January 2019

A Dynamic Statewide Water Budget for New Mexico: Phase III – Future Scenario Implementation

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WRRI Technical Completion Report No. 380

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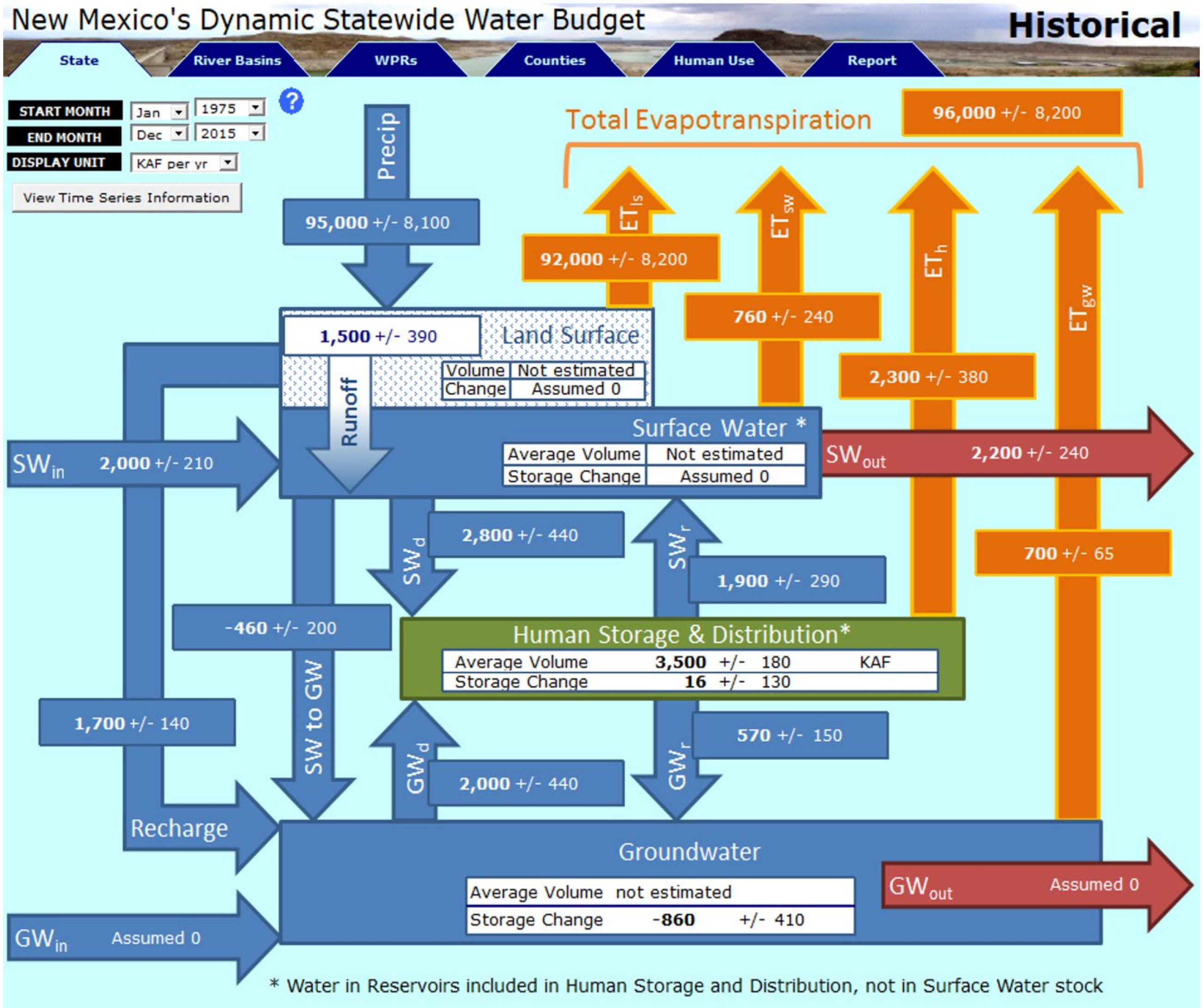
New Mexico's Dynamic Statewide Water Budget

Historical

START MONTH: Jan 1975
END MONTH: Dec 2015
DISPLAY UNIT: KAF per yr

* Water in Reservoirs included in Human Storage and Distribution, not in Surface Water stock

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University of New Mexico

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Executive Summary

With the support of New Mexico's Governor, the New Mexico Legislature, and New Mexico EPSCoR, funds were provided to the New Mexico Water Resources Research Institute (NM WRRI) for fiscal years (FYs) 15, 16, and 17 to support a legislative initiative that includes a Statewide Water Assessment. The Statewide Water Assessment is intended to complement existing state agency water resource assessments. It will provide new, dynamic spatially representative assessments of water budgets for the entire state of New Mexico. Projects included in the Statewide Water Assessment will introduce new technologies that expand existing studies and are applicable statewide. Of particular interest are water budget components for which state agencies require improved information such as evapotranspiration (ET), crop consumptive use, groundwater recharge, and streamflow. The NM WRRI is coordinating different components of the Statewide Water Assessment effort with work being done by researchers from New Mexico State University, New Mexico Tech, University of New Mexico, U.S. Geological Survey (USGS), New Mexico Bureau of Geology and Mineral Resources, Petroleum Recovery Research Center, Office of the State Engineer (OSE), Sandia National Laboratories, and Tetra Tech, Inc.

The New Mexico Dynamic Statewide Water Budget (NMDSWB) model is a tool that brings together the collaborative efforts of the Statewide Water Assessment. The NMDSWB can be used to account for the origin and fate of New Mexico's water resources through time, providing a more in-depth understanding of the temporal and spatial distribution of water in the state. This information can help policy makers and water managers make more informed and effective decisions about managing this critical and scarce resource.

The NMDSWB uses stocks to define quantities of water stored in given locations over specified time periods and uses fluxes to quantify how water moves to and from these stocks. The NMDSWB features four levels of mass balance accounting units (MBAUs): county, water planning region (WPR), river basin, and statewide. These four scales define the spatial boundaries over which stocks and fluxes are aggregated. Because of the complexity of working with multiple and overlapping hydrologic and political boundaries, minor inconsistencies in various flux and stock components might be noted at differing spatial resolutions. These inconsistencies are relatively small and within the margin of error of measurable values. In addition to a best estimate, the NMDSWB interface includes a 95% confidence interval to help visually represent uncertainty in the calculations and data (Figure 1).

The mass balance accounting occurs monthly, meaning that no flux or change in storage information is available for periods of less than one month. Thus, the impacts of a single storm on stocks or fluxes cannot be resolved. The historical period of the mass balance analysis extends from 1975 through 2015, while the future scenario period of the model runs from 2016 through 2099. The model is dynamic in that users can calculate mass balance terms over any set of consecutive months (with the caveat that the terms are more representative over longer time periods). In the NMDSWB, water storage is tracked in four separate stocks: land surface, surface water, human storage (reservoirs) and distribution, and groundwater stocks. The land surface stock consists of moisture stored in nonsaturated soils or geologic formations (the vadose zone), in vegetation, or in any other surface water source that cannot be practicably diverted for human use. The surface water stock represents the total amount of water in rivers and other natural waterways at any time. The human storage and distribution system (HSDS) stock represents water at any given time residing in man-made storage impoundments or distribution systems such as public water supplies, irrigation canals, and reservoirs. The groundwater stock consists of all water below the water table (water present in saturated soil and rock). Total groundwater storage for the state of New Mexico is largely unknown; however, the NMDSWB calculates changes in groundwater storage for the user-selected time period. Groundwater storage is not constrained by estimates of total volume present in each basin and, therefore, is implicitly assumed to be limitless. This assumption does not represent realistic conditions; however, it allows determination of storage changes as a result of water demand and other factors. If widespread estimates of total available water storage for New Mexico aquifers become available, they could potentially be included in the NMDSWB framework.

