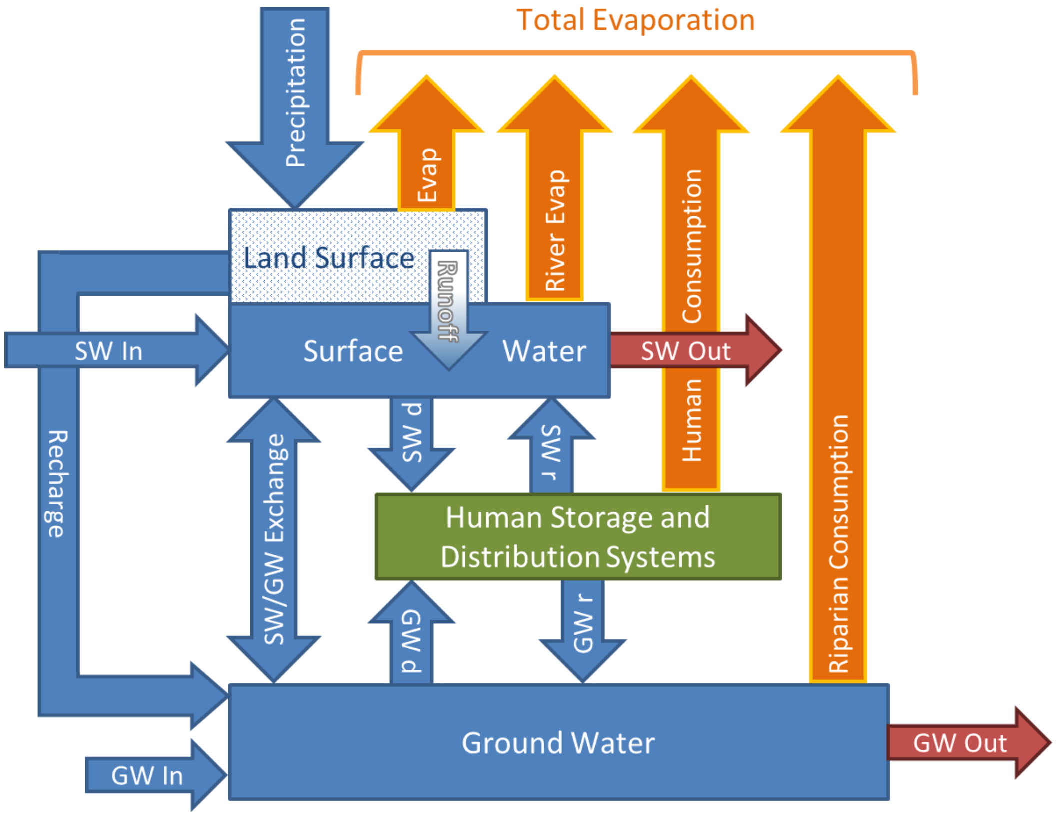
A DYNAMIC STATEWIDE WATER BUDGET FOR NEW MEXICO:
Phase I - MAJOR RIVER BASINS



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Contents

List of Figures

List of Tables

List of Acronyms

AF	Acre feet
BBER	Bureau of Business and Economic Research
BFI	Baseflow index
cfs	Cubic feet per second
CIR	Consumptive irrigation requirement
ET	Evapotranspiration
ft	Feet
°F	Degrees Fahrenheit
GPCD	Gallons per capita per day
GW	Groundwater
HSDS	Human storage & distribution system
in	Inches
LULC	Land use land cover
MBAU	Mass balance accounting unit
NASS	National Agricultural Statistics Service
NIPP	Navajo Indian Irrigation Project
NMDA	New Mexico Department of Agriculture
NMDSWB	New Mexico Dynamic Statewide Water Budget
NMISC	New Mexico Interstate Stream Commission
NMSU	New Mexico State University
OSE	Office of the State Engineer
PRISM	Parameter Relationship on Independent Slopes Model
R	Rainfall
R_e	Effective rainfall
SW	Surface water
TR-21	Technical Release 21
URGSiM	Upper Rio Grande Simulation Model
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA-NASS	United States Department of Agriculture National Statistics Service
USDA-SCS	United States Department of Agriculture Soil Conservation Service
USGS	United States Geological Service
WPR	Water Planning Region
WRRI	Water Resources Research Institute

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1 Dynamic Statewide Water Budget Framework

New Mexico Dynamic Statewide Water Budget (NMDSWB) is an effort to account for the origin and fate of New Mexico's water resources through time. As is common in formalized accounting methods, the NMDSWB uses stocks to define how much water of a given type is present in a given location over a given amount of time, and uses fluxes to determine how water moves from one stock to another, or into or out of the area of interest. This report describes the first phase of this study which was to develop a mass balance accounting of water in the major river basins of the state. Water budgets for the water planning regions (WPRs) and for individual counties will be completed in subsequent studies. The river basins defined are shown, in Figure 1. The 16 WPRs are defined by the State of New Mexico (New Mexico Interstate Stream Commission, 1994) as shown in Figure 2. County boundaries are shown in both Figure 1 and Figure 2.

The spatial extent for the framework of the analysis described in this report is the State of New Mexico, meaning summing terms across all river basins, WPRs, or counties considered will give values at the state level. The temporal resolution of the mass balance is monthly meaning no flux or change in storage information will be available averaged across less than a month of time. The historic data for the study extends from 1975 through 2010, and in future efforts will be extended forward from 2010 for scenario evaluation. The stocks and fluxes quantified in this effort are shown in Figure 3. The NMDSWB tracks human withdrawals, consumption, and returns of surface water and groundwater. Water is withdrawn for various uses including public water supply, irrigated agriculture, industry, commerce, mining, livestock, and domestic use. Some of this withdrawn water is returned to the surface water or groundwater systems, while the rest of that water is consumed (i.e. evaporated and returned to the atmosphere) which comprises the consumptive use of the NMDSWB. Because the NMDSWB tracks the amount of water in man-made storage and conveyance systems separately from water in rivers, additions to storage in reservoirs are considered withdrawals from the surface water system, reductions in storage are considered returns to the surface water system, while reservoir evaporation is accounted for as human consumption. In addition to human consumption, the NMDSWB accounts for riparian consumption, land surface evaporation, and surface water evaporation. The following sections describe and detail how the various demands for water are tabulated and or calculated.

In its current configuration, the NMDSWB is a retrospective accounting of all water resources, flows, and uses in each of the major watersheds in the state. This is accomplished by using historic data and calculations of stream flows, precipitation, climatological conditions (primarily precipitation and temperature), land use, and water use to estimate how much water was available, how it moved through the basin both as surface water and groundwater, and whether there were net accumulations or depletions of the resource. The NMDSWB was developed as a dynamic tool whose inputs eventually might be modified for use as a forecasting model by incorporating assumptions or projections related to future climatological conditions, runoff, population growth, land use and agricultural practices, and other factors that are important to the occurrence, flow, and consumptive use of water. The NMDSWB has been developed with this structure in mind and its ability to be used as a forecasting tool will be the subject of future work.

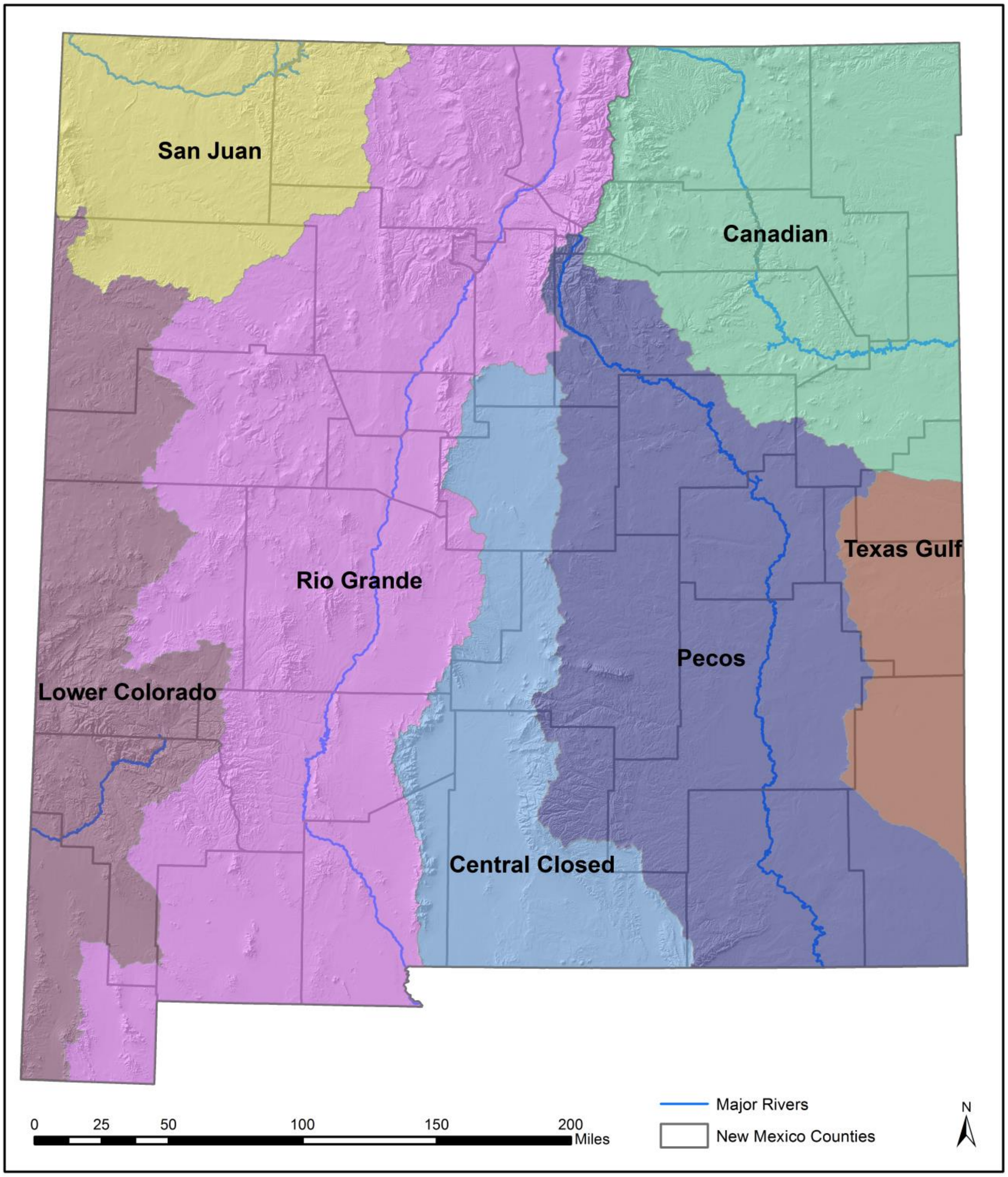

Figure 1 NMDSWB New Mexico River basins.

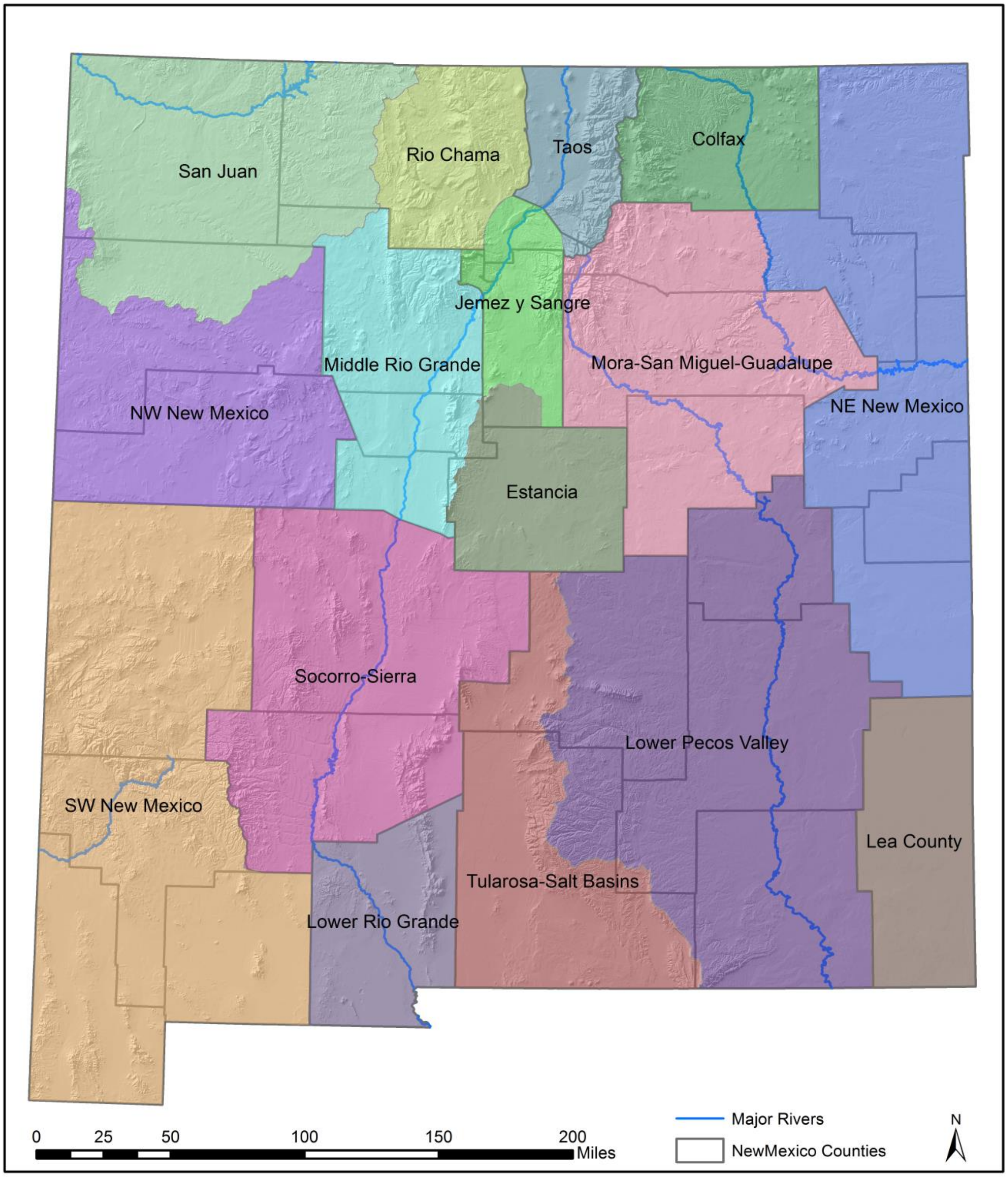

Figure 2 The 16 New Mexico Water Planning Regions.

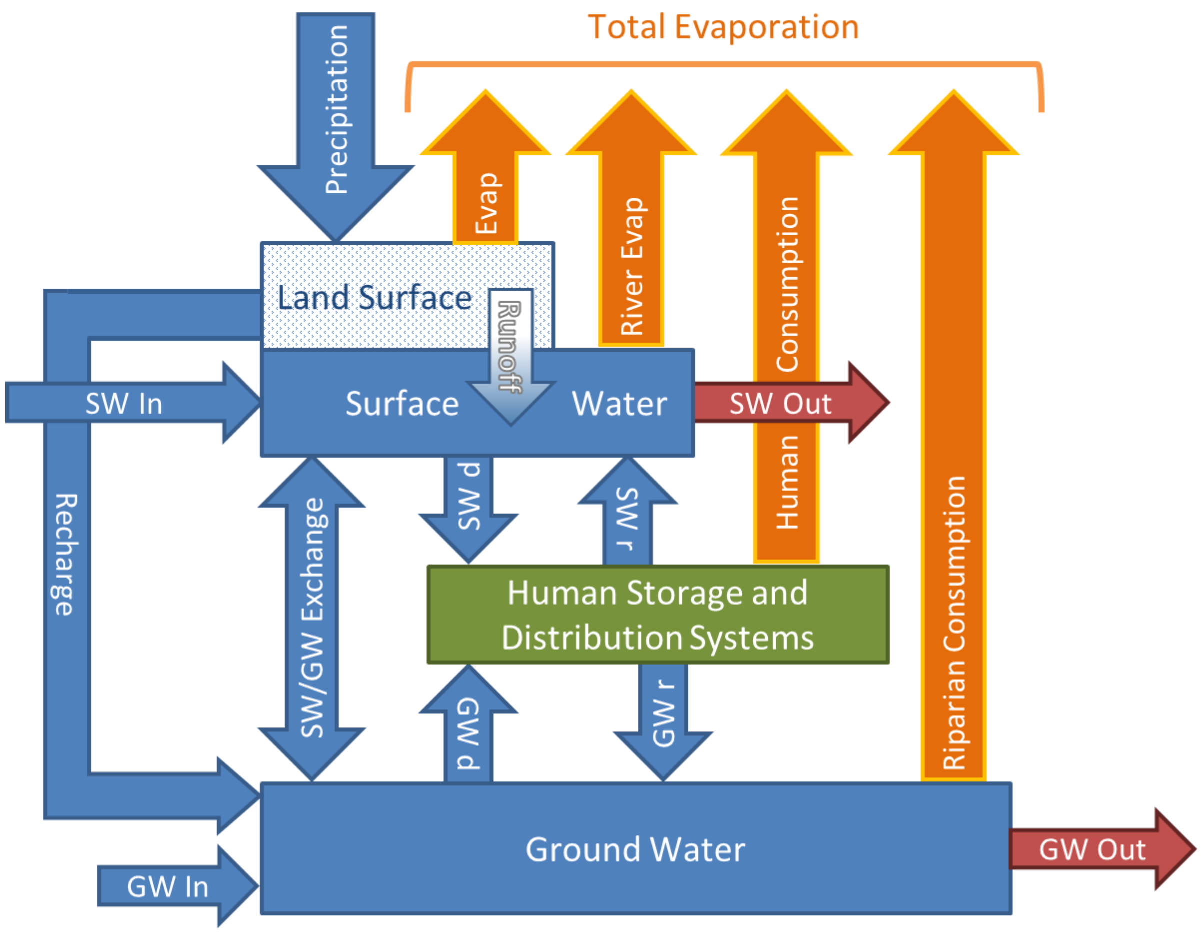

Figure 3 Conceptual water balance diagram.

2 Stocks (Stored Water)

In the terminology of system dynamics a stock refers to an amount of a specific resource. A stock could be money in a bank account, number of people in a country, or amount of gold in a gold mine. For this study the term refers to the amount of water in a specific category. The stocks of water in the NMDSWB represented by the rectangular blocks in Figure 3 and are described in this section.

2.1 Land Surface

For the purposes of the NMDSWB, the land surface system conceptually represents moisture stored in non-saturated soils or geologic formations (the vadose zone), in vegetation, or any other surface water source that cannot be practicably diverted for human use. The water stored in this stock is difficult to measure at large scale and changes rapidly, and is not calculated in this effort. Change in storage of this stock is set to zero in the NMDSWB for all timesteps. Thus, the land surface stock for purposes of this conceptual mass balance is a construct which allows precipitation to be partitioned into recharge, evaporation, and runoff at each timestep.

2.2 Surface Water

The surface water stock represents the total amount of water in rivers and other natural water ways at any time. For the purposes of this mass balance we assume that any water in the surface water system can be diverted or impounded for human use. Available Water comes from stream flows across the boundaries of the mass balance accounting unit (MBAU) in question (State, County, or Water Planning Region), or runoff to streams and rivers from rainfall or groundwater discharge within the MBAU. Because the volume of water in surface water channels is relatively constant with respect to the state's total water inventory, the actual storage of water in this stock will not be calculated, and storage change through time will be ignored. As a result of this simplifying assumptions, the fluxes into and out of this stock will be balanced at each timestep.

2.3 Human Storage and Distribution System

The human storage and distribution system (HSDS) stock represents water at any given time residing in manmade storage impoundments or distribution systems, such as public water supplies, irrigation canals, and reservoirs. Currently, only reservoir storage is tracked. For purposes of this mass balance, when water is added to storage in a reservoir, it is considered a diversion of available surface water to the HSDS, and when it is released from storage, it is considered a return to the available surface water system.

Reservoir volumes in the NMDSWB are calculated as the previous storage plus change in storage which is calculated as the difference between known or calculated inflows (gaged inflow, precipitation) and known or calculated outflows (gaged outflows, evaporation).

2.4 Groundwater Storage

The groundwater system conceptually represents all sub-surface water that is below the water table (saturated soil and rock). Total groundwater storage for the state of New Mexico is largely unknown. However, for select aquifers throughout the state, estimates of total groundwater storage do exist. Where these estimates are known they are used as input into the NMDSWB. Future work by other members of the New Mexico Water Resources Research Institute led Statewide Water Assessment includes plans to quantify total groundwater storage on a statewide basis. The NMDSWB does track groundwater storage changes over time. When groundwater storage estimates are not available the default initial storage is set to zero. Groundwater storage changes are calculated as follows:

$$\Delta GW = GW_i + \sum_i^n (GW_{in} + r + GW_r) - (GWsw + GW_d + GW_{et} + GW_{out}) \qquad \text{(Equation 1)}$$

Where:

$\Delta GW =$ Groundwater storage

$i =$ Time index for simulation

$n =$ Number of time steps in simulation

GW_i = Initial groundwater storage

$GW_{in} =$ Groundwater flow into the mass balance accounting unit

GW_r= Groundwater return flows (from human use)

r = Groundwater recharge

$GWsw =$ Surface water Groundwater interaction

$GW_d =$ Groundwater diversions (to human use)

$GW_d =$ Groundwater evapotranspiration

$GW_{out} =$ Groundwater outflows from the mass balance accounting unit

3 Inflows

3.1 Precipitation

The precipitation measurements used in this model are from the Parameter-Elevation Relationship on Independent Slopes Model (PRISM) data (Prism Climate Group, 2014). The PRISM data used here are the monthly precipitation totals for the PRISM defined “historical past” years of 1971 through 1980 and the “recent years” of 1981 through 2013. The historical past years are based on less extensive observations, but in the opinion of the authors, represent the best available spatially distributed estimate of precipitation on a statewide level for that time period. The PRISM precipitation is available as a gridded 4x4 Km resolution product; the monthly precipitation volume by county and WPR is calculated from the mean depth of precipitation in a given county or WPR multiplied by the area of said region. PRISM based statewide average annual precipitation depths and volumes through time are shown in Figure 4.

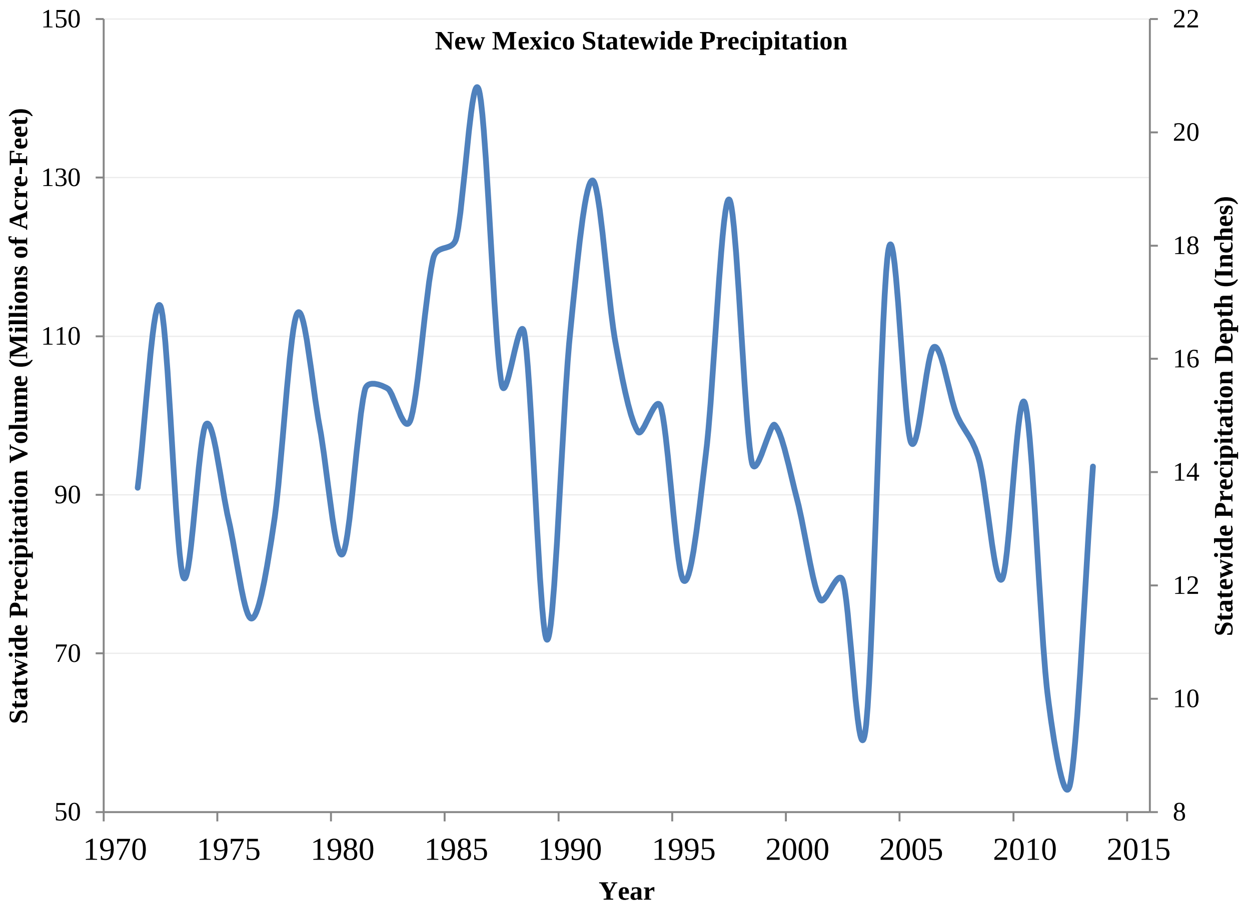

Figure 4 Statewide precipitation measurements. Data from PRISM (Prism Climate Group, 2014).

3.2 Surface Water Inflows

As used in the NMDSWB, surface water inflows into a given MBAU consist of flows which cross its boundary. Thus, MBAUs that occur at the headwaters of the river (for example the Pecos and Central Closed River Basins) do not have any surface water inflows. Where surface water inflows occur, they are estimated based on USGS stream gage data as available. When a stream gage is available near the upstream border of a WPR, NMISC river basin, or County boundary it is used to represent inflow accordingly. Surface water gages used in the NMDSWB were selected based on their locations, and periods of record. The gages that are used in the NMDSWB are either currently active, or have a minimum period of record of 15 years. Detailed information on surface water inflows are provided for each river basin in Section 6, River Basins.

3.3 Groundwater Inflows

As used in the NMDSWB, groundwater inflows into a given MBAU flow in from outside of the MBAU. For purposes of the NMDSWB, we assume that basin scale groundwater divides are the same as surface water divides, and thus, MBAUs that occur at the headwaters of surface water systems (for example the Pecos and Central Closed River Basins) do not have any groundwater inflows. In other words, there is no groundwater flow between basins. Where groundwater inflows into a given MBAU might occur, they are largely unquantified. Groundwater flow across a given (political) boundary cannot be directly measured, and must be calculated based on observed groundwater elevations and inferred geologic information, or extracted from regional groundwater models based on the same. In the 2015 version of the NMDSWB, groundwater inflows are largely unknown. If groundwater flow data is known, the user has the option of setting groundwater inflows or outflows to a user selected constant value (with a default of zero), allowing a change in groundwater storage over the selected period to be calculated.

4 Water Movement between Stocks

Water movement between stocks, also referred to as fluxes, are represented by arrows in Figure 3. Depending on the type of movement it may be based on actual data or calculated using published relationships or closing the water balance for a modeled region. The methods of quantifying water movements are discussed in this section.

4.1 Runoff

Runoff consists of water that goes from precipitation in a given MBAU into the surface water system in the same MBAU without moving through the groundwater system. Inflows from upstream MBAUs are counted as surface water inflows and not runoff. Because storage in the surface water stock is assumed constant as described in Section 2.2, runoff for each MBAU in the NMDSWB is calculated by estimating total gains to the surface water system within the MBAU, and then attributing a portion of those gains to baseflow, and defining the remainder as runoff. Total gains to the surface water system equal the sum of flows at headwater gages and net gains in flow between gages internal to the MBAU. Headwater gages are defined as the highest upstream gage (given an adequate period of record), on each gaged tributary within a MBAU. Net gains in flow between gages internal to the MBAU are calculated by summing the gains for reaches between internal gages for a given MBAU (excluding reaches containing reservoirs), and subtracting surface water returns which occur between those gages. Total gains to the surface water system are then separated into runoff and baseflow components using the USGS 1 km spatially gridded baseflow index map (Wolock, 2003). Baseflow index (BFI) values are spatially averaged for each river basin or WPR (Table 1, Table 2, and Table 3). This approach results in conceptually unappealing variability in baseflow. Future work will focus on changing the way baseflow is handled in the NMDSWB so that baseflow is less temporally variable. Conceptually there is no direct connection between historic precipitation and total gains to the surface water system (runoff + baseflow); total gains are calculated with stream gage data and consumptive use estimates. Precipitation in excess of total gains to the surface water system is assumed to evaporate from the land surface as described in Section 5.2.1. For scenario evaluation, a relationship between precipitation and surface water total gains will need to be developed based on historic patterns.

Table 1 BFI by NMISC Major River basin (Wolock, 2003).

NMISC Major River Basin	BFI (%)
Rio Grande	36.9
Pecos	22.8
Canadian	31.5
Texas Gulf	13.1
San Juan	46.2
Lower Colorado	45.1
Central Closed	26.9

Table 2 BFI by NMISC sub-basins (Wolock, 2003).

NMISC sub-basins	BFI (%)
Canadian sub-basin	36.2
Dry Cimaron	17.1
North Canadian	15.0
Carrizo	19.3
Red	15.6
Little Colorado	43.0
San Francisco	55.7
Gila	49.7
Animas	35.9
Upper Pecos	38.6
Lower Pecos	19.5
Rio Chama	54.4
Upper Rio Grande	67.5
Middle Rio Grande	29.3
Lower Rio Grande	45.0
Estancia	7.4
Tularosa	35.1
Salt	23.5
North Plains	40.1
San Augustin	52.7
Mimbres	38.7
Jornado del Muerto	36.9
Brazos	11.1
Lea Plateau	15.1
Upper Colorado	46.2

Table 3 BFI by Water Planning Region (Wolock, 2003).

Water Planning Regions	BFI (%)
Northeast WPR	18.7
San Juan WPR	46.2
Jemez y Sangre WPR	60.9
Southwest WPR	45.4
Tularosa-Salt-Sacramento WPR	30.0
Northwest WPR	34.0
Taos WPR	67.4
Mora-San Miguel WPR	37.9
Colfax WPR	45.7
Lower Pecos WPR	20.0
Lower Rio Grande WPR	39.4
Middle Rio Grande WPR	20.3
Estancia WPR	10.3
Rio Chama WPR	54.1
Socorro-Sierra WPR	38.5
Lea WPR	15.9

4.2 Recharge

Recharge in the NMDSWB is calculated by assuming that without human diversions and returns, the groundwater system would be in steady state. Under this assumption, non-anthropogenic inflows (groundwater inflows from another MBAU and recharge) are equal to non-human related outflows (groundwater outflows to another MBAU, ET, and baseflow). Baseflow is water moving to the surface water system from the groundwater system, and is calculated as the portion of the total gains to the surface water system not attributed to runoff as described above. For each MBAU at each timestep, recharge is set equal to a moving 10 year average of the sum of the baseflow terms (calculated above as headwaters baseflow and baseflow of net gains between gages) plus groundwater ET and groundwater out minus groundwater in. Without averaging this term of a long time period it would ignore a basic characteristic of temporal lags in groundwater systems. Additionally, human impacts that change mass balance groundwater fluxes are at play across the state. Thus, both the assumption that recharge is equal to baseflow plus groundwater ET, and the assumption that non-human related groundwater fluxes are in balance are both open to legitimate criticism. These assumptions have provided the NMDSWB with a self-consistent way to estimate recharge which results in state level mass balance terms (especially groundwater storage change) that are reasonable, but as will be seen, produces some basin scale results that do not seem reasonable. The assumptions are in theory worse in regions of higher levels of groundwater pumping.

4.3 Surface Water Groundwater Interactions

Groundwater and surface water interactions are determined as the closure term in the surface water system. The groundwater-surface water interaction term is equal to the sum of surface water inflows (runoff, surface water in, and surface water returns) minus the sum of surface water outflows (surface water ET, surface water diversions, and surface water outflows).

In equation form:

$$GWsw = (SW_{in} + \mathrm{R} + SW_r) - (SW_{et} + SW_d + SW_{out}) \qquad \text{(Equation 2)}$$

Where:

$GWsw$= Surface water Groundwater interactions

SW_{in} = Surface water inflows to MBAU

R = Runoff

SW_r = Surface water returns

SW_{et} = Surface water evaporation

SW_d = Surface water diversions

SW_{out} = Surface water outflows from MBAU

4.4 Human Diversions and Returns

4.4.1 Human Population Model

The human population model (population model) is an integral component of demand calculations in the statewide water budget and is driven primarily by data from the University of New Mexico's Bureau of Business and Economic Research (BBER) ("The University of New Mexico Bureau of Business and Economic Research," 2014). Historic Population data by county is input into the model on a decadal basis; historic growth rates are calculated using the following compound rate formula:

$$r = \left(\frac{N_{10}}{N_0}\right)^{\frac{1}{t}} - 1 \qquad \text{(Equation 3)}$$

r = population growth rate (%/year)

t = time (10 years)

N_0 = County Population at start of decade (# of people)

N_{10} = County Population ten years later (# of people)

Historic monthly populations at a given time step are calculated by multiplying the county population during the previous month by the current growth rate for that time period. County growth rates are consistent during a given decade. In 1981 Valencia County was split into Cibola and Valencia Counties. The next Census occurred in 1990, at which time the population of Cibola County was 23,794 people. Assuming a 1981 to 1990 growth rate equal to the growth rate the following decade (1990 to 2000) would mean a starting population of Cibola County of approximately 22,000 people. The population model adds 22,000 people in 1981 to the preexisting population of zero in Cibola County while subtracting 22,000 people from Valencia County population. The model readjusts the calculated county population every decade to match the Census data so that rounding errors are not propagated through time. Since population data is primarily available at the county level a method was developed to transform county populations into Water Planning Region (WPR) populations. This transformation uses data from the 2000 census (Alcantara & Lopez, 2003) where the population of a given county within a given WPR is estimated. The percentage of a county's population within a given WPR is multiplied by county population to estimate WPR population. Historic population by county and WPR used in the model from 1970 through 2010 are shown in Table 4 and Table 5 respectively.

Table 4 Historic decadal human populations 1970 – 2010 by county.

