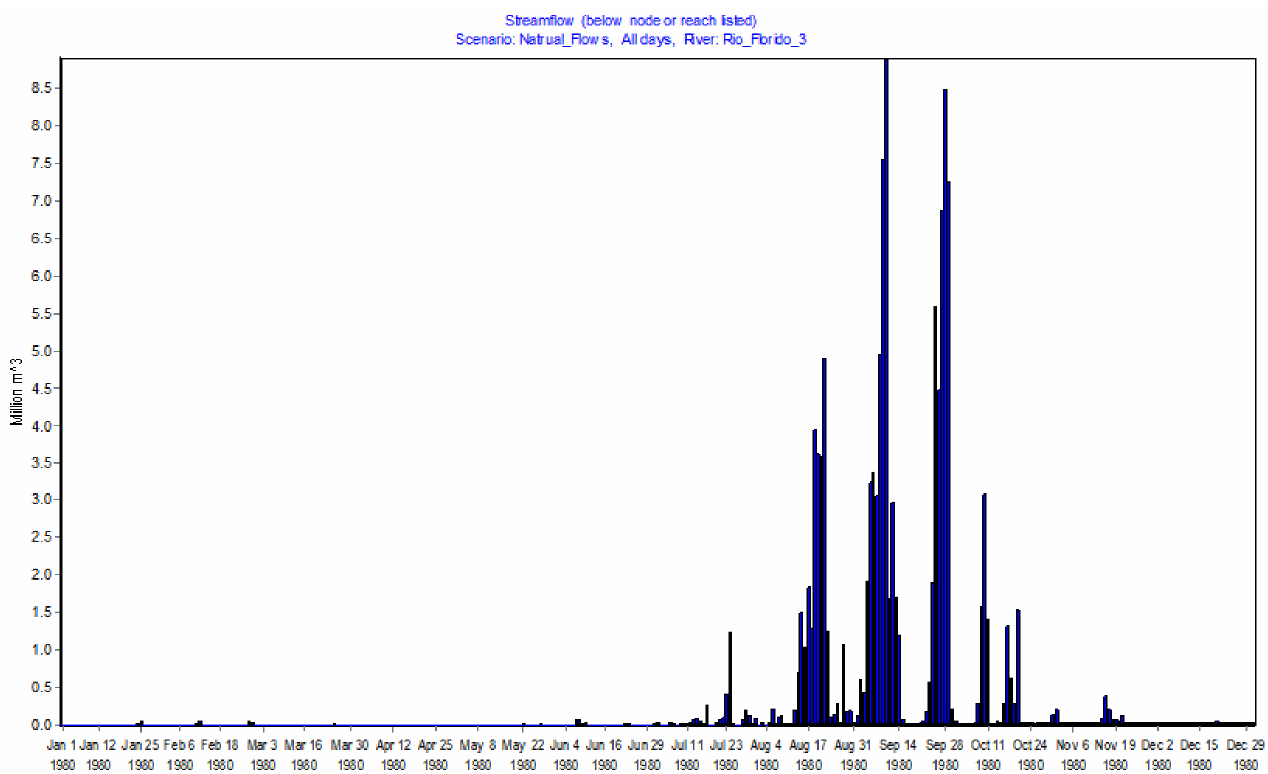


Figure 31. Daily WEAP simulated streamflow in the Rio Florido at Jimenez

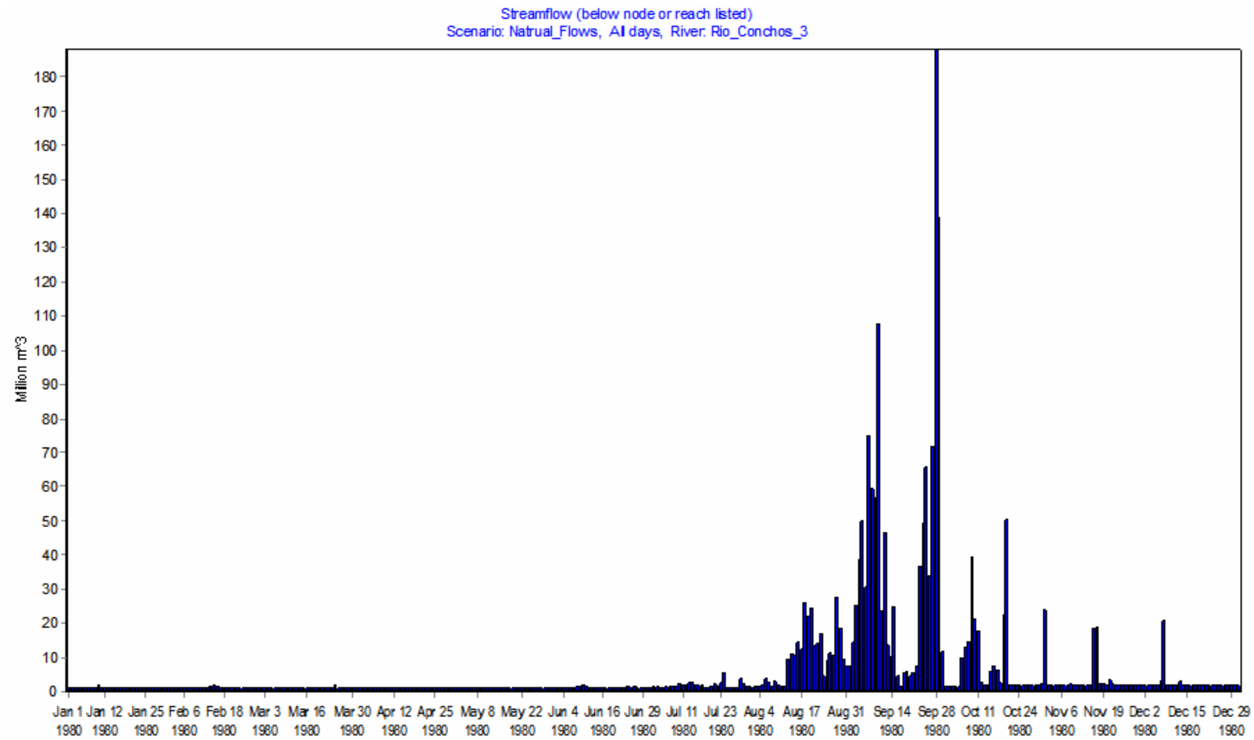


Figure 32. Daily WEAP simulated streamflow in the Rio Conchos at Las Burras

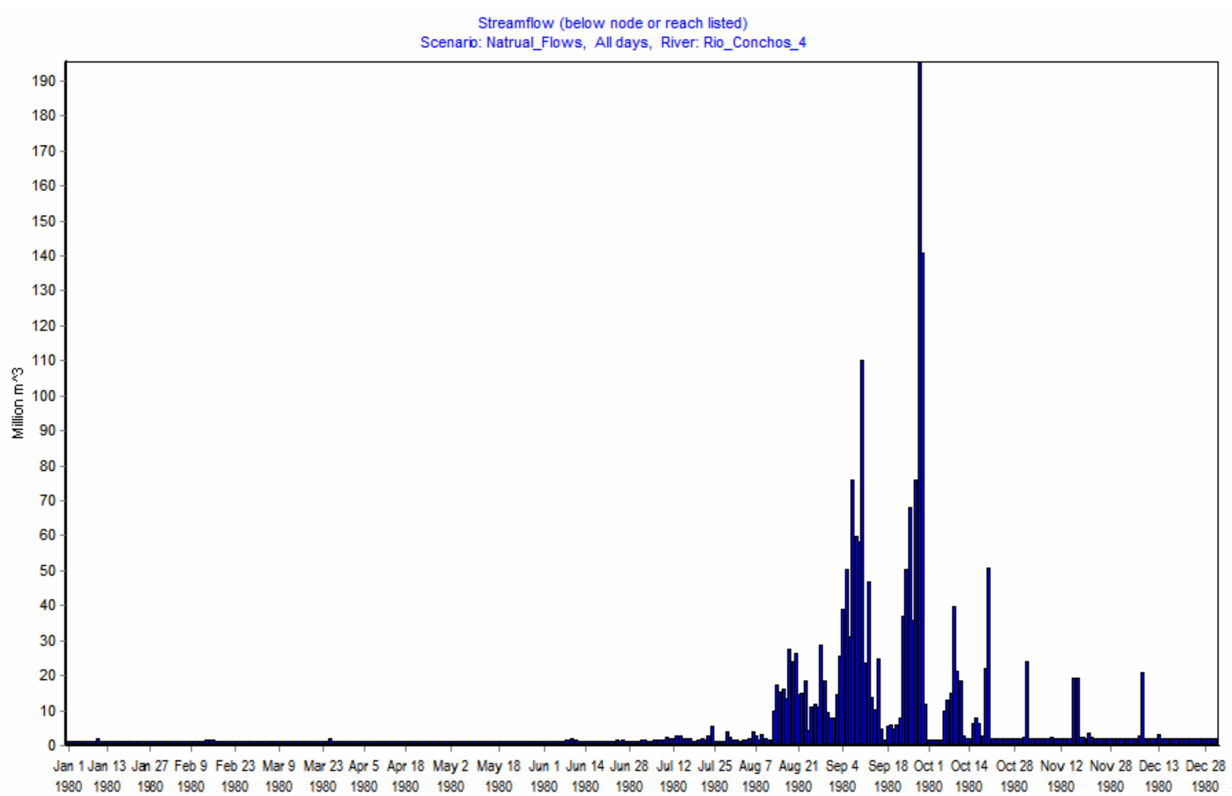


Figure 33. Daily WEAP simulated streamflow in the Rio Conchos at El Granero

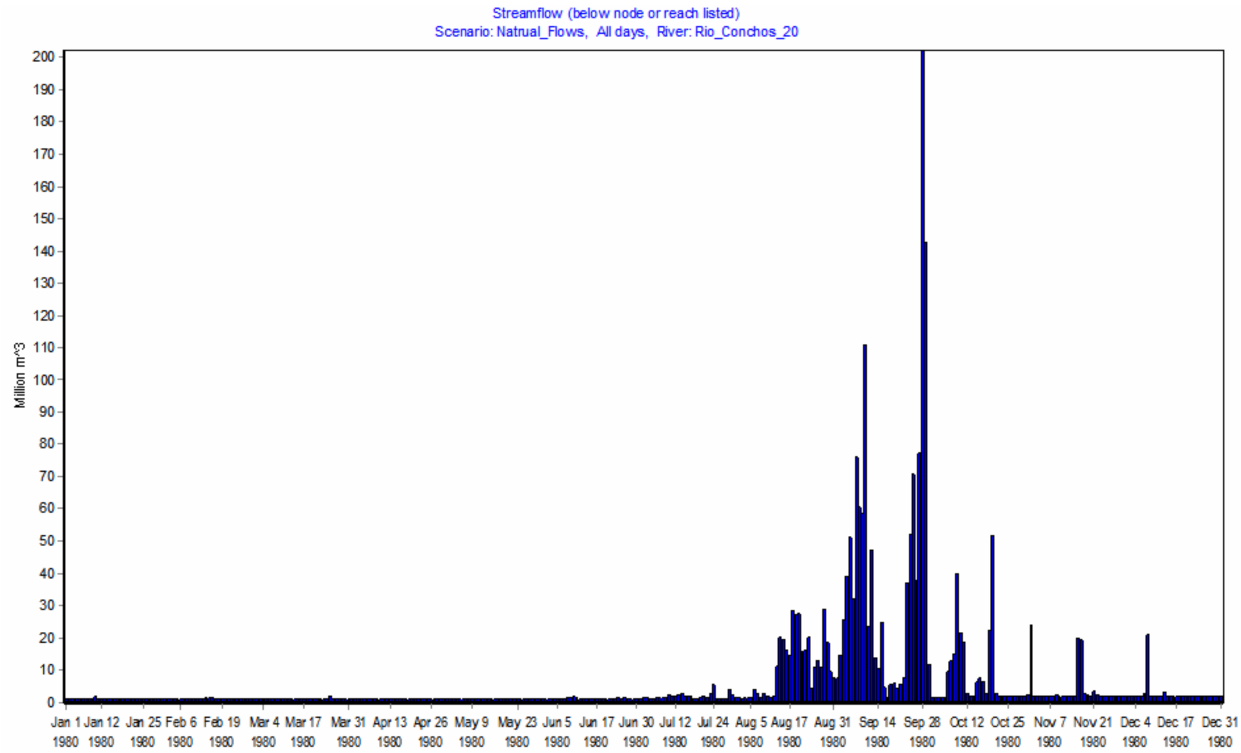


Figure 34. Daily WEAP simulated streamflow in the Rio Conchos at Ojinaga

6. Recommendations

The results show a good approximation to both annual and monthly flows. However, the hydrologic model needs to be validated for a period of time larger, making adjustments as necessary in some soil parameters in order to improve the accuracy in the hydrologic response of the whole basin, considering that the hydraulic conductivity and initial storage increase when the available water in the soil layers increases. In other words, the hydraulic conductivity should be larger in a period with significant rainfall than a period with little to no rainfall.