There are 16 fluxes representing water movement between stocks within or in and out of a given MBAU. Of these 16 fluxes, 10 have direct data-based, modeled estimates (historical period) and are calculated independently of other fluxes. Of the remaining six fluxes, four are closure terms calculated from the difference between other fluxes and stocks. The last two fluxes, groundwater inflow and outflow (GW_{in} and GW_{out}), which represent the movement of groundwater between MBAUs, are largely unknown and assumed to be negligible. This assumption is made because of a lack of information on regional groundwater flows, and, while it is reasonable at the river basin scale, it might introduce more notable errors at smaller scales.

Directly estimated (data-based) fluxes (historical period):

- Precipitation (P): Monthly PRISM data aggregated for a given MBAU (Prism Climate Group, 2018).
- Surface water in and out (SW_{in} and SW_{out}): USGS stream gage measurements (USGS, 2015).
- Surface water and groundwater diversions and returns (SW_d, GW_d, SW_r, and GW_r), and combined human consumption (ET_h): Modeled estimates of human water use for nine water use categories, including reservoir evaporation, are based on calculations and OSE water use by categories reports, which report average annual water use every five years (e.g., Longworth et al., 2013).
- Surface water ET (ET_{sw}): ET_{sw} accounts only for losses from rivers and streams (reservoir evaporation is counted as ET_h) and is calculated by one of two methods. The primary method is a direct estimate made using dynamic stream width calculations based on USGS field measurements at gage locations (USGS, 2015) and measured stream lengths to obtain an estimate of open water surface area. The surface area is multiplied by Hargreaves-Samani reference ET (Hargreaves and Samani, 1985) and an open water evaporation coefficient to estimate open water evaporation. The second method involves calculating ET as a closure term used in some cases based on MBAU-specific calibrations.
- Groundwater ET (ET_{gw}): Estimates of riparian vegetation area are derived from the USGS National Land Cover Database (e.g., Jin et al., 2013). The riparian area is multiplied by Hargreaves-Samani reference ET and a riparian vegetation crop coefficient to estimate riparian ET, all of which are assumed to be ET_{gw}.

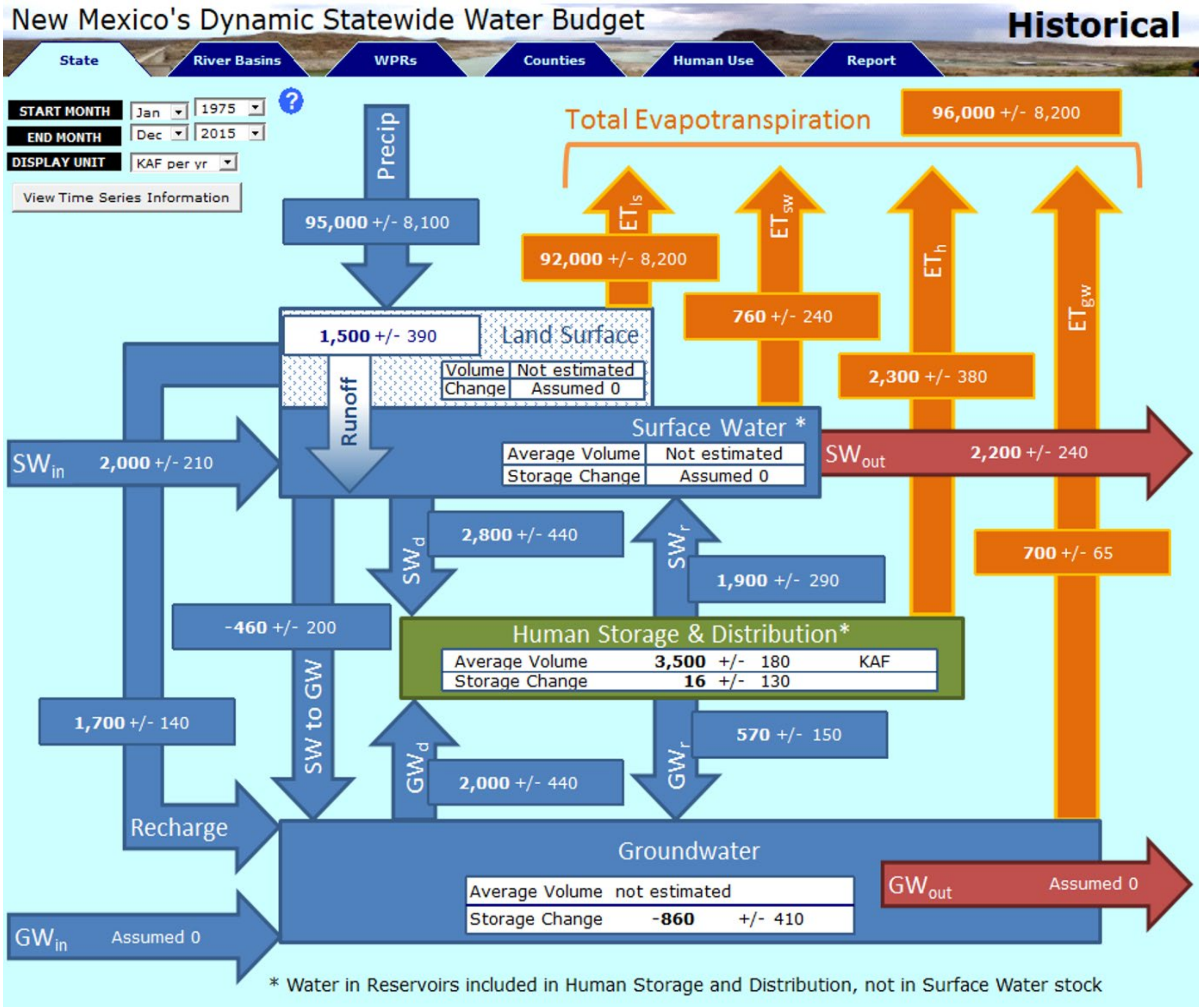
Closure term fluxes (historical period):

For fluxes into and out of the surface water stock, multiple closure terms are simultaneously calculated: surface water-groundwater interaction ($SW \Leftrightarrow GW$), runoff (RO), and a portion of ET_{sw}. When there is a deficit of water in the surface water stock at a given timestep based on directly estimated fluxes, water is assumed to come from RO and baseflow. Conversely, when there is a surplus of water in the surface water stock, the additional water is added to the $SW \Leftrightarrow GW$ flux or ET_{sw} flux depending on MBAU specific calibration.

- Runoff (RO): Closure term for a deficit in the surface water system; the surface water deficit is partitioned into RO and baseflow using the USGS 1-kilometer gridded baseflow index (BFI) map averaged for a given MBAU (Wolock, 2003).
- Surface water-groundwater interaction ($SW \Leftrightarrow GW$): Consists of two components, baseflow and surface water losses to the groundwater system. A negative $SW \Leftrightarrow GW$ net flux indicates a gaining stream (groundwater moving to surface water), whereas a positive value indicates surface water losses to the groundwater system. Baseflow always moves from groundwater to surface water and is calculated as the BFI multiplied by a running 10-year average of the water needed to balance the surface water system. If, on the other hand, there is surplus water in the surface water system, it is split into $SW \Leftrightarrow GW$ and ET_{sw} based on MBAU calibrations so changes in groundwater storage are consistent with reported estimates.
- Land surface ET (ET_{ls}): Equal to P less RO and recharge for each timestep so there is no change in storage of the land surface stock. Future efforts to quantify vadose zone storage through time may allow the assumption of zero storage change in the land surface stock to be relaxed.
- Recharge (R): To calculate R, the NMDSWB assumes a long-term, steady-state groundwater system when human terms (predominantly groundwater pumping) are ignored. As mentioned, groundwater flows into or out of a given MBAU are neglected. Therefore, R (predevelopment steady state groundwater stock inflow) is estimated as the sum of baseflow and ET_{gw} (i.e., predevelopment steady-state groundwater stock outflow).