County	1970	1980	1990	2000	2010
Bernalillo	315,774	419,700	480,577	556,678	662,564
Catron	2,198	2,720	2,563	3,543	3,725
Chaves	43,335	51,103	57,849	61,382	65,645
Cibola	-	-	23,794	25,595	27,213
Colfax	12,170	13,667	12,925	14,189	13,750
Curry	39,517	42,019	42,207	45,044	48,376
De Baca	2,547	2,454	2,252	2,240	2,022
Dona Ana	69,773	96,340	135,510	174,682	209,233
Eddy	41,119	47,855	48,605	51,658	53,829
Grant	22,030	26,204	27,676	31,002	29,514
Guadalupe	4,969	4,496	4,156	4,680	4,687
Harding	1,348	1,090	987	810	695
Hidalgo	4,734	6,049	5,958	5,932	4,894
Lea	49,554	55,993	55,765	55,511	64,727
Lincoln	7,560	10,997	12,219	19,411	20,497
Los Alamos	15,198	17,599	18,115	18,343	17,950
Luna	11,706	15,585	18,110	25,016	25,095
McKinley	43,208	56,449	60,686	74,798	71,492
Mora	4,673	4,205	4,264	5,180	4,881
Otero	41,097	44,665	51,928	62,298	63,797
Quay	10,903	10,577	10,823	10,155	9,041
Rio Arriba	25,170	29,282	34,365	41,190	40,246
Roosevelt	16,479	15,695	16,702	18,018	19,846
Sandoval	17,492	34,799	63,319	89,908	131,561
San Juan	52,517	81,433	91,605	113,801	130,044
San Miguel	21,951	22,751	25,743	30,126	29,393
Santa Fe	53,756	75,360	98,928	129,292	144,170
Sierra	7,189	8,454	9,912	13,270	11,988
Socorro	9,763	12,566	14,764	18,078	17,866
Taos	17,516	19,456	23,118	29,979	32,937
Torrance	5,290	7,491	10,285	16,911	16,383
Union	4,925	4,725	4,124	4,174	4,549
Valencia	40,539	61,115	45,235	66,152	76,569
New Mexico	**1,016,000**	**1,302,894**	**1,515,069**	**1,819,046**	**2,059,179**

Table 5 Historic decadal human populations 1970 – 2010 by WPR.

WPR	1970	1980	1990	2000	2010
Northeast	73,172	74,104	74,844	78,198	82,503
San Juan	62,199	93,712	105,485	130,914	146,952
Jemez y Sangre	83,440	108,844	134,979	168,384	181,212
Southwest	40,668	50,538	54,304	65,461	63,227
Tularosa-Salt-Sacramento	39,602	43,271	50,252	60,676	62,208
Northwest	35,932	46,980	73,962	87,889	86,883
Taos	17,526	19,466	23,127	29,979	32,951
Mora-San Miguel	31,593	31,451	34,160	39,976	38,964
Colfax	12,170	13,666	12,925	14,188	13,750
Lower Pecos	96,056	113,770	122,582	136,259	143,577
Lower Rio Grande	69,773	96,256	135,379	174,588	209,177
Middle Rio Grande	370,434	510,492	583,263	705,803	862,127
Estancia	12,195	16,925	21,973	31,449	33,055
Rio Chama	4,737	5,510	6,466	7,750	7,574
Socorro-Sierra	16,952	21,012	24,671	31,332	29,855
Lea	49,554	55,986	55,763	55,515	64,714
New Mexico	**1,016,003**	**1,302,894**	**1,515,069**	**1,819,046**	**2,059,179**

4.4.2 Water Use Data

Water use data in New Mexico is tabulated every five years by the New Mexico Office of the State Engineer (OSE) (Longworth et al., 2008; Longworth, Valdez, Magnuson, & Richard, 2013; Sorensen, 1977, 1982; Wilson & Lucero, 1992, 1997, 2003; Wilson, 1986). Each report represents an estimate of annual average water use for the specific year given in the title of the report. Water use is presented as withdrawals, depletions, and returns. Withdrawals are defined as the total amount of water taken from a source to be used elsewhere, depletions are defined as the quantity of water consumed, i.e. evaporated and no longer available for use elsewhere. Return flows are difference between withdrawals and depletions. The data is provided for each river basin and each county. This study starts with the 1975 OSE report (Sorensen, 1977). For report years from 1990 through 2010 the Water use categories do not change and consist of: Commercial (self-supplied), Domestic (self-supplied), Industrial (self-supplied), Irrigated Agriculture, Livestock (self-supplied), Mining (self-supplied), Power (self-supplied), Public Water Supply and Reservoir Evaporation (Table 6).

Table 6 OSE water use categories from 1975 to 2010.

2010	2005	2000	1995	1990	1985	1980	1975
Withdrawals only	Withdrawals only	Depletions, Withdrawals & Return Flows	Depletions, Withdrawals & Return Flows	Depletions, Withdrawals & Return Flows	Depletions, Withdrawals & Return Flows	Depletions, Withdrawals & Return Flows	Depletions, Withdrawals & Return Flows
Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Manufacturing (Includes Industrial and Commercial)
					Recreation	Recreation	Recreation
Domestic	Domestic	Domestic	Domestic	Domestic	Rural	Rural	Rural
Industrial	Industrial	Industrial	Industrial	Industrial	Industrial	Industrial	Manufacturing (Includes Industrial and Commercial)
Irrigated Agriculture	Irrigated Agriculture	Irrigated Agriculture	Irrigated Agriculture	Irrigated Agriculture	Irrigated Agriculture	Irrigated Agriculture	Irrigated Agriculture
					Fish and Wildlife	Fish and Wildlife	Fish and Wildlife
Livestock	Livestock	Livestock	Livestock	Livestock	Livestock	Livestock	Livestock
					~~Stockpond Evap~~	~~Stockpond Evap~~	~~Stockpond Evap~~
Mining	Mining	Mining	Mining	Mining	Minerals	Minerals	Minerals
Power	Power	Power	Power	Power	Power	Power	Power
Public Water Supply	Public Water Supply	Public Water Supply	Public Water Supply	Public Water Supply	Urban	Urban	Urban
					Military	Military	Military
Reservoir Evaporation	Reservoir Evaporation	Reservoir Evaporation	Reservoir Evaporation	Reservoir Evaporation	Reservoir Evaporation	Reservoir Evaporation	Reservoir Evaporation
							~~Lake and Playa Evaporation~~

The 1975, 1980, and 1985 reports used slightly different water use categories; these earlier categories are either aggregated or separated into the latter categories in order to maintain consistency throughout time. In the 1975 report, the categories of commercial and industrial water use do not exist, instead there is a single category dubbed manufacturing which we split 50/50 into commercial and industrial uses. In the 1975, 1980, and 1985 reports there are several additional categories that do not exist in the later reports, yet the use of the water in those early categories are included in a different category in later years. These additional categories are: Recreation, Fish and Wildlife, Stockpond Evaporation, Urban, Rural, Military and in the 1975 report only, Lake and Playa Evaporation. The Recreation category is combined with Commercial water use, Fish and Wildlife is combined with Irrigated Agriculture, Stockpond Evaporation is removed entirely as it is not included in the Livestock category in latter reports, Rural use makes up the domestic water use category, Urban and Military uses are combined to make up the Public Water Supply component, and the Lake and Playa Evaporation category is excluded entirely.

The 1975 through 2000 water use reports include withdrawals, depletions, and return flows. However the 2005 and 2010 water use reports only include withdrawals, although agricultural depletions for these years can be estimated from reported intermediate data. The 2005 and 2010 depletions for categories besides agriculture are estimated by calculating the depletions as a percentage of withdrawals for each use category from the 2000 water use report and then multiplying that percentage by the 2005 and 2010 withdrawals.

4.4.3 Municipal and Self Supplied Domestic

The OSE water use reports include the population of a county that is served by a public water supply. The water withdrawals/depletions by the public water supplier are divided by the population served to get per capita water withdrawals/depletions by county for public water supply users. The reported water withdrawals /depletions by domestic self-supplied users are divided by the remaining population in the county to estimate per capita water withdrawals/depletions for the domestic use category. The percentage of a county population served by public water supply calculated from the OSE reports is assumed constant for 5 years. This percentage is multiplied by the monthly average population in the population model to calculate the publicly served/domestic population at any given timestep. The publicly served/domestic populations are multiplied by the respective per capita withdrawals/depletions to calculate public/domestic water use for any given timestep. In the 1975, 1980, and 1985 reports, the water use categories are not separated into domestic and public water supply categories but instead rural and urban categories. The assumption made here is that rural water use during those years was all domestic use and that urban water use was all public water supply use. Per capita water withdrawals by county for public water supply users and domestic, self-supplied users is shown for each of the 5 year periods from 1971 through 2010 in Table 7 and Table 8. Return flows as a ratio of withdrawals can be seen in Figure 5 and Figure 6.

Table 7 Public Water Supply Per Capita Withdrawals.

	Public Water Supply Withdrawals Per Capita (Gallons/Person*day)							
Counties	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**
Bernalillo	270	259	262	253	246	211	187	157
Catron	n/a	n/a	n/a	153	173	225	148	112
Chavez	266	268	229	282	320	308	269	269
Cibola	n/a	n/a	218	218	207	230	251	195
Colfax	188	149	165	208	201	222	186	204
Curry	208	224	172	211	209	180	183	178
De Baca	n/a	n/a	n/a	228	230	210	222	209
Dona Ana	236	278	248	228	227	208	197	184
Eddy	310	303	317	286	301	295	254	269
Grant	161	172	114	168	180	173	170	129
Guadalupe	n/a	n/a	n/a	187	201	182	170	170
Harding	n/a	n/a	n/a	172	150	179	184	149
Hidalgo	316	218	243	297	327	218	286	166
Lea	216	274	258	282	332	304	259	236
Lincoln	181	300	348	270	249	279	230	188
Los Alamos	268	247	282	263	290	227	213	205
Luna	310	281	280	225	266	214	223	212
McKinley	136	132	141	132	165	149	143	118
Mora	n/a	n/a	n/a	109	152	205	157	130
Otero	316	242	263	256	235	216	139	135
Quay	225	230	251	214	217	228	180	185
Rio Arriba	121	90	92	108	117	114	103	96
Roosevelt	310	291	375	262	309	258	114	143
Sandoval	269	273	184	208	261	175	151	143
San Juan	304	285	203	205	196	181	202	164
San Miguel	137	168	178	153	157	140	130	159
Santa Fe	163	138	116	152	158	146	110	103
Sierra	240	244	235	242	223	143	167	149
Socorro	213	322	222	175	157	180	178	149
Taos	181	254	231	184	155	138	129	102
Torrance	n/a	n/a	n/a	195	192	149	172	135
Union	182	162	129	363	215	194	237	194
Valencia	74	186	126	150	167	154	140	136
New Mexico weighted average	**230**	**236**	**220**	**223**	**228**	**201**	**194**	**162**

Table 8 Domestic Self-Supplied Per Capita Withdrawals.

Counties	Domestic Self-Supplied Withdrawals Per Capita (Gallons/Person*day)							
	1975	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**
Bernalillo	115	100	105	103	104	102	103	101
Catron	45	54	79	68	62	71	73	71
Chavez	104	150	137	94	129	121	116	101
Cibola	n/a	n/a	85	66	71	71	77	71
Colfax	180	113	139	64	84	81	83	81
Curry	77	81	90	65	112	101	100	101
De Baca	116	123	159	65	87	81	87	81
Dona Ana	86	101	101	102	105	101	102	101
Eddy	100	94	120	65	107	101	100	102
Grant	93	99	81	65	84	81	84	81
Guadalupe	42	144	161	70	76	81	84	80
Harding	47	112	109	66	85	81	85	82
Hidalgo	41	63	62	65	85	81	90	81
Lea	60	73	78	65	104	101	96	96
Lincoln	100	77	112	65	78	81	89	81
Los Alamos	39	54	57	0	0	0	0	0
Luna	81	82	75	65	105	101	107	101
McKinley	48	44	61	66	68	71	76	71
Mora	91	93	99	65	79	81	88	81
Otero	42	68	71	61	121	96	98	101
Quay	54	72	92	65	80	81	86	81
Rio Arriba	48	59	62	65	80	81	86	81
Roosevelt	58	57	59	65	108	101	101	101
Sandoval	53	59	71	85	103	99	98	81
San Juan	52	45	65	65	70	71	74	71
San Miguel	40	50	68	65	81	81	84	81
Santa Fe	39	73	102	90	86	83	87	83
Sierra	102	55	58	65	75	81	88	81
Socorro	39	51	62	65	79	81	84	81
Taos	51	56	88	65	79	81	82	81
Torrance	91	94	92	65	79	81	89	81
Union	53	61	65	66	82	81	80	81
Valencia	128	61	46	81	107	102	102	101
New Mexico weighted average	**85**	**83**	**91**	**84**	**96**	**93**	**95**	**92**

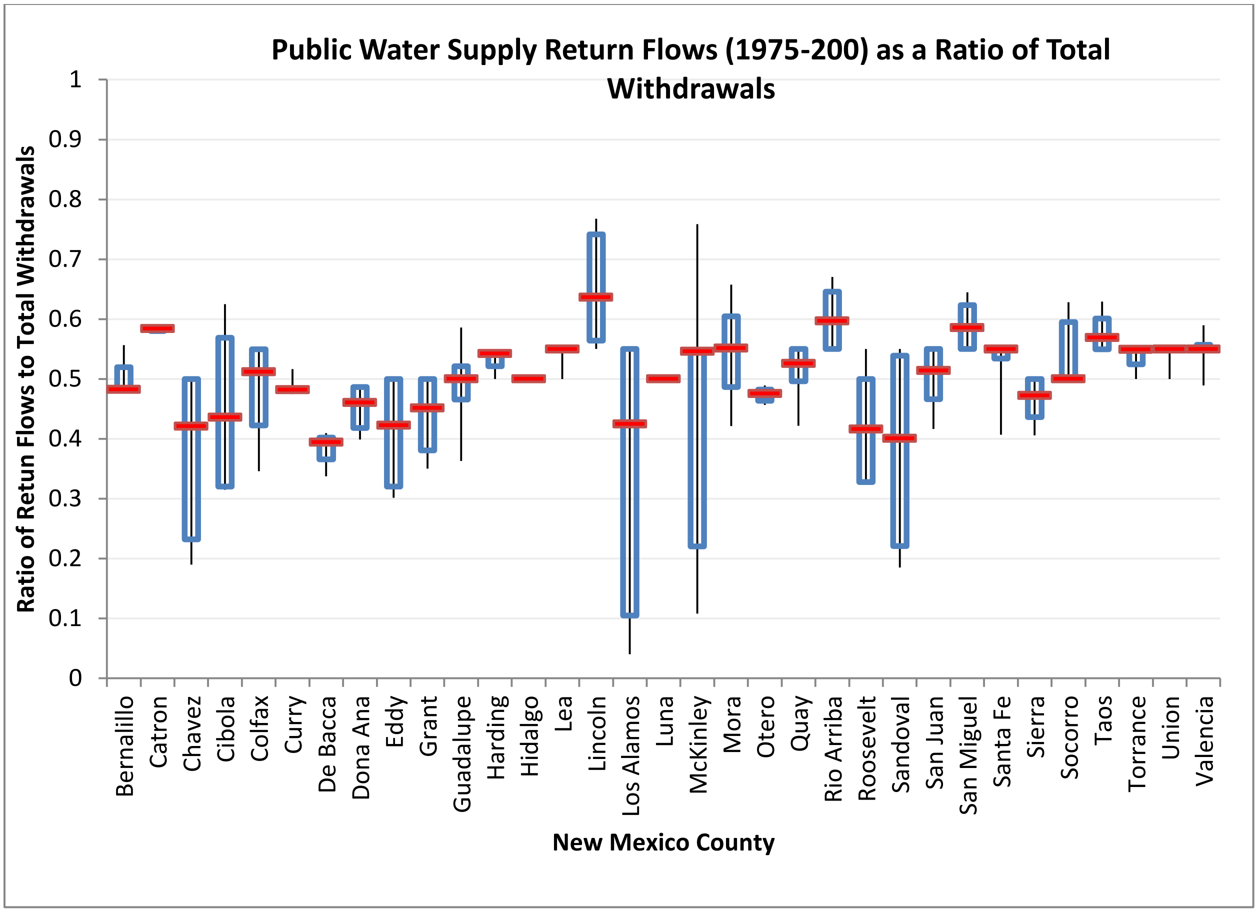

Figure 5 Public water supply return flows as a ratio of total public withdrawals. Median values are the solid red dashes, and the middle 50% of values are within the boxes. If there is not a visible box, the middle 50% of values are equal to the median value. Whiskers represent the maximum and minimum values. Catron, De Baca, Guadalupe, Harding, Mora, and Torrance County report zero public water use until 1990, these zero values are excluded from the calculation.

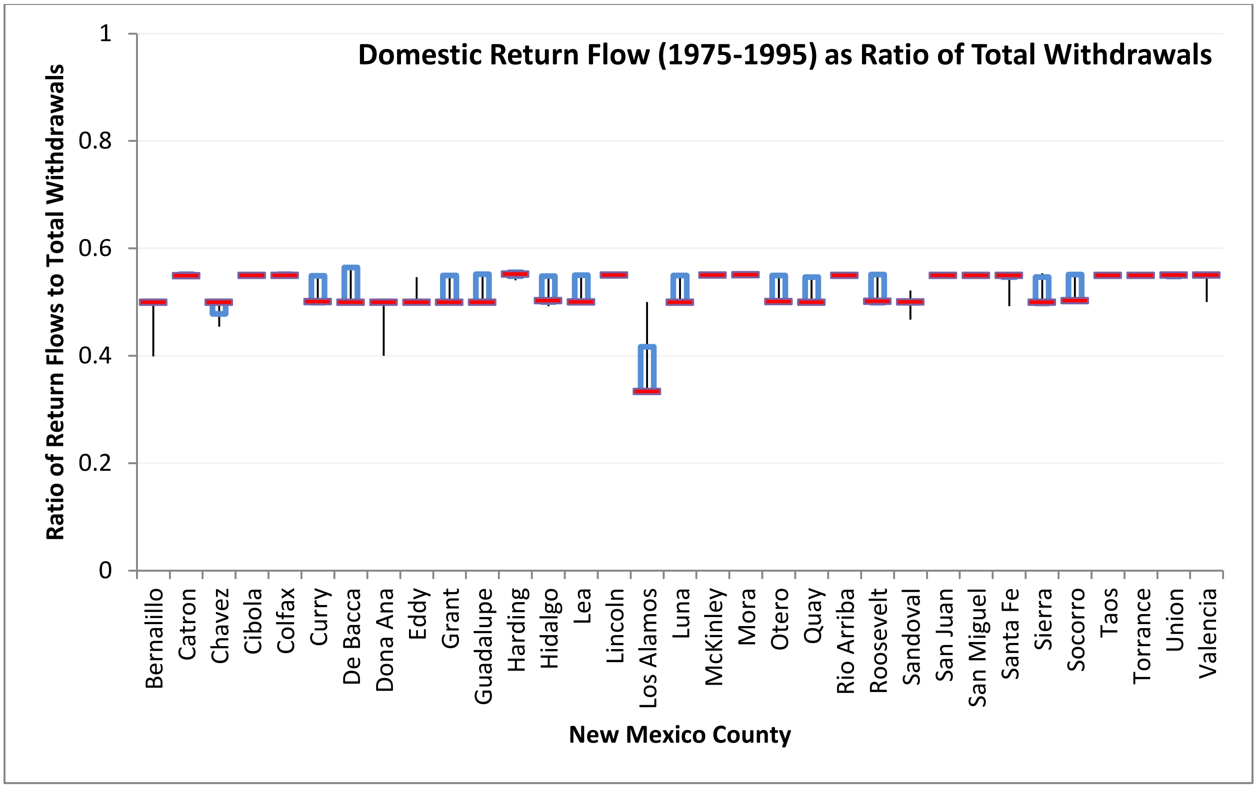

Figure 6 Domestic water use return flows as a ratio to total domestic withdrawals. Median values are the solid red dashes, and the middle 50% of values are within the boxes. If there is not a visible box, the middle 50% of values are equal to the median value. Whiskers represent the maximum and minimum values.

4.4.4 Irrigated Agriculture

The methods for calculating consumptive irrigation requirements for counties (CIR) are described in detail in section 5.1. Surface water and groundwater withdrawals for irrigated agriculture in counties and river basins are calculated by multiplying the estimated CIR by county and river basin surface water and groundwater irrigation efficiencies, respectively. County and river basin surface water and groundwater specific irrigation efficiencies are determined by taking the ratio of OSE reported depletions/ withdrawals. The irrigation efficiencies are held constant for five years. Since no depletions are reported by the OSE after the year 2000 (BC Wilson & Lucero, 2003), the 2000 irrigation efficiencies are used through 2013.

4.4.5 Livestock

Livestock withdrawals are estimated on a county level in the NMDSWB from 1975 to 2013. These estimates are made following methodology from the New Mexico OSE water use reports (e.g. Longworth et al., 2013) based on an assumed per capita water use by animal, multiplied by the county population of a given animal. Water use estimates include drinking water and miscellaneous uses of water, the values for water use per animal used in the NMDSWB are the same values reportedly used by the New Mexico OSE (Table 9). Animal population data at the county level for the NMDSWB is from the NMDA NASS Quick Stats Service (United States Department of Agriculture & National Agriculture Statistic Service, 2014). The NM OSE uses county assessor information in addition to the NMDA when tabulating animal populations in the state, but the NM OSE does not provide this information at the county level (Table 10). Livestock depletions are assumed to be 100% of withdrawals (BC Wilson & Lucero, 2003).

Table 9 Daily per capita water use by animal. (Sources: Non-Dairy Cattle-(Sweeten, O'Neal, & Withers, 1990), Horses-(Van der Leeden, Troise, & Todd, 1990), Dairy Cows-(Hagevoort, 2012; Wiersma, 1988), all others(Soil Conservation Service, 1975; Sykes, 1955). Gallons per capita per day (GPCD).

Species	Drinking Water (GPCD)	Miscellaneous Water (GPCD)	Total (GPCD)
Non-Dairy Cattle	9	1	10
Chickens	0.06	0.02	0.08
Hogs/Pigs	2	1	3
Horses and Mules	12	1	13
Dairy Cattle (1975-2005)	36.5	63.5	100
Dairy Cattle (2006 – present)[a]	38	27	65
Sheep/Lambs	2	0.2	2.2

[a]The New Mexico OSE uses new per capita water use information for dairy cattle in 2010, the NMDSWB begins using the revised per capita water use in 2006.

Table 10 Total New Mexico animal populations from the OSE, NMDA, and the populations used in the NMDSWB.

		All Cattle (non-dairy)	Dairy Cattle	Sheep/ Lambs	Hogs/Pigs[b]	Chickens[b]	Horses[c]
	OSE	571,000[a]	89,000	462,000	27,000	1,430,000	24,870
1990	NMDA	1,289,000	71,000	495,000	27,000	1,430,000	n/a
	NMDSWB	1,289,000	71,000	495,000	27,000	1,430,000	46,686
	OSE	560,000[a]	170,000	265,000	5,000	1,400,000	24,870
1995	NMDA	1,330,000	170,000	364,000	4,400	140,000	n/a
	NMDSWB	1,330,000	170,000	364,000	4,400	140,000	46,686
	OSE	564,000[a]	236,000	290,000	5,000	1,400,000	24,870
2000	NMDA	1,404,000	236,000	249,100	n/a	n/a	46,686
	NMDSWB	1,404,000	236,000	249,100	4,750	1,371,000	46,686
	OSE	1,307,703	379,472	160,555	2,551	1,400,852	31,799
2005	NMDA	1,275,000	235,000	142,800	n/a	n/a	53,616[d]
	NMDSWB	1,275,000	235,000	142,800	4,750	1,371,000	53,616
	OSE	1,327,584	319,552	123,679	801	807,660	34,287
2010	NMDA	1,248,300	307,700	117,600	n/a	n/a	50,723[e]
	NMDSWB	1,248,300	307,700	117,600	4,750	1,371,000	50,723

[a] non-dairy cattle populations in OSE reports prior to 2005 are exclusive of heifers.
[b] In 1999 the NMDA stops reporting populations of chickens and hog/pigs. The NMDSWB holds the 1999 population of those animals constant through the present.
[c] Horse populations data at the county level is not available until the 2002 USDA/NASS Census, the NMDSWB holds the 2002 horse population constant back to from 1970 to 2002.
[d] Horse population in 2005 is from 2007 USDA/NASS Census.
[e] Horse population in 2010 is from 2012 USDA/NASS Census.

4.4.6 Mining and Power

In this version of the NMDSWB water withdrawals and depletions from mines and power plants are not calculated. The model uses the water withdrawals/depletions (depletions when available) data provided by the OSE water use by categories reports (e.g. Longworth et al., 2013), and those values are held constant for the five years preceding the respective published report. Depletions after the year 2000 are estimated by multiplying the ratio of the 2000 (BC Wilson & Lucero, 2003) reported withdrawals/depletions by the 2005 and 2010 withdrawals.

4.4.7 Commercial and Industrial

In this version of the NMDSWB water withdrawals and depletions from commercial and industrial water uses are not calculated. The model uses the water withdrawals/depletions (depletions when available) data provided by the OSE water use by categories reports (e.g. Longworth et al., 2013), and those values are held constant for the five years preceding the respective published report. Depletions after the year 2000 are estimated by multiplying the ratio of the 2000 (BC Wilson & Lucero, 2003) reported withdrawals/depletions by the 2005 and 2010 withdrawals.

4.4.8 Reservoir Evaporation

Reservoir evaporation is calculated in the DSWB by multiplying reservoir surface area by Hargreaves reference ET and a monthly open water coefficient. Hargreaves Reference ET is described in detail in section 5.1.1. Information on individual reservoirs modeled can be seen in the basin specific documentation in section 6.

4.4.9 Groundwater and Surface Water Returns

The water use by categories reports issued by the OSE (i.e. Longworth et al., 2013) provides information on the sources of water returns(e.g. water that was withdrawn but not consumed) (before 2005), being either from groundwater or surface water. The information in these reports does not detail whether these returns are going to surface water or groundwater sources. The NMDSWB is set up with several assumptions, in order to partition returned water to groundwater or surface water sources. The default return options in the NMDSWB are as follows:

- 100% of public water supply returns go to surface water
- Domestic water is returned to ground water
- Irrigated agriculture water is returned to surface water[1]
- Livestock water use is returned to the origin of the withdrawal (moot no returns)
- 100% of commercial water returns go to surface water
- 100% of mining returns go to surface water
- 100% of power returns go to surface water

4.4.10 Gaged surface water returns

In each basin a portion of the surface water returns are estimated to be eventually gaged and the remaining portion non-gaged. While very few return flows are actually gaged in most water use sectors, the assumption for gaged return flows made here is that return flows physically reentering the surface water system will ultimately be gaged along the river or at the river basin outlet. The large majority of surface water returns are from agriculture, thus the percentage of agricultural land in a given basin that is determined to not provide returns to a gaged river system is deemed the percentage of surface water returns that are not gaged. This percentage is determined in each river basin by calculating the percentage of agricultural land (Jin et al., 2013) that is not within one mile of a stream or tributary. The portion of the returns that are not gaged are for accounting purposes lost, and are added to NMDSWB surface water evaporation. The gaged returns go back into the surface water system to be withdrawn again, enter the groundwater system through the surface water to groundwater flux, or leave the basin as surface water outflow.

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[1] Irrigated agricultural returns can be to the surface water or the groundwater. Returns to the groundwater via seepage through the root zone are often captured by drains to prevent groundwater mounding, and thus ultimately returned to the surface water system after some delay in the groundwater system. We make the simplifying assumption that all irrigated agricultural returns are to the surface water system.

4.4.11 Downscaling Data to County and Water Planning Regions Levels

Every 5 years water use data is reported at the county level and at the river basin level by the OSE (e.g. Longworth et al., 2013). The NMDSWB currently provides water information at river basin level. Future efforts will include generating the data at the county and WPR level. The NMDSWB has developed several transformations to convert county level water use data to the WPR level. Public water supply, domestic, commercial, industrial, and power water use data at the County level (e.g Longworth et al., 2013) are converted to the WPR level by multiplying the percentage of a county's population within a given WPR using 2000 Census data (Alcantara & Lopez, 2003) by the water use data for the given county. Public and Domestic water uses are calculated by river basin in the same fashion by multiplying county population by the proportion of each county within a river basin using 2010 Census data (Longworth et al., 2013). Commercial, Industrial, Mining, and Power water use data are provided by county level in the OSE reports (e.g. Longworth et al., 2013). Calculated Irrigated agriculture and livestock water use data are multiplied by the percentage of a county's agricultural land within a given WPR/river basin. The mining water use data conversion to county level relies on spatialized mining district data (McLemore et al., 2005) to determine the percentage of mining operations of each county within a given WPR.

5 Outflows

5.1 Evapotranspiration

Evapotranspiration (ET) represents the phase change of water from a liquid form on the land surface to the vapor phase that is lost to the atmosphere. It is by far the largest loss term in New Mexico's water budget. This section of the report summarizes methods utilized to estimate ET rates, season lengths, the portion of ET that is met directly by precipitation, and area data used to calculate volumetric flows.

5.1.1 Methods for Estimating ET

Evapotranspiration is calculated using two different methods: the Hargreaves-Samani Reference ET (Hargreaves & Samani, 1985), and the Blaney-Criddle consumptive irrigation requirement (Blaney & Criddle, 1950). Two methods are used because, although the Hargreaves-Samani is widely used in current modeling applications (when only temperature data is available), the Blaney-Criddle method carries an important historical legacy and is used in the OSE reports (Blaney & Criddle, 1950). The Hargreaves-Samani equation is as follows (Hargreaves & Samani, 1985):

$$ET_{oHS} = 0.0023Ra(T + 17.8)\sqrt{Tmax - Tmin} \qquad \text{(Equation 4)}$$

Where:

ET_{oHS} = Hargreaves-Samani based Reference ET [inches/month]

Ra = the water equivalent of the extraterrestrial radiation [mm/day]

T= mean temperature [°Celsius]

$Tmax$= maximum temperature [°Celsius]

$Tmin$= minimum temperature [°Celsius]

The temperature data is derived from monthly PRISM data (Prism Climate Group, 2014) . The monthly mean, minimum, and maximum temperatures are all the spatial average of the 4km^2 PRISM data for the entire county or WPR. The reference ET is multiplied by time varying crop coefficients to get crop specific potential ET, which represents an upper estimate of ET losses; the maximum amount of ET that may occur if a crop is not water limited. Crop coefficients used for conversion from reference ET to crop specific ET are shown in Table 11.

The Blaney-Criddle equation (Blaney & Criddle, 1950) is used by the OSE to calculate the consumptive irrigation requirements (CIR) for irrigated agriculture water withdrawals across the state. Blaney-Criddle is used as the default calculation for estimating crop ET in the NMDSWB. Blaney-Criddle consumptive use is calculated as follows:

$$ET_{BC} = TPK \quad \text{(Equation 5)}$$

Where:

ET_{BC} = Blaney-Criddle consumptive use [inch/mo]

T = Mean monthly temperature [°Fahrenheit]

P = Fraction of annual daylight hours occurring in a given month based on latitude [month^{-1}]

K = a unitless consumptive use coefficient which is constant throughout the growing season in the original Blaney-Criddle method. Values for K used in the NMDSWB are shown in Table 11.

Table 11 Original Blaney-Criddle Method consumptive use coefficients used in the NMDSWB.

Vegetation Type	$K_{growing}$	$K_{non\text{-}growing}$
Grains (irrigated cropland)	0.75	0.4
Alfalfa & Pasture (irrigated cropland)	0.8	0.5
Fruits & Vegetables (irrigated cropland)	0.7	0.4
Orchards (irrigated cropland)	0.65	0.4
Riparian	0.7	0.7

The modified Blaney-Criddle method (U.S. Department of Agriculture Soil Conservation Service 1970) is used by the OSE in the San Juan (Upper Colorado) basin to compute CIR so that the state is consistent with NMISC compact accounting (Longworth et al., 2013). The NMDSW also uses the modified Blaney-Criddle method to calculate CIR in the San Juan basin. With this method K is defined as a product of k_t*k_c where k_t = 0.0173T – 0.314 and k_c is an empirical crop stage coefficient which varies through the growing season. The kc values used in the NMDSWB are shown in Table 12. The values for Grains come from the U.S. Department of Agriculture's Technical Release 21 (TR-21) (U.S Department of Agriculture, Soil Conservation Service, 1970) crop growth stage coefficient curve for grain corn (Curve No. 1) assuming a 5 month growing period (10%, 30%, 50%, 70%, and 90% growth stage). The values for Alfalfa & Pasture come from TR-21 Curve No. 2 for alfalfa. The values for Riparian come from TR-21 Curve No. 16 for deciduous orchards with ground cover (which is almost identical to the alfalfa curve). The values for Fruits and Vegetables come from values for Chile used by New Mexico Office of the State Engineer (2015) assuming a 7 month growing period (7%, 21%, 35%, 50%, 65%, 79%, 93% growth stage). The values for Orchards come from values for Pecans used by the New Mexico Office of the State Engineer (2015).

Table 12 Crop stage coefficient used in the Modified Blaney-Criddle Method in the NMDSWB. Values are from a combination of TR-21 curves and an OSE spreadsheet as explained in the text.

Vegetation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Grains	0	0	0	0	0.5	0.71	1.05	1.06	0.95	0	0	0
Alfalfa & Pasture	0.63	0.73	0.86	0.99	1.08	1.13	1.11	1.06	0.99	0.91	0.78	0.64
Fruits & Vegetables	0	0	0	0.36	0.57	0.74	0.81	0.81	0.73	0.53	0	0
Orchards	0.56	0.82	0.55	0.97	1.14	1.1	0.95	1.02	1.11	1.18	0.79	0.75
Riparian	0.63	0.73	0.86	0.98	1.09	1.13	1.11	1.06	0.99	0.90	0.78	0.66

The Blaney-Criddle equation is given here in its native English units because it is so clean, but for the units to work there is an implicit factor of 1 [inch/°F] included in the equation.

The Blaney-Criddle method is an empirically based estimate of actual consumptive use rather than potential consumption as represented by the Hargreaves-Samani approach. In the NMDSWB Blaney-Criddle is used when water availability is a limiting factor on ET, such as with irrigated agriculture. The Hargreaves-Samani approach is used in the NMDSWB when water is abundantly available for ET, such as with reservoir evaporation and riparian groundwater ET. The Hargreaves-Samani and the Blaney-Criddle both rely on some metric of solar radiation based on latitude. For this study mean latitude by total area has been calculated for each county and WPR. River basin scale rates are determined by summing the WPR rates in each basin.

5.1.2 Irrigation Season Length

To capture spatial and temporal variability of the growing season, the NMDSWB calculates irrigation season based on monthly temperature data. (There is also an option in the model to define the months of the growing season by county, which are then used every year regardless of temperature). Table 3 in the U.S. Department of Agriculture's Technical Release 21 (TR-21) (U.S Department of Agriculture, Soil Conservation Service, 1970) provides some guidance, and suggests that depending on crop type, a mean monthly temperature of between 45 degrees Fahrenheit (°F) and 60°F begins the growing season, and a mean monthly temperature between 45°F and 50°F ends it. However, because we would expect growing season to be controlled more by minimum temperatures than mean temperatures, and climate change may impact minimum temperatures more than mean temperatures (Llewellyn, Vaddey, Roach, & Pinson, 2013), monthly mean minimum temperatures were used to initiate and end the irrigation season. Comparison of long term monthly average of daily minimum temperature data to spring and fall freeze probabilities (Western Regional Climate Center, 2015) at eight climate stations (Clovis, Portales, Farmington FAA Airport, Roswell WSO Airport, Las Cruces, Hobbs, Carlsbad, and Clayton WSO Airport) in the eight counties with the most agricultural area in New Mexico in 2010 (Curry, Roosevelt, San Juan, Chavez, Dona Ana, Lea, Eddy, and Union), suggested a sinusoidal relationship between monthly average minimum temperature and freeze probability as seen in Figure 7 and defined below.

$$P_f = \frac{[1+\cos(pi*\left(\frac{T_{min}-T_1}{T_2-T_1}\right)}{2} \qquad \text{(Equation 6)}$$

where P_f is the probability of a freeze occurring during the month, T_{min} is the monthly average minimum temperature, and T_1 and T_2 define the range of temperatures during which a freeze may or may not occur (below T_1, there is 100% chance of a freeze, and above T_2 there is 0% chance of a freeze). Parameters of 38°F and 55°F for T_1 and T_2 resulted in a fit to the data across counties of $R^2 = 0.96$. However, to reduce complexity, the probability of freeze was used as a deterministic predictor of what portion of a month would be frost free. For example, if in the spring (or fall) the first probability of freeze less than 100% (greater than 0%) is 75%, then it is assumed that irrigation occurs during 25% of the month. The switch from probabilistic to deterministic resulted in a calibration based adjustment of the T_1 and T_2 parameters to 32°F and 46°F[2]. These calibration parameters were found first by matching season length probabilities for the period of record at the eight weather stations mentioned above to the season length modeled values in the associated county, and then comparing state level consumption estimates. These parameters resulted in Blaney-Criddle based calculations of historic agricultural consumption comparable in magnitude to 5 year average consumptions reported by OSE as seen in Figure 8. The distribution of beginning and end months and the season lengths based on these parameters are shown in Table 13 and Figure 9.