The integration of WEAP's hydrologic flow predication capabilities into the existing WEAP model of the Rio Bravo basin creates a powerful tool for regional planners. There remains a great deal of work to bring this idea to fruition. The model could be useful in generating inflows to the basin under various sequences of future precipitation. These inflows could be used in the WEAP water management model (Danner et al., 2006) to assess the result for basin stakeholders on different scenarios of basin operation.

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Appendix 1. Soil Land Use Intersects by Sub-basin

Peguis Subbasin No. 1 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	10809	0.01	0.02
	20	0	0.00	0.00
	30	38164	0.04	0.05
	40	6380071	6.38	8.91
	50	6502437	6.50	9.08
	60	20395521	20.40	28.49
	70	27555676	27.56	38.49
	75	5846984	5.85	8.17
	80	2563815	2.56	3.58
	85	576152	0.58	0.80
	90	1721146	1.72	2.40
	95	0	0.00	0.00
Total Soil Area (sq km)			71.59	
% of Total Basin Area			0.93	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	28325	0.03	0.00
	20	1509	0.00	0.00
	30	210334	0.21	0.01
	40	718386	0.72	0.03
	50	5966293	5.97	0.28
	60	379643859	379.64	17.51
	70	1699345239	1699.35	78.36
	75	8675007	8.68	0.40
	80	63771996	63.77	2.94
	85	83173	0.08	0.00
	90	4760341	4.76	0.22
	95	5466388	5.47	0.25
Total Soil Area (sq km)			2168.67	
% of Total Basin Area			28.16	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	497	0.00	0.00
	20	30915	0.03	0.00
	30	61411	0.06	0.00
	40	1953737	1.95	0.06
	50	18742950	18.74	0.59
	60	1081764821	1081.76	33.82
	70	1677846763	1677.85	52.45
	75	117288454	117.29	3.67
	80	287986809	287.99	9.00
	85	935075	0.94	0.03
	90	3920024	3.92	0.12
	95	8285730	8.29	0.26
Total Soil Area (sq km)			3198.82	
% of Total Basin Area			41.53	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	784935	0.78	0.03
	20	0	0.00	0.00
	30	779358	0.78	0.03
	40	268422	0.27	0.01
	50	1145767	1.15	0.05
	60	196367414	196.37	8.68
	70	1896450935	1896.45	83.81
	75	43258657	43.26	1.91
	80	119299233	119.30	5.27
	85	152992	0.15	0.01
	90	348263	0.35	0.02
	95	3877069	3.88	0.17
Total Soil Area (sq km)			2262.73	
% of Total Basin Area			29.38	

Sacramento Subbasin No. 2 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	2080698	2.08	3.75
	60	8281386	8.28	14.93
	70	10034072	10.03	18.09
	75	0	0.00	0.00
	80	34897129	34.90	62.92
	85	136785	0.14	0.25
	90	0	0.00	0.00
	95	28815	0.03	0.05
Total Soil Area (sq km)			55.46	
% of Total Basin Area			5.55	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	421382	0.42	0.11
	20	9461908	9.46	2.36
	30	0	0.00	0.00
	40	864396	0.86	0.22
	50	106013400	106.01	26.46
	60	57268101	57.27	14.29
	70	27067093	27.07	6.76
	75	0	0.00	0.00
	80	177389566	177.39	44.28
	85	22133664	22.13	5.52
	90	0	0.00	0.00
	95	3602	0.00	0.00
Total Soil Area (sq km)			400.62	
% of Total Basin Area			40.10	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	58019667	58.02	10.69
	20	256652163	256.65	47.27
	30	54019	0.05	0.01
	40	3601	0.00	0.00
	50	3521854	3.52	0.65
	60	9638093	9.64	1.78
	70	20659107	20.66	3.80
	75	0	0.00	0.00
	80	194298060	194.30	35.79
	85	18005	0.02	0.00
	90	0	0.00	0.00
	95	86430	0.09	0.02
Total Soil Area (sq km)			542.95	
% of Total Basin Area			54.35	

Total Basin Area (sq km) 999.03

Las Burras Subbasin No. 3 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	1348679	1.35	0.22
	20	3491398	3.49	0.56
	30	268862	0.27	0.04
	40	51729070	51.73	8.25
	50	86410404	86.41	13.78
	60	82011311	82.01	13.08
	70	116617155	116.62	18.60
	75	34740718	34.74	5.54
	80	239524731	239.52	38.21
	85	9928058	9.93	1.58
	90	0	0.00	0.00
	95	816475	0.82	0.13
Total Soil Area (sq km)			626.89	
% of Total Basin Area			5.70	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	10808	0.01	0.00
	20	57645	0.06	0.00
	30	33211	0.03	0.00
	40	146417057	146.42	6.81
	50	152207712	152.21	7.08
	60	630808464	630.81	29.34
	70	489318169	489.32	22.76
	75	44466833	44.47	2.07
	80	666539542	666.54	31.00
	85	9861356	9.86	0.46
	90	10522179	10.52	0.49
	95	0	0.00	0.00
Total Soil Area (sq km)			2150.24	
% of Total Basin Area			19.54	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	100871	0.10	0.00
	20	8485561	8.49	0.13
	30	3383403	3.38	0.05
	40	520324527	520.32	7.79
	50	837594285	837.59	12.53
	60	2302947107	2302.95	34.46
	70	790753723	790.75	11.83
	75	618490117	618.49	9.25
	80	1451828717	1451.83	21.72
	85	24897806	24.90	0.37
	90	123750614	123.75	1.85
	95	887566	0.89	0.01
Total Soil Area (sq km)			6683.44	
% of Total Basin Area			60.75	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	8725885	8.73	0.57
	20	7897203	7.90	0.51
	30	5232815	5.23	0.34
	40	123439312	123.44	8.01
	50	98788610	98.79	6.41
	60	177172330	177.17	11.49
	70	346895520	346.90	22.50
	75	87087745	87.09	5.65
	80	661684417	661.68	42.92
	85	21056387	21.06	1.37
	90	3291647	3.29	0.21
	95	429987	0.43	0.03
Total Soil Area (sq km)			1541.70	
% of Total Basin Area			14.01	