Fluxes that are not determined in the NMDSWB:

- Groundwater flow between MBAUs (GW_{in} and GW_{out}): At the river basin scale, the assumption of zero groundwater movement between river basins is probably reasonable. The assumption that there is no groundwater movement across political boundaries such as WPRs or counties, however, is less defensible, but information on these flows is limited.



START MONTH Jan 1975

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* Water in Reservoirs included in Human Storage and Distribution, not in Surface Water stock

Figure 1. 1975–2015 statewide water budget from the NMDSWB. Values are expressed as the average annual flow over the time period.

The NMDSWB also tracks energy consumption for human uses of water. Depending on the source and use of the water, energy might be required to produce, transport, and/or treat water for use or after use. At a few locations releases of water from reservoirs could result in electric power generation. The NMDSWB tracks energy requirements associated with groundwater pumping for all uses; surface water pumping associated with five specific SW_d projects; water treatment for water used in the public water supply and the domestic, commercial, or industrial sectors; and wastewater treatment for all water returned from the public water supply and commercial, industrial, and mining sectors.

To determine how the historical calibration period might inform estimates of statewide water use and availability in the future, the NMDSWB includes a future scenario analysis capability. The future scenario is an extension of the historical model, but uses a different modeling approach to solve for a different set of unknowns in the absence of observed data. In the historical period, the water budgets for hydrologically connected spatial areas (e.g., adjoining counties along the Rio Grande) are calculated independently of one another based on available historical data. In the future scenario analysis, the hydrologically connected MBAUs are linked from upstream to downstream to enforce mass balances. As water flows through the system, the mass balance of water is maintained for each accounting unit and any remaining surface water flows into the next downstream unit (Figure 2).

In the future portion of the model, the model user can alter specific model variables to drive the model in place of observed historical data. The four future scenario drivers are the following:

1. Climate change impacts on supply and demand
2. Population growth
3. Municipal and domestic per-capita use rates
4. Agricultural acreage by crop type

Climate change is the main driver of variation in the future water supply within the model. Future temperature, precipitation, and streamflow estimates in the NMDSWB are derived from one of four separate General Circulation Model runs that span three different greenhouse gas (GHG) emissions climate change scenarios. Population growth can be altered from the baseline predicted population changes (UNM BBER, 2014) to determine the effects population growth has on municipal and domestic water use. The per-capita water use (i.e., depletion) rates can also be adjusted, an increased per-capita use rate will have a corresponding increase in per-capita withdrawals. Future agricultural acreage by crop type can be increased or decreased, thereby affecting irrigated agriculture depletion projections. These four future scenario options allow users to create unique future scenarios that can be compared to the historical water budget, showing how historical trends of water supply and use might change in the future.

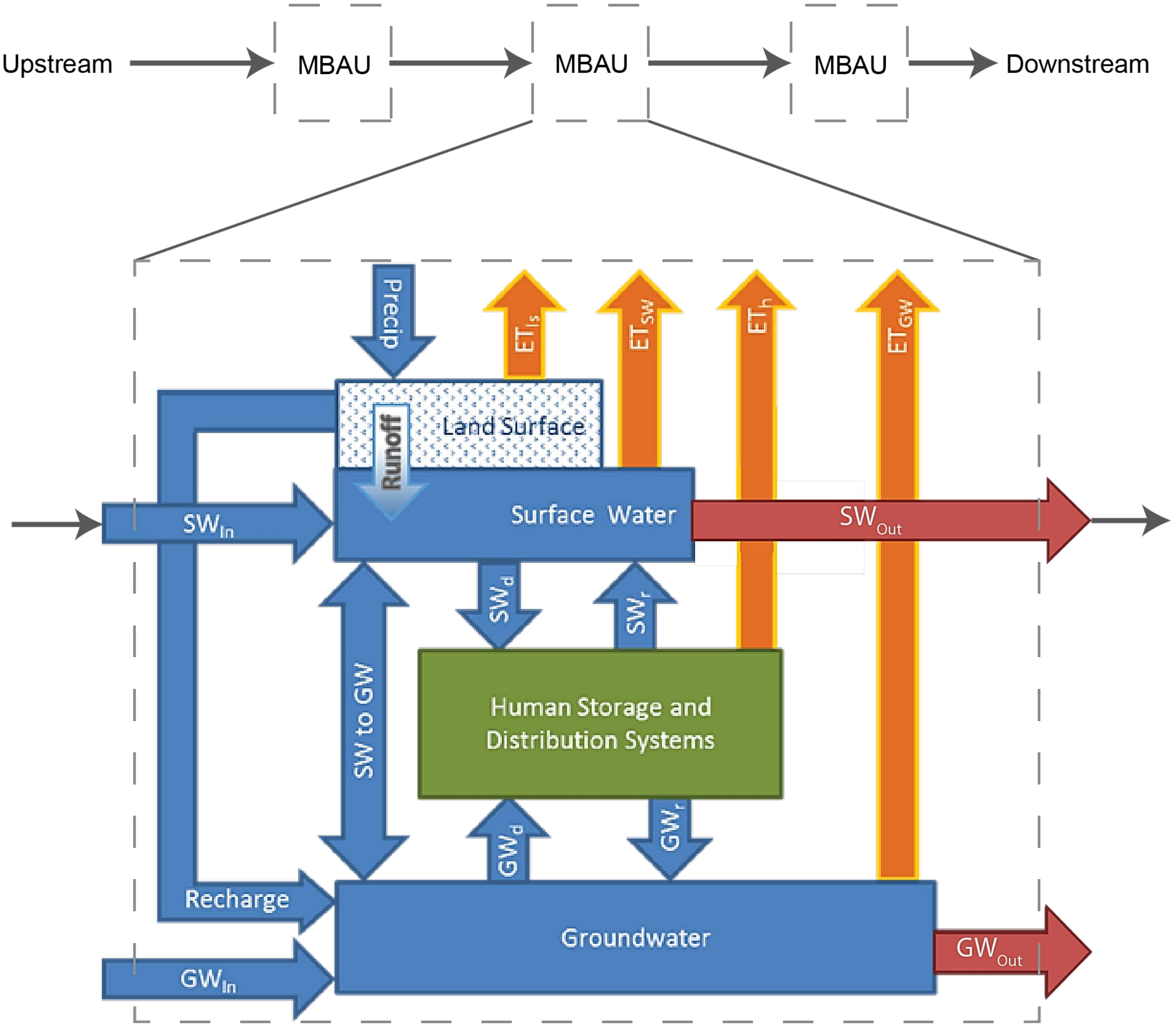

Figure 2. Hydrologic connection of MBAUs in the future period of the NMDSWB model showing the surface water connections within a given MBAU and how surface water is routed from upstream MBAUs to downstream MBAUs.

As an example of future scenario period capabilities, three basic scenarios were run for Torrance County: a low-impact water use scenario (A), a baseline water use scenario (B), and a high-impact water use scenario (C). Scenario A consists of a low GHG emissions climate option, a low population growth rate, a decreased municipal and domestic per-capita use rate, and a decrease in agricultural land acreage. Scenario B was modeled with a moderate emissions climate option, the standard population growth rate estimate (UNM BBER, 2014), and the historically derived projections for municipal and domestic per-capita water use rates, and agricultural land acreage. Scenario C consists of a high emissions climate option, a high population growth rate, an increased municipal and domestic per-capita use rate, and an increase in agricultural land acreage. These projections represent three potential future scenarios for Torrance County; however, the scenario options allow for many more scenarios to be modeled and compared.