[2] Best fit to season length at the 8 weather stations was 34°F and 48 °F, but they were reduced to get a better match to statewide 5 year OSE CIR calculations (e.g. Longworth et al 2013). This may be partly due to irrigation starting and ending with the last or first 28 degree temperature (rather than 32 degree temperature) for some crops.

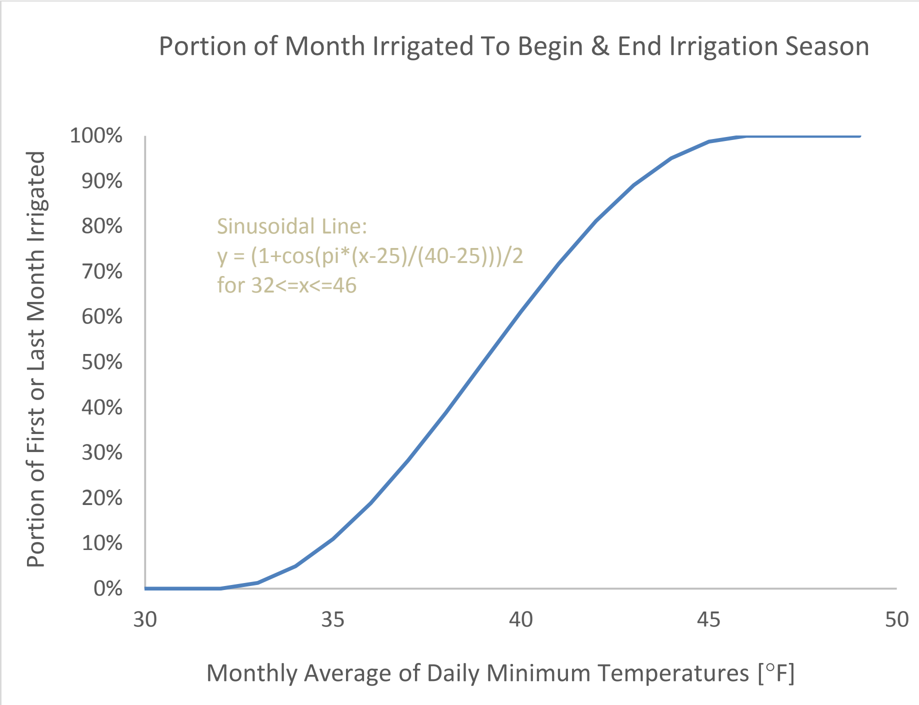

Figure 7 Functional relationship between monthly average minimum flow, and irrigation season start and end. The first month where T_{min} goes above 25F a calculated portion of that month starts the irrigation season, which then continues until the first month T_{min} goes below 40F and a calculated portion of that month ends the irrigation season.

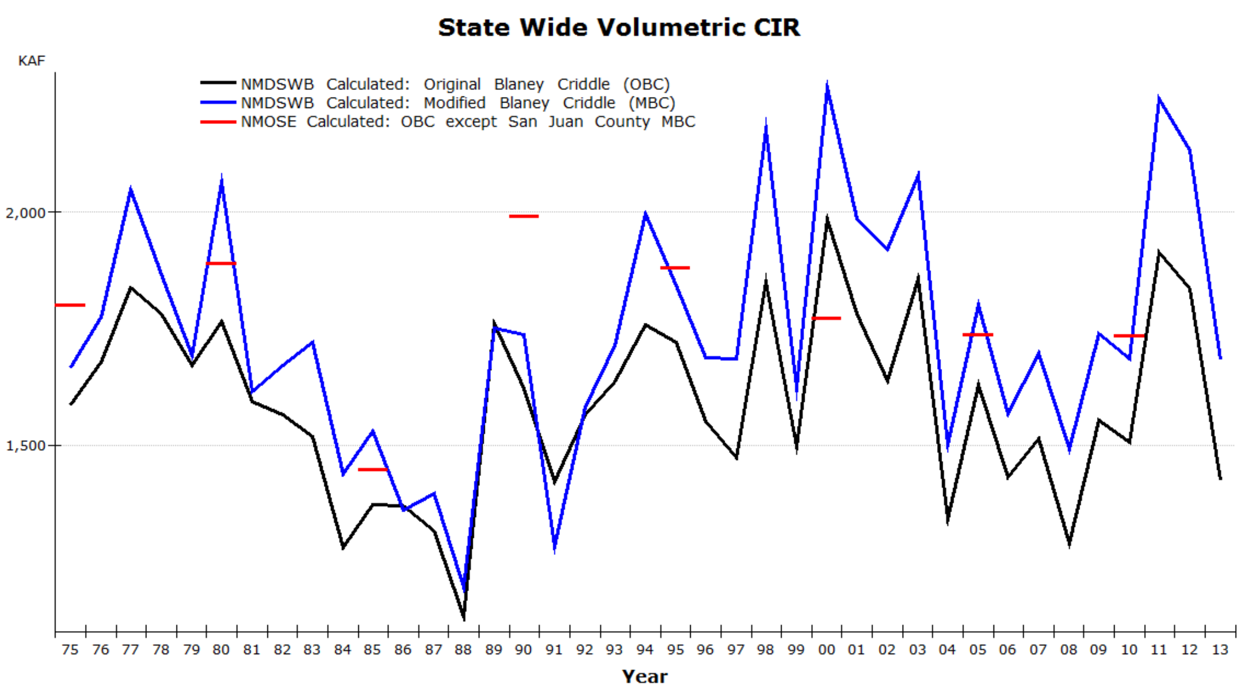

Figure 8 Total agricultural irrigation requirement calculated by NMDSWB compared to OSE reported values (e.g. Longworth et al 2013).

Table 13 Irrigation start and end months (end month is the last month irrigation occurs) and season length calculated from 1971 through 2009 using PRISM mean minimum monthly temperatures between 32°F and 46°F to start and end the season following the relationship shown in Figure 7. Season length includes fractional months to start and end the season.

	Irrigation Season:																
	First Month						Last Month			Length (months)							
County	Jan	Feb	Mar	Apr	May	Aug	Sep	Oct	Nov	2+	3+	4+	5+	6+	7+	8+	9+
Bernalillo			8%	**85%**	8%			**100%**				5%	**67%**	28%			
Catron				3%	**90%**		**90%**	10%			41%	**59%**					
Chavez		5%	**73%**	23%				**90%**	10%				5%	49%	44%	3%	
Cibola				15%	**85%**		**73%**	28%				**95%**	5%				
Colfax				15%	**85%**		**95%**	5%			3%	**95%**	3%				
Curry			**68%**	33%				**90%**	10%				5%	**69%**	26%		
De Baca			**63%**	38%				**93%**	8%				10%	**72%**	18%		
Dona Ana	8%	40%	**50%**	3%				33%	**68%**					3%	**51%**	38%	8%
Eddy	3%	38%	**60%**					20%	**80%**						**56%**	41%	3%
Grant		8%	38%	**50%**	5%			**95%**	5%				26%	**56%**	15%	3%	
Guadalupe			20%	**78%**	3%			**100%**					46%	**54%**			
Harding			10%	**88%**	3%			**100%**					**51%**	49%			
Hidalgo	3%	10%	**58%**	30%				**78%**	23%				5%	46%	38%	10%	
Lea	3%	25%	**68%**	5%				40%	**60%**					10%	**69%**	18%	3%
Lincoln			20%	**73%**	8%			**100%**					**54%**	46%			
Los Alamos				**55%**	45%		40%	**60%**				49%	**51%**				
Luna	5%	18%	**65%**	13%				**53%**	48%				3%	21%	**62%**	13%	3%
McKinley				20%	**80%**		**63%**	38%				**90%**	10%				
Mora				13%	**88%**		**98%**	3%			10%	**90%**					
Otero		13%	**70%**	18%				**83%**	18%				5%	38%	46%	10%	
Quay			**70%**	30%				**90%**	10%				3%	**72%**	26%		
Rio Arriba					**98%**	3%	**98%**				**51%**	49%					
Roosevelt			**68%**	33%				**88%**	13%				5%	**72%**	23%		
Sandoval				**70%**	30%		13%	**88%**				15%	**85%**				
San Juan			3%	**83%**	15%			**100%**					**92%**	8%			
San Miguel				**50%**	**50%**		35%	**65%**				46%	**54%**				
Santa Fe				**63%**	38%		30%	**70%**				36%	**64%**				
Sierra		8%	**63%**	30%				**93%**	8%				10%	**54%**	33%	3%	
Socorro			10%	**78%**	13%			**100%**				5%	**67%**	28%			
Taos					**88%**	33%	**68%**			13%	**79%**	8%					
Torrance			3%	**55%**	43%		28%	**73%**				28%	**72%**				
Union			3%	**80%**	18%		3%	**98%**				5%	**85%**	10%			
Valencia			18%	**80%**	3%			**100%**					**56%**	44%			

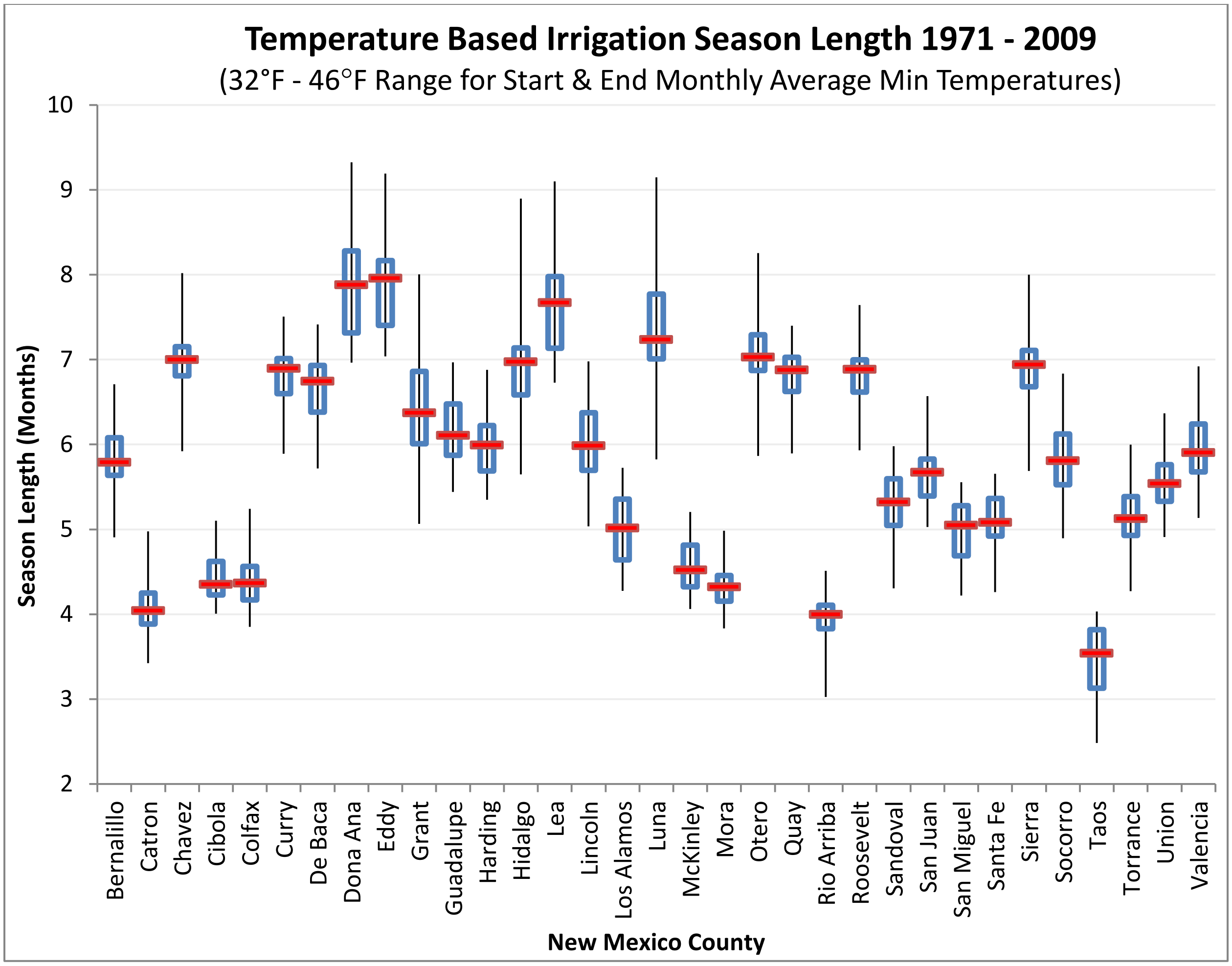

Figure 9 Calculated irrigation season lengths by county for historic years 1971 through 2009 if the irrigation season starts during the first month the county average PRISM mean minimum monthly temperature is more than 32°F, and ends during the month when the same is less than 46°F. Median values are the solid red dashes, and the middle 50% of values are within the boxes. Whiskers represent the maximum and minimum values.

5.1.4 Effective Precipitation

Effective precipitation (that precipitation which can be utilized by the crops to offset irrigation demand) is subtracted from Hargreaves-Samani potential ET and Blaney-Criddle consumptive use to get estimates of potential and actual crop irrigation requirements (CIR) respectively. By default, effective precipitation is calculated with the USDA-SCS (1970) method, but the NMDSWB also can calculate effective precipitation with a USBR method documented by Longworth et al (2013).

The USDA-SCS (1970) method is calculated as follows:

$$P_e = SF(0.70917P_t^{0.82416} - 0.11556)(10^{0.002426ET_c}) \quad \text{(Equation 7)}$$

Where:

P_e= average monthly effective precipitation (in)

P_t= monthly mean precipitation (in)

ET_c= average monthly crop evapotranspiration (in)

SF = soil water storage factor

The soil water storage factor is defined as:

$$SF = (0.531747 + 0.295164\,D - 0.057697\,D^2 + 0.003804\,D^3) \quad \text{(Equation 8)}$$

Where:

D = the net depth of irrigation water applied per month (in)

The term D is generally calculated as 40 to 60 percent of the available soil water capacity in the root zone, depending on the irrigation management practices used (U.S Department of Agriculture, Soil Conservation Service, 1970). The NMDSWB assumes a soil water storage factor of 3 inches which is the default value for New Mexico according to Longworth et al. (2013).

The USBR method expresses effective rainfall as a percentage of the total monthly rainfall. With each 1-inch increment in rainfall, there is a corresponding decrease in the percentage of monthly rainfall (Table 14) (Stamm, 1967).

Table 14 USBR Effective Rainfall.

Monthly Rainfall (R) (inches)	Effective Rainfall (R_e) (inches)
1≤R	R_e=0.95R
1≤R≤2	R_e=0.95R+0.90(R-1)
2≤R≤3	R_e=1.85R+0.82(R-2)
3≤R≤4	R_e=2.67R+0.65(R-3)
4≤R≤5	R_e=3.32R+0.45(R-4)
5≤R≤6	R_e=3.77R+0.25(R-5)
R>6	R_e=4.02R+0.0.5(R-6)

5.1.5 Irrigated Area

To go from consumption depth per time (i.e. ET rate) to volume of water lost per time, the depth rate must be multiplied by the total acreage. The irrigated agricultural data necessary for this was gathered from four sources: the OSE technical reports on water use by categories and irrigated acreages (Longworth et al., 2008, 2013; Sorensen, 1977, 1982; B Wilson, 1986; BC Wilson & Lucero, 1992, 1997, 2003), The USDA National Agricultural Statistics Service (NASS) Quick Stats (United States Department of Agriculture & National Agriculture Statistic Service, 2014), The New Mexico State University (NMSU) Cooperative Extension Service's technical report on trends in irrigated and dryland acreages in New Mexico 1970-1994 (Lansford, 1997), and the USGS's National Land Cover Datasets (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013; Price, Nakagaki, Hitt, & Clawges, 2003; Vogelmann et al., 2001).

The OSE calculates the total irrigated acreage by county every five years and this information is included within the water use by categories reports (Longworth et al., 2008, 2013; Sorensen, 1977, 1982; B Wilson, 1986; BC Wilson & Lucero, 1992, 1997, 2003). Each report represents an estimate of the total irrigated acreage for the report year only. However, the OSE reports do not include any information on the crop type which is needed in order to calculate specific crop consumptive irrigation requirements. Specific crop acreages are determined from the USDA NASS quick stats service (United States Department of Agriculture & National Agriculture Statistic Service, 2014) and Lansford (1997).

The USDA/NASS has an annual survey which reports on the total acres and irrigated acres of various crops by county. The major crops included in the NASS reports for New Mexico are: corn, barley, cotton, hay, sorghum, peanuts, and wheat. The data used here begins in 1971 for most crops and ends in 2007 (after 2007 the dataset is incomplete and less reliable). The data available for corn from 1971 to 1983 reports only acres planted, while from 1984 to 2007 the acres reported for corn are for irrigated acres. The assumption is made that all acres planted before 1984 are irrigated. Visual examination of the data before and after 1984 suggests this is a reasonable assumption. The data reported for barley is available from 1972 to 1989 and only includes acres planted; the assumption is made that all barley planted during this time is irrigated. For cotton, data is available for irrigated acres planted from 1972 to 2007 and includes acreage for both Upland and Pima cotton varieties. The data availability for hay on the county level is reported only as acres harvested, the assumption is made that all hay harvested from 1971 to 2007 is irrigated. For sorghum and peanuts, data is available for irrigated acreage from 1971 to 2007 and for wheat; irrigated acreage data is available from 1972 to 2007. Annual crop acreage is available only for the crops listed above. However there is additional data from the USDA/NASS Census available every five years starting in 1997. The acreages collected from these reports are used for irrigated orchards and irrigated vegetable totals. The 1997 Census is used in the model for the years 1995 to 1999, the 2002 Census for the years 2000 to 2004, and the 2007 census for years 2005 to 2009.

NMSU precisely details irrigated acreages of 22 different crops by county from 1970 through 1994 (Lansford, 1997). These crops include: corn, sorghum-grain, sorghum-all other, wheat, barley, other small grains, cotton-upland, cotton-pima, peanuts, sugar beets, dry beans, all other field crops, potatoes, lettuce, onions, chiles, all other vegetables, orchards, vineyards, alfalfa, planted pasture and native pasture. This report also includes the total acreages by county which are multiple cropped as well as those which are planted but not irrigated, but does not include this data by crop type. A summary of information available from these 3 sources is shown in Table 15.

Table 15 Information Summary for Irrigated Agriculture reports.

	NMSU	USDA	OSE
Spatial resolution	County	County	County
Temporal resolution	Annual	Annual[a]	Every 5 years
Temporal extent	1970-1994	1970-2013[b]	1970-2010
Information on Crop type by county	Yes	Yes	No
Information on multiple-cropped acreage	Yes	No	No

[a] Information for vegetable totals and orchards are is only available every five years.
[b] Missing data from 2008 to present, NMDSWB only uses reported data from USDA/NASS up to 2008.

The previously described NMSU crops (Lansford, 1997) and USDA field crops (United States Department of Agriculture & National Agriculture Statistic Service, 2014) are aggregated into four categories; grains, alfalfa and pasture grass, fruits and vegetables, and tree orchards (Table 16). The NMSU crops comprising the grain category are: barley, corn, Upland and Pima cotton, sorghum-grain, sorghum-all other, other small grains, and wheat. The USDA crops comprising the grains category are barley, corn, cotton, sorghum, and wheat. The alfalfa and pasture category is comprised of alfalfa, planted pasture, and native pasture for the NMSU crops, and hay from the USDA surveys. For the fruits and vegetables category, the following NMSU crops are aggregated: peanuts, sugar beets, dry beans, all other field crops, potatoes, lettuce, onions, chiles, all other vegetables and vineyards. On the USDA side there was only annual data available for peanuts from 1971-2007; however, starting in 1997 data is available for vegetable totals form the USDA NASS crops Census.

Table 16 Crop type and aggregation.

NMSU Crops	USDA Crops	Model Combined Crops
Barley	Barley	**Grains**
Corn	Corn	
Cotton-Upland	Cotton	
Cotton-Pima		
Sorghum-Grain	Sorghum	
Sorghum-All Other		
Other Small Grains		
Wheat	Wheat	
Alfalfa		**Alfalfa & Pasture**
Planted Pasture	Hay	
Native Pasture		
Peanuts	Peanuts	**Fruits & Vegetables**
Sugar Beets		
Dry Beans		
All Other Field		
Potatoes	Vegetable Totals[a]	
Lettuce		
Onions		
Chile		
All Other Vegetable		
Vineyards		
Orchards	Orchards[a]	**Orchards**

[a] Information only available every five years starting in 1997 from USDA/NASS crop census.

Lansford (1997) does not make the distinction between fields that are planted but not irrigated or fields that are multiple cropped, thus we calculate the adjusted acreage of each crop by calculating the crop's percentage of total area in a given county and multiplying by the sub-total irrigated acreage (sub-total acreage is the total irrigated acreage minus the planted but not irrigated and multiple cropped acreage). For 1971 to 1994 the acres of a given crop as a percentage are used from Lansford (1997) as the USDA NASS data does not include acreage for orchards or vegetable totals until the first census in 1997. From 1995 to 2007 crop acreages as a percent are supplied from a combination of USDA NASS survey and census data, and from 2008 to 2014 the crop acreages as a percent from 2007 are used and held constant. The model uses the sub-total acreage reported by Lansford (1997) for 1971 to 1994 and OSE reported acreage for 1995 to 2014. Statewide total crop acreages estimated in this manner are shown in Figure 10.

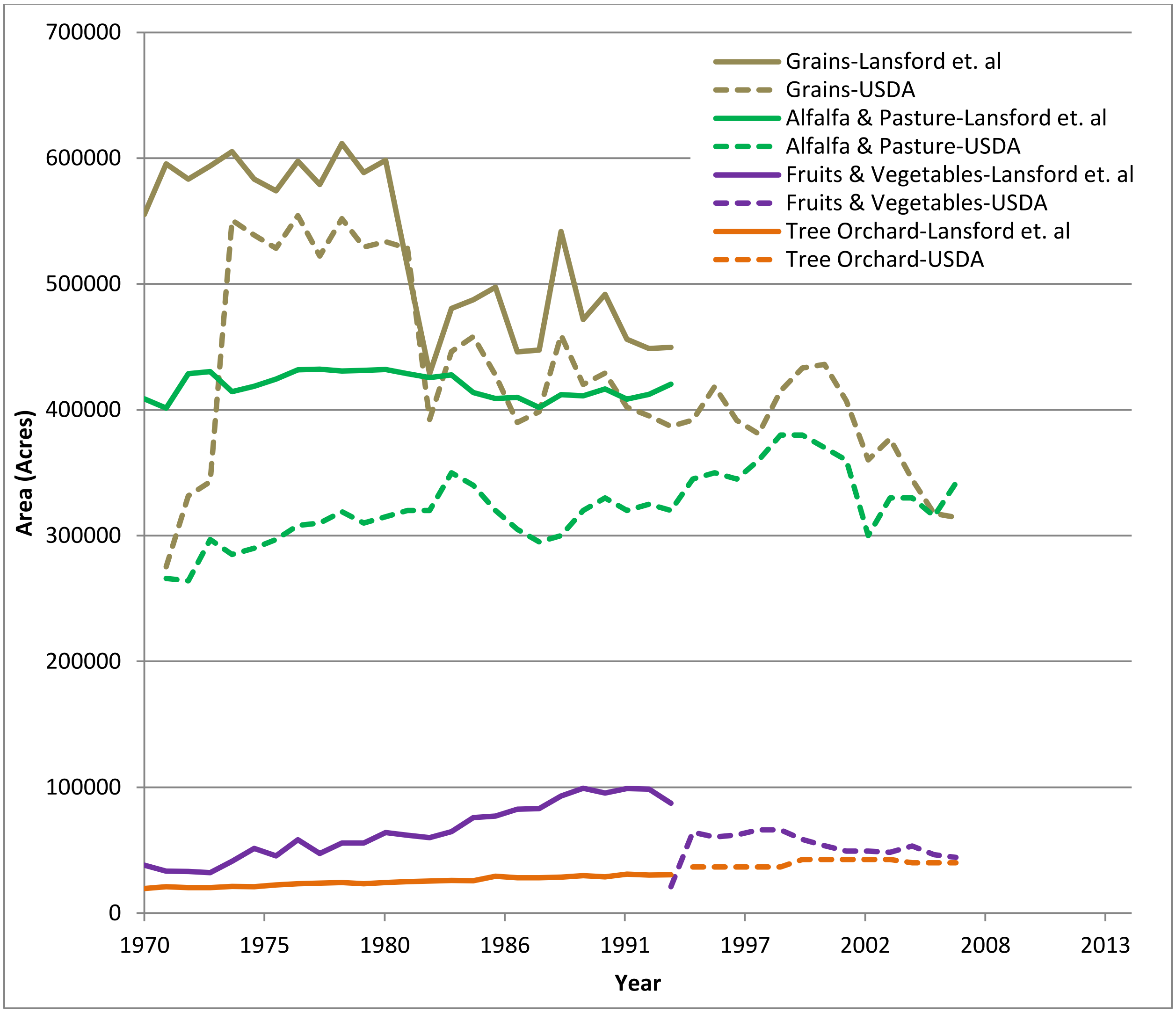

Figure 10 Estimated statewide crop acreages.

5.1.6 Riparian Area and Spatial Transformations of Ag Area from Remotely Sensed Data

Agricultural acreage from the previous sources is only reported at the county level. Because some counties are located within multiple planning regions, it is not possible to sum the agricultural areas by county to determine the agricultural areas by WPR. The agricultural acreage at the WPR and river basin scale is determined from remotely sensed land cover data from the USGS. For 1970 to 2003 agricultural and riparian acreage were measured from the 2001 USGS LULC data (Homer et al., 2007), for 2004 to 2008 from the 2006 USGS LULC data (Fry et al., 2011), and for 2009 to 2014 from the USGS LULC data (Jin et al., 2013). Early land use data sets from the 1970s and 80s (Price et al., 2003) as well as 1992 (Vogelmann et al., 2001) were explored but total riparian and agricultural areas from those data sets where inconsistent with later data sets, thus they were not used in the NMDSWB. Detailed information regarding the land cover classifications used to determine agricultural and riparian areas can be seen in Table 17. The total riparian areas calculated from the various land cover data sets are used directly for county, WPR, and river basin scales in the NMDSWB, statewide total agriculture and riparian areas can be seen in Figure 11. It is apparent from this figure that there are large discrepancies in agricultural land areas reported by different sources. Due to changes in methodologies of categorizing land cover over the years the total areas of agricultural land are not used. Instead the percentages of agricultural area by county within each WPR are calculated. Percentages of a given county's agricultural area within multiple WPRs or river basins are multiplied by the reported values of agricultural area by county to calculate the agricultural area by WPR or river basin.

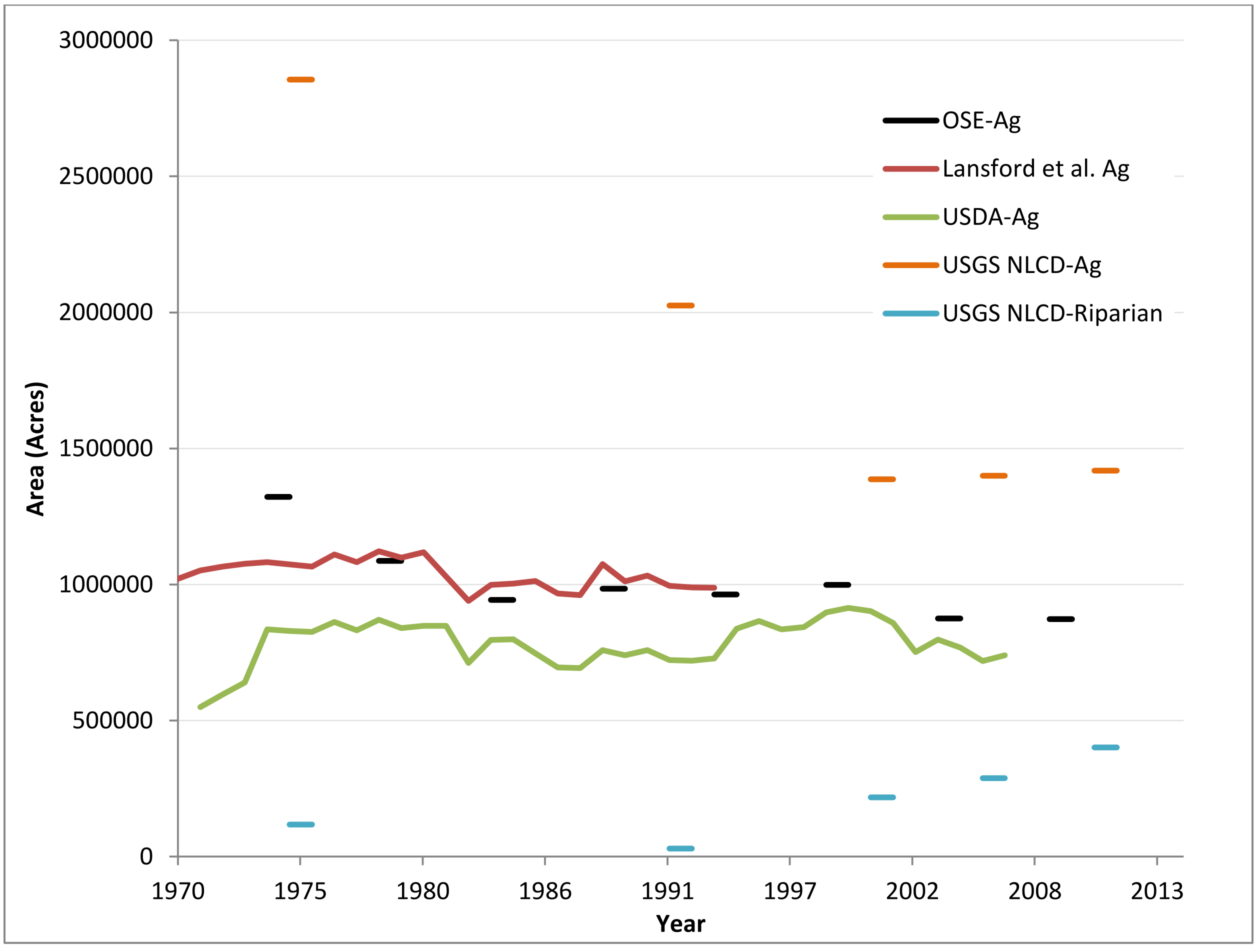

Figure 11 Statewide total agriculture and riparian land cover.

Table 17 Detailed information on land cover classifications used to determine agricultural and riparian areas.

Year of image	Years image used in NMDSWB	Agriculture	Riparian	Source
1970-1980s	Not used	21- crop/pasture 22- orchards, groves, vineyards, nurseries 23- confined feeding operations 24- other agriculture	61-forested wetland 62-non-forested wetland	(Price et al., 2003)
1992	Not used	61-orchards/vineyards 81-pasture/hay 82-row crops 83- small grains 84-fallow	90-woodly wetlands 95-emergent herbaceous wetlands	(Vogelmann et al., 2001)
2001	1970-2003	81-pasture/hay 82-cultivated crops	90-woodly wetlands 95-emergent herbaceous wetlands	(Homer et al., 2007)
2006	2004-2008	81-pasture/hay 82-cultivated crops	90-woodly wetlands 95-emergent herbaceous wetlands	(Fry et al., 2011)
2011	2009-2015	81-pasture/hay 82-cultivated crops	90-woodly wetlands 95-emergent herbaceous wetlands	(Jin et al., 2013)

5.2 Water Budget ET Terms

5.2.1 Land Surface Evapotranspiration

In this version of the NMDSWB estimates of land surface evaporation are not used. Because changes in water storage in the land were ignored (Section 2.2) land surface evaporation is calculated by setting evaporation equal to precipitation less surface water runoff and recharge. In other words, of the rain that falls in an area in a given period of time, we assume that what doesn't runoff or recharge evaporates to the atmosphere.

5.2.2 Surface Water Evaporation

Surface water evaporation is calculated by multiplying river area by Hargreaves reference ET and an open water coefficient for the respective basin. The river areas are dynamically calculated in the NMDSWB by correlating streamflow at a given stream gage to approximate stream width. Three stream widths are selected for each stream gage based on the field observed relationship between flow and stream width, for low, median, and high flows. The NMDSWB then interpolates stream width based on streamflow at a given timestep. The calculated area at a given timestep is held constant for half of the distance to the upstream gage (or to the start of a river/tributary for headwater gages) and for half the distance to the downstream gauge (or to the basin boarder for river stretches between basin boundaries). All stream length segments where measured using ARC GIS.

In addition to the physically based estimate of river channel evaporation described above, the surface water evaporation term also includes the portion of surface water return flows that do not end up back in a gaged stream. Because surface water flows out of a MBAU are based on gaged flows, returns that do not end up being gaged cannot be included, and thus must be removed from the mass balance accounting somehow. Rather than creating another flux to handle these returns, the portion of the returns that are not gaged enter the surface water system and are added to surface water evaporation (Section4.4.10). Reservoir evaporation is classified as a human induced consumptive use and is described in Section 5.2.3.

5.2.3 Human consumption

In the default setting of the NMDSWB human consumption is calculated for public and domestic water supplies (section 4.4.3), Irrigated agriculture (section 5.1), and livestock (4.4.4). Commercial, Industrial, Mining, and Power uses of water are provided by the OSE water use by categories report for counties and river basins (e.g. Longworth et al., 2013), see section 4.4.11 for information on data transformations from county level to WPR level.

Reservoir evaporation is calculated similarly to that for river surface water evaporation. The lake surface area is multiplied by the Hargreaves reference ET and an open water coefficient for the respective reservoir. For each lake a relationship between its capacity and its surface area is obtained from its managing agency. These relationships are often referred to as area-capacity or ACAP curves. For retrospective water budget calculations historic data on reservoir volumes were used. For future model projections reservoir volumes will be determined by performing a mass balance of inflows and outflows.

5.2.4 Human Returns

In the NMDSWB return flows are calculated as the difference between withdrawals and consumption (depletions). (Section 4.4.9 describes how return flows are partitioned to groundwater or surface water.) The surface water return flux from human storage also includes releases from reservoir storage.