Total Basin Area (sq km)			11002.28	

Luis L Leon Subbasin No. 4 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	244063	0.24	3.08
	50	978266	0.98	12.35
	60	1685046	1.69	21.27
	70	3233952	3.23	40.81
	75	0	0.00	0.00
	80	1782518	1.78	22.50
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			7.92	
% of Total Basin Area			0.16	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	22933	0.02	0.00
	20	183851	0.18	0.02
	30	481725	0.48	0.05
	40	15393824	15.39	1.69
	50	45813616	45.81	5.03
	60	207607031	207.61	22.78
	70	388365033	388.37	42.61
	75	7949771	7.95	0.87
	80	234443639	234.44	25.72
	85	9379959	9.38	1.03
	90	7206	0.01	0.00
	95	1717651	1.72	0.19
Total Soil Area (sq km)			911.37	
% of Total Basin Area			18.01	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	513492	0.51	0.02
	20	132648	0.13	0.01
	30	460195	0.46	0.02
	40	47912375	47.91	1.89
	50	175992744	175.99	6.93
	60	1116136960	1116.14	43.93
	70	671332564	671.33	26.43
	75	58332673	58.33	2.30
	80	348657461	348.66	13.72
	85	111326273	111.33	4.38
	90	52882	0.05	0.00
	95	9619594	9.62	0.38
Total Soil Area (sq km)			2540.47	
% of Total Basin Area			50.22	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	5980885	5.98	0.37
	20	10580280	10.58	0.66
	30	13338357	13.34	0.83
	40	2970647	2.97	0.19
	50	14201108	14.20	0.89
	60	223999441	224.00	14.01
	70	937009929	937.01	58.59
	75	3783948	3.78	0.24
	80	368206205	368.21	23.02
	85	16899482	16.90	1.06
	90	414581	0.41	0.03
	95	1867838	1.87	0.12
Total Soil Area (sq km)			1599.25	
% of Total Basin Area			31.61	

Total Basin Area (sq km)			5059.01	

Fco. I Madero Subbasin No. 5 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	14409	0.01	0.01
	20	3602	0.00	0.00
	30	718311	0.72	0.29
	40	617966	0.62	0.25
	50	96833	0.10	0.04
	60	96709578	96.71	38.86
	70	127171804	127.17	51.11
	75	3362445	3.36	1.35
	80	19442604	19.44	7.81
	85	0	0.00	0.00
	90	320622	0.32	0.13
	95	384658	0.38	0.15
Total Soil Area (sq km)			248.84	
% of Total Basin Area			20.55	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	0.00
	20	10806	0.01	0.01
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	529854	0.53	0.57
	60	8404140	8.40	9.01
	70	64451280	64.45	69.10
	75	244893	0.24	0.26
	80	19180655	19.18	20.57
	85	0	0.00	0.00
	90	199476	0.20	0.21
	95	246604	0.25	0.26
Total Soil Area (sq km)			93.27	
% of Total Basin Area			7.70	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	21615	0.02	0.01
	20	177022	0.18	0.05
	30	850377	0.85	0.23
	40	454043	0.45	0.12
	50	5502779	5.50	1.46
	60	66640433	66.64	17.68
	70	85946828	85.95	22.80
	75	6576606	6.58	1.74
	80	209290902	209.29	55.52
	85	0	0.00	0.00
	90	1296603	1.30	0.34
	95	218890	0.22	0.06
Total Soil Area (sq km)			376.98	
% of Total Basin Area			31.12	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	9180988	9.18	1.87
	20	9229651	9.23	1.88
	30	16087745	16.09	3.27
	40	930897	0.93	0.19
	50	2272540	2.27	0.46
	60	26940121	26.94	5.47
	70	137512567	137.51	27.94
	75	5368029	5.37	1.09
	80	284000170	284.00	57.71
	85	479061	0.48	0.10
	90	56554	0.06	0.01
	95	36020	0.04	0.01
Total Soil Area (sq km)			492.09	
% of Total Basin Area			40.63	

Total Basin Area (sq km)		1211.18

Villalba Subbasin No. 6 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	198132641	198.13	8.56
	20	413894292	413.89	17.87
	30	187225	0.19	0.01
	40	8933646	8.93	0.39
	50	533238747	533.24	23.03
	60	98264833	98.26	4.24
	70	107702593	107.70	4.65
	75	0	0.00	0.00
	80	952504833	952.50	41.13
	85	1555012	1.56	0.07
	90	0	0.00	0.00
	95	1228024	1.23	0.05
Total Soil Area (sq km)			2315.64	
% of Total Basin Area			24.78	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	125748168	125.75	4.65
	20	161637049	161.64	5.98
	30	0	0.00	0.00
	40	5899623	5.90	0.22
	50	555046757	555.05	20.54
	60	182512530	182.51	6.75
	70	291867882	291.87	10.80
	75	375438	0.38	0.01
	80	1375486854	1375.49	50.90
	85	439389	0.44	0.02
	90	381	0.00	0.00
	95	3179484	3.18	0.12
Total Soil Area (sq km)			2702.19	
% of Total Basin Area			28.92	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	362443991	362.44	12.56
	20	443870114	443.87	15.38
	30	7201	0.01	0.00
	40	7068322	7.07	0.24
	50	269218659	269.22	9.33
	60	220214230	220.21	7.63
	70	126818601	126.82	4.39
	75	0	0.00	0.00
	80	1452923855	1452.92	50.33
	85	3010849	3.01	0.10
	90	3221	0.00	0.00
	95	965096	0.97	0.03
Total Soil Area (sq km)			2886.54	
% of Total Basin Area			30.89	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	335729645	335.73	23.31
	20	370882733	370.88	25.75
	30	0	0.00	0.00
	40	21603	0.02	0.00
	50	54475310	54.48	3.78
	60	28195313	28.20	1.96
	70	156117713	156.12	10.84
	75	0	0.00	0.00
	80	492312880	492.31	34.18
	85	2211562	2.21	0.15
	90	10906	0.01	0.00
	95	317715	0.32	0.02
Total Soil Area (sq km)			1440.28	
% of Total Basin Area			15.41	