Changes in climatic conditions, population growth rate, per-capita use rates, and agricultural land area will alter future water budgets, as can be seen by looking at projected groundwater withdrawals in Torrance County (Figure 3). The majority of water used in Torrance County comes from groundwater, and understanding how and why different scenarios change estimates of groundwater withdrawals in the county can be an important planning tool. For scenario B, groundwater withdrawals have a slightly increasing trend relative to the historical period (Figure 3). This trend is the result of an increase in both population and temperatures, which increases municipal and agricultural water demands. For scenario C, there are significant increases in groundwater withdrawals compared to historical values. For scenario A, decreases in municipal and domestic per-capita use rates, and decreases in population growth rate and agricultural land acreage result in a fairly constant rate of groundwater withdrawals at near historical levels.

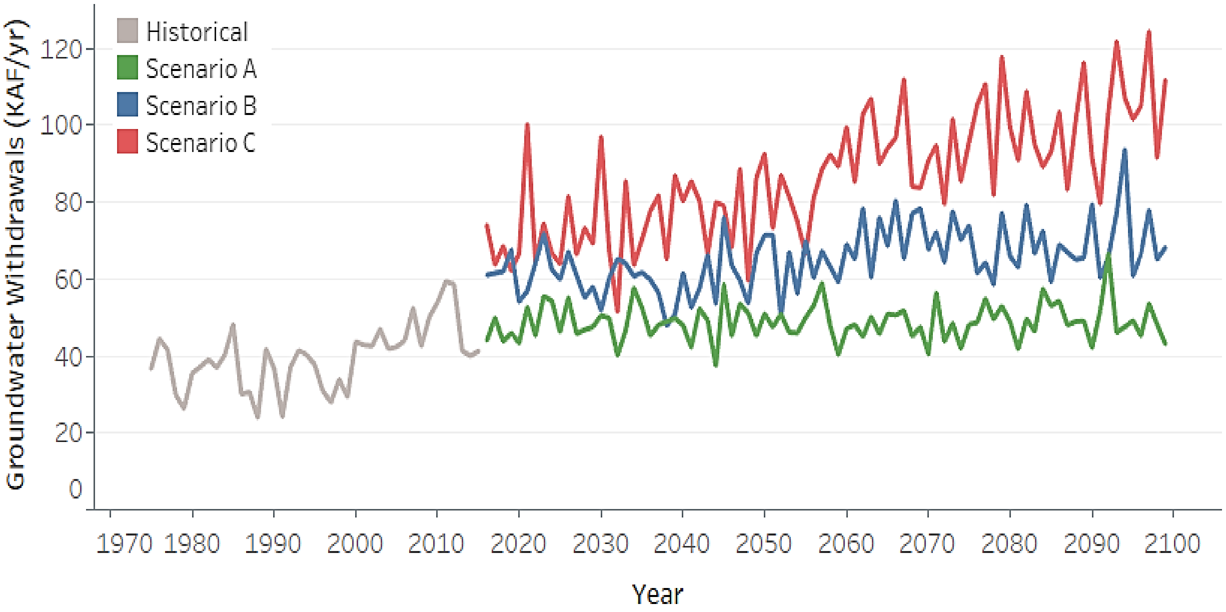

Figure 3. Torrance County annual groundwater withdrawals (kilo acre-feet per year) for the historical period and three future scenarios.

The NMDSWB model can also provide estimates of possible impacts to groundwater storage moving into the future. In the case of Torrance County, which is essentially a closed basin with no $SW \Leftrightarrow GW$ and limited R, model results indicate the changes in groundwater storage are expected to closely mirror the total groundwater withdrawals. Scenario C would result in the greatest loss in annual groundwater withdrawals, while changes in groundwater withdrawals in scenario A would be similar to the groundwater withdrawals seen during the historical period. The NMDSWB model tracks only groundwater storage change and cannot indicate whether there is physically enough water available in storage to meet continued or growing demands.

By making both the historical and future scenario periods available for analysis, the NMDSWB model can be used for historical accounting and projecting estimates of supply and demand under different potential future scenarios, making it a valuable tool for water planning in New Mexico. The model is intended to be an engagement point with water users, planners, and managers throughout the state of New Mexico. An interactive visualization tool is available on the NMDSWB page on the NM WRRI website (New Mexico Water Resources Research Intitute, 2018), which allows for exploration and application of the modeled results for the historical period and for numerous user-defined future scenarios. This tool also provides information and resources for the model and science engagement. Work by other researchers that is ongoing as part of the Statewide Water Assessment that will be incorporated into future iterations of the NMDSWB model as available includes more direct estimates of groundwater storage change (Rinehart et al., 2016) and a land surface ET-runoff-recharge model (Ketchum et al., 2015) (Appendices 8.2A.25). As those efforts mature, they will be targeted for incorporation into future iterations of the NMDSWB model.

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Acronyms and Abbreviations

°C	Degrees Celsius
°F	Degrees Fahrenheit
Δ	Delta (change)
ρ	Rho (density)
η_p	Unitless pump efficiency
A	Area of reservoir
ABCWUA SJC DWP	Albuquerque Bernalillo County Water Utility Authority San Juan-Chama Drinking Water Project
AF	Acre-feet
Ag	Agriculture
BBER	Bureau of Business and Economic Research
BDD	Buckman Direct Diversion
BFI	Baseflow index
C-V	Cross-validation
cfs	Cubic feet per second
CIR	Consumptive irrigation requirement
C_l	Mean county latitude
CMIP3	Phase 3 of the Coupled Model Intercomparison Project
CO	Colorado
D	Net depth of irrigation water applied per month
EPRI	Electric Power Research Institute
ET	Evapotranspiration
ET_{BC}	Blaney-Criddle consumptive use
ET_c	Average monthly crop evapotranspiration
ET_{gw}	Groundwater evapotranspiration
ET_h	Human consumption evapotranspiration
$ET_{\circ HS}$	Hargreaves-Samani based reference ET
ET_{ls}	Land surface evapotranspiration
ETRM	Evapotranspiration and Recharge Model
E_{sd}	Earth sun distance (by month)
ET_{sw}	Surface water evapotranspiration
$ET_{sw\ rb}$	River basin surface water evapotranspiration
f	Force
ft	Feet
g	Acceleration due to gravity
GCM	General Circulation Model
GHG	Greenhouse gas
GPCD	Gallons per capita per day
GW	Groundwater
GW_d	Groundwater diversion
GW_i	Initial groundwater storage
GW_{in}	Groundwater in(flow)
GW_{out}	Groundwater out(flow)
GW_r	Groundwater return

h	Height the water is lifted
HSDS	Human storage and distribution system
i	Time index for simulation
in	Inches
K	Consumptive use coefficient
k_c	Empirical crop stage coefficient
KAF	Kilo acre-feet
kWh	Kilowatt hours
l	Dimension of length
LULC	Land use land cover
m	Dimension of mass
mm	Millimeter
MBAU	Mass balance accounting unit
MG	Million gallons
mo	Month
n	Number of timesteps in simulation
N_0	County population at start of decade
N_{10}	County population 10 years later
NAIP	National Agricultural Imagery Program
NAPP	National Aerial Photography Program
NASS	National Agricultural Statistics Service
NHAP	National High Altitude Photography
NIIP	Navajo Indian Irrigation Project
NLCD	National Land Cover Database
NMDA	New Mexico Department of Agriculture
NMDSWB	New Mexico Dynamic Statewide Water Budget
NMEMNRD	New Mexico Energy, Mineral and Natural Resources Department
NMISC	New Mexico Interstate Stream Commission
NMSU	New Mexico State University
OSE	New Mexico Office of the State Engineer
P	Precipitation
P	Fraction of annual daylight hours occurring in a given month based on latitude
p	Power
P_e	Average monthly effective precipitation
P_t	Monthly mean precipitation
psi	Pounds per square inch
PRISM	Parameter Relationship on Independent Slopes Model
PVID	Pojoaque Valley Irrigation District
Q	Volumetric flow rate
R	Rainfall
R	Recharge
r	Population growth rate
R_a	Water equivalent of extraterrestrial radiation
R_e	Effective rainfall
RO	Runoff