5.2.5 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area. (Sections 5.1.1 and 5.1.6 describe how riparian ET rates and remotely sensed riparian areas are calculated).

5.3 Surface Water outflows

Surface water outflows are estimated based on USGS stream gage data as available. When a stream gage is available near the downstream border of a WPR, NMISC river basin, or County boundary it is used to represent the outflow. Surface water gages used in the NMDSWB were selected based on their locations, and periods of record. The gages that are used in the NMDSWB for surface water outflows are all currently active (except for the Zuni River at the NM-AZ state line in the Lower Colorado River basin, section 6.4.1) and have a minimum period of record of 35 years (except for the Gila River at Duncan, AZ and the Zuni River at the NM-AZ state line, both in the Lower Colorado River basin, section 6.4.1 . In some cases, lack of gage data requires outflows to be estimated. Detailed information on specifics of surface water outflows in these cases are provided for each river basin in Section 6, River Basins.

5.4 Groundwater Outflows

Groundwater flow across a political or watershed boundary cannot be directly measured, and must be calculated based on observed groundwater elevations and inferred geologic information, or extracted from regional groundwater models based on the same. In the 2015 version of the NMDSWB, groundwater outflows are largely unknown. The user has the option of setting groundwater outflows to a user selected constant value (with a default of zero), allowing a change in groundwater storage over the selected period to be calculated. However, this change would be averaged over the entire region being modeled (i.e. watershed, WPR, or county). This change in storage cannot be related to a change in groundwater elevation without detailed knowledge of aquifer characteristics, pumping and recharge, and developing a mechanistic groundwater model of the basin.

6 River Basins

6.1 San Juan River Basin

The San Juan River basin is located in the Northwest corner of New Mexico and encompasses all of San Juan County and portions of McKinley, Sandoval, and Rio Arriba counties (Figure 12). The San Juan River basin is defined by the same boundary as the San Juan WPR. The only river flowing through the basin is the San Juan River, which is fed from tributaries originating primarily in Colorado, and to a lesser degree New Mexico and small portions of Arizona. For a detailed description of the San Juan River basin/San Juan WPR refer to the San Juan Hydrologic Unit Regional Water Plan (San Juan Water Commission, 2003). One major reservoir, Navajo Reservoir, is modeled in the NMDSWB as described in section 6.1.6.

6.1.1 Surface water inflows/outflows in the San Juan River basin

The surface water inflows to the Upper Colorado River basin are defined by the sum of five USGS gages (United States Geological Survey, 2015): the San Juan River near Carracas, CO [USGS# 9346400], the Piedra River near Arboles, CO [USGS# 9349800], Los Pinos River at La Boca, CO [USGS# 9354500], La Plata River at CO-NM State Line [USGS# 9366500], and the Animas River near Cedar Hill, NM [USGS# 9363500]. The surface water outflow is equal to the San Juan River at Four Corners, CO [USGS# 9371010]. The Four Corners gage does not have any data before October of 1977. Before that time the outflow is estimated as the addition of the San Juan River at Shiprock, NM [USGS# 9368000], the Mancos River near Towaoc, CO [USGS# 9371000], and estimated agricultural returns below Shiprock, NM. For more information on the gages used in the NMDSWB for the Upper Colorado River Basin refer to Table 18 and Figure 13 San Juan River basin stream gages

Table 18 Gages used in the San Juan River basin.

Site Name	USGS Gage Number	Latitude	Longitude	Begin Date	End Date
San Juan River at Four Corners, CO	9371010	37.001139	109.02958	1977-10	Active
Mancos River near Towaoc, CO	9371000	37.027500	108.74083	1921-04	Active
San Juan River at Shiprock, NM	9368000	36.776667	108.68306	1934-10	Active
La Plata River near Farmington, NM	9367500	36.737575	108.25034	1938-03	Active
San Juan River at Farmington, NM	9365000	36.723017	108.22559	1930-10	Active
Animas River at Farmington, NM	9364500	36.722500	108.20175	1913-10	Active
La Plata River at CO-NM State Line	9366500	36.999722	108.18806	1920-10	Active
Animas River near Cedar Hill, NM	9363500	37.036569	107.87533	1933-11	Active
San Juan River near Archuleta, NM	9355500	36.801889	107.69864	1954-12	Active
Los Pinos River at La Boca, CO	9354500	37.009444	107.59889	1951-01	Active
Piedra River near Arboles, CO	9349800	37.088333	107.39722	1962-09	Active
San Juan River near Carracas, CO	9346400	37.013611	107.31167	1970-10	Active

*Headwaters gages

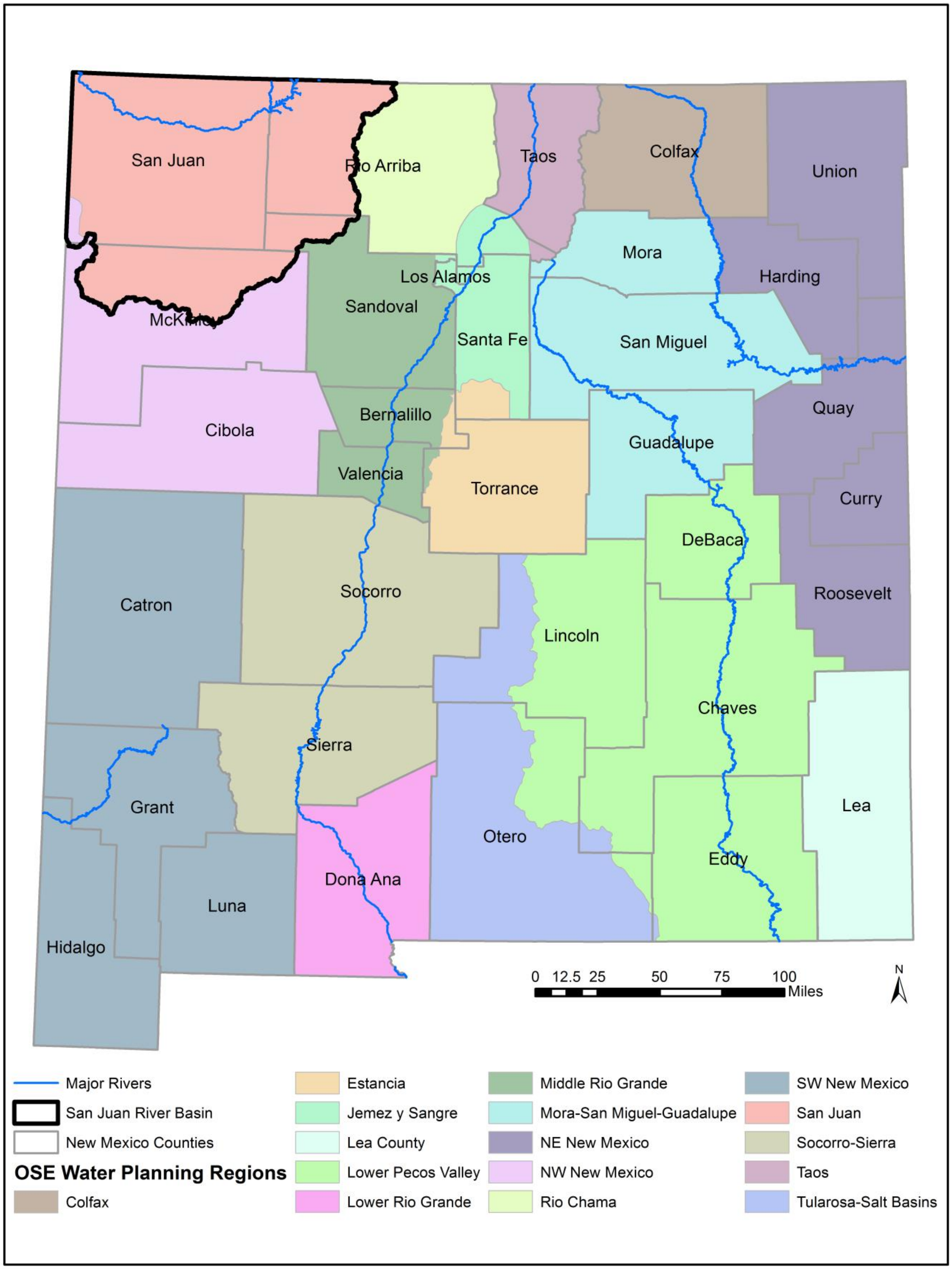

Figure 12 Spatial extent of San Juan River basin.

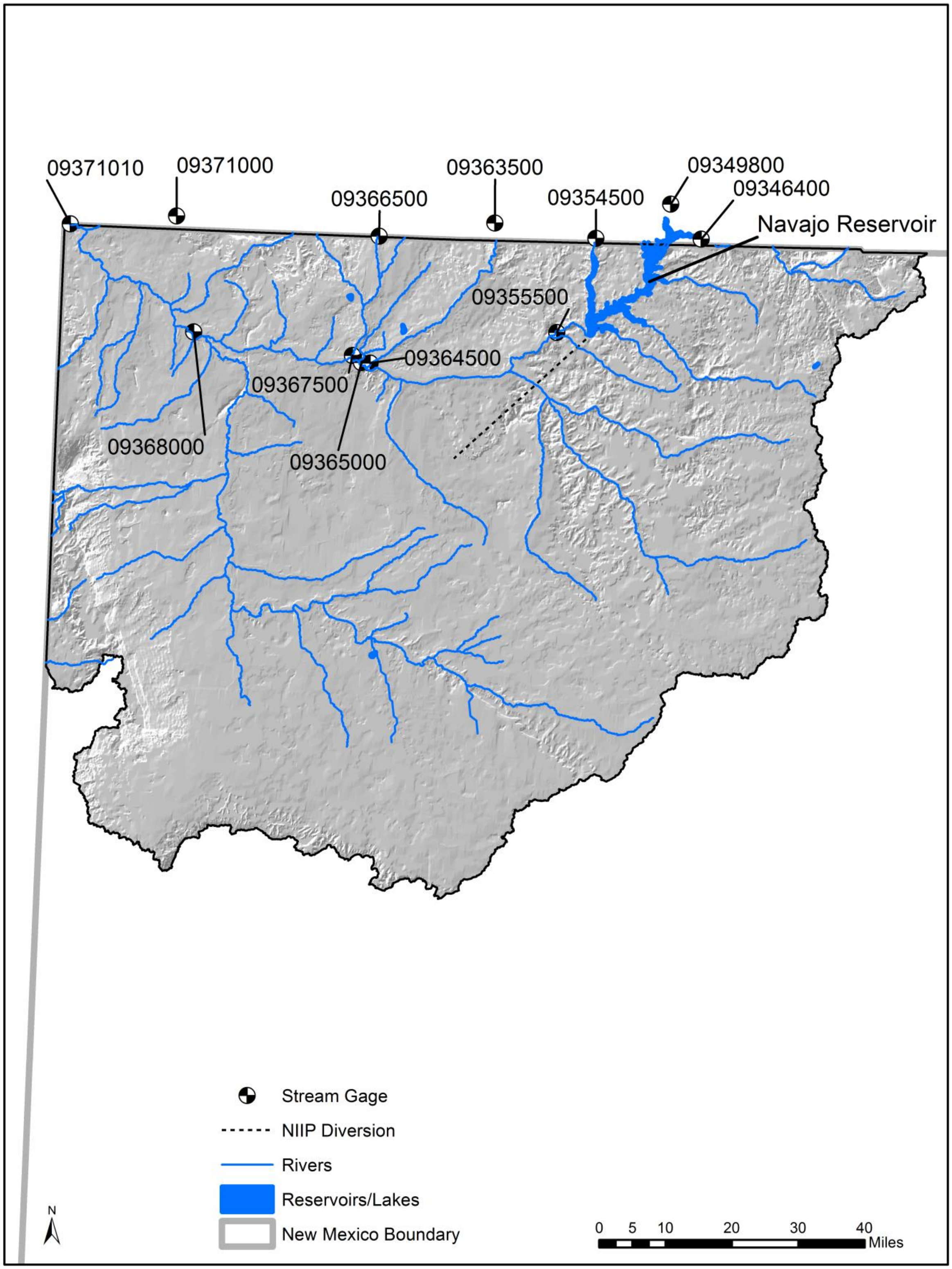

Figure 13 San Juan River basin stream gages used in NMDSWB. The 8 number codes are the USGS gage numbers.

6.1.2 Runoff

In the San Juan basin no headwater gages are present to calculate runoff; the gages along the Stateline are only used to represent surface water inflows into the basin. Runoff in the San Juan basin is calculated from gains between the gaged river stretches. The River reaches used in this study are the San Juan River from near Archuleta to Farmington, Farmington to Shiprock, and Shiprock to Four Corners, the Animas River from near Cedar Hill to Farmington, and La Plata River from the Colorado-New Mexico Stateline to Farmington. Surface water returns for each time step are then subtracted from the gross gains to get the net gains. The net gains are multiplied by the San Juan BFI of 46.2% to differentiate between runoff and baseflow. The average annual runoff from 1975 through 2010 was calculated to be approximately 41,000 acre feet per year.

6.1.3 Surface Water Groundwater Interactions

Groundwater surface water interactions are solved as a closure term to the surface water system. See section 4.3 for more information. The average annual surface water to groundwater flux in the San Juan Basin from 1975 through 2010 was calculated to be 15,000 acre feet per year of groundwater moving to surface water.

6.1.4 Groundwater

No information has been obtained or calculated to estimate groundwater flow into or out of the San Juan River basin for use within the NMDSWB. Setting both terms to zero, resulted in an average groundwater storage change of about 20,000 acre feet per year for the period from 1975 through 2010.

6.1.5 ET

6.1.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which (neglecting land surface storage change) is equal to precipitation less runoff and recharge. Calculated land surface ET from the San Juan River Basin from 1970 through 2010 averaged approximately 5,800,000 acre feet per year, which represents about 97% of precipitation.

6.1.5.2 Surface Water

Surface water evaporation is calculated in the San Juan basin by multiplying river area by Hargreaves reference ET and a monthly open water coefficient (Table 19). The river areas are dynamically calculated in the NMDSWB by correlating streamflow at a given stream gage to stream widths of variable dimensions. Three stream widths are selected for each stream gage used based on low, median, and high flows. The NMDSWB then interpolates stream width based on streamflow at each time step. Stream widths and lengths used in the NMDSWB to estimate open water surface evaporation for the San Juan river basin can be seen in Table 20. In the San Juan River basin 58% of surface water returns are estimated to flow to a stream that is gaged before leaving the State, the remaining 42% of returns are assumed to be lost to evaporation. See Section 4.4.10 for more information on how this was calculated. From 1975 to 2010 the average surface water evaporative losses were calculated as approximately 47,000 acre feet per year, 9,500 is directly from open water evaporation, the remaining 37,500 acre feet per year is from non-gaged surface water returns.

Table 19 Monthly open water ET coefficients in San Juan River basin.

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8

Table 20 San Juan basin stream widths and lengths used to estimate open water evaporation.

USGS stream gage site name	Low flow		Median flow		High flow		Length of stream segment associated with gage (miles)
	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	
San Juan near Carracas	0	0	-	-	-	-	0
Piedra near Arboles	0	0	-	-	-	-	0
Los Pinos at La Baca	0	0	-	-	-	-	0
San Juan near Archuleta	0	0	250	165	2000	172	20
Animas at Cedar Hill	0	0	200	130	1500	140	13
Animas near Farmington	0	0	200	125	6000	135	13
San Juan at Farmington	0	0	750	160	8000	180	34
La Plata near CO-NM border	0	0	-	-	-	-	0
La Plata near Farmington	0	0	5	15	120	23	18
San Juan at Shiprock	0	0	750	175	8000	200	32
Mancos near Towaoc	0	0	30	30	1000	50	15
San Juan at 4 corners	0	0	800	200	8000	250	18

6.1.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data obtained from OSE Water use categories reports for commercial, industrial, mining, and power uses of water. Open water evaporation from Navajo reservoir is calculated (section 6.1.6) and is included as human activity related consumption. The only storage change due to human activity in the San Juan River Basin is the storage change at Navajo reservoir as described below (section 6.1.6).

6.1.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6), and is estimated at an average of 83,000 AF per year for an average of 27,900 acres of riparian vegetation in the San Juan River Basin from 1975 through 2010.

6.1.6 Human Storage - Navajo Reservoir

Navajo Reservoir (Figure 13) a component of the Colorado River Storage Project, serves a variety of purposes including furnishing municipal and industrial water supplies to the surrounding population centers, irrigation water to the Navajo Indian Irrigation Project (NIIP), and upstream storage to regulate water for power generation at the Glen Canyon Dam (Lineberger, 1998). The Navajo Reservoir has a total capacity of 1,708,600 acre feet and occupies 15,610 acres when filled (Lineberger, 1998). Construction of the dam was finished around 1963 and the first irrigation releases were made that summer (Lineberger, 1998).

Navajo reservoir storage change each month is calculated in the NMDSWB as the difference between inflows and outflows. Modeled inflows include precipitation directly on the reservoir, and gaged and non-gaged inflows. Modeled outflows include gaged releases to the San Juan River, gaged diversions to NIIP, modeled reservoir evaporation, and unknown losses.

Navajo Reservoir is fed by three rivers all of which are gaged by the USGS: the San Juan River near Carracas, CO [USGS# 9346400], the Piedra River near Arboles, CO [USGS# 9349800], Los Pinos River at La Boca, CO [USGS# 9354500] (United States Geological Survey, 2015). The sum of these gages provides the gaged inflow to Navajo Reservoir. The outflow from the reservoir is gaged on the San Juan River near Archuleta, NM [USGS# 9355500] (United States Geological Survey, 2015).

Diversion information to the NIIP is provided as an average annual value of 126,263 acre feet from 1976 to 1997, from 1998 through 2013 annual diversion volumes are reported (Beutler, 2014). The annual diversion volume is disaggregated to a monthly time step in the NMDSWB by assuming that 10 % of the annual volume is diverted in April, 15% in May, 20% in June, 15% in July, 15% in August, 15% in September, 10% in October and 0% the remaining months of the year.

The precipitation falling on the reservoir is calculated using the PRISM monthly average precipitation depth for the Upper Colorado River basin multiplied by the surface area of the reservoir (at the given timestep). The surface area of the reservoir is calculated at each timestep using a pool elevation to surface area look up table provided by the USBR (U.S Bureau of Reclamation, 2015). During the historic period, pool elevation is known, during the scenario period it will be calculated based on modeled volume.

Evaporation from the reservoir is calculated using the Hargreaves reference ET (Section 5.1.1), multiplied by the surface area of the reservoir as well as by a monthly open water coefficient of 0.9 for January through June, and 0.8 for July through December (Roach, 2012). Reservoir operations data: storage, pool elevation, and an area-elevation-capacity table is provided by the USBR (U.S Bureau of Reclamation, 2015).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses such as leakage through the dam are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is adapted for predicting future balances, the patterns of ungaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

The average storage volume in Navajo Reservoir from 1975 through 2010 was 1,300,000 acre feet, with an increase in storage over that time period of 10,900 acre feet. However, it is important to recognize that all reservoirs experience large water level fluctuations that depend on how they are operated as well as hydrologic and climatic conditions. These fluctuations occur over times ranging from a few days to many years. Hence, reporting a long term average volume or comparing changes over a specified time frame may not provide a useful indication of the basin's water budget.

6.1.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation ($ET_{sw2,}$ ET_{gw} and ET_h), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 14 for the calculated average mass balance values in the San Juan River basin from 1975 through 2010.

Modeled human uses of water correlate well to the values reported by the NM OSE (i.e. Longworth et al., 2013), except for the modeled irrigated agriculture water uses. The modeled values are close to half that of the values reported by the OSE, even though the NDSWB uses the Modified Blanney-Criddle method to calculate CIR, the same methodology used by the OSE for the San Juan. The total irrigated acreage used by the NMDSWB is consistent with the values reported by the OSE. The lower CIR values modeled may be due, in part, to fact that temperature data is spatially averaged for the whole river basin, resulting in lower temperatures than may exist in the agricultural portions of the basin.

Groundwater storage and inflow/outflow estimates have not yet been obtained in this version of the model. Setting the groundwater inflow/outflow terms to zero, resulted in an average groundwater storage change of about 20,000 acre feet per year for the period from 1975 through 2010. If the groundwater system in the San Juan basin were in a steady state, the annual depletions would roughly be equal to the groundwater diversion minus the returns (4,000 acre feet per year). However, it is possible that irrigation from the NIIP project is playing a significant role in recharging the aquifer. From 1976 through 1995 the average annual diversions to the NIIP project were approximately 175 cfs, during this time period the estimated average change in groundwater storage was a decrease of 41,000 acre feet per year. From 1996 through 2010 the average annual diversions to the NIIP project were approximately 250 cfs, during this time period the estimated average change in groundwater storage was an increase of 95,000 acre feet per year.

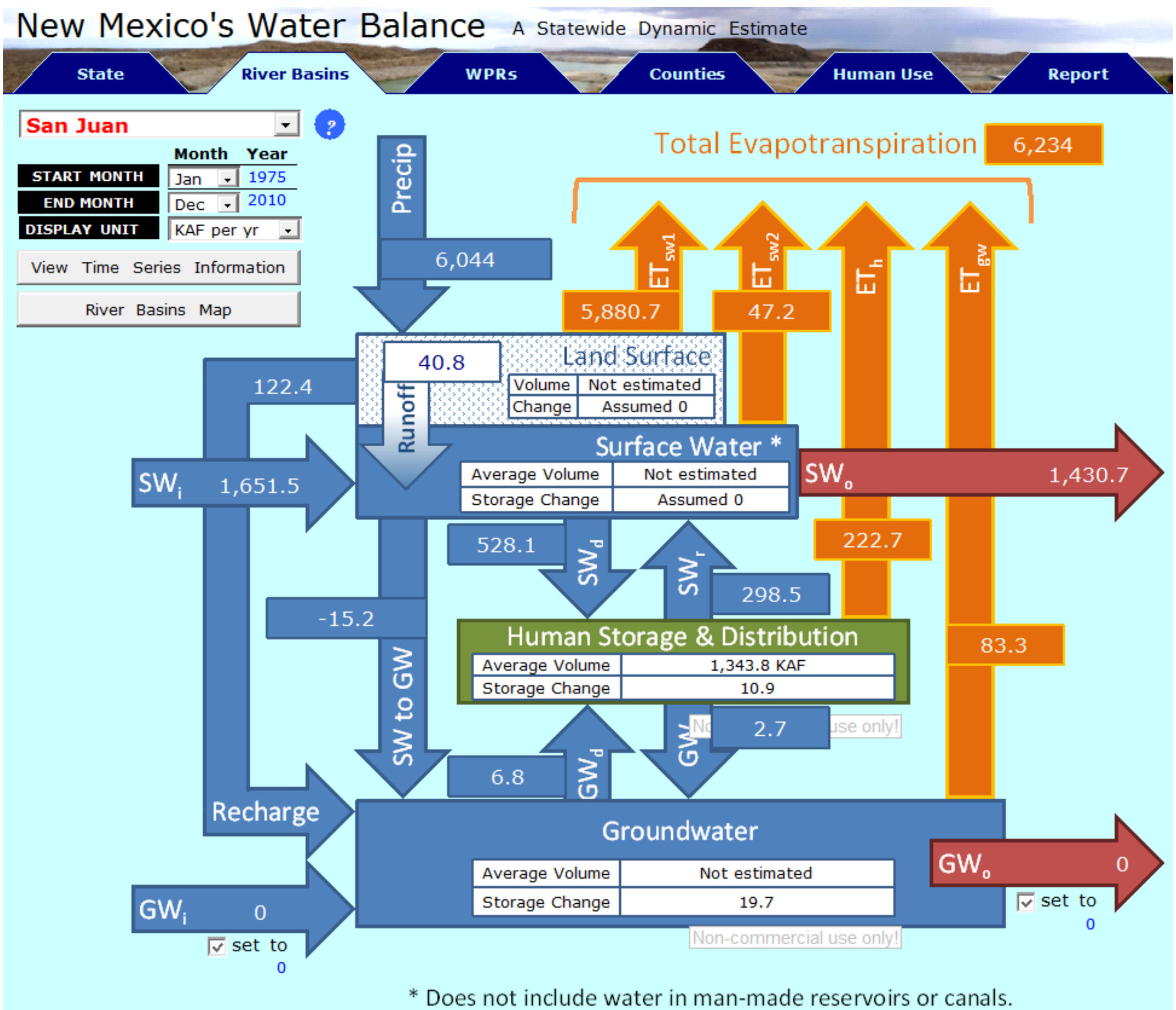

Figure 14 Average mass balance terms calculated for the San Juan Basin from 1975 through 2010.

6.2 Pecos River Basin

The Pecos River basin encompasses portions of six WPRs, Jemez y Sangre, Estancia, Mora-San Miguel-Guadaplupe, North Eastern New Mexico, Lower Pecos Valley, and Lea, as well as portions of 14 counties, Sante Fe, Mora, San Miguel, Guadalupe, Torrance, Quay, Currry, Roosevelt, De Baca, Lincoln, Chaves, Eddy, Otero, and Lea. The spatial extent of the Pecos River basin is shown in Figure 15.

6.2.1 Surface Water Inflows/Outflows in the Pecos River Basin

The Pecos river basin in New Mexico is a headwaters basin, there are no streams or rivers that flow into the basin; all of the streamflow in the basin originates entirely from within the basin. There are two USGS stream gages that define surface water flowing out of the Pecos River basin, the Pecos River at Red Bluff, NM [USGS# 8407500] and the Delaware River near Red Bluff, NM [USGS# 8408500]. The locations of stream gages in the Pecos River basin are presented Figure 16 and a list provided in .

Table 21. For 1975 to 2010 the average surface water outflow from the basin was approximately 73,000 acre feet per year.

6.2.2 Runoff

Runoff in the Pecos River basin is calculated as a sum of headwaters runoff and runoff between gaged river stretches. The headwaters gages are defined as the highest upstream gage (given an adequate period of record) on each gaged tributary within the river basin (.

Table 21).The total surface water returns for a given timestep are subtracted from the gross gains between gaged river stretches to get net gains. Table 22 identifies the gaged river stretches in the Pecos River basin. The net gains and headwaters flow are multiplied by BFI values of 38.6% for the Upper Pecos River basin and 19.5% for the Lower Pecos River basin. For 1975 to 2010 the average runoff equaled approximately 150,000 acre feet per year.

6.2.3 Surface Water Groundwater Interactions

Groundwater surface water interactions are solved as a closure term to the surface water system as described in section 4.3. For 1975 to 2010 the average surface water to groundwater flux equaled approximately -65,000 acre feet per year, meaning there was a net flow of groundwater to surface water (i.e. the Pecos River was a gaining stream). This observation is likely explained by the very long reach of stream over which the budget was determined. It is likely that the upper reaches of the river, upstream from about Sumner Reservoir are gaining whereas the lower Pecos, which is a wide slow moving and meandering stream, is an important source of recharge to the shallow alluvial aquifer.

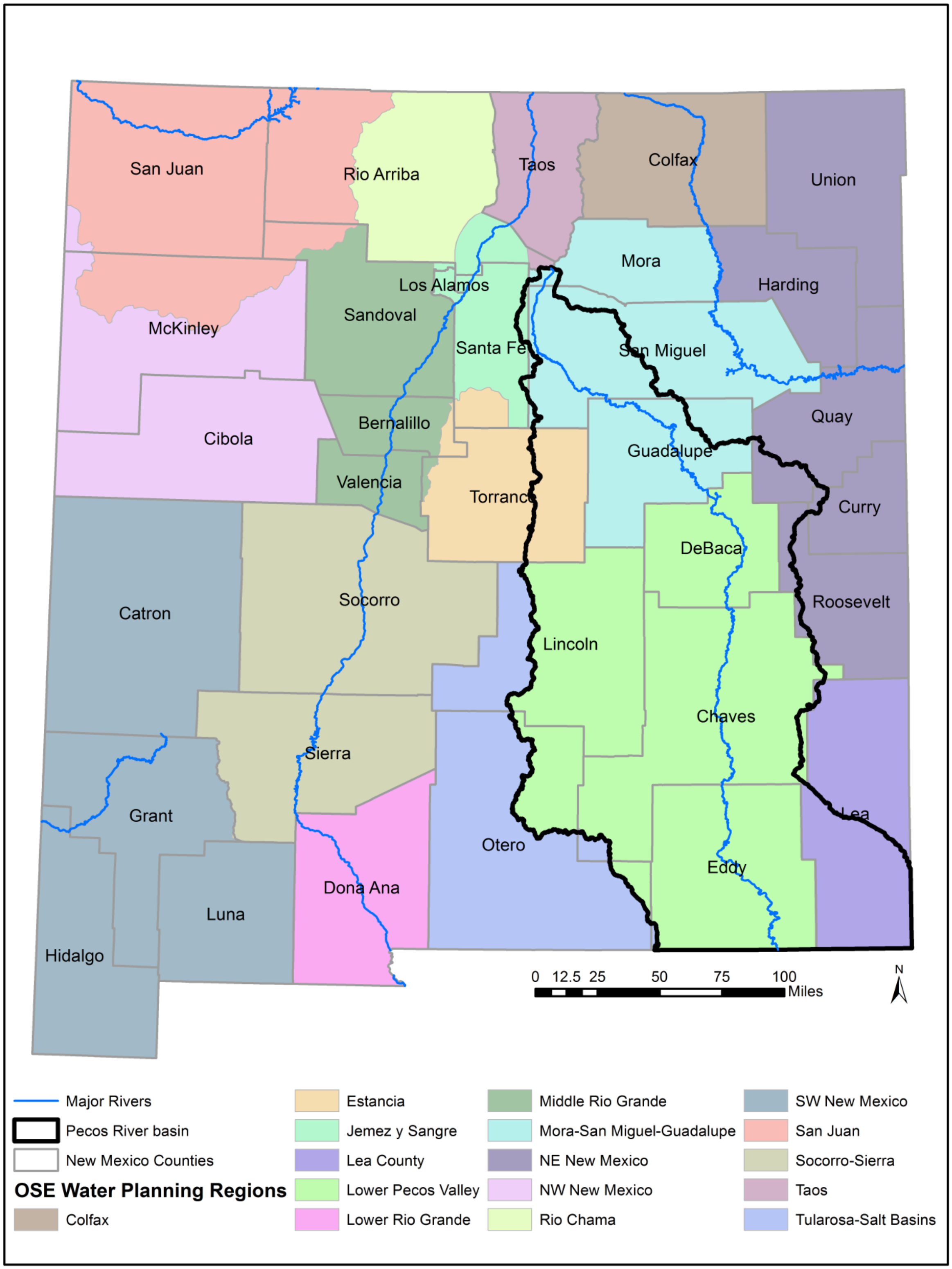

Figure 15 Spatial extent of Pecos River basin.

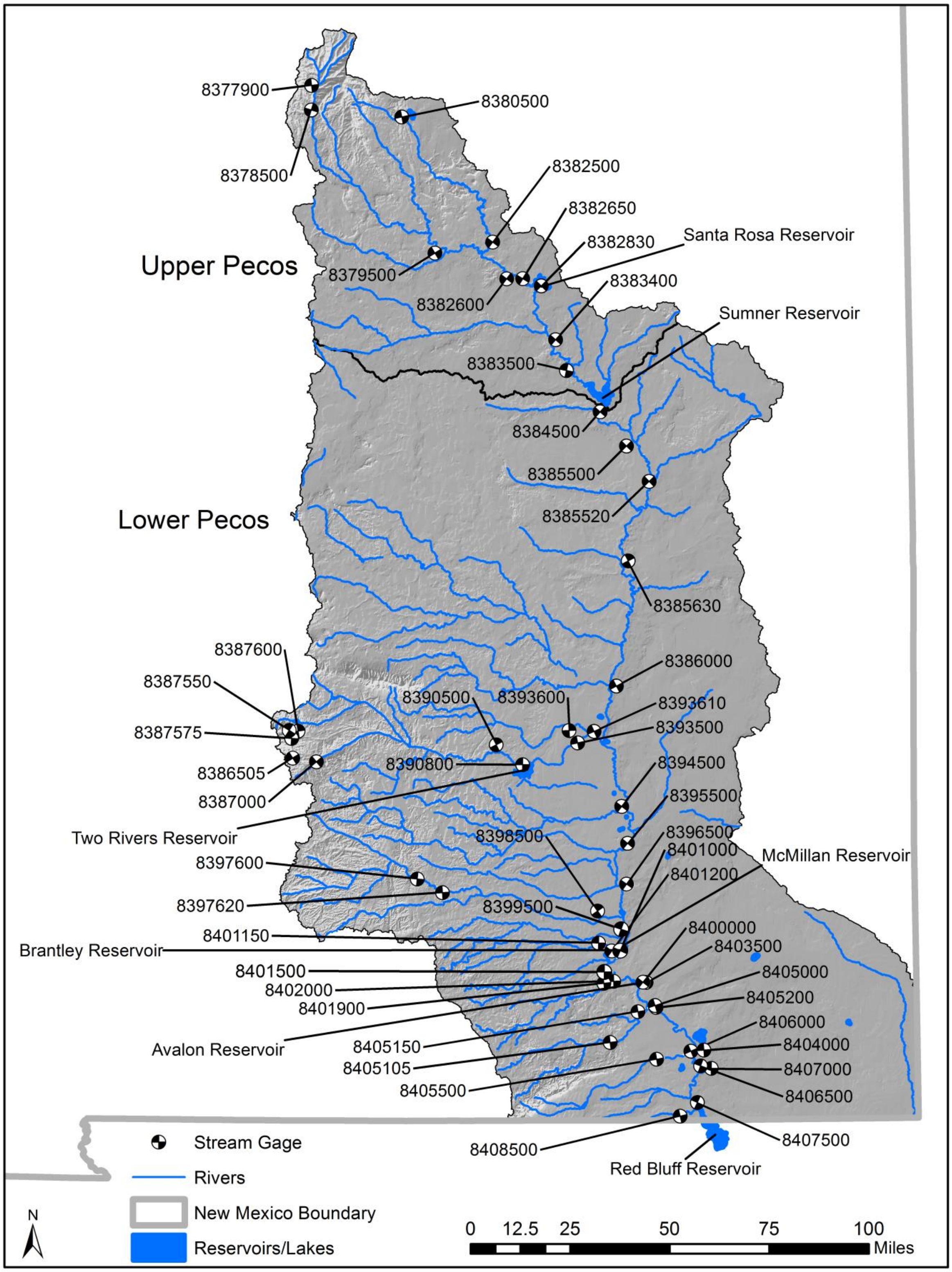

Figure 16 USGS gages used in NMDSWB for the Pecos River basin. The 8 number codes are the USGS gage numbers.