Total Basin Area (sq km) 9344.65

Conchos Subbasin No. 7 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	0.00
	20	50436	0.05	0.02
	30	0	0.00	0.00
	40	408759	0.41	0.18
	50	309305	0.31	0.14
	60	83971705	83.97	36.98
	70	35919750	35.92	15.82
	75	43267506	43.27	19.06
	80	57232239	57.23	25.21
	85	0	0.00	0.00
	90	158360	0.16	0.07
	95	5743406	5.74	2.53
Total Soil Area (sq km)			227.06	
% of Total Basin Area			20.38	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	0.00
	20	0	0.00	0.00
	30	110478	0.11	0.02
	40	43823515	43.82	8.95
	50	17907504	17.91	3.66
	60	237194242	237.19	48.47
	70	70536060	70.54	14.41
	75	57198139	57.20	11.69
	80	47225575	47.23	9.65
	85	2708745	2.71	0.55
	90	12673210	12.67	2.59
	95	0	0.00	0.00
Total Soil Area (sq km)			489.38	
% of Total Basin Area			43.92	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	347434	0.35	0.12
	50	1253316	1.25	0.44
	60	72240662	72.24	25.41
	70	6163864	6.16	2.17
	75	69507528	69.51	24.45
	80	124531733	124.53	43.80
	85	0	0.00	0.00
	90	8414032	8.41	2.96
	95	1852499	1.85	0.65
Total Soil Area (sq km)			284.31	
% of Total Basin Area			25.52	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	0	0.00	0.00
	20	36025	0.04	0.03
	30	0	0.00	0.00
	40	9770	0.01	0.01
	50	133881	0.13	0.12
	60	23126719	23.13	20.38
	70	31533083	31.53	27.79
	75	3644145	3.64	3.21
	80	52251006	52.25	46.06
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	2717052	2.72	2.39
Total Soil Area (sq km)			113.45	
% of Total Basin Area			10.18	

Total Basin Area (sq km)			1114.20	

Jimenez Subbasin No. 8 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	34913902	34.91	3.76
	20	28441541	28.44	3.07
	30	1389805	1.39	0.15
	40	4202684	4.20	0.45
	50	97692805	97.69	10.53
	60	84047669	84.05	9.06
	70	1924469	1.92	0.21
	75	0	0.00	0.00
	80	666241918	666.24	71.84
	85	5153187	5.15	0.56
	90	3341768	3.34	0.36
	95	0	0.00	0.00
Total Soil Area (sq km)			927.35	
% of Total Basin Area			20.98	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	23815323	23.82	6.21
	20	48552171	48.55	12.67
	30	0	0.00	0.00
	40	3189980	3.19	0.83
	50	29959563	29.96	7.82
	60	43308066	43.31	11.30
	70	21440609	21.44	5.59
	75	0	0.00	0.00
	80	212842931	212.84	55.54
	85	113220	0.11	0.03
	90	0	0.00	0.00
	95	32421	0.03	0.01
Total Soil Area (sq km)			383.25	
% of Total Basin Area			8.67	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	15956187	15.96	0.60
	20	31508941	31.51	1.18
	30	1505934	1.51	0.06
	40	63100775	63.10	2.35
	50	464100157	464.10	17.32
	60	558066867	558.07	20.82
	70	191146341	191.15	7.13
	75	20821027	20.82	0.78
	80	1317856274	1317.86	49.17
	85	2615272	2.62	0.10
	90	13393245	13.39	0.50
	95	3602	0.00	0.00
Total Soil Area (sq km)			2680.07	
% of Total Basin Area			60.62	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	48816092	48.82	11.34
	20	33443498	33.44	7.77
	30	0	0.00	0.00
	40	78064788	78.06	18.14
	50	68821328	68.82	15.99
	60	54500399	54.50	12.66
	70	11771107	11.77	2.73
	75	0	0.00	0.00
	80	128987283	128.99	29.97
	85	1247547	1.25	0.29
	90	4748616	4.75	1.10
	95	0	0.00	0.00
Total Soil Area (sq km)			430.40	
% of Total Basin Area			9.74	

Total Basin Area (sq km) 4421.08

Chuviscar Subbasin No. 9 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	64830	0.06	0.20
	20	0	0.00	0.00
	30	374542	0.37	1.14
	40	0	0.00	0.00
	50	4194101	4.19	12.75
	60	5450720	5.45	16.56
	70	10403415	10.40	31.61
	75	0	0.00	0.00
	80	6810254	6.81	20.70
	85	5608765	5.61	17.04
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			32.91	
% of Total Basin Area			31.69	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	0	0.00	0.00
	20	1085320	1.09	1.53
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	362367	0.36	0.51
	60	6543030	6.54	9.23
	70	48892701	48.89	68.94
	75	0	0.00	0.00
	80	6040955	6.04	8.52
	85	7997881	8.00	11.28
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			70.92	
% of Total Basin Area			68.31	

Total Basin Area (sq km) 103.83

El Rejon Subbasin No. 10 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	6387713	6.39	38.39
	60	3037632	3.04	18.26
	70	3075528	3.08	18.48
	75	0	0.00	0.00
	80	4138956	4.14	24.87
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			16.64	
% of Total Basin Area			11.34	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	6056313	6.06	4.65
	20	41631691	41.63	31.99
	30	0	0.00	0.00
	40	28813	0.03	0.02
	50	2486618	2.49	1.91
	60	4600997	4.60	3.54
	70	11264658	11.26	8.66
	75	0	0.00	0.00
	80	64079278	64.08	49.24
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			130.15	
% of Total Basin Area			88.66	