RO_{rb}	River basin runoff
S	Storage of reservoir
s	Second
S_d	Solar declination (by month)
SF	Soil water storage factor
S_{ha}	Sunset hour angle (by month and county)
SJC	San Juan-Chama
SW	Surface water
$SW \Leftrightarrow GW$	Surface water-groundwater interaction
$SW \Leftrightarrow GW_{rb}$	River basin surface water-groundwater interaction
SW_d	Surface water diversion
$SW_{d\ rb}$	River basin surface water diversions
SW_{in}	Surface water in(flow)
$SW_{in\ rb}$	Surface water inflow to river basin
SW_{out}	Surface water out(flow)
$SW_{out\ rb}$	Surface water outflow from river basin
SW_r	Surface water return
$SW_{r\ rb}$	River basin surface water return
SW_z	Surface water surplus
T	Mean temperature
t	Dimension of time
$Tmax$	Maximum temperature
$Tmin$	Minimum temperature
TR-21	Technical Release 21
UNM	University of New Mexico
URGIA	Upper Rio Grande Impact Assessment
URGSiM	Upper Rio Grande Simulation Model
URGWOM	Upper Rio Grande Water Operation Model
U.S.	United States
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
USDA SCS	United States Department of Agriculture Soil Conservation Service
USGS	United States Geological Survey
USGS LULC	United States Geological Survey Land Use and Land Cover
USGS NLCD	United States Geological Survey Nation Land Cover Dataset
VIC	Variable Infiltration Capacity
WPR	Water Planning Region
WRF	Water Research Foundation
NM WRRI	New Mexico Water Resources Research Institute
yr	Year

Mass Balance Stock and Flux Terms

Fluxes and Stocks	**Definition**
Precipitation (*P*)	Rain, snow, sleet, or hail that falls on Earth's surface.
Land Surface Stock	Water stored in the vadose zone, in vegetation, or in any other surface water source that cannot be practicably diverted for human use.
Land Surface Evapotranspiration (ET_{ls})	Evapotranspiration from the land surface stock.
Runoff (*RO*)	Precipitation that flows from the land surface stock into the surface water stock.
Recharge (*R*)	Assuming a long-term, steady-state groundwater system without human intervention and neglecting GW_{in} and GW_{out}, between mass balance accounting units (MBAUs), the addition of water to the groundwater stock, which is equal to the depletions of the groundwater stock (ET_{gw} + baseflow). Baseflow is the movement of water from the groundwater stock to the surface water system.
Surface Water Stock	The total amount of water in rivers, natural lakes, and other natural waterways that is available for human use.
Surface Water In (SW_{in})	Surface water inflows that cross into the boundary of a given MBAU.
Surface Water Out (SW_{out})	Surface water outflows that leave the boundary of a given MBAU.
Surface Water Evapotranspiration (ET_{sw})	Evapotranspiration from the surface water stock. This is evaporation only from stream and rivers. Reservoir evaporation is accounted for in human consumption (ET_h).
Surface Water-Groundwater Interaction ($SW \Leftrightarrow GW$)	Net movement of water between the surface water and groundwater stocks. A negative $SW \Leftrightarrow GW$ value is indicative of baseflow, and a positive $SW \Leftrightarrow GW$ value represents surface water losses to the groundwater system.

Surface Water Diversions (SW_d)	Total amount of surface water taken from the surface water stock to be used elsewhere.
Human Storage and Distribution System (HSDS) Stock	Total water residing in man-made storage impoundments or distribution systems such as public water supplies, irrigation canals, and reservoirs.
Surface Water Returns (SW_r)	Total amount of water returned from the HSDS to the surface water stock.
Human Consumption (ET_h)	Water consumed by all Office of the State Engineer water use categories, which includes reservoir evaporation.
Groundwater Returns (GW_r)	Total amount of water returned from the HSDS to the groundwater stock.
Groundwater Stock	All subsurface water below the water table.
Groundwater Diversion (GW_d)	Total amount of groundwater taken from the groundwater stock to be used elsewhere.
Groundwater Evapotranspiration (ET_{gw})	Riparian evapotranspiration.
Groundwater In (GW_{in})	Subsurface groundwater flow into the boundary of a given MBAU.
Groundwater Out (GW_{out})	Subsurface groundwater flow out of the boundary of a given MBAU.

Units and Conversions

Acronym/Abbreviation	**Definition**	**Acre-Feet Conversion**
AF/mo	Acre-feet per month	AF/mo *12 = AF/yr
AF/yr	Acre-feet per year	AF/yr / *12 = AF/mo
cfs	Cubic feet per second	cfs * 59.4954 = AF/mo
KAF/mo	Kilo acre-feet per month	KAF/mo * 1,000 = AF/mo
KAF/yr	Kilo acre-feet per year	KAF/yr * 1,000 = AF/yr
MGD	Million gallons per day	MGD * 92.0565 = AF/mo

1 Dynamic Statewide Water Budget Framework

The 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, providing a more in-depth understanding of the spatial and temporal distribution of water in the state. This information can help policy makers and water managers manage this critical and scarce resource. As is common in accounting methods, the NMDSWB uses stocks to identify water stored in a given water containing unit such as a river, an aquifer, or unsaturated soils over a specified time period and uses fluxes to quantify how water moves from one stock to another, or into or out of the area of interest. This report describes how mass balance accounting was developed for New Mexico counties, water planning regions (WPRs), major river basins, and the entire state (NMISC, 1994).

The spatial extent for the analysis described in this report is the state of New Mexico, meaning summing terms across mass balance accounting units (MBAUs); river basins, WPRs, or counties considered will generate stocks and fluxes for water at the state level. The seven river basins, 16 WPRs, and 33 counties are shown in Figure 4, Figure 5, and Figure 6, respectively. The temporal resolution of the mass balance is monthly, meaning no flux or change in storage information is available for shorter time periods. The historical mass balance accounting extends from 1975 through 2015, and future projections under different possible scenarios are available from 2016 through 2099. The stocks and fluxes quantified in this effort are shown in Figure 7. 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 consumed (i.e., lost to the atmosphere through evaporation and transpiration), while the remainder is returned to the surface water or groundwater systems. Because the NMDSWB tracks the amount of water in human storage (reservoirs) and conveyance systems separately from water in rivers, additions to storage in reservoirs are considered withdrawals from the surface water system, reductions in storage through reservoir releases are considered returns to the surface water system, and reservoir evaporation is accounted for as human consumption (ET_h). In addition to ET_h, the NMDSWB accounts for riparian consumption, land surface evapotranspiration (ET_{ls}), and surface water evapotranspiration (ET_{sw}). The following sections describe how the various demands for water are tabulated and or calculated.

1.1 Historical Period

In the historical period (1975–2015), the NMDSWB provides a retrospective accounting of estimated water movement and use throughout the state. Historical data and observations or calculations of streamflows, precipitation (*P*), climatological conditions (primarily *P* and temperature), land use, and water consumption are used to estimate how much water was available, how it moved through the different watersheds both as surface water and groundwater, and how storage in the different stocks changed through time. The historical periods of the NMDSWB model were created to calibrate and verify the accounting procedures to quantify water availability, movement, and use throughout the state. This calibrated accounting procedure was then incorporated into the future scenario portion of the model, which is used to evaluate how supply and demand might change under different future conditions (e.g., changes to climate).