Table 21 Stream gages in the Pecos River basin

Site Name	Site Number	Site Agency	Site Longitude	Site Latitude	Start Date	End Date
*RIO MORA NEAR TERRERO, NM	8377900	USGS	-105.6580278	35.7771139	1963-10-01	ACTIVE
*PECOS RIVER NEAR PECOS, NM	8378500	USGS	-105.6827028	35.7083500	1919-10-01	ACTIVE
PECOS RIVER NEAR ANTON CHICO, NM	8379500	USGS	-105.1088028	35.1786694	1910-10-01	ACTIVE
GALLINAS CREEK NEAR MONTEZUMA, NM	8380500	USGS	-105.3188306	35.6519944	1926-09-01	ACTIVE
GALLINAS RIVER NEAR COLONIAS, NM	8382500	USGS	-104.9002667	35.1819611	1951-01-01	ACTIVE
PECOS R ABV CANON DEL UTA NR COLONIAS, NM	8382600	USGS	-104.8005556	35.0913889	1976-01-01	ACTIVE
PECOS RIVER ABOVE SANTA ROSA LAKE, NM	8382650	USGS	-104.7611111	35.0594444	1976-02-28	ACTIVE
PECOS RIVER BELOW SANTA ROSA DAM, NM	8382830	USGS	-104.6888889	35.0241667	1980-01-17	ACTIVE
PECOS RIVER AT PUERTO DE LUNA, NM	8383400	USGS	-104.6258213	34.8264499	1949-01-11	1958-11-30
PECOS RIVER NEAR PUERTO DE LUNA, NM	8383500	USGS	-104.5249111	34.7300833	1938-05-01	ACTIVE
PECOS RIVER BELOW SUMNER DAM, NM	8384500	USGS	-104.3879167	34.6040556	1912-10-01	ACTIVE
PECOS RIVER NEAR FORT SUMNER, NM	8385500	USGS	-104.2724756	34.4786776	1994-10-01	2003-09-30
PECOS RIVER BELOW FORT SUMNER, NM	8385520	USGS	-104.1730273	34.3481265	1957-08-22	1970-09-15
PECOS RIVER NEAR DUNLAP, NM	8385630	USGS	-104.3066667	34.0633333	1993-08-20	ACTIVE
PECOS RIVER NEAR ACME, NM	8386000	USGS	-104.3736028	33.5718556	1937-07-01	ACTIVE
*RIO RUIDOSO AT RUIDOSO, NM	8386505	USGS	-105.7263083	33.3365306	1998-10-30	ACTIVE
RIO RUIDOSO AT HOLLYWOOD, NM	8387000	USGS	-105.6253333	33.3266917	1953-10-01	ACTIVE
NORTH FORK EAGLE CREEK NEAR ALTO, NM	8387550	USGS	-105.7407639	33.4095472	2007-09-07	ACTIVE
SOUTH FORK EAGLE CREEK NEAR ALTO, NM	8387575	USGS	-105.7246806	33.3924083	2007-09-06	ACTIVE
*EAGLE CREEK BELOW SOUTH FORK NEAR ALTO, NM	8387600	USGS	-105.7233444	33.3928528	1969-08-27	ACTIVE
RIO HONDO AT DIAMOND A RANCH NR ROSWELL, NM	8390500	USGS	-104.8516667	33.3491667	1939-10-01	ACTIVE
RIO HONDO BLW DIAMOND A DAM NR ROSWELL, NM	8390800	USGS	-104.7216750	33.2998694	1963-10-01	ACTIVE
RIO HONDO AT ROSWELL, NM	8393500	USGS	-104.5458024	33.3720438	1981-02-19	1997-05-18
RIO HONDO NEAR ROSWELL, NM	8393610	USGS	-104.4717167	33.4087750	1997-06-01	ACTIVE
RIO FELIX AT OLD HWY BRD NR HAGERMAN, NM	8394500	USGS	-104.3449634	33.1251075	1939-10-01	ACTIVE
PECOS RIVER NEAR LAKE ARTHUR, NM	8395500	USGS	-104.3209722	32.9893056	1938-08-24	ACTIVE
PECOS RIVER NEAR ARTESIA, NM	8396500	USGS	-104.3238333	32.8408611	1905-10-01	ACTIVE
*RIO PENASCO NEAR DUNKEN, NM	8397600	USGS	-105.1780556	32.8815278	2000-03-01	ACTIVE
RIO PENASCO NEAR HOPE, NM	8397620	USGS	-105.0694222	32.8367722	2000-02-19	ACTIVE
RIO PENASCO AT DAYTON, NM	8398500	USGS	-104.4141306	32.7434472	1951-04-01	ACTIVE
PECOS RIVER (KAISER CHANNEL) NEAR LAKEWOOD, NM	8399500	USGS	-104.2992194	32.6893750	1950-05-16	ACTIVE

Site Name	Site Number	Site Agency	Site Longitude	Site Latitude	Start Date	End Date
*FOURMILE DRAW NR LAKEWOOD, NM	8400000	USGS	-104.3689694	32.6726889	1951-10-01	ACTIVE
PECOS RIVER BELOW MCMILLAN DAM, NM	8401000	USGS	-104.3502360	32.5945595	1906-02-08	1988-09-30
NORTH SEVEN RIVERS NR LAKEWOOD, NM	8401150	USGS	-104.3971834	32.6495586	1989-08-01	1995-02-07
*SOUTH SEVEN RIVERS NR LAKEWOOD, NM	8401200	USGS	-104.4213889	32.5886111	1963-10-01	ACTIVE
PECOS RIVER BELOW BRANTLEY DAM NEAR CARLSBAD, NM	8401500	USGS	-104.3711000	32.5431889	1971-10-01	ACTIVE
*ROCKY ARROYO AT HWY BRD NR CARLSBAD, NM	8401900	USGS	-104.3749889	32.5060806	1963-10-01	ACTIVE
PECOS R AT DAMSITE 3 NR CARLSBAD, NM	8402000	USGS	-104.3332889	32.5112278	1939-08-22	ACTIVE
CARLSBAD MAIN CANAL AT HEAD NEAR CARLSBAD, NM	8403500	USGS	-104.2527278	32.4903944	1939-07-01	ACTIVE
PECOS RIVER BELOW AVALON DAM	8404000	USGS	-104.2629806	32.4808556	1951-06-01	ACTIVE
PECOS RIVER AT CARLSBAD, NM	8405000	USGS	-104.2174480	32.4112293	1903-10-01	1969-12-31
*DARK CANYON DRAW NEAR WHITES CITY, NM	8405105	USGS	-104.3491667	32.2904306	2002-02-03	ACTIVE
*DARK CANYON AT CARLSBAD, NM	8405150	USGS	-104.2294444	32.4033333	1973-01-01	ACTIVE
PECOS RIVER BELOW DARK CANYON AT CARLSBAD, NM	8405200	USGS	-104.2149722	32.4092750	1970-01-01	ACTIVE
*BLACK RIVER ABOVE MALAGA, NM	8405500	USGS	-104.1518528	32.2290889	1947-01-01	ACTIVE
BLACK RIVER AT MALAGA, NM	8406000	USGS	-104.0646861	32.2408667	2000-02-24	ACTIVE
PECOS RIVER NEAR MALAGA, NM	8406500	USGS	-104.0238750	32.2075417	1938-08-01	ACTIVE
PECOS RIVER AT PIERCE CANYON CROSSING, NM	8407000	USGS	-103.9793861	32.1885306	1938-08-01	ACTIVE
PECOS RIVER AT RED BLUFF, NM	8407500	USGS	-104.0394361	32.0751917	1937-10-01	ACTIVE
DELEWARE RIVER NEAR RED BLUFF, NM	8408500	USGS	-104.0544456	32.0231417	1937-10-01	ACTIVE

*Headwaters gages

Table 22 Gaged river stretches in Pecos River basin.

River	Upstream Gage	Downstream Gage	Notes	Subtracted side flows
Gallinas	GALLINAS CREEK NEAR MONTEZUMA, NM	GALLINAS R NR COLONIAS, NM		
Pecos	PECOS RIVER NEAR PECOS, NM	PECOS RIVER NEAR ANTON CHICO, NM		
Pecos	PECOS RIVER NEAR ANTON CHICO, NM	PECOS RIVER NEAR PUERTO DE LUNA, NM	Only before 1980	GALLINAS R NR COLONIAS, NM
Pecos	PECOS RIVER NEAR ANTON CHICO, NM	PECOS R ABV CANON DEL UTA NR COLONIAS, NM	Only after 1980	GALLINAS R NR COLONIAS, NM
Pecos	PECOS R ABV CANON DEL UTA NR COLONIAS, NM	PECOS RIVER ABOVE SANTA ROSA LAKE, NM	Only after 1981	
Pecos	PECOS RIVER BELOW SANTA ROSA DAM, NM	PECOS RIVER NEAR PUERTO DE LUNA, NM	Only after 1982	
Pecos	PECOS RIVER BELOW SUMNER DAM, NM	PECOS RIVER NEAR ACME, NM		
Pecos	PECOS RIVER NEAR ACME, NM	PECOS RIVER NEAR LAKE ARTHUR, NM		Before 1981 RIO HONDO AT DIAMOND A RANCH NR ROSWELL, NM. After 1981 RIO HONDO AT ROSWELL, NM

Pecos	PECOS RIVER NEAR LAKE ARTHUR, NM	PECOS RIVER NEAR ARTESIA, NM		
Rio Hondo	RIO RUIDOSO AT HOLLYWOOD, NM	RIO HONDO AT DIAMOND A RANCH NR ROSWELL, NM		
Rio Hondo	RIO HONDO BLW DIAMOND A DAM NR ROSWELL, NM	RIO HONDO AT ROSWELL, NM	Only after 1981	
Rio Penasco	RIO PENASCO NEAR DUNKEN, NM	RIO PENASCO AT DAYTON, NM	Only after March, 2000	
Pecos	PECOS RIVER NEAR ARTESIA, NM	PECOS RIVER (KAISER CHANNEL) NEAR LAKEWOOD, NM		RIO PENASCO AT DAYTON, NM
Pecos	PECOS RIVER BELOW AVALON DAM	PECOS RIVER BELOW DARK CANYON AT CARLSBAD, NM		DARK CANYON DRAW NEAR WHITES CITY, NM
Dark Canyon	DARK CANYON DRAW NEAR WHITES CITY, NM	DARK CANYON AT CARLSBAD, NM	Only after March, 2002	
Pecos	PECOS RIVER BELOW DARK CANYON AT CARLSBAD, NM	PECOS RIVER NEAR MALAGA, NM		BLACK RIVER ABOVE MALAGA, NM
Pecos	PECOS RIVER NEAR MALAGA, NM	PECOS RIVER AT PIERCE CANYON CROSSING, NM		
Pecos	PECOS RIVER AT PIERCE CANYON CROSSING, NM	PECOS RIVER AT RED BLUFF, NM		

6.2.4 Groundwater

The groundwater basin associated with the Pecos River basin is assumed to match the surface water basin meaning there are no groundwater inflows into the Pecos River basin from adjacent basins. No information has been obtained or calculated to estimate groundwater flow out of the Pecos River basin for use within the NMDSWB. Under the assumption of zero groundwater in and out of the basin the average net depletion of groundwater for 1975 through 2010 equals approximately 550,000 acre feet per year.

6.2.5 ET

6.2.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which (neglecting land surface storage change) is equal to precipitation less runoff and recharge. Calculated land surface ET from the Pecos River basin from 1975 through 2010 averaged approximately 21,000,000 acre feet per year, which accounts for about 98% of precipitation.

6.2.5.2 Surface Water

Surface water evaporation is calculated in the Pecos River basin by multiplying river area by Hargreaves reference ET and an open water coefficient. The open water coefficients used in the Upper and Lower Pecos River basins can be seen in Table 23.

Table 23 Open Water Coefficients used to calculate open water river evaporation in Pecos River basin.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upper Pecos	1.5	1.4	1.6	1.6	1.5	1.4	1.4	1.1	1.1	1.1	1.5	1.6
Lower Pecos	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8

The river areas are dynamically calculated in the NMDSWB by correlating streamflow at a given stream gage to stream widths of variable dimensions. Three stream widths are selected for each stream gage based on low, median, and high flows. The NMDSWB then interpolates stream width based on streamflow at each timestep. Stream widths and lengths used in the NMDSWB to estimate open water surface evaporation can be seen in Table 24.

In the Pecos River basin 47% of surface water returns are estimated to return to a stream that is gaged before leaving the State, the remaining 53% of returns are assumed to be lost from the accounting system to evaporation (see Section 4.4.10 for more information on how this was calculated). For 1975 through 2010 the average annual surface water evaporation was calculated to be approximately 180,000 acre feet per year, 33,000 of which are direct from open water evaporation, the remaining 147,000 acre feet are from non-gaged returns.

Table 24 Pecos River basin stream widths.

	Low flow		**Median flow**		**High flow**		
USGS stream gage site name	**flow (cfs)**	**stream width (ft)**	**flow (cfs)**	**stream width (ft)**	**flow (cfs)**	**stream width (ft)**	**Length of stream segment associated with gage (miles)**
Gallinas Creek near Montezuma (Upper Pecos)	5.5	11	105	24	380	27	32
Gallinas Creek near Colonias (Upper Pecos)	1	5	42	32	267	52	25
Pecos River near Pecos NM (Upper Pecos)	8.5	26	244	46	493	84	45
Pecos River near Anton Chico (Upper Pecos)	1	11	125	36	670	135	55
Pecos River near Puerto de Luna (Upper Pecos)	55	55	110	75	1560	117	85
Pecos River near Acme (Lower Pecos)	8	14	85	74	1250	125	52
Rio Ruidoso at Hollywood NM (Lower Pecos)	2.5	9	118	26	411	56	65
Rio Hondo below Diamond A Dam (Lower Pecos)	0.5	5.5	46	17	217	26	35
Pecos near Lake Arthur (Lower Pecos)	1	8	100	120	16100	195	30
Pecos near Artesia (Lower Pecos)	8.5	40	270	59	1590	98	5
Pecos Kaiser channel near Lakewood (Lower Pecos)	1.5	15	88	40	1860	72	20

Pecos below Dark Canyon at Carlsbad (Lower Pecos)	1.5	10	145	35	1280	325	25
Pecos at Pierce Canyon Crossing (Lower Pecos)	3	6	80	35	700	335	20
Pecos at Red Bluff (Lower Pecos)	2	8.5	350	100	52600	750	14
Rio Penasco at Dayton (Lower Pecos)	5	10	25	26	190	65	85
Delaware River near Red Bluff (Lower Pecos)	0.2	2	40	28	34600	380	18

6.2.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data driven from OSE Water use categories reports for commercial, industrial, mining, and power uses of water. Open water evaporation from the Pecos River basin reservoirs is calculated (section 6.1.6) and is included here as a human activity related consumption. The storage changes tracked for the Pecos River basin are the storage change at reservoirs as described below (section 6.1.6).

6.2.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6) 48,250 acres of riparian vegetation result in an estimated ET loss of 198,000 acre feet per year, from 1975 through 2010.

6.2.6 Human Storage Pecos River Basin Reservoirs

Six reservoirs are modeled for the NMDSWB within the Pecos River basin; these are shown in Figure 16. The average storage capacity for 1975 through 2010 equaled approximately 94,000 acre feet. From 1975 to 2010 the storage change in the Pecos reservoirs was negligible which is due in large part to the operations of these reservoirs for water supply storage.

6.2.6.1 Santa Rosa Reservoir

Santa Rosa reservoir is the most upstream reservoir on the Pecos River. The dam was constructed in 1979 by the U.S Army Corps of Engineers for storage of irrigation water and flood control. Reservoir operations data (storage, area-capacity table, pan evaporation rates, and precipitation rates) were provided by the Army Corps of Engineers (Young, 2015a). In the NMDSWB, Santa Rosa reservoir storage is calculated as zero before October 1982, due to missing data before that time.

Reservoir inflow/outflow data comes from the USGS stream gages, Pecos River above Santa Rosa Lake, NM [USGS# 8382650], and Pecos River below Santa Rosa Dam, NM [USGS# 8382830], respectively (United States Geological Survey, 2015).

Precipitation falling on the reservoir is calculated using the USACE monthly average precipitation at Santa Rosa Reservoir (Young, 2015a) multiplied by the surface area of the reservoir (at the given timestep). The surface area of the reservoir is calculated at each timestep using a pool volume to surface area look up table provided by the USBR (U.S Bureau of Reclamation, 2015).

Evaporation from the reservoir is calculated using USACE calculated reservoir evaporation depth (Young, 2015a) multiplied by the surface area of the reservoir as well as by a monthly open water coefficient of 0.9 for January through June, and 0.8 for July through December (Roach, 2012).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified for modeling future conditions, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

6.2.6.2 Sumner Reservoir

The Fort Sumner irrigation project was developed by private interests in the late 19th and early 20th centuries. In the early 1950's the Sumner Damn was reconstructed and rehabilitated by the U.S Bureau of Reclamation (U.S Bureau of Reclamation, 2015). Reservoir storage and area-capacity data were provided by the U.S Bureau of Reclamation (Donnelly, 2015). Reservoir inflow/outflow data comes from the USGS stream gages, Pecos River near Puerto de Luna, NM [USGS# 8383500], and Pecos River below Sumner Dam, NM [USGS# 8384500] respectively (United States Geological Survey, 2015).

Precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for De Baca County multiplied by the surface area of the reservoir (at the given timestep). The surface area of the reservoir is calculated at each timestep using a pool volume to surface area look up table provided by the USBR (Donnelly, 2015).

Reservoir pan evaporation rates from the U.S. Bureau of Reclamation were only available from 1997 through 2007 (Donnelly, 2015). The NMDSWB uses Hargreaves reference ET (section 5.1.1) to calculate evaporation from the area of the reservoir at any given timestep. The U.S. Bureau of Reclamation evaporation data was used to calibrate monthly open water coefficients for Sumner Reservoir as shown in Table 25.

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified for modeling future conditions, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

Table 25 Pecos River basin reservoir open water evaporation coefficients.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sumner	1.5	1.4	1.6	1.6	1.5	1.4	1.4	1.1	1.1	1.1	1.5	1.6
Two Rivers	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.0	1.3	1.4	1.8
McMillan	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8
Brantley	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8
Avalon	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8

6.2.6.3 Two Rivers Reservoir

Two rivers reservoir is comprised of two dams, the Diamond A dam on the Rio Hondo, and the Rocky Dam on the Rocky Arroyo. Both dams' primary function is for flood control, and the majority of the time the reservoirs are dry. Diamond A is gated and the releases can be regulated, Rocky Dam is non-gated and drains at maximum rate of 300 cfs. During large flood events the two reservoirs breach the dike separating them and become one common pool.

The inflows/outflows on the Rio Hondo are gaged by the USGS: Rio Hondo at Diamond A Ranch near Roswell, NM [USGS# 8390500], and Rio Hondo below Diamond A Dam near Roswell, NM [USGS# 8390500] (United States Geological Survey, 2015). Inflows and outflows along Rocky Arroyo are not gaged.

Precipitation falling on the reservoir is calculated using monthly average precipitation depth at Two Rivers Reservoir (Young, 2015b) multiplied by the surface area of the reservoir (at the given timestep). The surface area of the reservoir is calculated at each timestep using a pool elevation to surface area look up table provided by the USACE (Young, 2015b).

Evaporation from the reservoir is calculated using the Hargreaves reference ET for the Lower Pecos River basin(Section 5.1.1), multiplied by the surface area of the reservoir as well as by an open water evaporation coefficient which was calibrated for Brantley Reservoir (Table 25) (section 6.2.6.5).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified for modeling future conditions, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

6.2.6.4 McMillan Reservoir

McMillan Reservoir was decommissioned in 1988 and replaced by the Brantley reservoir located downstream. In retrospective runs of the NMDSWB, McMillan is only active prior to December of 1988. Storage data for McMillan reservoir was provided by the U.S Bureau of Reclamation (Donnelly, 2015).

The gaged reservoir inflows are USGS gages, Pecos River (Kaiser Channel) near Lakewood, NM [USGS# 8399500] and Fourmile Draw near Lakewood, NM [USGS# 8400000]. The gaged outflow is represented by USGS gage, Pecos River below McMillan Dam, NM [USGS# 8401000] (United States Geological Survey, 2015).

Reservoir evaporation rate is calculated using Hargreaves reference ET (section 5.1.1) multiplied by the surface area of the reservoir at the current timestep and by an open water evaporation coefficient which was calibrated for Brantley Reservoir (Table 25) (section 6.2.6.5). An area-capacity table was not available to convert storage to surface area, thus a simple linear relationship was developed assuming the area of a cone with a surface area of zero at zero storage and surface area of 4,285 acres at the crest of the 56 feet high dam with a maximum storage of 80,000 acre feet (Bogner, 1993). Storage at the current timestep is multiplied by 0.0536 feet^{-1} to calculate surface area.

The volume of precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for Eddy County multiplied by the surface area of the reservoir (at the given timestep).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified for modeling future conditions, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

6.2.6.5 Brantley Reservoir

In the NMDSWB Brantley reservoir begins to fill October of 1988. Storage and area-capacity data for Brantley reservoir was provided by the U.S Bureau of Reclamation (Donnelly, 2015).

The gaged reservoir inflows are USGS gages, Pecos River (Kaiser Channel) near Lakewood, NM [USGS# 8399500], Fourmile Draw near Lakewood, NM [8400000], and South Seven Rivers near Lakewood [8401200]. The gaged outflow is represented by USGS gage, Pecos River below Brantley Dam near Carlsbad, NM [8401500] (United States Geological Survey, 2015).

Precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for Eddy County multiplied by the surface area of the reservoir (at the given timestep). Reservoir surface area is calculated from reservoir storage using an acre capacity lookup table (Donnelly, 2015).

Reservoir evaporation rate is calculated using Hargreaves reference ET (section 5.1.1) multiplied surface area at the given timestep and an open water evaporation coefficient which was calibrated for Brantley Reservoir (Table 25) (section 6.2.6.5) using U.S Bureau of Reclamation Brantley Reservoir evaporation data from 1997-2011 (Donnelly, 2015).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified for modeling future conditions, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

6.2.6.6 Avalon Reservoir

Avalon is the furthest downstream reservoir on the Pecos River within New Mexico. Storage and area-capacity data for Avalon reservoir was provided by the U.S Bureau of Reclamation (Donnelly, 2015).

The gaged reservoir inflow is the USGS gage, Pecos River at Damsite 3 near Carlsbad, NM [USGS# 8402000]. The gaged outflows are USGS gages, Pecos River below Avalon Dam [USGS# 8404000] and Carlsbad Main Canal at Head near Carlsbad, NM [8403500] (United States Geological Survey, 2015).

Precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for Eddy County multiplied by the surface area of the reservoir (at the given timestep). Reservoir surface area is calculated from reservoir storage using an acre capacity lookup table (Donnelly, 2015).

Reservoir evaporation is calculated using Hargreaves reference ET (section 5.1.1) multiplied by an open water evaporation coefficient which was calibrated for Brantley Reservoir (Table 25) (section 6.2.6.5) (Donnelly, 2015).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified for modeling future conditions, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

6.2.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation ($ET_{sw2,}$ ET_{gw} and ET_{h}), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 17 for the average mass balance terms calculated for the Pecos River basin from 1975 through 2010.

Modeled human uses of water correlate well to the values reported by the NM OSE (i.e. Longworth et al., 2013). Total withdrawals and depletions for irrigated agriculture are consistent with the OSE reported values; however, the NMDSWB surface water withdrawals/depletions are slightly lower (~20%) and the groundwater withdrawals/depletions slightly higher (~20%) than OSE values.

Groundwater storage and inflow/outflow estimates have not yet been obtained in this version of the model, since the Pecos is a headwaters basin; groundwater inflow is most likely zero. Setting the groundwater inflow/outflow terms to zero, resulted in an average groundwater storage depletion of about 550,000 acre feet per year for the period from 1975 through 2010. If the groundwater system in the Pecos River basin were in a steady state, the annual depletions would roughly be equal to the groundwater diversion minus the returns (390,000 acre feet per year). The NMDSWB estimates of groundwater depletion may be high but are within a reasonable range based on the available data.

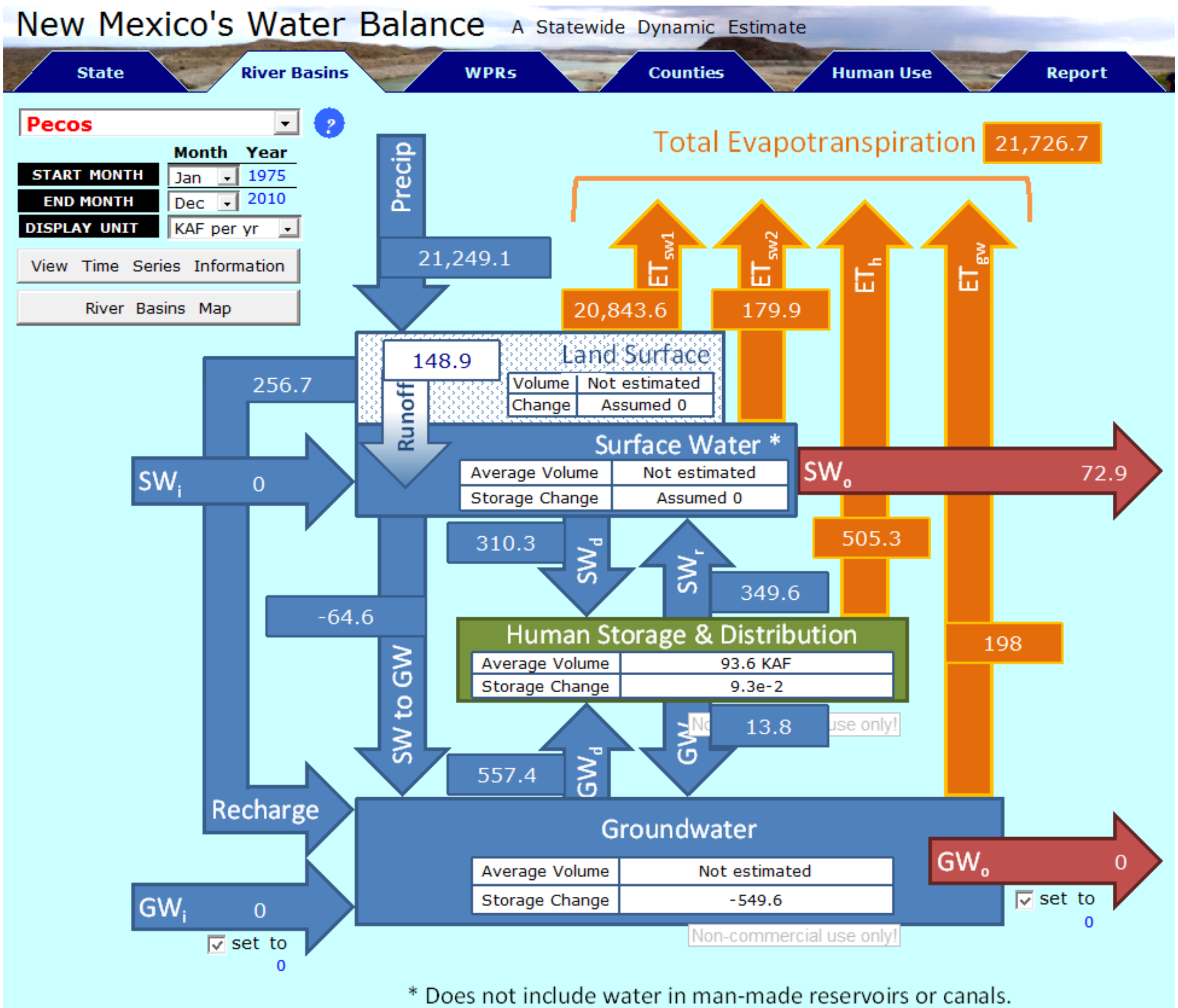

Figure 17 Average mass balance terms calculated for the Pecos River Basin from 1975 through 2010.

6.3 Canadian River Basin

The Canadian River basin is in the Northeast corner of the state. Colfax, Union and Harding are the only counties located entirely in the Canadian River basin, portions of Mora, San Miguel, Guadalupe, Quay and Curry counties are within the river basin. The Canadian River basin also contains the entire Colfax WPR and portions of the Mora-San Miguel-Guadalupe and Northeast WPRs. The major river in the basin is the Canadian River; an overview of the basin can be seen in Figure 18.

6.3.1 Surface Water Inflows/Outflows in the Canadian River basin

The headwaters of the Canadian river originate near the Colorado New Mexico border. There are no gaged inflows from Colorado into New Mexico within the Canadian River basin. Outflow from the basin is the sum of the Canadian River at Logan, NM [USGS# 07227000] and Revuelto Creek near Logan, NM [USGS# 07227100]. From 1975 through 2010 the average annual flow of surface water out of the basin was approximately 58,000 acre feet per year. A map of all the USGS stream gages used in the Canadian River basin can be seen in Figure 19 and a detailed list of all gages can be seen in Table 26.

6.3.2 Runoff

Following the methodology described in Section 4.1, runoff in the Canadian basin is calculated as a summation of headwaters runoff and runoff between gaged river stretches. The headwaters gages are defined as the highest upstream gage (given an adequate period of record) on each gaged tributary within the river basin (Table 26). The total surface water returns for a given timestep are subtracted from the gross gains between gaged river stretches to determine net gains, see Table 27 for the gaged river stretches in the Canadian River basin. The net gains and headwaters flow in the Canadian River basin are multiplied by BFI values of 31.5% to differentiate between runoff and baseflow. From 1975 through 2010 the annual average runoff was calculated to approximately 88,000 acre feet per year.

6.3.3 Surface Water Groundwater Interactions

Groundwater surface water interactions are solved as a closure term to the surface water system. See section 4.3 for more information. In the Canadian River basin this term was calculated as an average annual flux of approximately 200,000 acre feet per year of groundwater moving to surface water over the entire length of the river. This value seems high, and will be investigated more closely in future work when baseflow and recharge methods are reconsidered. As with the Pecos basin, it is likely that most of this flux occurs in the upper reaches of the river.

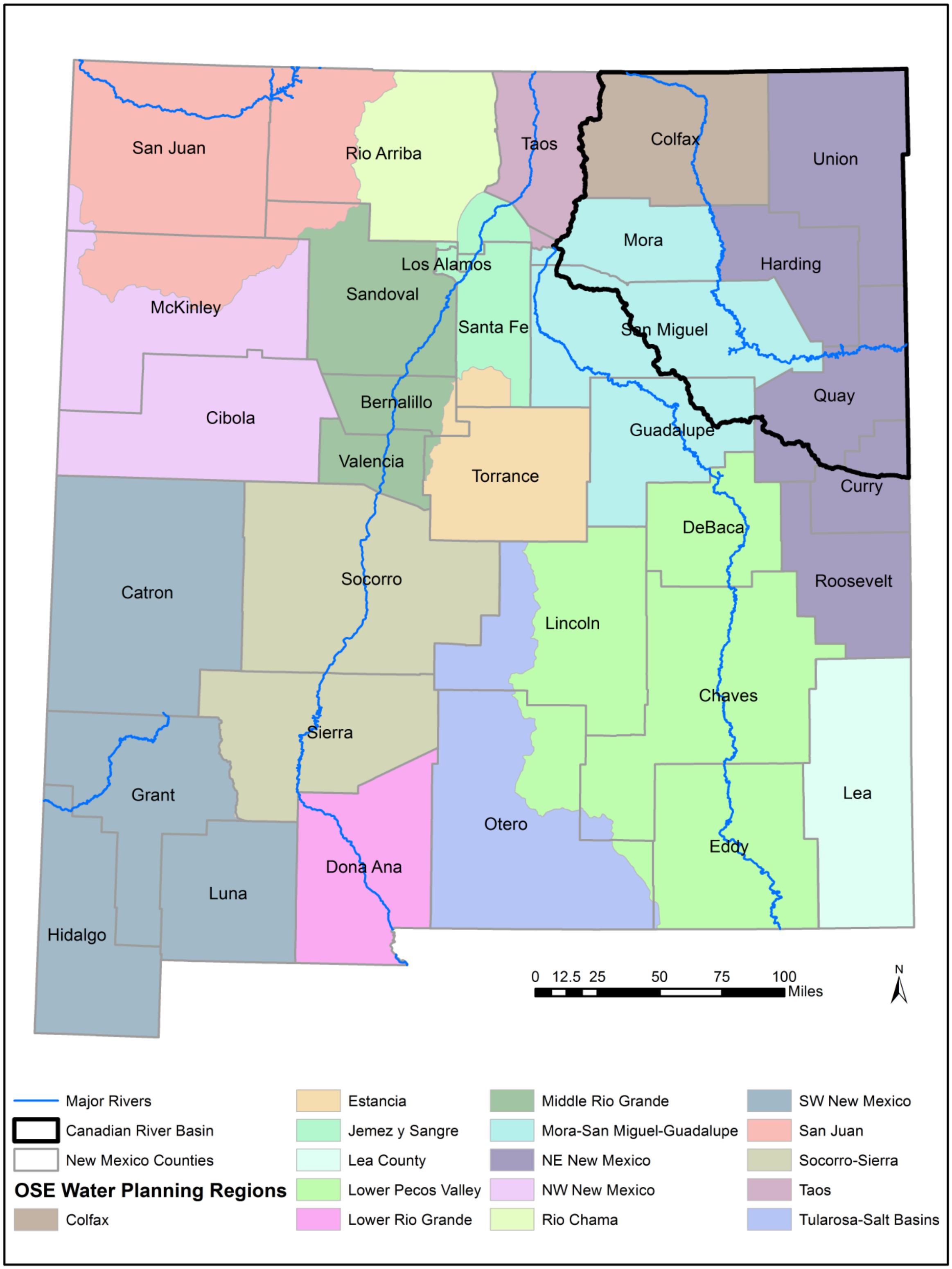

Figure 18 Spatail extent of Canadian River basin.

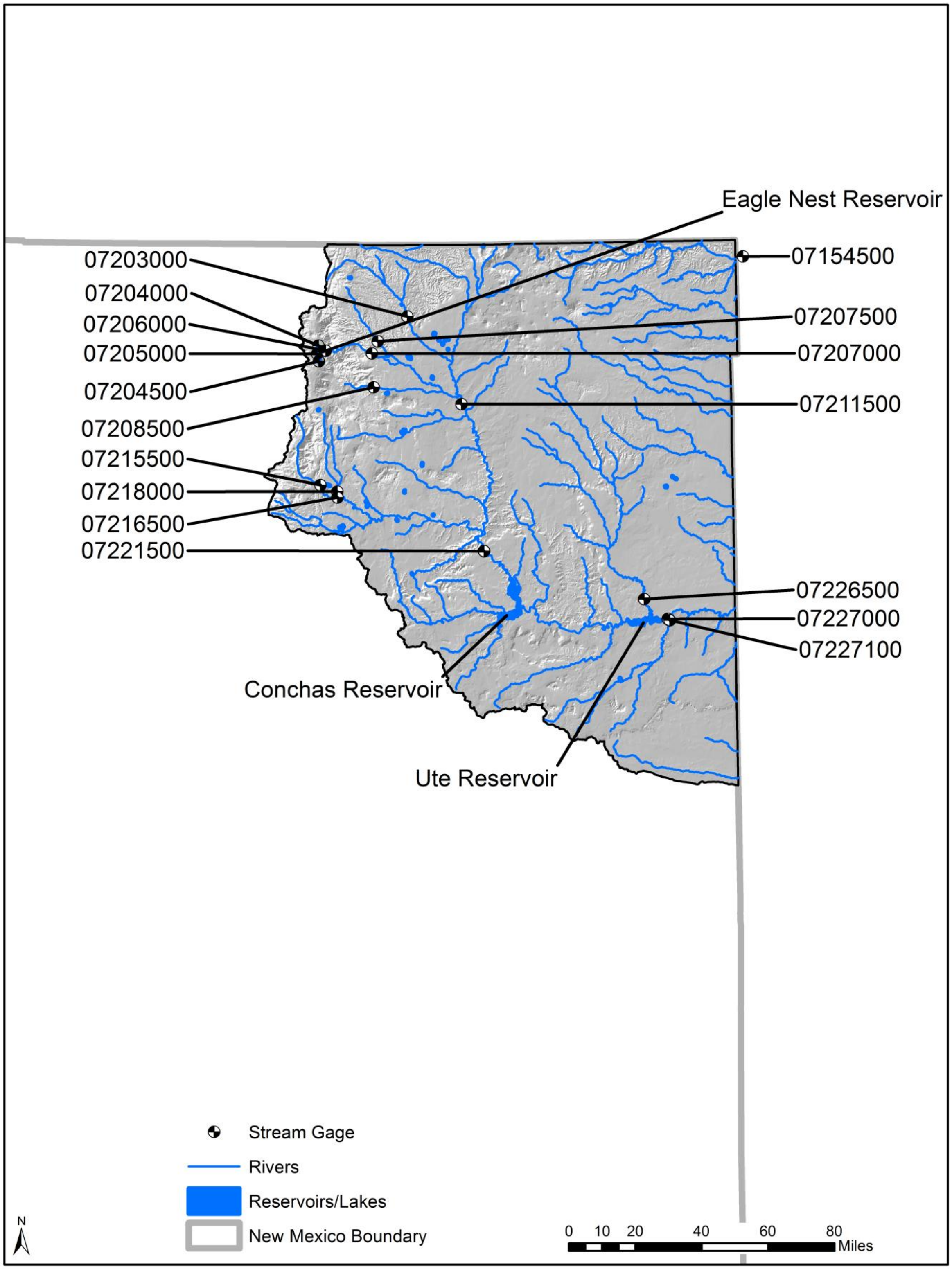

Figure 19 USGS gages used in NMDSWB for the Canadian River basin. The 8 number codes are the USGS gage numbers.