Total Basin Area (sq km)			146.79	

Chihuahua Subbasin No. 11 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	5980028	5.98	20.05
	20	2063619	2.06	6.92
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	15126355	15.13	50.71
	60	234106	0.23	0.78
	70	314262	0.31	1.05
	75	0	0.00	0.00
	80	6111300	6.11	20.49
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			29.83	
% of Total Basin Area			7.46	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	241982	0.24	32.57
	20	25687	0.03	3.46
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	300345	0.30	40.42
	60	0	0.00	0.00
	70	51689	0.05	6.96
	75	0	0.00	0.00
	80	123307	0.12	16.60
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			0.74	
% of Total Basin Area			0.19	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	43220	0.04	0.06
	20	1825414	1.83	2.33
	30	551099	0.55	0.70
	40	0	0.00	0.00
	50	11020715	11.02	14.06
	60	3614801	3.61	4.61
	70	32032113	32.03	40.85
	75	0	0.00	0.00
	80	29321473	29.32	37.40
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			78.41	
% of Total Basin Area			19.61	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	25436490	25.44	8.75
	20	79428062	79.43	27.31
	30	0	0.00	0.00
	40	32412	0.03	0.01
	50	5477565	5.48	1.88
	60	1361756	1.36	0.47
	70	44840350	44.84	15.42
	75	0	0.00	0.00
	80	134267868	134.27	46.16
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	18008	0.02	0.01
Total Soil Area (sq km)			290.86	
% of Total Basin Area			72.74	

Total Basin Area (sq km)			399.84	

Llanitos Subbasin No. 12 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	207646613	207.65	66.46
	20	46749497	46.75	14.96
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	622991	0.62	0.20
	60	567584	0.57	0.18
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	55468865	55.47	17.75
	85	1378106	1.38	0.44
	90	0	0.00	0.00
	95	7203	0.01	0.00
Total Soil Area (sq km)			312.44	
% of Total Basin Area			18.85	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	424400774	424.40	47.59
	20	289603320	289.60	32.47
	30	0	0.00	0.00
	40	115251	0.12	0.01
	50	4628554	4.63	0.52
	60	9684430	9.68	1.09
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	162060957	162.06	18.17
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	1311011	1.31	0.15
Total Soil Area (sq km)			891.80	
% of Total Basin Area			53.81	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	6519778	6.52	8.68
	20	15990376	15.99	21.29
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	9375068	9.38	12.48
	60	1530698	1.53	2.04
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	41693464	41.69	55.50
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	14406	0.01	0.02
Total Soil Area (sq km)			75.12	
% of Total Basin Area			4.53	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	260274965	260.27	68.85
	20	71044864	71.04	18.79
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	3075931	3.08	0.81
	60	375746	0.38	0.10
	70	0	0.00	0.00
	75	64830	0.06	0.02
	80	41570696	41.57	11.00
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	1615693	1.62	0.43
Total Soil Area (sq km)			378.02	
% of Total Basin Area			22.81	

Total Basin Area (sq km)			1657.39	

Pico del Aguila Subbasin No. 13 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	563035	0.56	0.29
	20	3633432	3.63	1.90
	30	3499174	3.50	1.83
	40	248823	0.25	0.13
	50	3411540	3.41	1.79
	60	6280169	6.28	3.29
	70	10814	0.01	0.01
	75	0	0.00	0.00
	80	173088051	173.09	90.57
	85	0	0.00	0.00
	90	365534	0.37	0.19
	95	0	0.00	0.00
Total Soil Area (sq km)			191.10	
% of Total Basin Area			29.60	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	1943288	1.94	1.07
	20	4702495	4.70	2.59
	30	0	0.00	0.00
	40	1456622	1.46	0.80
	50	30130067	30.13	16.61
	60	22652882	22.65	12.49
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	118993787	118.99	65.61
	85	555938	0.56	0.31
	90	936755	0.94	0.52
	95	0	0.00	0.00
Total Soil Area (sq km)			181.37	
% of Total Basin Area			28.10	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	35215145	35.22	13.91
	20	11339547	11.34	4.48
	30	183745	0.18	0.07
	40	270212	0.27	0.11
	50	20267463	20.27	8.00
	60	8301945	8.30	3.28
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	177661692	177.66	70.16
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			253.24	
% of Total Basin Area			39.23	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	0	0.00	0.00
	20	525530	0.53	2.65
	30	0	0.00	0.00
	40	1396	0.00	0.01
	50	2943179	2.94	14.84
	60	3456129	3.46	17.43
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	12888235	12.89	65.00
	85	13305	0.01	0.07
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			19.83	
% of Total Basin Area			3.07	

Total Basin Area (sq km)			645.54	

San Antonio Subbasin No. 14 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	12245098	12.25	3.37
	20	10223355	10.22	2.81
	30	0	0.00	0.00
	40	6803211	6.80	1.87
	50	70427757	70.43	19.36
	60	93638097	93.64	25.73
	70	24514	0.02	0.01
	75	0	0.00	0.00
	80	168993744	168.99	46.44
	85	529094	0.53	0.15
	90	974165	0.97	0.27
	95	0	0.00	0.00
Total Soil Area (sq km)			363.86	
% of Total Basin Area			44.58	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	1006218	1.01	5.15
	20	1137574	1.14	5.82
	30	0	0.00	0.00
	40	59303	0.06	0.30
	50	601006	0.60	3.08
	60	3761115	3.76	19.25
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	12589580	12.59	64.45
	85	0	0.00	0.00
	90	379312	0.38	1.94
	95	0	0.00	0.00
Total Soil Area (sq km)			19.53	
% of Total Basin Area			2.39	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	9386	0.01	0.01
	20	7938507	7.94	4.55
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	66525125	66.53	38.14
	60	14968165	14.97	8.58
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	84987486	84.99	48.72
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			174.43	
% of Total Basin Area			21.37	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	7055845	7.06	2.73
	20	34584464	34.58	13.38
	30	0	0.00	0.00
	40	5054908	5.05	1.96
	50	23854670	23.85	9.23
	60	30056910	30.06	11.63
	70	225807	0.23	0.09
	75	0	0.00	0.00
	80	151562386	151.56	58.65
	85	2558464	2.56	0.99
	90	3472480	3.47	1.34
	95	0	0.00	0.00
Total Soil Area (sq km)			258.43	
% of Total Basin Area			31.66	