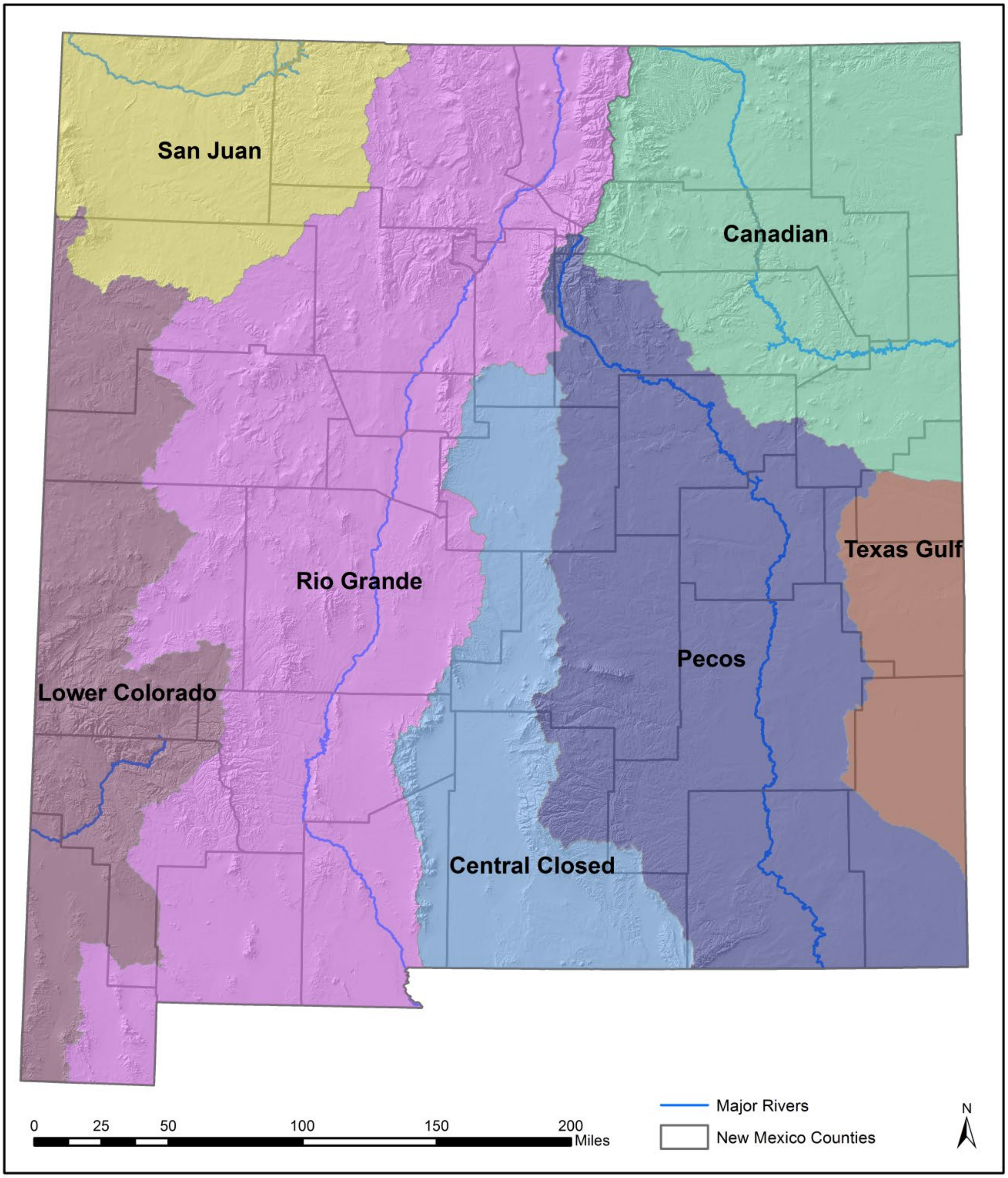

Figure 4. The seven river basins represented in the NMDSWB.

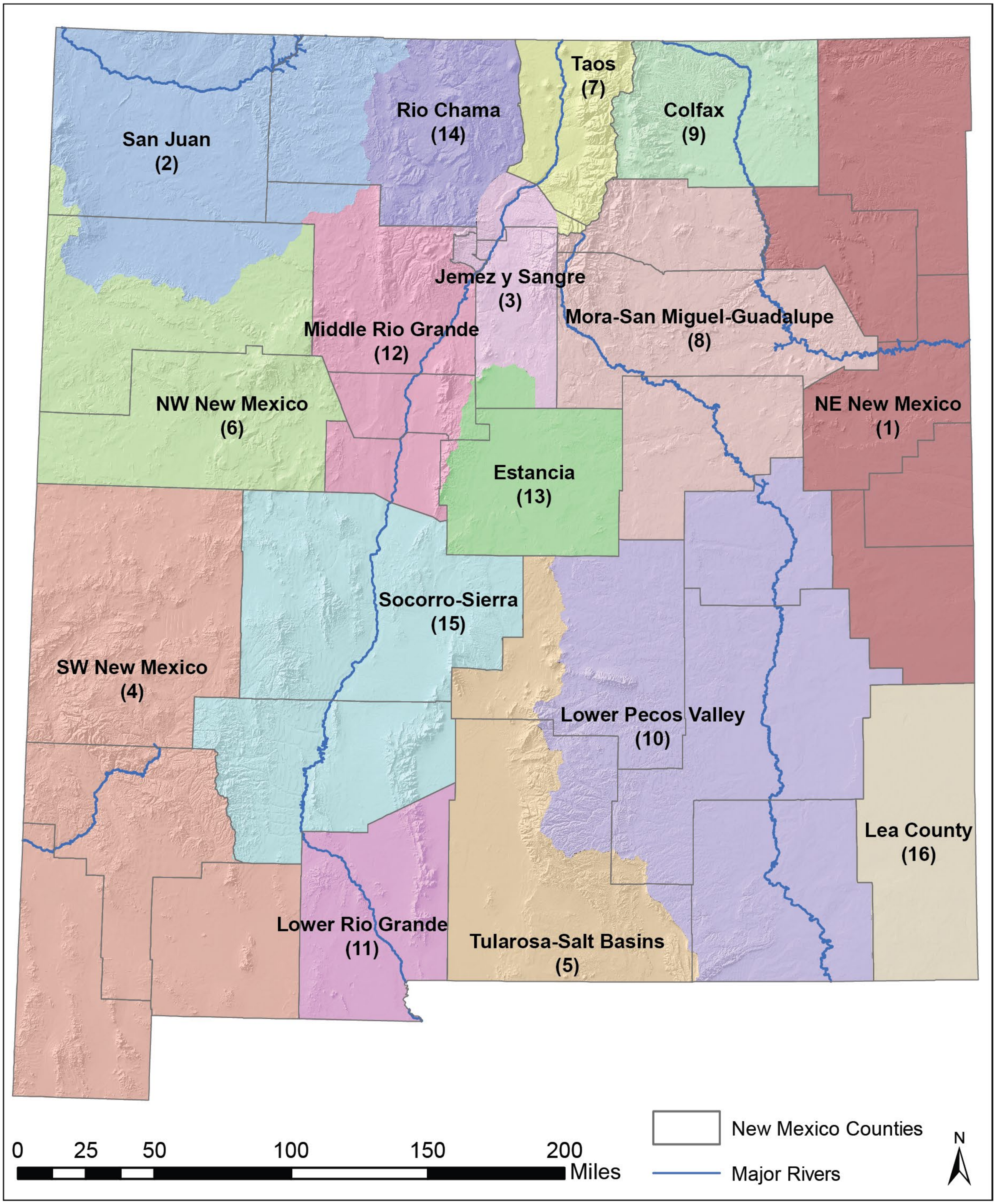

Figure 5. The 16 water planning regions represented in the NMDSWB.