Table 26 Canadian River basin stream gages.

Site Name	Site Number	Latitude	Longitude	Begin Date	End Date
CANADIAN RIVER AT LOGAN, NM	07227000	35.35000000	103.3997222	1/1/1909	Active
CANADIAN RIVER NEAR HEBRON, NM	07199000	36.78722222	104.4616667	10/1/1946	9/30/1986
CANADIAN RIVER NEAR SANCHEZ, NM	07221500	35.65483333	104.3786111	10/1/1912	Active
CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	07211500	36.29756944	104.4954722	10/1/1939	Active
*CIENEGUILLA CR NR EAGLE NEST, NM	07204500	36.48521667	105.2653806	4/1/1928	6/21/2010
CIMARRON RIVER AT SPRINGER, NM	07211000	36.36027778	104.5980556	10/1/1907	9/30/2004
CIMARRON RIVER BELOW EAGLE NEST DAM, NM	07206000	36.53212500	105.2281444	5/1/1950	Active
CIMARRON RIVER NEAR CIMARRON, NM	07207000	36.51983333	104.9786111	6/1/1950	Active
CONCHAS CANAL BELOW CONCHAS DAM, NM	07223300	35.37638889	104.1675000	10/1/1970	9/30/1992
CONCHAS RIVER AT VARIADERO, NM	07222500	35.40277778	104.4430556	10/1/1936	9/30/1996
*COYOTE CREEK NEAR GOLONDRINAS, NM	07218000	35.91652222	105.1640833	10/1/1929	Active
EAGLE TAIL DITCH NR MAXWELL, NM	07202500	36.64864167	104.5591556	1/1/1945	Active
*MORA RIVER AT LA CUEVA, NM	07215500	35.94511667	105.2557333	5/1/1906	Active
MORA RIVER NEAR GOLONDRINAS, NM	07216500	35.89087222	105.1636194	4/1/1915	Active
MORA RIVER NR SHOEMAKER, NM	07221000	35.80027778	104.7827778	10/1/1919	9/30/1996
*MORENO CREEK AT EAGLE NEST, N. MEX.	07204000	36.55387222	105.2679806	4/1/1928	6/21/2010
*PONIL CREEK NEAR CIMARRON, NM	07207500	36.57369444	104.9468056	1/1/1916	Active
*RAYADO CREEK NEAR CIMARRON, NM	07208500	36.37234444	104.9692889	10/1/1911	Active
REVUELTO CREEK NEAR LOGAN, NM	07227100	35.34438611	103.3896056	8/1/1959	Active
*SIXMILE CREEK NEAR EAGLE NEST, NM	07205000	36.51852500	105.2752472	8/1/1958	6/21/2010
*UTE CREEK NEAR LOGAN, NM	07226500	35.43852778	103.5257944	1/1/1942	Active
VERMEJO DITCH NEAR COLFAX, NM	07203505	36.57833333	104.6925000	12/20/1980	9/30/1996
*VERMEJO RIVER NEAR DAWSON, NM	07203000	36.68102778	104.7863944	10/1/1915	Active

*Headwaters gages

6.3.4 GW

No information has been obtained or calculated to estimate groundwater flow into or out of the Canadian River basin. Under the assumption that the net flow of groundwater into and out of the basin is zero, from 1975 through 2010 average net annual groundwater depletion is estimated to be 330,000 acre feet per year.

Table 27 Gages used for flow calculation between gages in Canadian River basin.

River	Upstream Gage	Downstream Gage	Subtracted side flows
Cimarron	CIMARRON RIVER BELOW EAGLE NEST DAM, NM	CIMARRON RIVER NEAR CIMARRON, NM	
Canadian	VERMEJO RIVER NEAR DAWSON, NM	CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	PONIL CREEK NEAR CIMARRON, NM; RAYADO CREEK NEAR CIMARRON, NM
Mora	MORA RIVER AT LA CUEVA, NM	MORA RIVER NEAR GOLONDRINAS, NM	
Canadian	CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	CANADIAN RIVER NEAR SANCHEZ, NM	MORA RIVER NEAR GOLONDRINAS, NM; COYOTE CREEK NEAR GOLONDRINAS, NM

6.3.5 ET

6.3.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which when storage change is neglected equals precipitation less runoff and recharge. Calculated land surface ET from the Canadian River basin from 1975 through 2010 averaged approximately 16,000,000 acre feet per year, which represents about 98% of precipitation.

6.3.5.2 Surface Water

Surface water evaporation is calculated in the Canadian River basin by multiplying river area by Hargreaves reference ET and a monthly open water coefficient (Table 28). The coefficients were calibrated based on pan evaporation data from Ute and Conchas reservoirs. The river areas are dynamically calculated in the NMDSWB by correlating streamflow at a given stream gage to stream widths of variable dimensions. Three stream widths are selected for each stream gage based on low, median, and high flows. The NMDSWB then interpolates stream width based on streamflow at a given timestep. Stream widths and lengths used in the NMDSWB to estimate open water surface evaporation can be seen in Table 29. In the Canadian River basin 24% of surface water returns are estimated to return to a stream that is gaged before leaving the State, the remaining 76% of returns are assumed to be lost from the accounting system to evaporation. See Section 4.4.10 for more information on how this was calculated. From 1975 through 2010 the average annual surface ET is estimated to be 122,000 acre feet per year, 8,000 directly from open water evaporation and 114,000 acre feet per year from non-gaged returns.

Table 28 Canadian River basin monthly open water coefficients.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1.8	1.5	1.45	1.15	1.05	0.9	0.95	0.9	1.0	1.2	1.5	1.55

Table 29 Canadian River basin dynamic stream area measurements.

USGS stream gage site name	Low flow		Median flow		High flow		Length of stream segment associated with gage (miles)
	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	
Cimmaron River below Eagle's Nest Dam	0.4	8	18	150	165	307	10
Cimarron River near Cimarron	1.5	10	15	20	215	27	40
Vermejo River near Dawson	3.3	16	10	20	100	27	55
Rayado Creek near Cimarron	1.5	11	5.5	27	160	33	30
Ponil Creek near Cimarron	0.08	3	3.5	12	240	23	25
Canadian River near Taylor Springs	0.25	5	13	28	2920	120	75
Canadian River near Sanchez	0.3	6	30	36	2610	129	75
Coyote Creek near Golondrias	0.4	4	5	12	180	30	25
Mora River at La Cueva	0.4	6	13	22	405	44	29
Mora River near Golondrinas	0.75	6	12	30	270	39	59
Ute Creek near Logan	0.6	6	9		630	57	90
Canadian River at Logan	1.5	10	3	13	22147	375	55
Revuelto Creek near Logan	0.03	1	9	25	3120	137	50
Cimarron River near Kenton, OK	0.04	1	40	20	3070	196	70

6.3.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data driven from OSE Water use categories reports for water withdrawals by commercial, industrial, mining, and power sectors. Open water evaporation from Eagles Nest, Conchas, and Ute reservoirs is calculated (section 6.3.6 and is included here as a human activity related consumption. The storage changes tracked for the Canadian River basin are the storage changes at the three reservoirs as described below (section 6.3.6).

6.3.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6), and is estimated at 132,000 acre feet per year for an average of 52,500 acres of riparian vegetation, for the Canadian River basin from 1975 through 2010.

6.3.6 Human Storage Canadian River basin Reservoirs

Three reservoirs are modeled in the NMDSWB for the Canadian River basin, Eagles Nest Reservoir, Conchas Reservoir, and Ute Reservoir (Figure 19). From 1975 through 2010 the average storage volume equaled approximately 395,000 acre feet; the change in storage over that time period was 2,200 acre feet.

6.3.6.1 Eagle Nest Reservoir

Eagle Nest Reservoir, located in Colfax County, is in the Northwest portion of the Canadian River Basin. Storage data is provided from by the USGS Water Resources Data for New Mexico annual reports from 1970-2013 (*Water resources data for New Mexico, water year 1969-2013; Part 1. Surface water records*, n.d.).

Three stream gages measure inflow into Eagles Nest: Cineguilla Creek near Eagle Nest, NM [USGS# 07204500], Moreno Creek at Eagle Nest, NM [USGS# 07204000], and Sixmile Creek near Eagle Nest, NM [USGS# 07205000] (United States Geological Survey, 2015). Outflow from the reservoir is measured from the USGS gage, Cimarron River below Eagle Nest Dam [USGS# 07206000] (United States Geological Survey, 2015).

Surface area is estimated using a stage rating curve manual developed using four aerial images. See Table 30 for dates and type of imagery, reported reservoir storage, and measured reservoir surface area. Aerial images where manually traced in Arc-GIS to measure reservoir surface area. The developed stage area equation has an R^2 of 0.9927 and is written as:

$$A = -3E^{-7} * S^2 + 0.0575S - 7.5205 \qquad \text{(Equation 9)}$$

A =Area of reservoir

S =Storage or reservoir

Table 30 Aerial Images used to develop stage rating curve for Eagle Nest Reservoir.

Date	Storage (AF)	Area (acres)	Imagery
10/6/1982	32,310	1,390	NHAP
9/17/1991	74,550	2,357	NAPP
10/4/1997	64,600	2,194	NAPP
8/8/2007	41,200	1,886	NAIPP
N/A	0	0	N/A

Precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for Colfax County multiplied by the surface area of the reservoir (at the given timestep).

Eagle Nest reservoir evaporation is calculated by multiplying the surface area by Hargreaves reference ET (for Colfax County) and a monthly open water coefficient. The monthly open water coefficients used can be seen in Table 31, and are based on values for Heron and El Vado from URGSiM (Roach, 2007). Precipitation data is provided by the PRISM dataset (Prism Climate Group, 2014).

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB begins to be run into the future, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

Table 31 Monthly open water coefficients used for Eagle Nest Reservoir.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8

6.3.6.2 Conchas Reservoir

Conchas Reservoir storage data was provided by the USACE for 1970 through 2014 (Ball, 2014). Reservoir surface area is calculated from two area-capacity look up tables, one for 1970 through 1987 and one for 1988 through the present (Ball, 2014).

Inflow into Conchas Reservoir is measured from the USGS gage, Canadian River near Sanchez, NM [USGS# 07221500] (United States Geological Survey, 2015). Reservoir outflow is by the USACE, as total outflow before 1991, and from 1992 through 2014 as Canadian River mainstem releases, Arch-Hurley irrigation district releases, and Bell Ranch Irrigation District releases (Ball, 2014). Before 1991 the NMDSWB assumes all releases below 400 cfs and 1/3 of the releases above that amount went to the irrigation districts, and the remainder to the Canadian River mainstem. Of irrigation district water, 97% is assumed to go to the Arch-Hurley Irrigation District, and 3% to the Bell Ranch Irrigation District. The above estimates were determined from hydrograph analysis of the releases data from 1992 through 2014.

Precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for San Miguel County multiplied by the surface area of the reservoir (at the given timestep).

Hargreaves reference ET is used to calculate reservoir evaporation and is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 32) which is calibrated for Conchas Reservoir using monthly USACE pan-based reservoir evaporation estimates for 1970-2013.

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified to run into the future, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

Table 32 Conchas Reservoir monthly open water ET coefficient.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1.6	1.5	1.5	1.3	1.2	1.1	1.1	1	1.1	1.2	1.4	1.6

6.3.6.3 Ute Reservoir

Ute Reservoir is the final reservoir on the Canadian River within New Mexico. Storage data for Ute Reservoir is provided by the USGS (United States Geological Survey, 2015).

Inflow into Ute Reservoir is measured from the USGS stream gage, Ute Creek near Logan, NM [USGS# 07226500] (United States Geological Survey, 2015), as well as the Canadian River mainstem releases from Conchas Reservoir (Conchas Reservoir is 55 miles upstream of Ute Reservoir). Data for Conchas Reservoir mainstem releases was provided by the USACE for 1991 through 2014 (Ball, 2014), and estimated from total releases before 1991 (See Section 6.3.6.2).Outflow from Ute reservoir is measured at the USGS gage, Canadian River at Logan, NM [USGS# 07227000] (United States Geological Survey, 2015).

Surface area or the reservoir is calculated from five area-capacity lookup tables, each starting in the following years 1963, 1976, 1984, 1992, and 2002.

The precipitation falling on the reservoir is calculated using the PRISM (Prism Climate Group, 2014) monthly average precipitation depth for Quay County multiplied by the surface area of the reservoir (at the given timestep).

Hargreaves reference ET is used to calculate reservoir evaporation and is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 33) which has been calibrated for Ute reservoir using USACE evaporation data from 1970 through 2005.

In addition to the known inflows/outflows of the reservoir there are additional unknown gains/losses. Non-gaged inflows and unknown losses are used to account for modeled storage change less than or greater than observed storage change respectively. When the NMDSWB is modified to run into the future, the patterns of non-gaged inflows and unknown losses observed during the historic period will be modeled into the scenario period.

Table 33 Ute Reservoir monthly open water ET coefficients.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2.0	1.5	1.4	1.0	0.9	0.7	0.8	0.8	0.9	1.2	1.6	1.5

6.3.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation ($ET_{sw2,}$ ET_{gw} and ET_{h}), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 20 for the average mass balance terms calculated for the Canadian River basin from 1975 through 2010.

Modeled human uses of water correlate well to the values reported by the NM OSE (i.e. Longworth et al., 2013). However, total withdrawals and depletions for irrigated agriculture are slightly larger than the OSE reported values, approximately 10% higher for surface water and 40% higher for groundwater withdrawals/depletions.

Groundwater storage and inflow/outflow estimates have not yet been obtained in this version of the model, since the Canadian River basin is essentially a headwaters basin; groundwater inflow is most likely zero. Setting the groundwater inflow/outflow terms to zero, resulted in an average groundwater storage depletion of about 330,000 acre feet per year for the period from 1975 through 2010. If the groundwater system in the Canadian River basin were in a steady state, the annual depletions would roughly be equal to the groundwater diversion minus the returns (124,000 acre feet per year). The NMDSWB estimates of groundwater depletion are nearly double expected steady state groundwater depletions, suggesting a large uncertainty in NMDSWB calculated groundwater depletion. The surface water to groundwater flux is calculated as 200,000 acre feet moving from groundwater to surface water, and is approximately 40,000 acre feet per year greater than the recharge term. The sum of the groundwater moving to surface water and the groundwater (riparian ET) is approximately 170,000 acre feet larger than the recharge term. Under steady state conditions (with groundwater inflows/outflows at zero) the flux of groundwater to surface water plus groundwater ET should be equal to recharge. It is the opinion of the authors that the surface water groundwater term is misrepresented in this version of the model. The NMDSWB relies heavily on stream gage data to calculate many of the mass balance terms (recharge, surface water inflow/outflow, runoff, surface water ET) and the network of stream gages with continuous data in the Canadian River basin is sparse. It is possible that the runoff and recharge terms are low estimates of reality, which would account for the high volume of water moving from groundwater to surface water as the closure term.

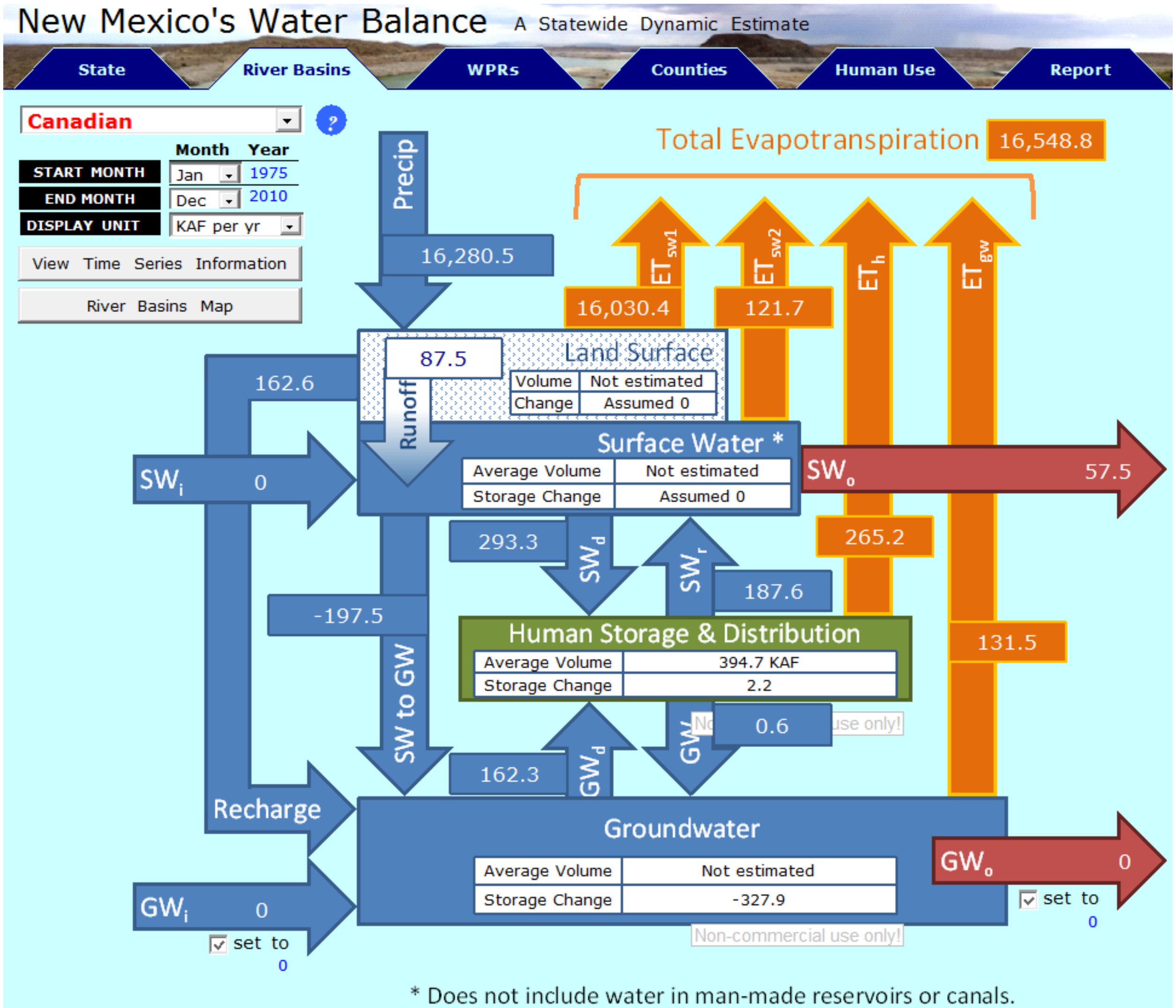

Figure 20 Average mass balance terms calculated for the Canadian River Basin from 1975 through 2010.

6.4 Lower Colorado River Basin

The Lower Colorado River basin does not fully enclose any counties or WPRs. The counties that are partially within the Lower Colorado River basin are: McKinley, Cibola, Catron, Grant, Hidalgo, Luna and Sierra counties. The Southwest and Northwest planning regions are the Water Planning regions partially residing in the Lower Colorado River basin. For an overview of the Lower Colorado River basin refer to Figure 21.

6.4.1 Surface Water Inflows/Outflows in the Lower Colorado River basin

The Lower Colorado River basin is a headwaters basin for the Gila River and Little Colorado River tributaries of the Colorado River. Because these rivers rise in New Mexico, there are no surface water flows entering the Lower Colorado River basin. The water originating in this basin flows into Arizona and ultimately the Colorado River. The major gaged rivers in this basin are the Gila River, The San Francisco River, and the Zuni River. Gaged outflows from the basin are measured at the following USGS gages; San Francisco River near Glenwood, NM [USGS# 09444000], Gila River at Duncan, AZ [USGS# 09439000], and the Zuni River near the NM-AZ Stateline [USGS# 09387300] (United States Geological Survey, 2015). The Gila River gage near Duncan did not become operational until October, 2003. In the NMDSWB flow at the Duncan gage prior to 2003 is estimated from a linear correlation to 2003 – 2014 flow in the Gila River below Blue Creek near Virden, NM [USGS# 09432000] gage (United States Geological Survey, 2015). The R^2 between these gages for the available overlapping period of record is 0.987. The Zuni River near the NM-AZ State line gage was only active from October, 1987 through September, 1994. The Zuni River flow at the state line is estimated from a linear correlation of flow at the Zuni River above Black Rock Reservoir gage [USGS# 09386950] (United States Geological Survey, 2015). The R^2 between these gages is 0.984 for the available period of record. More information on the USGS gages used in the NMDSWB for the Lower Colorado River basin can be seen in Table 34 and Figure 22. From 1975 through 2010 the average annual gaged surface water flow out of the basin was approximately 254,000 acre feet per year.

6.4.2 Runoff

Runoff in the Lower Colorado River basin is calculated as a summation of headwaters runoff and runoff between gaged river stretches. The headwaters gages are defined as the highest upstream gage (given an adequate period of record) on each gaged tributary within the river basin (Table 34). The total surface water returns for a given timestep are subtracted from the gross gains between gaged river stretches to get net gains, see Table 35 for the gaged river stretches in the Lower Colorado River basin. The net gains and headwaters flow are multiplied by a BFI value 45.1% as an estimate of baseflow and the remainder is applied to the mass balance as runoff. From 1975 through 2010 the average annual runoff in the basin was approximately 150,000 acre feet per year.

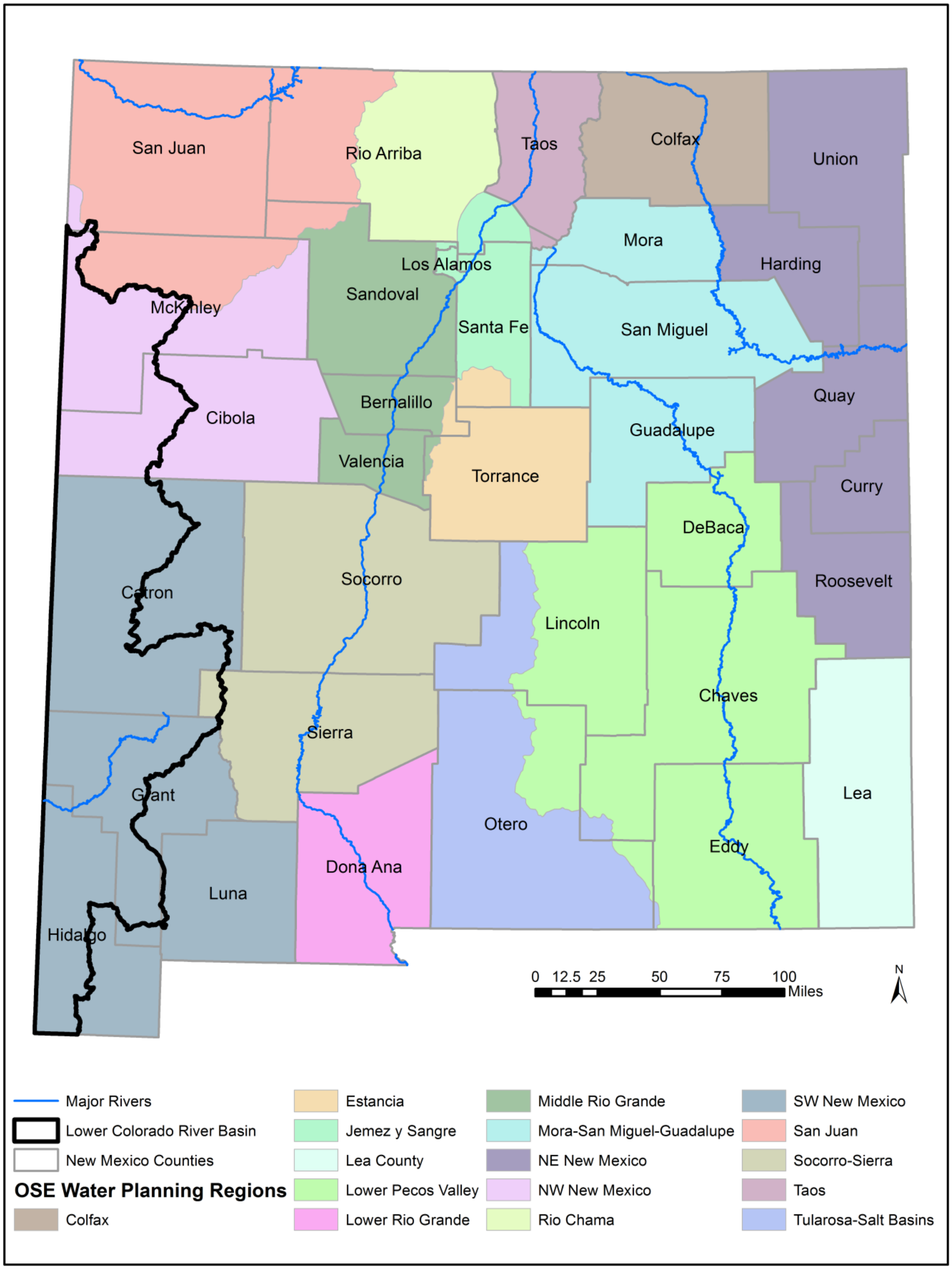

Figure 21 Spatial extent of the Lower Colorado River basin.

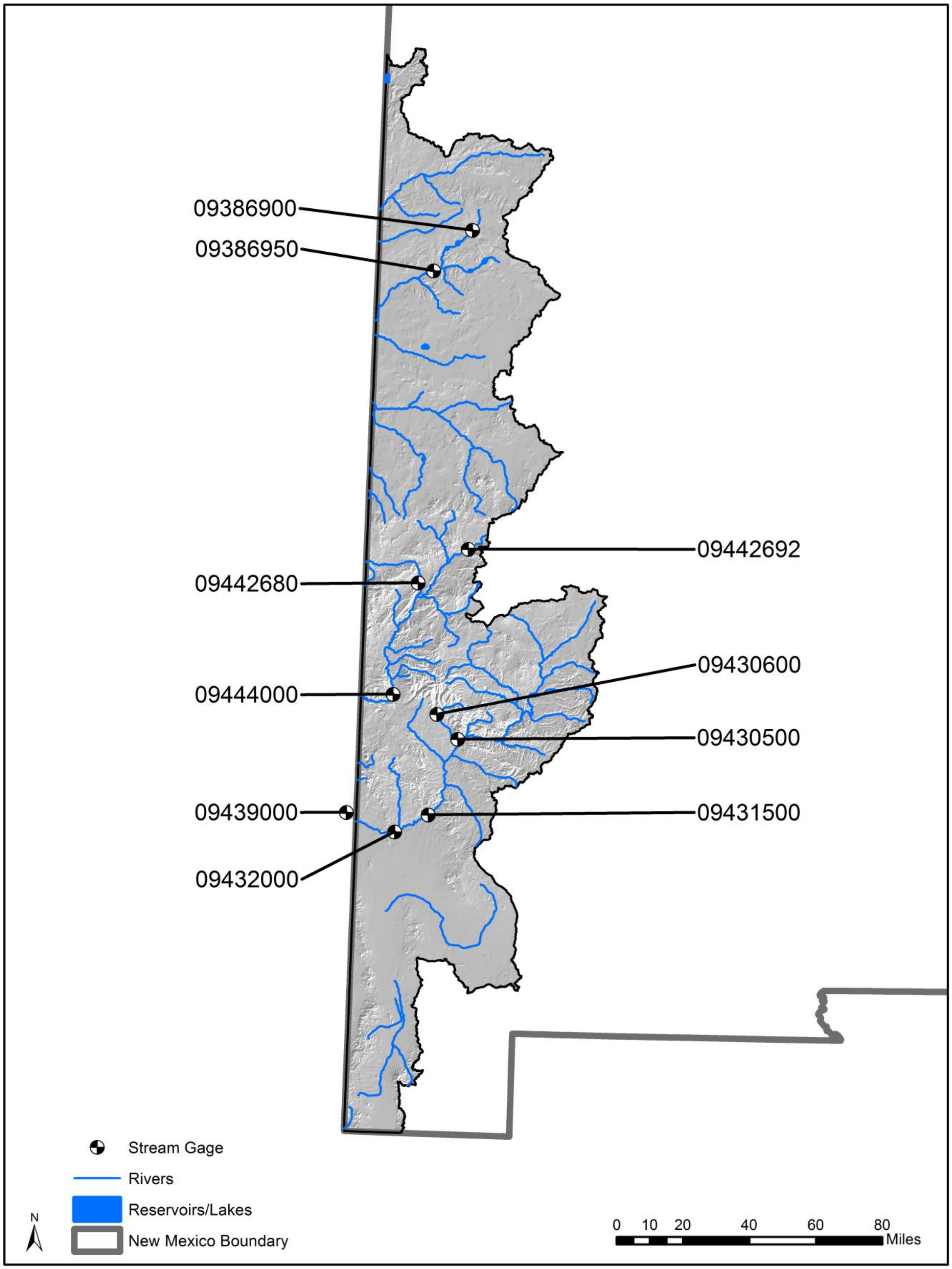

Figure 22 USGS gages used in NMDSWB for the Lower Colorado River basin. The 8 number codes are the USGS gage numbers.

Table 34 Stream gages used in the NMDSWB for the Lower Colorado River basin.

Site Name	Site Number	Latitude	Longitude	Begin Date	End Date
GILA RIVER AT DUNCAN, AZ	09439000	32.72444444	109.0991667	10/1/2003	Active
GILA RIVER BELOW BLUE CREEK, NEAR VIRDEN, NM	09432000	32.64805556	108.8452778	7/1/1927	Active
*GILA RIVER NEAR GILA, NM	09430500	33.06150278	108.5373861	12/1/1927	Active
GILA RIVER NEAR REDROCK, NM	09431500	32.72694444	108.6755556	10/1/1930	Active
*MOGOLLON CREEK NEAR CLIFF, NM	09430600	33.16666667	108.6497222	1/21/1967	Active
*RIO NUTRIA NEAR RAMAH, NM	09386900	35.28255278	108.5529750	10/1/1969	Active
SAN FRANCISCO RIVER NEAR GLENWOOD, NM	09444000	33.24716667	108.8800000	10/1/1927	Active
*SAN FRANCISCO RIVER NEAR RESERVE, NM	09442680	33.73671944	108.7711750	3/1/1959	Active
*TULAROSA RIVER ABOVE ARAGON, NM	09442692	33.89138889	108.5150000	7/1/1966	9/30/1996
ZUNI RIVER NEAR NM-AZ STATE LINE, NM	09387300	34.87642440	109.0420318	10/1/1987	9/30/1994
ZUNI RIVER ABV BLACK ROCK RESERVOIR, NM	09386950	35.10027778	108.7516667	10/1/1969	Active

*Headwaters gages

Table 35 Gages used for flow calculations between gages in Lower Colorado River basin.

River	Upstream Gage	Downstream Gage	Subtracted side flows
Rio Nutria / Zuni River	RIO NUTRIA NEAR RAMAH, NM	ZUNI RIVER ABOVE BLACK ROCK RESERVOIR, NM	
Zuni River	ZUNI RIVER ABOVE BLACK ROCK RESERVOIR, NM	ZUNI RIVER NEAR NM-AZ STATELINE	
Gila River	GILA RIVER NEAR GILA, NM	GILA RIVER NEAR REDROCK, NM	MOGOLLON CREEK NEAR CLIFF, NM
Gila River	GILA RIVER NEAR REDROCK, NM	GILA RIVER BELOW BLUE CREEK NEAR VIRDEN, NM	
Gila River	GILA RIVER BELOW BLUE CREEK NEAR VIRDEN, NM	GILA RIVER AT DUNCAN, AZ	
San Francisco River	SAN FRANCISCO RIVER NEAR RESERVE	SAN FRANCISCO RIVER NEAR GLENWOOD, NM	TULAROSA RIVER ABOVE ARAGON, NM

6.4.3 Surface Water to Groundwater

Groundwater surface water interactions are solved as a closure term to the surface water system. See section 4.3 for more information. From 1975 through 2010 approximately 130,000 acre feet moved from groundwater to surface water, annually in the lower Colorado Basin.

6.4.4 GW

Because the Lower Colorado River Basin is a headwater basin, we assume no groundwater flows into the basin from outside of the state. No information has been obtained or calculated to estimate groundwater flow out of the Lower Colorado River Basin. Assuming zero groundwater flow out of the basin, results in net groundwater depletion equal to approximately 63,000 acre feet per year from 1975 through 2010.

6.4.5 ET

6.4.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which when storage change is neglected equals precipitation less runoff and recharge. Calculated land surface ET for the Lower Colorado River basin from 1975 through 2010 averaged approximately 10,900,000 acre feet per year, which represents about 97% of precipitation.

6.4.5.2 Surface Water

Surface water evaporation is calculated in the Lower Colorado River basin by multiplying river area by Hargreaves reference ET and a monthly open water coefficient (Table 36). The river areas are dynamically calculated in the NMDSWB by correlating streamflow at a given stream gage to stream widths of variable dimensions. Three stream widths are selected for each stream gage used based on low, median, and high flows. The NMDSWB then interpolates stream width based on streamflow at a given timestep. Stream widths and lengths used in the NMDSWB to estimate open water surface evaporation for the Lower Colorado River basin can be seen in Table 37. In the Lower Colorado River basin 54% of surface water returns are estimated to return to a stream that is gaged before leaving the State, the remaining 46% of returns are assumed to be lost from the accounting system to evaporation. See Section 4.4.10 for more information on how this was calculated. From 1975 through 2010 the average annual surface ET is calculated to be 30,000 acre feet per year, 6,000 acre feet per year directly from open water evaporation and the reaming 24,000 acre feet per year from non-gaged returns.

Table 36 Monthly Open Water ET coefficients for Lower Colorado River basin.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8

Table 37 Dynamic Stream area calculations for Lower Colorado River basin.