Total Basin Area (sq km)			816.25	

San Gabriel Subbasin No. 15 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	9792047	9.79	6.31
	20	2553014	2.55	1.64
	30	2113306	2.11	1.36
	40	2898077	2.90	1.87
	50	23577971	23.58	15.18
	60	49325485	49.33	31.76
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	64658424	64.66	41.64
	85	0	0.00	0.00
	90	376775	0.38	0.24
	95	0	0.00	0.00
Total Soil Area (sq km)			155.30	
% of Total Basin Area			50.97	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	16709344	16.71	29.90
	20	7096729	7.10	12.70
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	268279	0.27	0.48
	60	1166782	1.17	2.09
	70	41548	0.04	0.07
	75	203977	0.20	0.37
	80	30392781	30.39	54.39
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			55.88	
% of Total Basin Area			18.34	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	7575164	7.58	8.10
	20	33131067	33.13	35.43
	30	7361479	7.36	7.87
	40	2260	0.00	0.00
	50	3276839	3.28	3.50
	60	7467932	7.47	7.99
	70	650342	0.65	0.70
	75	0	0.00	0.00
	80	34040505	34.04	36.40
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			93.51	
% of Total Basin Area			30.69	

Total Basin Area (sq km)			304.68	

Puente FFCC Subbasin No. 16 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	13674219	13.67	9.36
	20	5234650	5.23	3.58
	30	0	0.00	0.00
	40	1159997	1.16	0.79
	50	53005090	53.01	36.28
	60	15190917	15.19	10.40
	70	889732	0.89	0.61
	75	0	0.00	0.00
	80	55854892	55.85	38.23
	85	1018642	1.02	0.70
	90	64841	0.06	0.04
	95	0	0.00	0.00
Total Soil Area (sq km)			146.09	
% of Total Basin Area			12.23	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	0	0.00	0.00
	60	0	0.00	0.00
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	366379	0.37	100.00
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			0.37	
% of Total Basin Area			0.03	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	91085210	91.09	21.30
	20	133778292	133.78	31.29
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	60150210	60.15	14.07
	60	8993159	8.99	2.10
	70	204982	0.20	0.05
	75	558517	0.56	0.13
	80	132792471	132.79	31.06
	85	10807	0.01	0.00
	90	0	0.00	0.00
	95	3552	0.00	0.00
Total Soil Area (sq km)			427.58	
% of Total Basin Area			35.80	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	341348993	341.35	55.03
	20	206538030	206.54	33.30
	30	0	0.00	0.00
	40	37	0.00	0.00
	50	3998262	4.00	0.64
	60	2448281	2.45	0.39
	70	2417668	2.42	0.39
	75	21612	0.02	0.00
	80	60283452	60.28	9.72
	85	231431	0.23	0.04
	90	0	0.00	0.00
	95	3004692	3.00	0.48
Total Soil Area (sq km)			620.29	
% of Total Basin Area			51.94	

Total Basin Area (sq km) 1194.33

Parral Subbasin No. 17 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	516654	0.52	0.67
	20	4846086	4.85	6.27
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	19084748	19.08	24.68
	60	2770671	2.77	3.58
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	49733890	49.73	64.33
	85	364463	0.36	0.47
	90	0	0.00	0.00
	95	0	0.00	0.00
			77.32	
			21.26	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	18939225	18.94	11.57
	20	38996986	39.00	23.82
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	4084334	4.08	2.49
	60	2998509	3.00	1.83
	70	319330	0.32	0.20
	75	0	0.00	0.00
	80	95929175	95.93	58.60
	85	2445131	2.45	1.49
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			163.71	
% of Total Basin Area			45.01	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	0	0.00	0.00
	20	356330	0.36	57.64
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	0	0.00	0.00
	60	0	0.00	0.00
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	261833	0.26	42.36
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			0.62	
% of Total Basin Area			0.17	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	35647474	35.65	29.19
	20	7732552	7.73	6.33
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	19077829	19.08	15.62
	60	3005443	3.01	2.46
	70	280	0.00	0.00
	75	0	0.00	0.00
	80	56054692	56.05	45.91
	85	587348	0.59	0.48
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			122.11	
% of Total Basin Area			33.57	

Total Basin Area (sq km)	363.75

Colina Subbasin No. 18 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	0	0.00	0.00
	60	47971579	47.97	39.93
	70	20500895	20.50	17.06
	75	20308646	20.31	16.90
	80	26849590	26.85	22.35
	85	0	0.00	0.00
	90	1253886	1.25	1.04
	95	3249572	3.25	2.70
Total Soil Area (sq km)			120.13	
% of Total Basin Area			46.94	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	0.00
	20	0	0.00	0.00
	30	121537	0.12	0.25
	40	2379373	2.38	4.97
	50	615402	0.62	1.29
	60	15650886	15.65	32.69
	70	23176041	23.18	48.41
	75	0	0.00	0.00
	80	5893782	5.89	12.31
	85	0	0.00	0.00
	90	36028	0.04	0.08
	95	0	0.00	0.00
Total Soil Area (sq km)			47.87	
% of Total Basin Area			18.71	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	258856	0.26	0.40
	20	0	0.00	0.00
	30	5161004	5.16	8.06
	40	4142957	4.14	6.47
	50	3509971	3.51	5.48
	60	25459693	25.46	39.78
	70	4716003	4.72	7.37
	75	0	0.00	0.00
	80	20750688	20.75	32.42
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			64.00	
% of Total Basin Area			25.01	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	274349	0.27	1.15
	20	0	0.00	0.00
	30	2650974	2.65	11.08
	40	2098721	2.10	8.77
	50	1447651	1.45	6.05
	60	7382191	7.38	30.86
	70	9806207	9.81	40.99
	75	0	0.00	0.00
	80	261624	0.26	1.09
	85	0	0.00	0.00
	90	3603	0.00	0.02
	95	0	0.00	0.00
Total Soil Area (sq km)			23.93	
% of Total Basin Area			9.35	