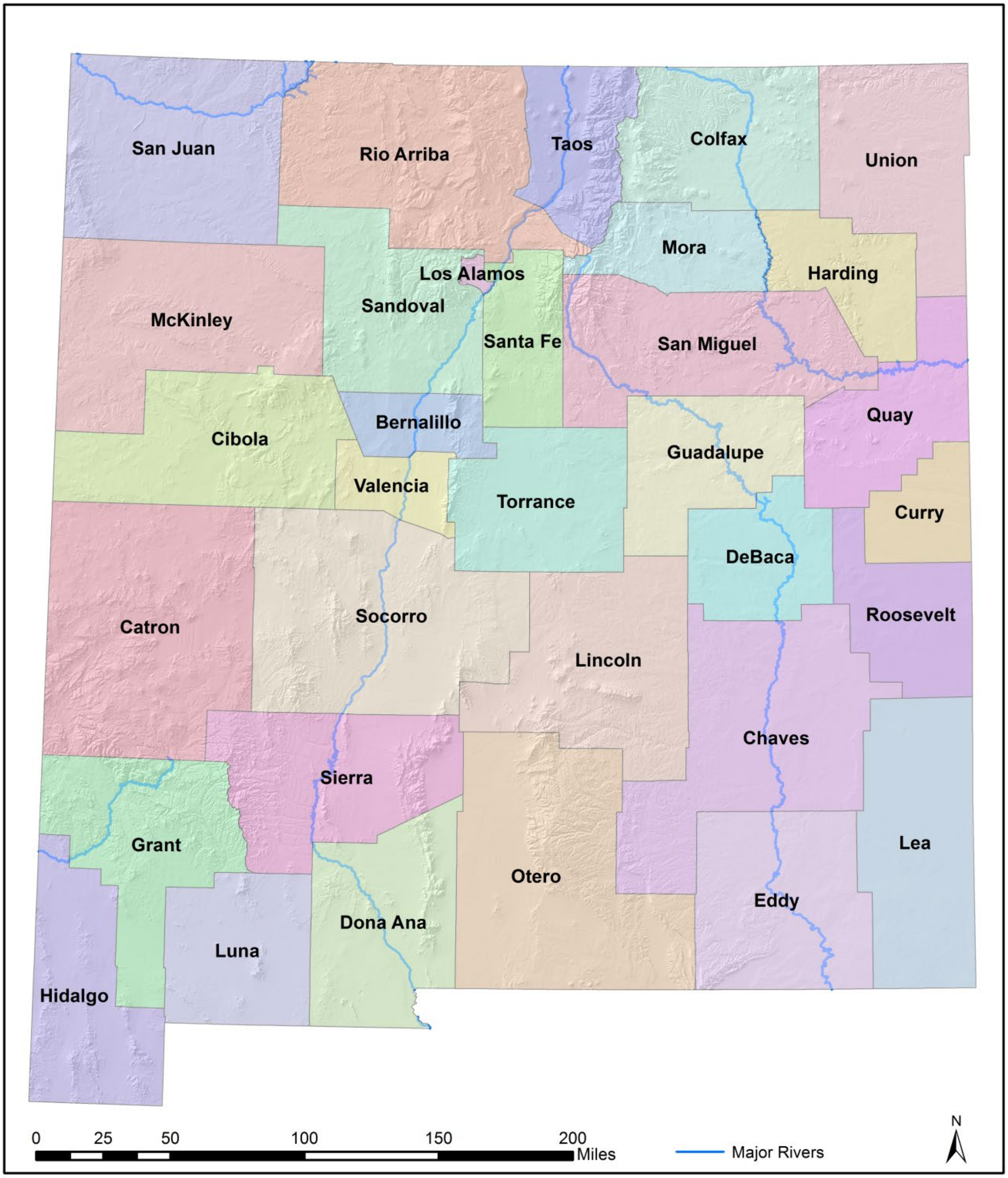

Figure 6. The 33 counties represented in the NMDSWB.

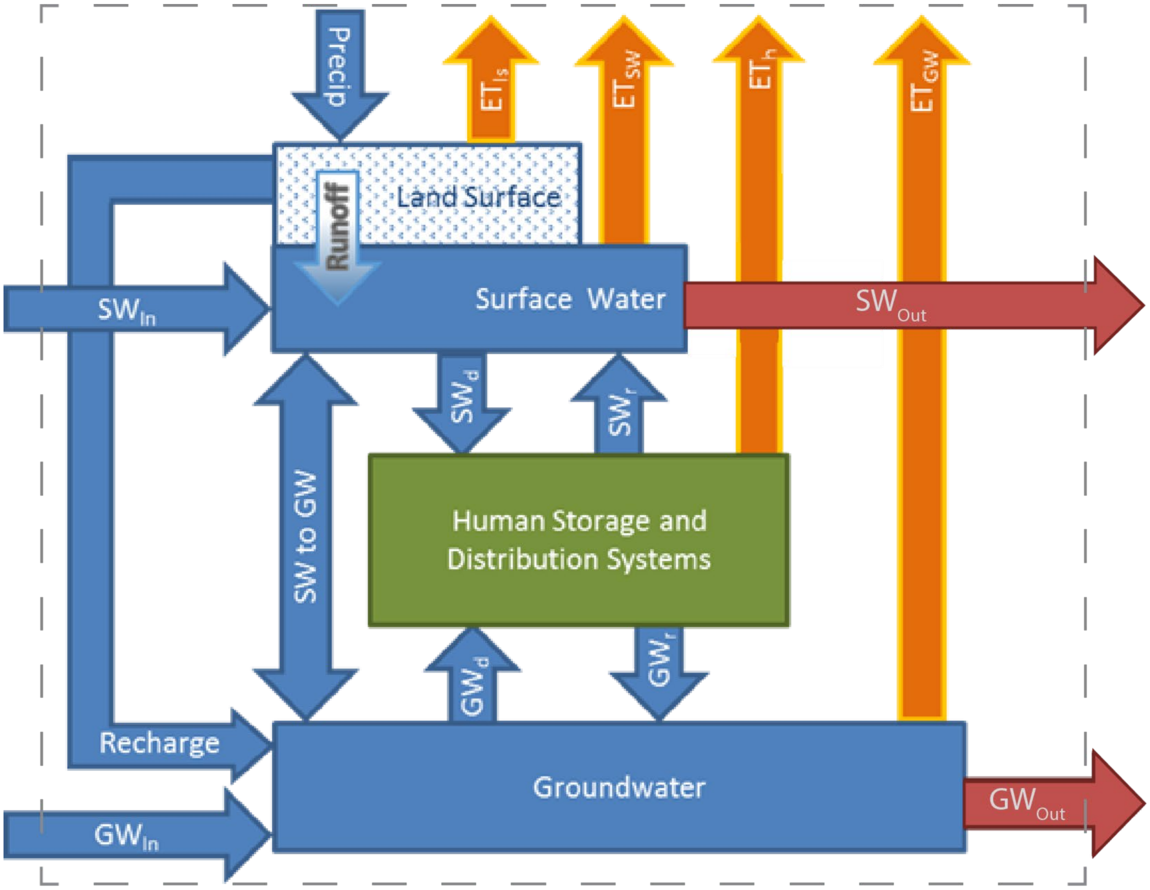

Figure 7. Conceptual water balance diagram for a given MBAU.

1.2 Future Period

While the NMDSWB model provides a detailed accounting of historical water supply and use in New Mexico, the future scenario analyses provide a way to estimate how the water budgets might change in the future. Growing evidence suggests that variables such as population growth and climate change will further exacerbate the already delicate balance between demand and supply of water resources in the western United States and in New Mexico (e.g., Llewellyn et al., 2013). Thus, this model is intended to be a potential resource for planners, policy makers, and the interested public. In its current configuration, the future period of the water budget model includes four scenario options that can be adjusted by the model user to evaluate possible future water supplies and demands. These scenario options are variable per-capita water use rates by the municipal and domestic sectors, agricultural acreage by crop type, population growth rate, and alternative climate scenarios. The per-capita water use rate option allows for a change to be made in per-capita public and domestic water use rates. An increase in per-capita use (i.e., depletion) has a corresponding increase in water withdrawn. The agricultural acreage by crop type option allows for alterations to be made to irrigated land acreage. Future estimates of population growth (UNM BBER, 2014) can also be altered, which in turn impacts the demand of public and domestic water use sectors. The four different climate change options are derived from four different General Circulation Model (GCM) runs driven by three separate global greenhouse gas (GHG) emission scenarios that will affect future hydrology, P, and temperature throughout the state (Appendix A.1). It is important to note that these GCM-based inputs do not represent specific monthly predictions of streamflow, P, or temperature, but rather a single possible scenario based on evolving climatic conditions that could be seen in the future as represented by specific GCM runs. As such, the value of the NMDSWB model is greatly diminished when looking at sub yearly water budget estimates, and users are encouraged to use this tool primarily to look at long-term trends rather than finite values when evaluating policy and planning options in the future.