USGS stream gage site name	Low flow		Median flow		High flow		Length of stream segment associated with gage (miles)
	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	
Rio Nutria near Ramah	0.02	1	0.2	2	230	75	24
Zuni River above Black Rock Reservoir	0.085	1.75	1.5	6	550	60	45
San Francisco near Reserve	2	9	9	15	470	70	65
San Francisco near Glenwood	11	25	36	30	2600	105	30
Mogollon Creek near Cliff	0.2	4	8	20	210	45	25
Gila River near Gila	19	30	85	60	3000	140	35
Gila River near Redrock	12	20	105	60	210	130	20
Gila River below Blue Creek	3.5	15	130	50	6250	255	15
Gila River near Duncan AZ	1	10	60	45	2800	1230	10

6.4.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data driven from OSE Water use categories reports for commercial, industrial, mining, and power uses of water. No reservoir evaporation is included in the Lower Colorado River basin for the NMDSWB.

6.4.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6), and is estimated at 22,000 AF per year for an average of 6,150 acres of riparian vegetation, for the Lower Colorado River basin from 1975 through 2010.

6.4.6 Human Storage in the Lower Colorado River basin

No reservoirs are modeled by the NMDSWB for the Lower Colorado River basin.

6.4.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation (ET_{sw2}, ET_{gw} and ET_{h}), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 23 for the average mass balance terms calculated for the Lower Colorado River basin from 1975 through 2010.

Modeled human uses of water correlate well to the values reported by the NM OSE (i.e. Longworth et al., 2013). Total withdrawals and depletions for irrigated agriculture are consistent with the OSE reported values; however, the NMDSWB surface water withdrawals/depletions are slightly lower (~15%) and the groundwater withdrawals/depletions slightly higher (~10%) than OSE values.

Groundwater storage and inflow/outflow estimates were not available for this version of the model. Setting the groundwater inflow/outflow terms to zero, resulted in an average groundwater storage depletion of about 63,000 acre feet per year for the period from 1975 through 2010. If the groundwater system in the Lower Colorado River basin were in a steady state, the annual depletions would roughly be equal to the groundwater diversion minus the returns (43,000 acre feet per year). The NMDSWB estimates of groundwater depletion are within a reasonable range based on the available data.

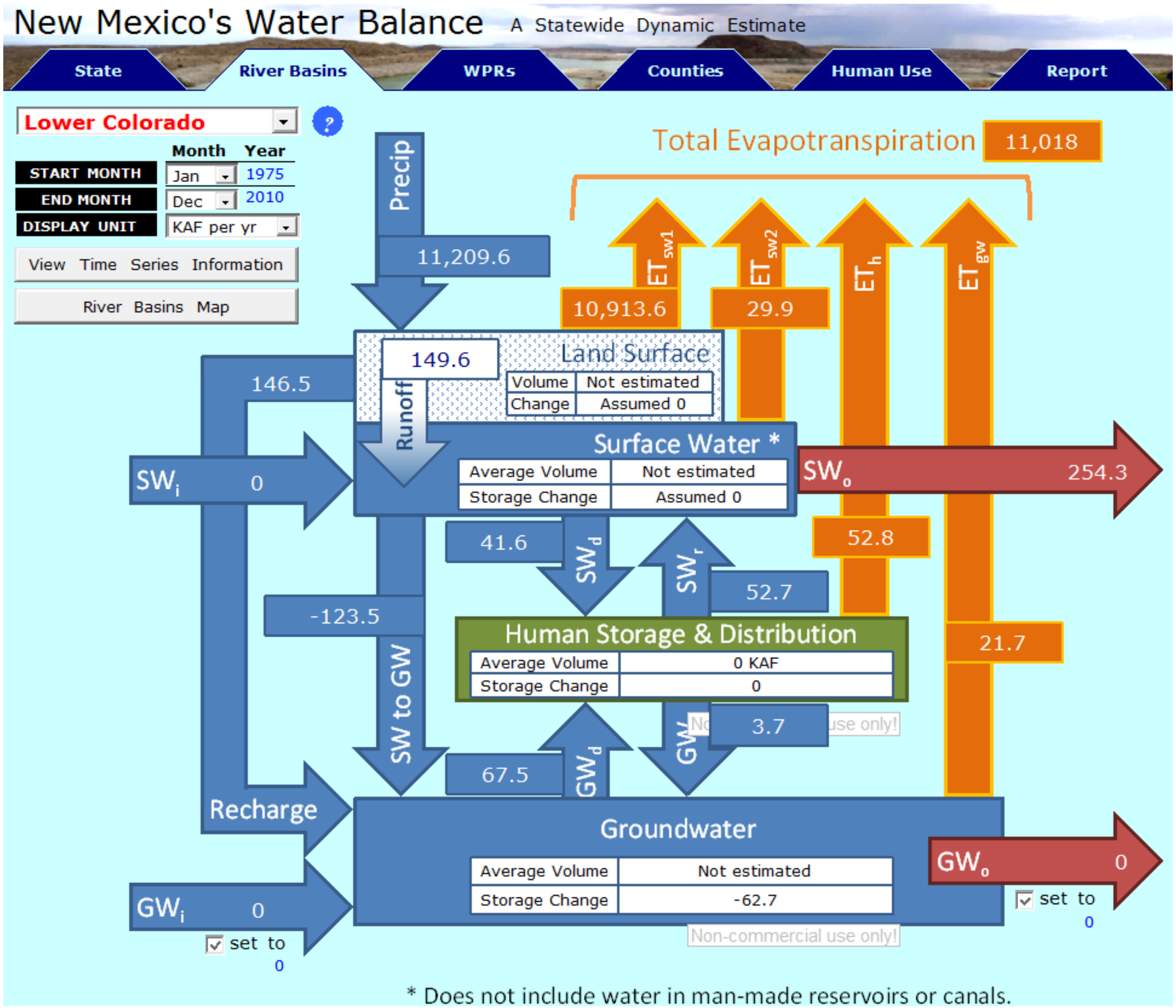

Figure 23 Average mass balance terms calculated for the Lower Colorado River Basin from 1975 through 2010.

6.5 Rio Grande River Basin

The Rio Grande River basin encompasses approximately one third of the area of the state. For a depiction of the Rio Grande River basin refer to Figure 24.

6.5.1 Surface Water Inflows/Outflows in the Rio Grande River basin

Surface water inflows in the Rio Grande are measured at the USGS gage, Rio Grande near Lobatos, CO [USGS# 08251500], as well as Azotea Tunnel Outlet near Chama, NM [USGS# 08284160] which is the supply of San Juan-Chama project water diverted from the Upper Colorado River basin (above Navajo Reservoir) for use in the Rio Grande basin (United States Geological Survey, 2015)(U.S. Department of the Interior Bureau of Reclamation, 2014). The average annual surface water inflow on the Rio Grande from 1975 through 2010 was approximately 430,000 acre feet per year, 340,000 acre feet from the Rio Grande at Lobatos and 90,000 from the San-Juan Chama project. Surface water outflow from the basin is measured at the gage, Rio Grande at El Paso, TX [USGS# 08364000] (USACE, U.S. Bureau of Reclamation, & New Mexico Interstate Stream Commission, 2013). The average annual surface water outflow from 1975 through 2010 was 415,000 acre-feet per year. A map of the gages used by the NMDSWB in the Rio Grande River basin can be seen in Figure 25 and a detailed list of the gages used can be seen in Table 38.

6.5.2 Surface Water to Groundwater

Groundwater surface water interactions are solved as a closure term to the surface water system. See section 4.3 for more information. From 1975 through 2010 the average annual flux of surface water to groundwater in the Rio Grande is calculated to be approximately -114,000 acre feet per year. The negative value here means that there is a net movement of groundwater to surface water. This observation is likely explained by the very long reach of stream over which the budget was determined. It is likely that the upper reaches of the river, are gaining whereas the middle and lower Rio Grande, which are wide and slow moving sections, are an important source of recharge to the shallow alluvial aquifer.

6.5.3 GW

No information has been obtained or calculated to estimate groundwater flow into or out of the Rio Grande River basin. Under the assumption that groundwater inflows and outflows are zero the Rio Grande groundwater system has a net decrease in storage in the NMDSWB of approximately 130,000 acre feet per year. Groundwater overdraft has been well documented in several of the regional aquifers including the Espanola basin, the Middle Rio Grande, and the lower Rio Grande.

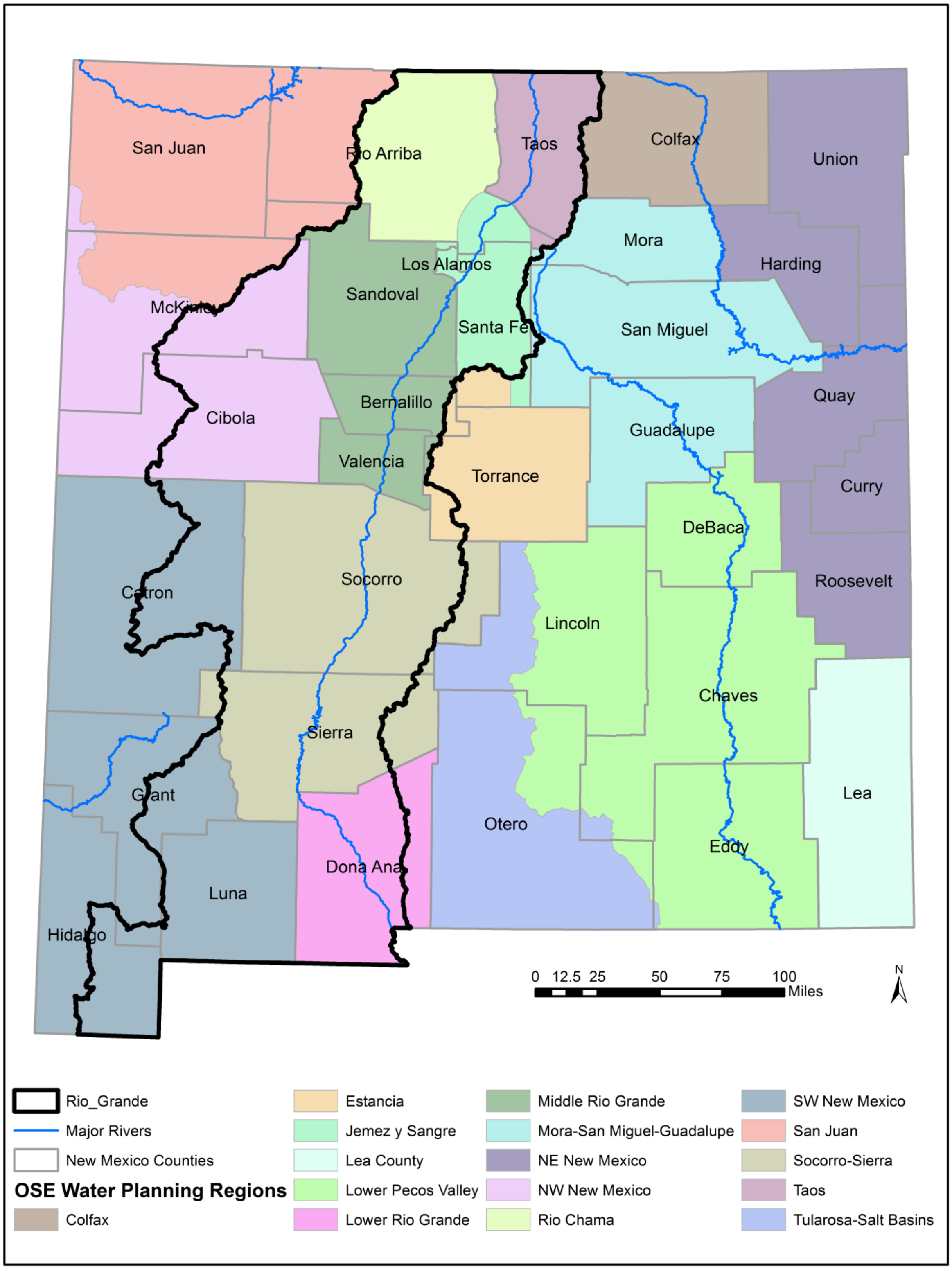

Figure 24 Spatial extent of Rio Grande River basin.

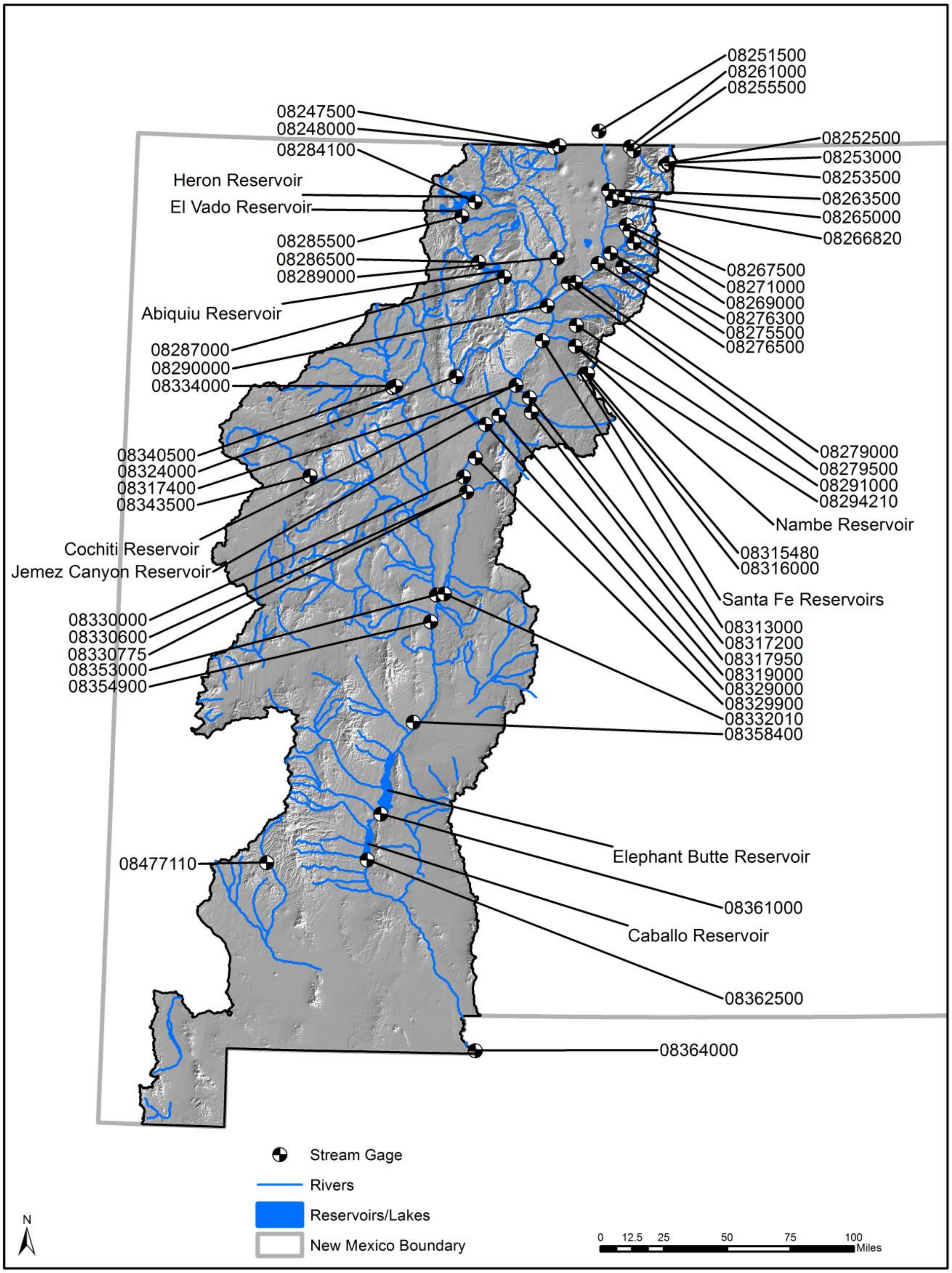

Figure 25 USGS gages used in NMDSWB for the Rio Grande River basin. The 8 number codes are the USGS gage numbers.

Table 38 Gages used in the NMDSWB for the Rio Grande River basin.

Site Name	Site Number	Latitude (N)	Longitude (W)	Begin Date	End Date
*ARROYO CHICO NR GUADALUPE, NM	08340500	35.59225000	107.1894444	10/1/1943	Active
AZOTEA TUNNEL AT OUTLET NEAR CHAMA, NM	08284160	36.85333333	106.6716667	10/1/1970	9/30/2008
CASIAS CREEK NEAR COSTILLA, NM	08253000	36.89685556	105.2604583	5/1/1937	Active
COSTILLA CREEK ABOVE COSTILLA DAM, NM	08252500	36.89836111	105.2546667	5/1/1937	Active
*COSTILLA CREEK NEAR COSTILLA, NM	08255500	36.96686111	105.5071111	3/7/1936	Active
COSTILLA CREEK NEAR GARCIA, CO	08261000	36.98902778	105.5324583	10/1/1965	Active
*EMBUDO CREEK AT DIXON, NM	08279000	36.21085556	105.9136306	10/1/1923	Active
*GALISTEO CREEK BELOW GALISTEO DAM, NM	08317950	35.46465278	106.2133889	3/20/1970	Active
JEMEZ RIVER BELOW JEMEZ CANYON DAM, NM	08329000	35.39041667	106.5346111	4/1/1936	Active
*JEMEZ RIVER NEAR JEMEZ, NM	08324000	35.66198333	106.7434389	10/1/1936	Active
LOS PINOS RIVER NEAR ORTIZ, CO	08248000	36.98222222	106.0730556	1/1/1915	Active
MIMBRES RIVER AT MIMBRES, NM	08477110	32.85467500	107.9737889	3/1/1978	Active
*NORTH FLOODWAY CHANNEL NEAR ALAMEDA, NM	08329900	35.19805556	106.5997222	7/1/1968	Active
*RED RIVER NEAR QUESTA, NM	08265000	36.70331111	105.5684306	10/1/1924	Active
RED RIVERBELOW FISH HATCHERY, NEAR QUESTA, NM	08266820	36.68283889	105.6541222	8/9/1978	Active
RIO CHAMA ABOVE ABIQUIU RESERVOIR, NM	08286500	36.31882222	106.5995306	8/1/1961	Active
RIO CHAMA BELOW ABIQUIU DAM, NM	08287000	36.23722222	106.4174167	11/1/1961	Active
RIO CHAMA BELOW EL VADO DAM, NM	08285500	36.58038333	106.7247667	10/30/1935	Active
RIO CHAMA NEAR CHAMITA, NM	08290000	36.07355556	106.1116944	10/1/1912	Active
*RIO CHAMA NEAR LA PUENTE, NM	08284100	36.66265833	106.6333667	10/1/1955	Active
RIO GRANDE AT ALBUQUERQUE, NM	08330000	35.08916667	106.6806944	3/1/1942	Active
RIO GRANDE AT EL PASO, TX	08364000	31.80277778	106.5402778	N/A	Active
RIO GRANDE AT EMBUDO, NM	08279500	36.20555556	105.9639722	1/1/1889	Active
RIO GRANDE AT OTOWI BRIDGE, NM	08313000	35.87450000	106.1424444	2/1/1895	Active
RIO GRANDE AT SAN FELIPE, NM	08319000	35.44458333	106.4398333	1/1/1927	Active
RIO GRANDE BELOW CABALLO DAM, NM	08362500	32.88491111	107.2926972	1/1/1938	Active
RIO GRANDE BELOW COCHITI DAM, NM	08317400	35.61800000	106.3239444	10/1/1970	Active
RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	08361000	33.14851111	107.2067833	10/1/1916	Active
RIO GRANDE BLW TAOS JUNCTION BRIDGE NEAR TAOS, NM	08276500	36.32003333	105.7544444	10/1/1925	Active
RIO GRANDE DEL RANCHO NEAR TALPA, NM	08275500	36.30310278	105.5810028	10/1/1952	Active
RIO GRANDE FLOODWAY AT SAN ACACIA, NM	08354900	34.25638889	106.8908333	10/1/1958	Active
RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	08358400	33.67908333	106.9970000	10/1/1949	Active
RIO GRANDE FLOODWAY NEAR BERNARDO, NM	08332010	34.41694444	106.8000000	10/1/1957	Active
RIO GRANDE NEAR CERRO, NM	08263500	36.74001667	105.6834417	10/1/1948	Active
RIO GRANDE NEAR LOBATOS, CO	08251500	37.07861111	105.7569444	7/1/1899	Active
*RIO HONDO NEAR VALDEZ, NM	08267500	36.54179722	105.5565222	10/1/1934	Active
RIO LUCERO NEAR ARROYO SECO, NM	08271000	36.50828889	105.5309639	1/1/1913	Active
*RIO NAMBE BELOW NAMBE FALLS DAM NEAR NAMBE, NM	08294210	35.84611111	105.9097222	1/1/1979	Active
*RIO OJO CALIENTE AT LA MADERA, NM	08289000	36.34974167	106.0441861	10/1/1932	Active
*RIO PUEBLO DE TAOS BELOW LOS CORDOVAS, NM	08276300	36.37933333	105.6678333	4/1/1957	Active

Site Name	Site Number	Latitude (N)	Longitude (W)	Begin Date	End Date
RIO PUEBLO DE TAOS NEAR TAOS, NM	08269000	36.43944444	105.5036111	1/1/1913	Active
*RIO PUERCO ABV ARROYO CHICO NR GUADALUPE, NM	08334000	35.60088889	107.1666111	10/1/1951	Active
RIO PUERCO NEAR BERNARDO, NM	08353000	34.41027778	106.8544444	11/1/1939	Active
RIO SAN JOSE AT ACOMA PUEBLO, NM	08343500	35.07441110	107.7511139	10/01/1936	Active
SAN ANTONIO RIVER AT ORTIZ, CO	08247500	36.99305556	106.0380556	10/1/1919	Active
*SANTA CRUZ RIVER NEAR CUNDIYO, NM	08291000	35.96472222	105.9047222	10/1/1923	Active
SANTA FE RIVER ABOVE COCHITI LAKE, NM	08317200	35.54722222	106.2288889	3/20/1970	Active
*SANTA FE RIVER ABV MCCLURE RESERVOIR, NR SANTA FE, NM	08315480	35.68891667	105.8228333	7/1/1998	Active
SANTA FE RIVER NEAR SANTA FE, NM	08316000	35.68644444	105.8436111	2/1/1913	Active
SANTISTEVAN CREEK NEAR COSTILLA, NM	08253500	36.88416667	105.2811111	5/1/1937	Active
*SOUTH DIV. CHANNEL ABV TIJERAS ARROYO NR ALBUQUERQUE	08330775	35.00277778	106.6572222	6/8/1988	Active
*TIJERAS ARROYO NEAR ALBURQUERQUE, NM	08330600	35.00194444	106.6575000	10/1/1982	Active

* Headwaters gage

6.5.4 Runoff

Runoff in the Rio Grande River basin is calculated as a summation of headwaters runoff and runoff between gaged river stretches. The headwaters gages are defined as the highest upstream gage (given an adequate period of record) on each gaged tributary within the river basin, see Table 38.The total surface water returns for a given timestep are subtracted from the gross gains between gaged river stretches to get net gains, see Table 39 for the gaged river stretches in the Rio Grande River basin. The net gains and headwaters flow are multiplied by BFI values for the respective WPR of the gage location to get baseflow, and runoff is the remainder. The BFI per WPR used are as follows: Taos WPR 67.4%, Rio Chama WPR 54.1%, Jemez y Sangre WPR 60.9%, Middle Rio Grande WPR 20.3%, the portion of the Northwest WPR in the Rio Grande basin 30.6%, Socorro-Sierra WPR 38.5%, and the Lower Rio Grande WPR 39.4%. Following this approach, runoff in the basin was calculated to be an average of 437,000 acre feet per year between 1975 and 2010.

6.5.5 ET

6.5.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which when storage change is neglected equals precipitation less runoff and recharge. Calculated land surface ET from the Rio Grande River basin from 1975 through 2010 averaged approximately 27,000,000 acre feet per year.

Table 39 Gages used for flow difference between gages calculation in Rio Grande River basin.

River	Upstream Gage	Downstream Gage	Subtracted side flows
Rio Grande	RIO GRANDE NEAR CERRO, NM	RIO GRANDE AT LOBATOS, CO	COSTILLA CREEK NEAR COSTILLA, NM
Red River	RED RIVER NEAR QUESTA, NM	RED RIVER BELOW FISH HATCHERY, NEAR QUESTA, NM	
Rio Grande	RIO GRANDE NEAR CERRO, NM	RIO GRANDE BELOW TAOS JUNCTION BRIDGE NEAR TAOS, NM	RED RIVER BELOW FISH HATCHERY, NEAR QUESTA, NM RIO HONDO NEAR VALDEZ, NM RIO PUEBLO DE TAOS BELOW LOS CORDOVAS, NM
Rio Grande	RIO GRANDE BELOW TAOS JUNCTION BRIDGE NEAR TAOS, NM	RIO GRANDE AT EMBUDO, NM	EMBUDO CREEK AT DIXON, NM
Rio Chama	RIO CHAMA BELOW EL VADO DAM, NM	RIO CHAMA ABOVE ABIQUIU RESERVOIR, NM	
Rio Chama	RIO CHAMA NEAR CHAMITA, NM	RIO CHAMA BELOW ABIQUIU DAM, NM	RIO OJO CALIENTE AT LA MADERA, NM
Rio Grande	RIO GRANDE AT EMBUDO, NM	RIO GRANDE AT OTOWI BRIDGE, NM	RIO CHAMA NEAR CHAMITA, NM RIO NAMBE BELOW NAMBE FALLS DAM NEAR NAMBE, NM SANTA CRUZ RIVER NEAR CUNDIYO, NM
Santa Fe	SANTA FE RIVER NEAR SANTA FE, NM	SANTA FE RIVER ABOVE COCHITI LAKE, NM	
Rio Grande	RIO GRANDE BELOW COCHITI DAM, NM	RIO GRANDE AT SAN FELIPE, NM	SANTA FE RIVER ABOVE COCHITI LAKE, NM GALISTEO CREEK BELOW GALISTEO DAM, NM
Rio Grande	RIO GRANDE AT SAN FELIPE, NM	RIO GRANDE AT ALBUQUERQUE, NM	NORTH FLOODWAY CHANNEL NEAR ALAMEDA, NM JEMEZ RIVER BELOW JEMEZ CANYON DAM, NM
Rio Puerco	RIO PUERCO ABOVE RIO CHICO NEAR GUADALUPE, NM	RIO PUERCO NEAR BERNARDO, NM	ARROYO CHICO NEAR GUADALUPE, NM RIO SAN JOSE AT ACOMA PUEBLO, NM
Rio Grande	RIO GRANDE AT ALBUQUERQUE, NM	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	SOUTH DIVERSION CHANNEL ABOVE TIJERAS ARROYO NEAR ALBUQUERQUE, NM TIJERAS ARROYO NEAR ALBUQUERQUE, NM
Rio Grande	RIO GRANDE FLOODWAY NEAR BERNARDO, NM	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	RIO PUERCO NEAR BERNARDO, NM
Rio Grande	RIO GRANDE FLOODWAY AT SAN ACACIA, NM	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	
Rio Grande	RIO GRANDE BELOW CABALLO DAM, NM	RIO GRANDE AT EL PASO, TX	

6.5.5.2 Surface Water

Surface water evaporation for the Rio Grande River basin is modeled in the Upper Rio Grande Simulation Model (URGSiM) (Roach, 2007), and exported for use into the NMDSWB. Additionally, the portion of surface water returns estimated to return to a gaged surface water body that is not gaged is added to the surface water evaporation term. In the Rio Grande basin we estimate that 69% of surface water returns eventually pass a gage, the remaining 31% of surface water returns are added to surface water evaporation. See Section 4.4.10 for more information on how this was calculated. From 1975 through 2010 surface water evaporation is calculated to be on average 270,000 acre feet annually, 60,000 acre feet per year directly from open water evaporation, 210,000 acre feet per year from non-gaged returns.

6.5.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data driven from OSE Water use categories reports for commercial, industrial, mining, and power uses of water. Open water evaporation from Heron, El Vado, Abiquiu, Santa Fe, Cochiti, Jemez, Elephant Butte, and Caballo reservoirs is calculated (section 6.1.6) and is included here as a human activity related consumption. The only storage changes tracked for the Rio Grande River basin are the storage change at Heron, El Vado, Abiquiu, Santa Fe, Cochiti, Jemez, Elephant Butte, and Caballo Reservoirs. (Section 6.1.6).

6.5.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6), and is estimated at 255,000 acre feet per year for an average of 90,650 acres of riparian vegetation, for the Rio Grande River basin from 1975 through 2010.

6.5.6 Human Storage Rio Grande Reservoirs

The values used in the NMDSWB for human storage are derived from the URGSiM model; the reservoirs modeled in URGSiM can be seen in Figure 25. From 1975 through 2010 the average storage volume in all reservoirs in the Rio Grande basin was approximately 1,900,000 acre feet. The change in storage over this time period was in an increase of 5,700 acre feet.

However, this value is due in part to the long time period over which the calculation is performed. Since the year 2000 the volume of many of the reservoirs in the Rio Grande has dropped precipitously in response to drought conditions. This is illustrated by the volume of Elephant Butte reservoir which was near its capacity of 2,000,000 acre feet from 1985 to 2000 then dropped to less than 10 % of capacity by 2003.

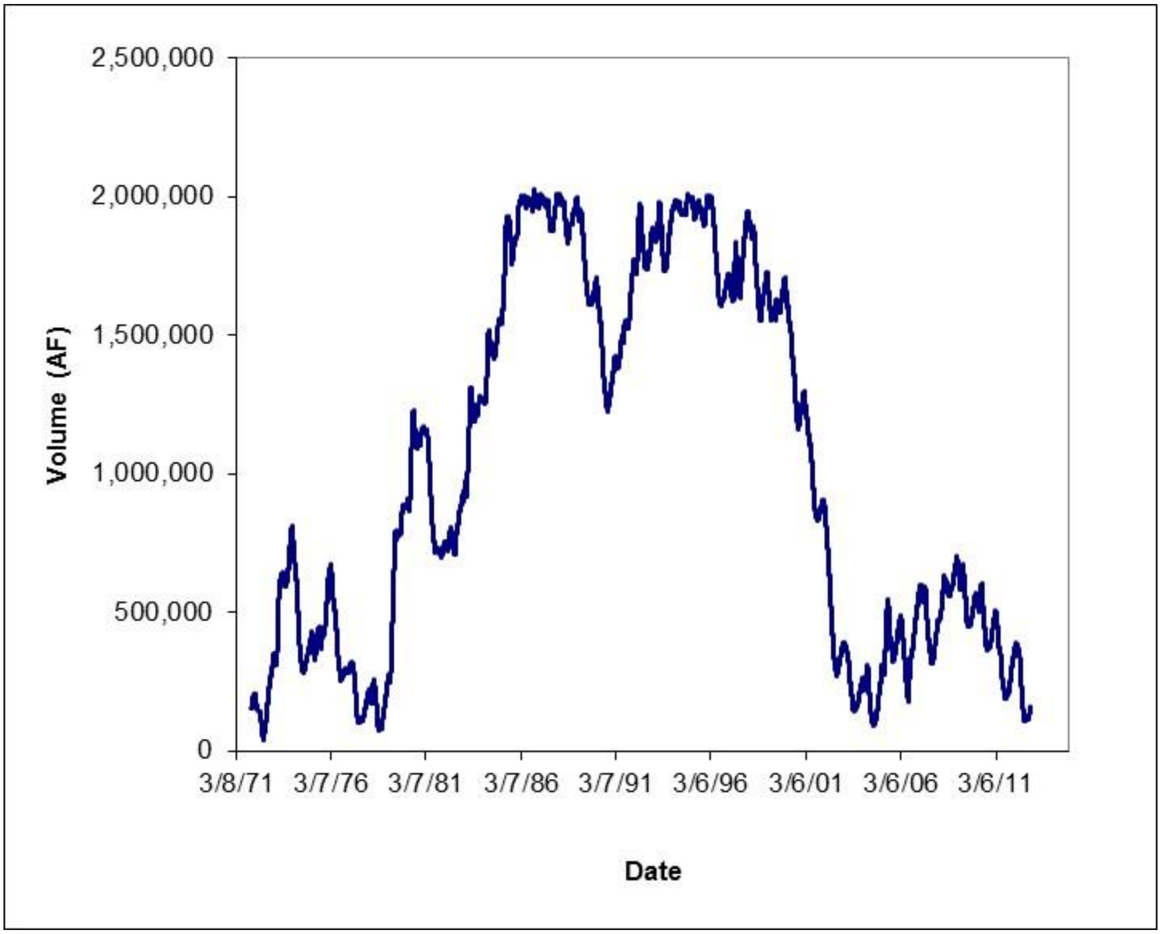

Figure 26 Elephant Butte Reservoir storage.

6.5.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation ($ET_{sw2,}$ ET_{gw} and ET_h), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 27 for the average mass balance terms calculated for the Rio Grande River basin from 1975 through 2010.

An important note is that the Boundary of the Rio Grande Basin in the NMDSWB is different from the boundary used to define the Rio Grande by the New Mexico Office of the State Engineer. The NMDSWB does not include the central closed basins of Estancia and Tularosa, in the Rio Grande Basin. When looking at the Human Use time series information, note that the NM OSE includes water use in the central closed basins for their published values in the Rio Grande basin.

Modeled human uses of water correlate well to the values reported by the NM OSE (i.e. Longworth et al., 2013), except for surface water withdrawals and depletions for irrigated agriculture. The NMDSWB withdrawals are approximately 25% less than the values reported by the OSE.

Figure 28 summarizes surface water flows and diversions in the Rio Grande basin for the period of 1975 to 2010. The sources of surface water supply are Surface Water In (SW_i) and Runoff. Surface Diversions (SW_d) represent diversions from the river for human uses. Surface Water Out (SW_o) is water that flows leaves the state and flows into Texas. The graph shows that the source of supply SW_i and Runoff are highly variable and reflect precipitation patterns associated with climate variability. For example the two decades 1980 to 2000 were inordinately wet which is reflected in both high annual sources of supply and large annual diversions and deliveries to Texas. In contrast drought conditions were experienced throughout the state beginning in 2008 resulting in reduced sources of supply, diversions and deliveries to Texas.