Total Basin Area (sq km) 255.93

La Boquilla Subbasin No. 19 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	1170628229	1170.63	24.86
	20	746690894	746.69	15.86
	30	400181	0.40	0.01
	40	10911772	10.91	0.23
	50	619673766	619.67	13.16
	60	422781624	422.78	8.98
	70	85146360	85.15	1.81
	75	317979	0.32	0.01
	80	1633173132	1633.17	34.68
	85	1313984	1.31	0.03
	90	50402	0.05	0.00
	95	17931306	17.93	0.38
Total Soil Area (sq km)			4709.02	
% of Total Basin Area			26.56	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	2076083278	2076.08	30.18
	20	1610168768	1610.17	23.41
	30	0	0.00	0.00
	40	9992579	9.99	0.15
	50	497251893	497.25	7.23
	60	257303211	257.30	3.74
	70	42635586	42.64	0.62
	75	523486	0.52	0.01
	80	2380528535	2380.53	34.60
	85	1871345	1.87	0.03
	90	1260822	1.26	0.02
	95	1808601	1.81	0.03
Total Soil Area (sq km)			6879.43	
% of Total Basin Area			38.80	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	494974896	494.97	12.79
	20	471496196	471.50	12.18
	30	17042455	17.04	0.44
	40	4733926	4.73	0.12
	50	343967487	343.97	8.89
	60	446845917	446.85	11.54
	70	63865488	63.87	1.65
	75	1594508	1.59	0.04
	80	2005201600	2005.20	51.80
	85	5061537	5.06	0.13
	90	0	0.00	0.00
	95	16256688	16.26	0.42
Total Soil Area (sq km)			3871.04	
% of Total Basin Area			21.83	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	343710053	343.71	15.13
	20	395442448	395.44	17.41
	30	32836869	32.84	1.45
	40	3428887	3.43	0.15
	50	108937067	108.94	4.80
	60	392471158	392.47	17.28
	70	70823994	70.82	3.12
	75	2142447	2.14	0.09
	80	909521959	909.52	40.04
	85	284184	0.28	0.01
	90	57591	0.06	0.00
	95	11918114	11.92	0.52
Total Soil Area (sq km)			2271.57	
% of Total Basin Area			12.81	

Total Basin Area (sq km) 17731.06

Ojinaga Subbasin No. 20 Soil - Land Use Intersect

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
A	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
B	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	0	0.00	0.00
	60	16361	0.02	59.07
	70	11338	0.01	40.93
	75	0	0.00	0.00
	80	0	0.00	0.00
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			0.03	
% of Total Basin Area			60.01	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
C	10	0	0.00	#DIV/0!
	20	0	0.00	#DIV/0!
	30	0	0.00	#DIV/0!
	40	0	0.00	#DIV/0!
	50	0	0.00	#DIV/0!
	60	0	0.00	#DIV/0!
	70	0	0.00	#DIV/0!
	75	0	0.00	#DIV/0!
	80	0	0.00	#DIV/0!
	85	0	0.00	#DIV/0!
	90	0	0.00	#DIV/0!
	95	0	0.00	#DIV/0!
Total Soil Area (sq km)			0.00	
% of Total Basin Area			0.00	

Soil Group	Land Use	Area (sq m)	Area (sq km)	% of Soil Group
D	10	0	0.00	0.00
	20	0	0.00	0.00
	30	0	0.00	0.00
	40	0	0.00	0.00
	50	0	0.00	0.00
	60	18458	0.02	100.00
	70	0	0.00	0.00
	75	0	0.00	0.00
	80	0	0.00	0.00
	85	0	0.00	0.00
	90	0	0.00	0.00
	95	0	0.00	0.00
Total Soil Area (sq km)			0.02	
% of Total Basin Area			39.99	

Total Basin Area (sq km)			0.05	

Appendix 2. CRWR Geodatabase Reach Lengths

Basin Name	IMTA Basin ID	Reach Name	Reach Length (km)	Notes
Peguis	1	Rio_Conchos_1	142.32	DS Reach Rio_Conchos_20
Sacramento	2	-	-	Headwater to Rio_Sacramento_4
Las Burras	3	Rio_Conchos_3	135.41	DS Reach Rio_Conchos_4
		Rio_Florido_3	89.05	DS Reach Rio_Conchos_3
		Arroyo_El_Parral_3	148.77	DS Reach Rio_Florido_3
		Rio_San_Pedro_3	38.65	DS Reach Rio_Conchos_3
Luis L. Leon	4	Rio_Conchos_4	88.74	DS Reach Rio_Conchos_1
		Rio_Sacramento_4	103.49	DS Reach Rio_Conchos_4
		Arroyo_Sacramento_4	5.55	DS Reach Rio_Sacramento_4
FCO. Madero	5	Rio_San_Pedro_5	29.15	Headwater to Rio_San_Pedro_3
Villalba	6	-	-	Headwater to Rio_San_Pedro_5
Conchos	7	Rio_Conchos_7	25.94	DS Reach: Rio_Conchos_3
Jimenez	8	Rio_Florido_8	88.08	DS Reach: Rio_FLorido_3
Chuviscar	9	Arroyo_Sacramento_9	140.41	DS Reach: Arroyo_Sacramento_4
		River_10	3.12	DS Reach Arroyo_Sacramento_9
El Rejon	10	-	-	Headwater to River_10
Chihuahua	11	-	-	Headwater to Arroyo_Sacramento_9
Llanitos	12	-	-	Headwater to RioBalleza_Conchos_19
Pico del Aguila	13	Rio_Florido_13	24.05	DS Reach Rio_Florido_8
San Antonio	14	Rio_Florido_14	28.33	DS Reach Rio_Florido_13
San Gabriel	15	Rio_Florido_15	12.54	DS Reach Rio_Florido_14
Puente FFCC	16	-	-	Headwater to Rio_Florido_15
Parral	17	-	-	Headwater to Arroyo_El_Parral_3
Colina	18	Rio_Conchos_18	18210.59	DS Reach Rio_Conchos_7
La Boquilla	19	RioBalleza_Conchos_19	259.86	DS Reach Rio_Conchos_18
Ojinaga	20	Rio_Conchos_20	45.90	Outfall