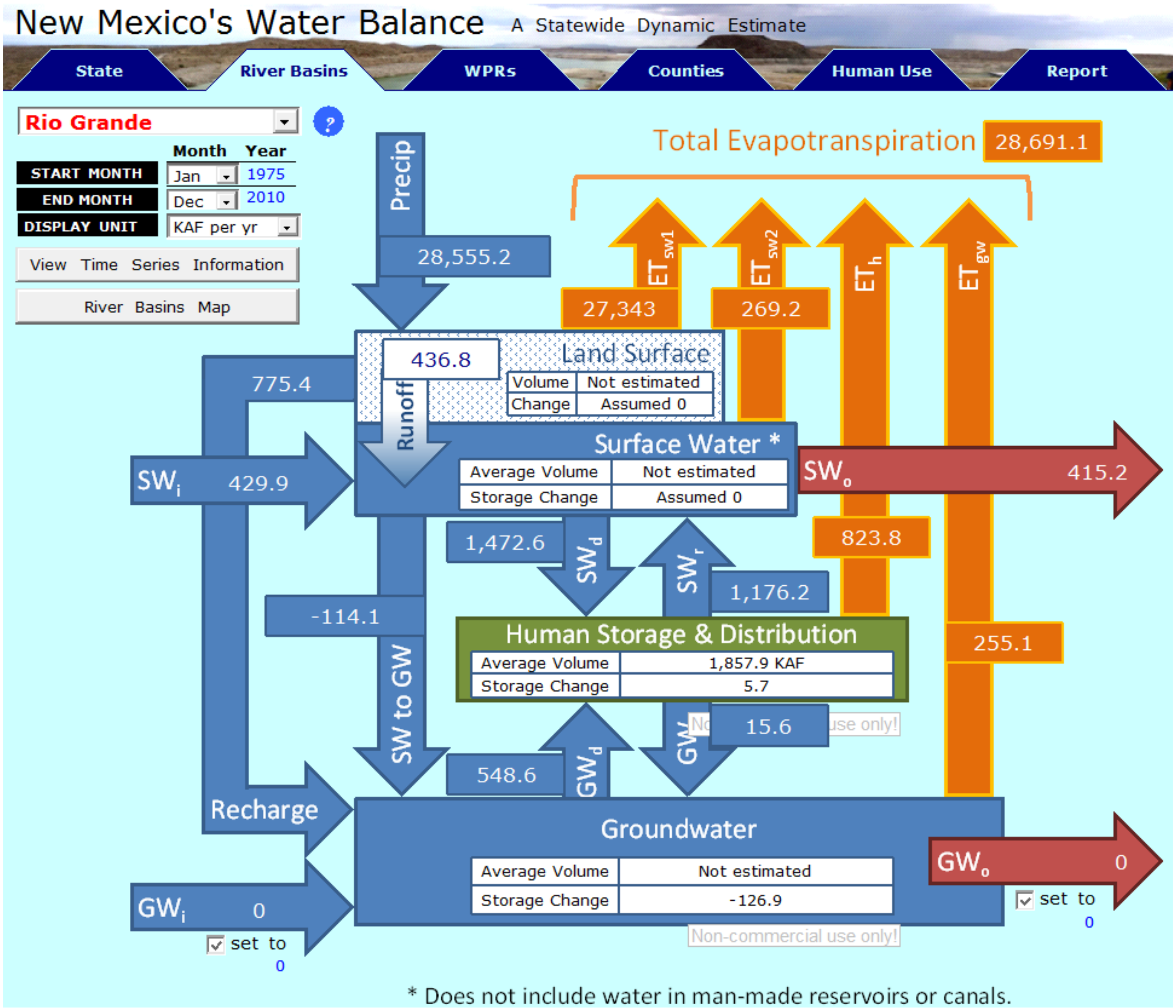

Figure 27 Average mass balance terms calculated for the Rio Grande River Basin from 1975 through 2010.

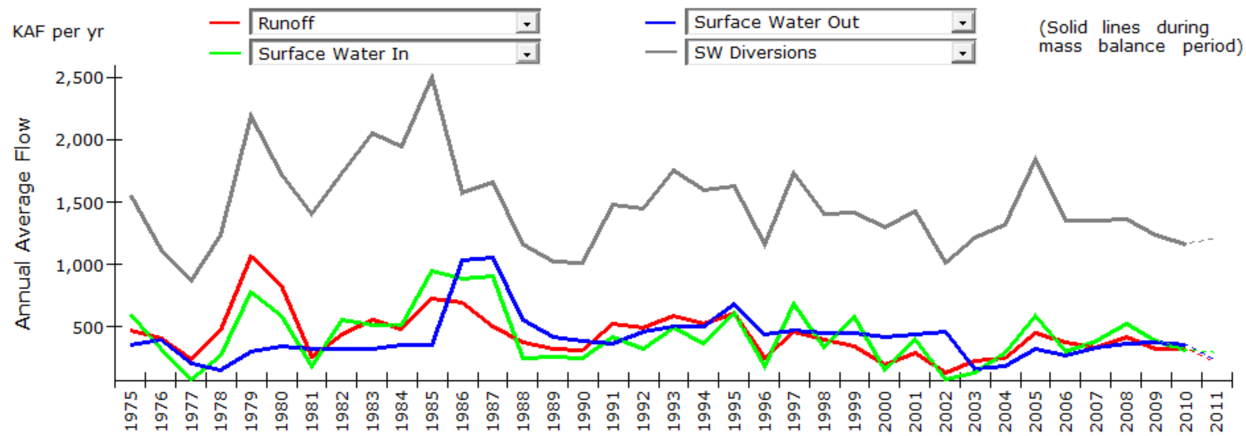

Figure 28 Summary of surface water flows and diversions in the Rio Grande basin.

Figure 29 summarizes the major groundwater fluxes in the Rio Grande basin for the period of 1975 to 2010. Total GW Diversions and ET due to Human Use are much less variable principally because the factors that affect them, land area and pumping rates, do not change much from year to year. Similarly, surface water evaporation doesn't change much from year to year, but does reflect the status of Rio Grande reservoirs. So for example surface water evaporation was high from 1985 to 2000 when Elephant Butte and other reservoirs were full but declined after 2000 as the water levels and resulting surface areas decreased.

Because of the very large spatial extent of the Rio Grande Basin the data shown are intended as an illustration of the information that can be generated by the NMSDWR model. Once finalized, it will be possible to the plot and analyze any of the components of the basin's water budget on a monthly time step for any period of time from 1975 to 2010.

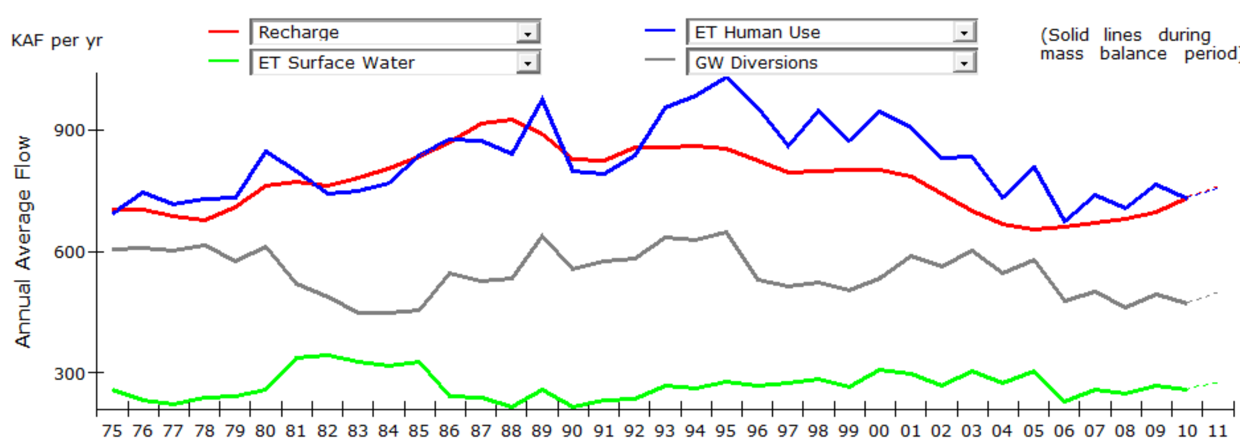

Figure 29 Summary of groundwater recharge, groundwater diversions, ET associated with human use, and surface water evaporation losses.

6.6 Texas Gulf River Basin

The Texas Gulf River basin is located in the Southeast corner of the state. This river basin encompasses portions of Roosevelt, Curry, and Lea Counties, as well as portions of the Northeast and Lea WPRs. For an overview of the Texas Gulf River basin refer to Figure 30.

6.6.1 Surface Water Inflows/Outflows in the Texas Gulf River basin

The Texas Gulf River is a headwaters river basin and does not contain any continuous surface water gages, or perennial streams. The NMDSWB calculates zero surface water inflow and outflow from the basin.

6.6.2 Runoff

There are no perennial streams in this basin. Due to the fact that no continuous surface water gages exist in the Texas Gulf River basin, runoff cannot be calculated in a format consistent with the other basins. Runoff is assumed to be equal to surface water depletions for all timesteps, this is a conservative estimate for runoff, but allows for the surface water system to be balanced. From 1975 through 2010 runoff is estimated to be an average of 500 acre feet per year.

6.6.3 Surface Water to Groundwater

Groundwater surface water interactions are solved as a closure term to the surface water system. See section 4.3 for more information. From 1975 through 2010 the surface water to groundwater flux is calculated to be zero acre feet per year.

6.6.4 GW

Because it is a headwater basin, we assume no groundwater inflows to the Texas Gulf River basin. No information has been obtained or calculated to estimate groundwater flow out of the Texas Gulf River basin. Under the assumption that groundwater outflows are zero the net annual depletion of groundwater is calculated be 470,000 acre feet annually from 1975 through 2010.

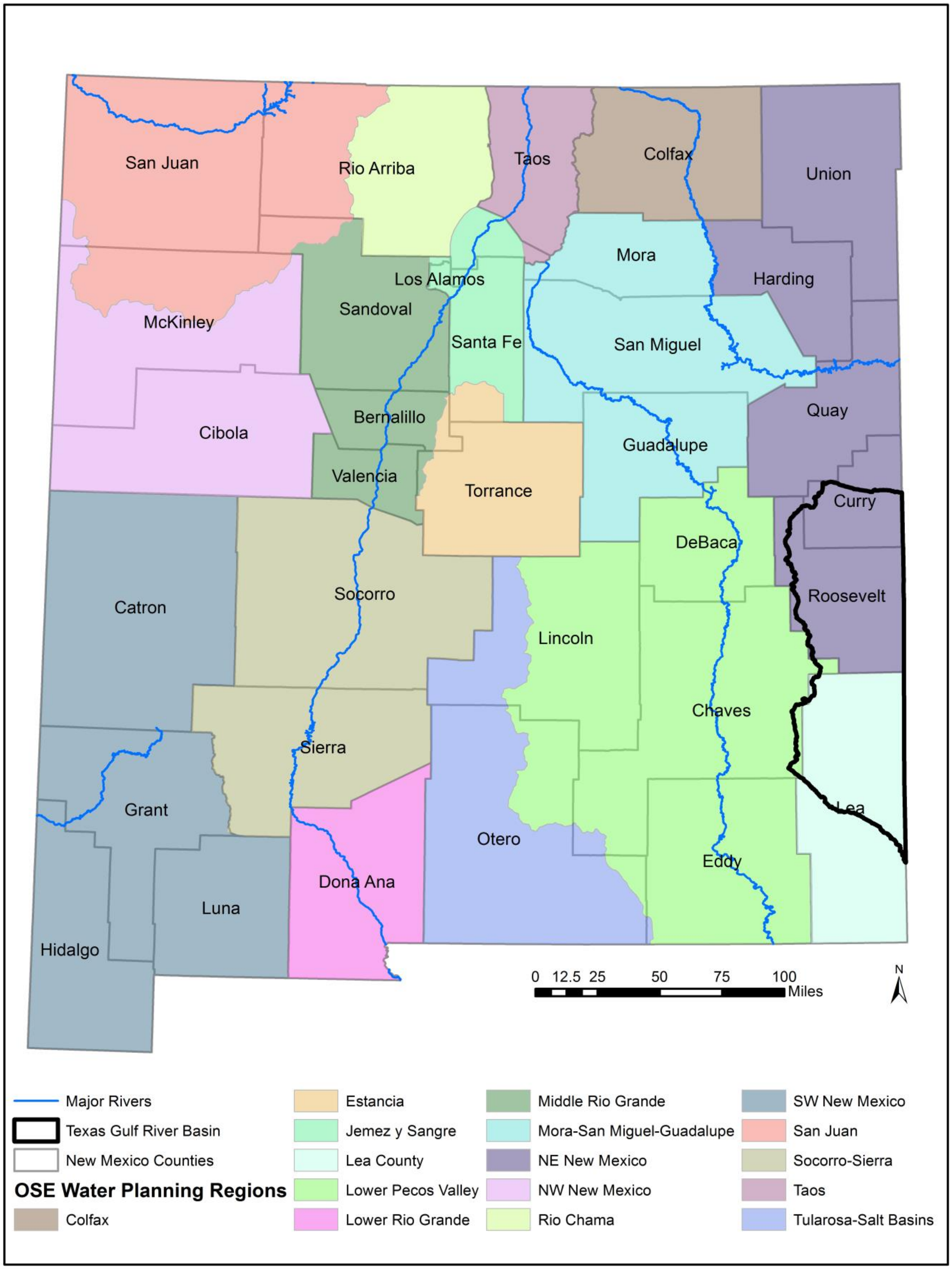

Figure 30 Spatial extent of Texas Gulf River basin.

6.6.5 ET

6.6.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which when storage change is neglected equals precipitation less runoff and recharge. Calculated land surface ET from the Texas Gulf River basin from 1975 through 2010 averaged approximately 4,700,000 acre feet per year, which represents about 99% of precipitation.

6.6.5.2 Surface Water

Surface water evaporation in the Texas Gulf Basin is equal to surface water returns. Since no return flows are gaged in the basin, the assumption is made that all returns to surface water are evaporated. See Section 4.4.10 for more information on how this was calculated. On average from 1975 through 2010 surface water evaporation was estimated to be 110,000 acre feet per year, all of which is from non-gaged returns to surface water.

6.6.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data driven from OSE Water use categories reports for commercial, industrial, mining, and power uses of water. No reservoir evaporation or changes is human storage are calculated for the Texas Gulf River basin.

6.6.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6), and is estimated at 12,500 acre feet per year for an average of 1,500 acres of riparian vegetation, for the Texas Gulf River basin from 1975 through 2010.

6.6.6 Human Storage Texas Gulf Reservoirs

No human storage is modeled in the Texas Gulf River basin for the NMDSWB.

6.6.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation ($ET_{sw2,}$ ET_{gw} and ET_h), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 31 for the average mass balance terms calculated for the Texas Gulf basin from 1975 through 2010.

Modeled human uses of water correlate well to the values reported by the NM OSE (i.e. Longworth et al., 2013). However, the groundwater withdrawals and depletions for irrigated agriculture are approximately 20% lower than the values reported by the OSE, on average.

Groundwater storage and inflow/outflow estimates have not yet been obtained in this version of the model. Setting the groundwater inflow/outflow terms to zero, resulted in an average groundwater storage depletion of about 470,000 acre feet per year for the period from 1975 through 2010. If the groundwater system in Texas Gulf River basin were in a steady state, the annual depletions would roughly be equal to the groundwater diversion minus the returns (370,000 acre feet per year). The NMDSWB estimates of groundwater depletion are within a reasonable range based on the available data. Estimates of groundwater depletion in Curry (136,500 acre feet per year) and Roosevelt (115,200 acre feet per year) total to 251,700 acre feet per year (Daniel B. Stephens & Associate INC., 2007). There is still a large portion of the Texas Gulf basin in Lea County, no groundwater depletion estimates have been found for this region.

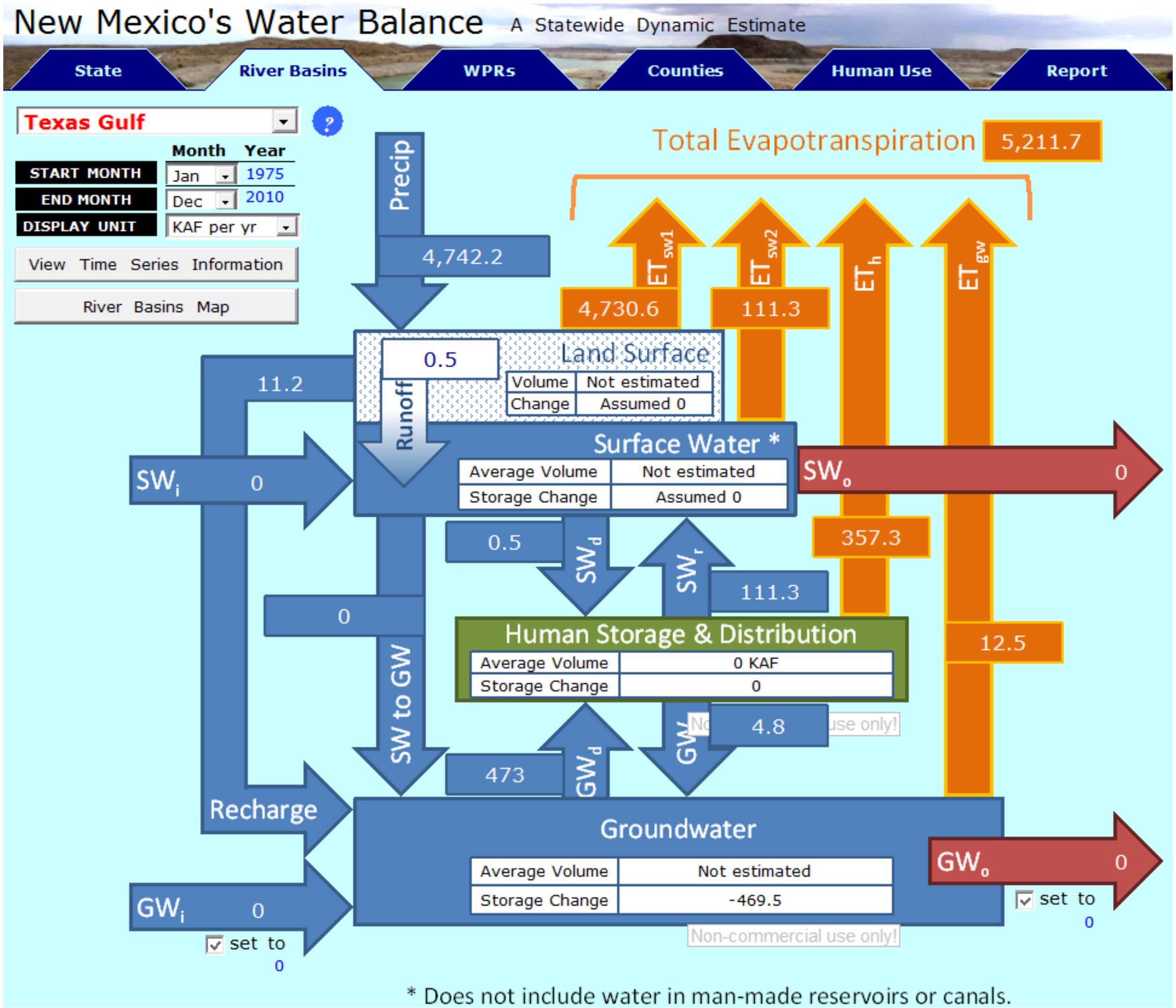

Figure 31 Average mass balance terms calculated for the Texas Gulf River Basin from 1975 through 2010.

6.7 Central Closed Basin

The Central Closed basin includes the Estancia basin and the Tularosa basin. This basin encompasses portions of Santa Fe, Torrance, Socorro, Lincoln, Sierra, Dona Ana, Chaves, and Otero County. The Tularosa-Sacramento-Salt WPR is fully contained within the Central Closed basin, and portions of the Jemez y Sangre, Estancia, Socorro-Sierra, and Lower Rio Grande WPRs are also contained in the Central Closed basin. Refer to Figure 32 for an overview of the Central Closed basin.

6.7.1 Surface Water Inflows/Outflows in the Central Closed River basins

There are no surface water inflows or outflows from the Central Closed basin.

6.7.2 Runoff

Runoff in the Central Closed basin is calculated from the one gage in the basin (with continuous data), Tularosa Creek near Bent, NM [USGS# 08481500]. The stream flow at this gage is multiplied by a BFI of 26.9% to separate streamflow into runoff and baseflow. See Figure 33 for the location of the Tularosa Creek near Bent, NM stream gage in in the Central Closed basin. There are other tributaries in the basin that are not gaged, and surface water diversions are calculated to be greater than runoff calculated from this one gage. The NMDSWB is set up so that runoff is equal to surface water diversions when the surface water diversions are greater than calculated runoff. This is likely a low end estimate for runoff in the basin but allows for the surface water system to be balanced.

6.7.3 Surface Water to Groundwater

Groundwater surface water interactions are solved as a closure term to the surface water system. See section 4.3 for more information. From 1975 through 2010 the average surface water to groundwater flux is calculated to be zero acre feet per year.

6.7.4 GW

The groundwater basin associated with the Central Closed basin is assumed to match the surface water basin meaning there are no groundwater inflows into the Central Closed basin. No information has been obtained or calculated to estimate groundwater flow out of the Central Closed basin for use within the NMDSWB. Under the assumption of zero groundwater in and out of the basin the average net depletion of groundwater for 1975 through 2010 equals approximately 80,000 acre feet per year.

6.7.5 ET

6.7.5.1 Land Surface

Land surface ET is calculated as the closure term for the land surface stock, which when storage change is neglected is precipitation less runoff and recharge. Calculated land surface ET from the Central Closed basin from 1975 through 2010 averaged approximately 8,400,000 acre feet per year, which represents about 99% of precipitation.

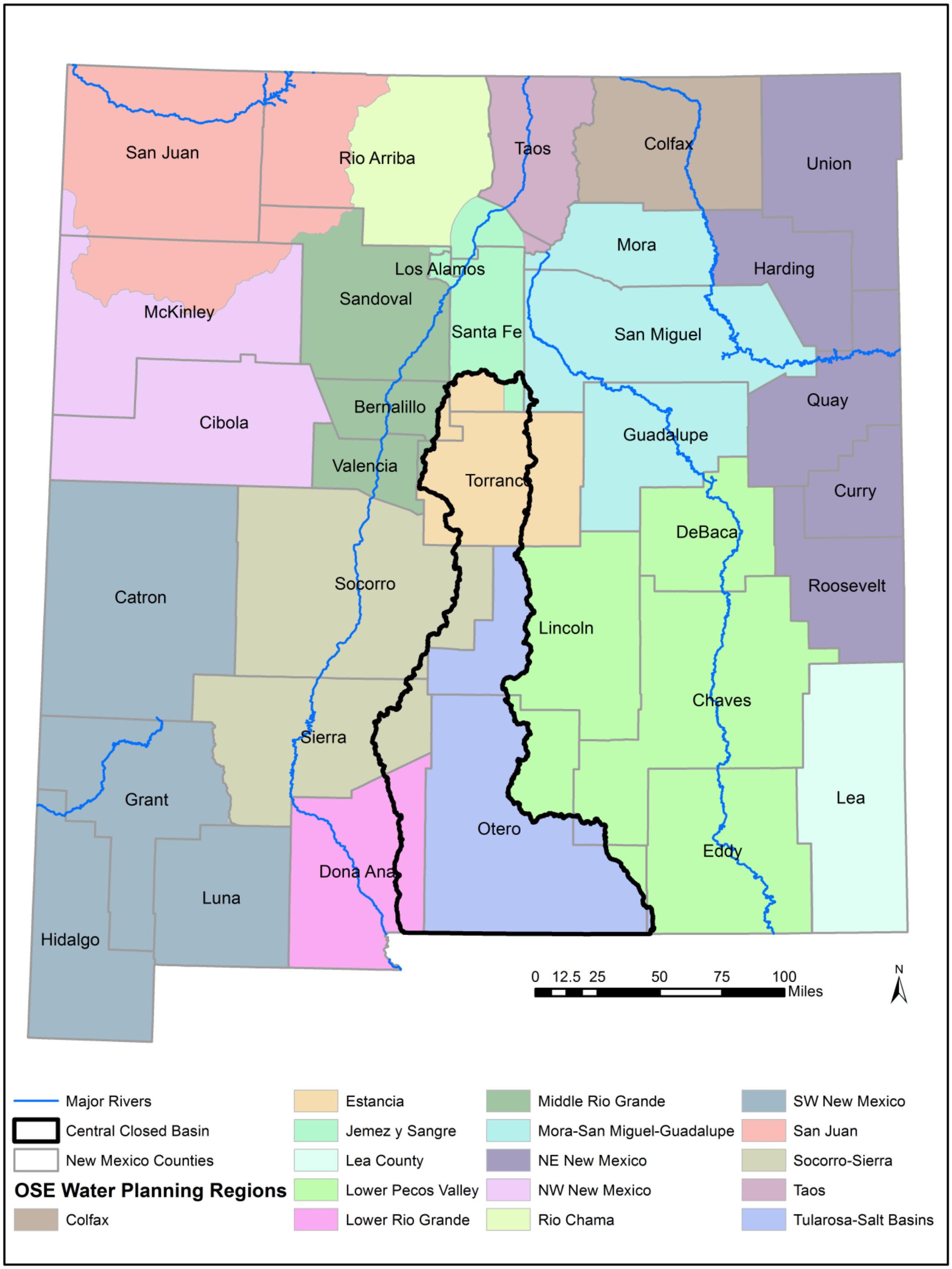

Figure 32 Spatial extent of Central Closed basin.

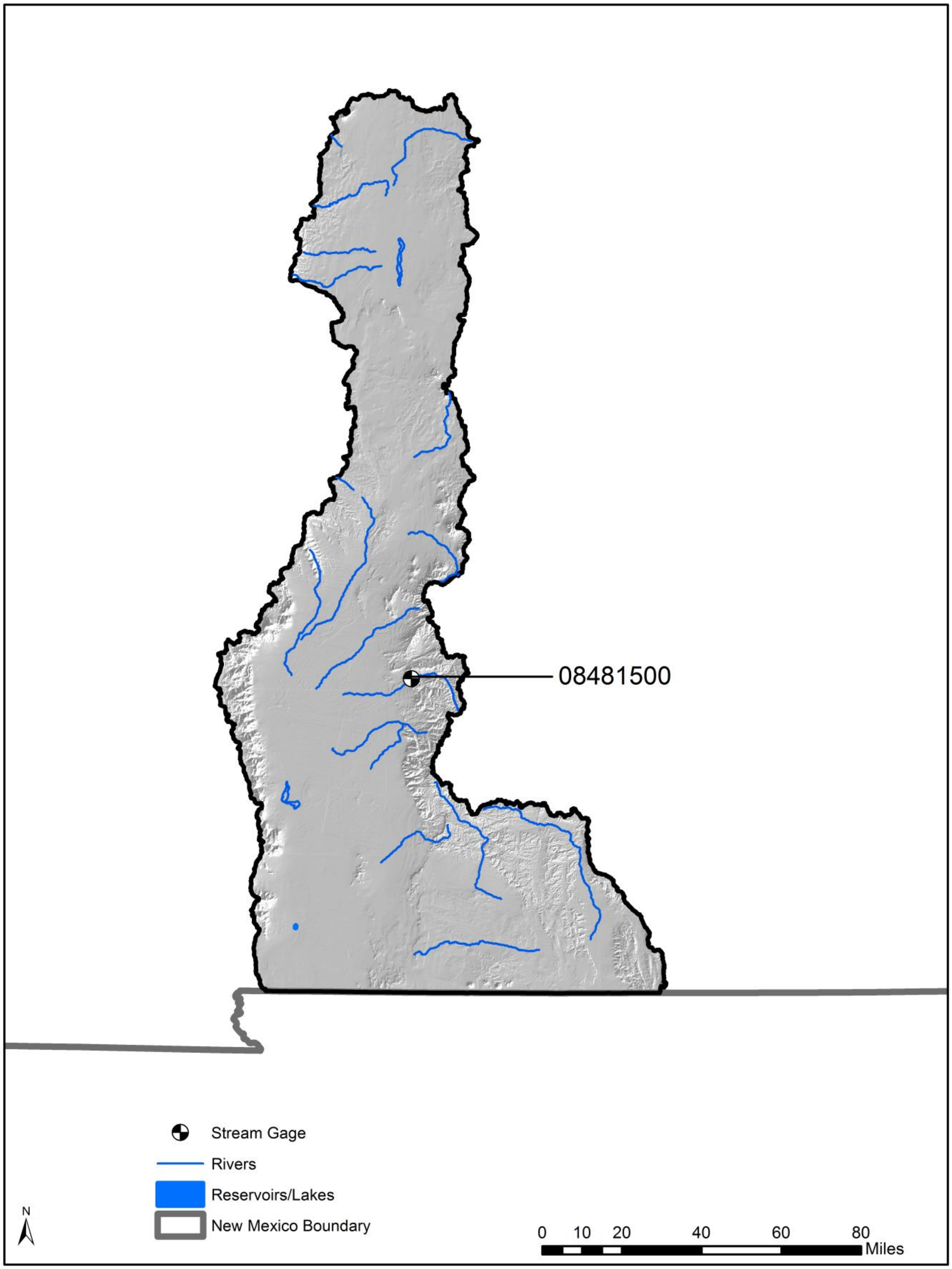

Figure 33 USGS gages used in NMDSWB for the Rio Grande River basin. The 8 number codes are the USGS gage numbers.

6.7.5.2 Surface Water

Surface water evaporation is calculated in the Central Closed basin by multiplying river area by Hargreaves reference ET and a monthly open water coefficient (Table 40). The river areas are dynamically calculated in the NMDSWB by correlating streamflow at a given stream gage to stream widths of variable dimensions. Three stream widths are selected for each stream gage used based on low, median, and high flows. The NMDSWB then interpolates stream width based on streamflow at a given timestep. Stream widths and lengths used in the NMDSWB to estimate open water surface evaporation can be seen in Table 41. In the Central Closed basin 0% of surface water returns are estimated to return to a stream that is gaged before leaving the State, the remaining 100% of returns are assumed to be lost from the accounting system to evaporation. See Section 4.4.10 for more information on how this was calculated. From 1975 through 2010 the average annual surface water evaporation was calculated to be 42,000 acre feet per year, all of which is from non-gaged returns.

Table 40 Monthly open water ET coefficients used in Central Closed basin.

Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1.3	1.3	1.6	1.6	1.6	1.4	1.3	1.2	1.3	1.4	1.5	1.3

Table 41 Dynamic river area calculation for Central Closed basin.

USGS stream gage site name	Low flow		Median flow		High flow		Length of stream segment associated with gage (miles)
	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	flow (cfs)	stream width (ft)	
Tularosa Creek near Bent	10	10	20	15	25	25	20

6.7.5.3 Human Activity Related Consumption (ET)

Human activity related consumption is calculated for public/domestic water supplies (section 4.4.3), irrigated agriculture (section 5.1) and livestock (section 4.4.4), and data driven from OSE Water use categories reports for commercial, industrial, mining, and power uses of water. No Reservoir evaporation or human storage changes are calculated in the NMDSWB for the Central Closed basin

6.7.5.4 Groundwater ET

Groundwater ET is calculated based on a calculated riparian ET rate multiplied by a remote sensing based estimate of riparian area (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013) (see 5.1.1 and 5.1.6), and is estimated at 20,000 AF per year for an average of 4,750 acres of riparian vegetation for the Central Closed River basin from 1975 through 2010.

6.7.6 Human Storage Central Closed basin

No human storage is modeled for the Central Closed basin in the NMDSWB.

6.7.7 Discussion

Model uncertainty at this time is largely unknown. Future work aims to quantify this uncertainty for the stocks and fluxes within each basin. At present the authors believe the largest uncertainties are associated with the surface water to groundwater flux, land surface ET (ET_{sw1}), and the groundwater storage change. In general these values are not measured directly and instead are estimated using empirical relationships such as the Hargreaves equation for ET by irrigated agriculture, riparian vegetation and lake evaporation ($ET_{sw2,}$ ET_{gw} and ET_h), or calculated as closure terms to balance the water budget (ET_{sw1} and Recharge). Uncertainties in the measured and modeled values used to derive these closure terms are propagated through the model combining to increase the uncertainty of the closure terms. Refer to Figure 34 for the average mass balance terms calculated for the Central Closed basin from 1975 through 2010.

Groundwater storage and inflow/outflow estimates have not yet been obtained in this version of the model. Setting the groundwater inflow/outflow terms to zero, resulted in an average groundwater storage depletion of about 80,000 acre feet per year for the period from 1975 through 2010. If the groundwater system in Central Closed basin were in a steady state, the annual depletions would roughly be equal to the groundwater diversion minus the returns (56,000 acre feet per year). The NMDSWB estimates of groundwater depletion are well within a reasonable range based on the available data. In 1995 the valley fill aquifer of Estancia basin was estimated to have an annual depletion of 43,000 acre feet (Corbin Consulting, 1999). This is only for one year and only a portion of the central closed basin. However, if depletions are similar in the Tularosa basin than basin wide totals would be equal to the 80,000 acre feet per year estimates of the NMDSWB.

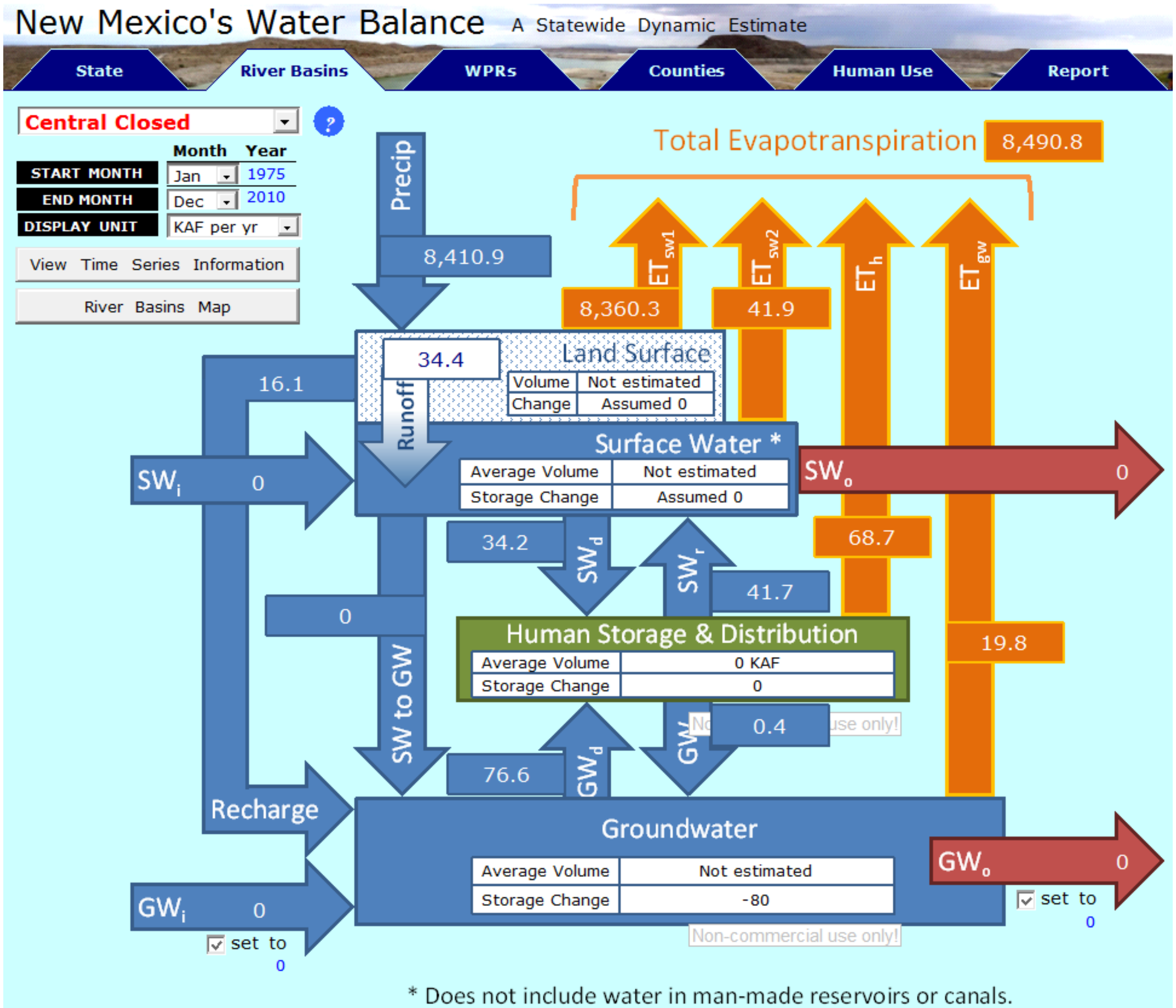

Figure 34 Average mass balance terms calculated for the Central Closed Basin from 1975 through 2010.

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