Mass balance calculations for simulating future conditions are slightly different from those used in the historical period. The main difference is the connection of surface water flows from one MBAU (e.g., WPRs) to the next. During the historical period, SW_{in} / surface water outflows (SW_{out}) of a given MBAU are available from stream gage data (Section 3.2). To develop future projections, the modeled SW_{in} is projected only at the "top" of the system (e.g., the Colorado-New Mexico state line) (Appendix A.1.5). The mass balance water budget is solved for the most upstream MBAUs first, outflow from those MBAUs become the SW_{in} to the downstream MBAUs (Figure 2), and so on until the mass balance has been solved for all MBAUs.

Withdrawals of surface water for human uses are limited by the available surface water (i.e., more water cannot be withdrawn for human use than is physically available). If there is not enough water available to meet human demand, shortages are shared proportionally among all water use sectors. In the current configuration of the NMDSWB model, no attempts have been made to account for water rights, priorities, or downstream delivery requirements. The NMDSWB model does currently track compact agreements along the Rio Grande and Canadian rivers within New Mexico (Appendix A.2.20 and A.2.10); however, work still needs to be completed to incorporate compact agreements for the San Juan and Pecos river basins.

1.3 Scenarios

1.3.1 Climate Model

Future climate model-based inputs (P, temperature, and state line SW_{in}) are based on modeled outputs from one of four downscaled GCM runs, representing a range of low (one B1 GCM run), medium (one A1b GCM run), and high (two A2 GCM runs) GHG emissions and resulting modeled climate impacts (Table 1). Data from the two A2 scenarios have been dynamically downscaled in New Mexico, making these runs suitable for use by other researchers involved in the Statewide Water Assessment (e.g., Ketchum et al., 2015; Rinehart et al., 2016), and thus a natural choice for inclusion in the NMDSWB scenario options. In addition to these two high-emission scenario runs, two additional runs were included to capture low and medium GHG emission scenarios, which increases the range of potential temperature, P, and streamflow estimates. These two models were specifically selected based on the average New Mexico-specific temperature and P changes predicted by each GCM in three future periods compared to the entire suite of available GCM runs. The GCM models and corresponding emission scenarios were selected represent as a wide range of potential climate change futures as possible while limiting model input to increase model speed and usability. For more detail on how these specific models were selected, see Appendix A.1.2.

Each GCM run is used to provide the *P*, modeled streamflow, and temperature data for the NMDSWB model. *P* data drives the *P* input to the model. Streamflows that either enter the New Mexico state line area or originate within a county are flux term input to the NMDSWB model. Temperature data drives reference ET and, thus, reservoir, surface water, riparian, and agricultural ET estimates. For more information on generation of NMDSWB inputs from GCM output, see Appendix A.1.

Table 1. Climate model options for the future portion of the NMDSWB model.

GCM	Source	Emissions Scenario
UKMO	United Kingdom Met Office (UKMO HadCM3)	Moderate (A1b)
GFDL*	Geophysical Fluid Dynamics Laboratory (GFDL CM2.0)	High (A2)
MPIM*	Max Planck Institute for Meteorology (MPI ECHAM5)	High (A2)
NCAR	National Center for Atmospheric Research (NCAR CCSM3.0)	Low (B1)

* Dynamically downscaled GCM (Hostetler, Alder, and Allan, 2011)

1.3.2 Population

The population scenario option alters the 2010–2040 estimated population change rate (UNM BBER, 2014) from -20% to 20% of default. For example, a default population growth rate of 2% per year can be adjusted between 1.6% and 2.4% per year by the model user. No population growth rate projections are available beyond 2040, so the 2040 estimated growth rate is used for 2041–2099. Since domestic and public water use are directly related to population size, changes in population will affect total human water use in those sectors.

1.3.3 Per-capita Water Use Rates

The per-capita water use scenario option of the model allows the model user the ability to change the daily per-capita water use for both self-supplied domestic and public water use by plus or minus 20% from the 2010 based default (Longworth et al., 2013). The per-capita use rate determines the total depletions per person in a given MBAU. For example, a 20% increase of per-capita water use of 100 gallons per person per day with withdrawals of 150 gallons per person per day (50 gallons per person per day return flow), would result in depletions of 120 gallons per day. The total per capita withdrawals increase proportionally by 20% to meet the increased depletion of 20 gallons per person per day resulting in withdrawals of 180 gallons per person per day (60 gallons per person per day return flow).

1.3.4 Agricultural Acreage by Crop Type

Agricultural depletion calculations are based on the estimated consumptive irrigation requirements (CIRs) (Section 4.2.4). During the scenario period, users have the option to adjust agricultural acreage by crop type. In the NMDSWB, the model crops are aggregated into four groups: grains, alfalfa and pasture, fruits and vegetables, and tree orchards (Section 4.2.4). The irrigated acreage option allows users to manipulate the acreage of a given crop type by plus or minus 25%. The acreage of each crop type can be manipulated interdependently, effectively allowing the user to manipulate total acreage and the crop mix ratio. An increase in agricultural area will result in more water being withdrawn to meet the increase in CIR, however the degree of change will be specific for each individual crop type.

1.4 Spatial Scales

The NMDSWB model calculates mass balances for MBAUs at four different spatial scales: county, WPR, river basin, and statewide.

1.4.1 County Scale

As the smallest spatial scale in the NMDSWB, the county-level mass balance is a building block for other scales. At the county level, all of the fluxes and stocks seen in Figure 7 are independently calculated and are not derived from values at a larger spatial resolution (e.g., WPRs). Descriptions of how individual fluxes and stocks are calculated are presented in Sections 2 through 5.

1.4.2 Water Planning Region Scale

There are 16 WPRs in New Mexico delineated by a combination of political and hydrologic boundaries (NMISC, 1994). Where the WPR boundaries closely match county boundaries, the flux and storage values for the WPR are summed from the associated county values. For WPRs based more closely on hydrologic boundaries, summing or splitting county-level data across these boundaries was complicated by data limitations, so flux and storage values are calculated independently following the methodology used at the county level. Table 2 shows which WPRs mass balance terms were derived by summing county results and which terms were derived independently.

Table 2. Calculation methods of WPR mass balance values.

Water Planning Region	Counties Summed or Independent Calculations
1-Northeast	Curry, Harding, Quay, Roosevelt, Union
2-San Juan	Independent
3-Jemez y Sangre	Independent
4-Southwest	Catron, Grant, Hidalgo, Luna
5-Tularosa-Sacramento-Salt	Independent
6-Northwest	Independent
7-Taos	Taos
8-Mora-San Miguel-Guadalupe	Guadalupe, Mora, San Miguel
9-Colfax	Colfax
10-Lower Pecos Valley	Independent
11-Lower Rio Grande	Dona Ana

12-Middle Rio Grande	Bernalillo, Sandoval, Valencia
13-Estancia	Independent
14-Rio Chama	Independent
15-Socorro-Sierra	Sierra, Socorro
16-Lea	Lea

1.4.3 River Basin Scale

The methodology for calculating the river basin mass balance values has been updated from previous efforts to provide consistency at all spatial resolutions, including statewide values (Peterson et al., 2016; Peterson et al., 2015). The seven major river basins closely match and include most of the WPRs in the state; however, there are still WPRs that have watersheds in as many as three separate river basins (Figure 8). At the river basin level, the flux values for P, SW_{in} and SW_{out}, groundwater ET (ET_{gw}), and ET_{ls} are solved independently using the methodology used at the county-level scale. All human use terms (SW_d, SW_r, GW_d, GW_r, and ET_h) (Figure 7) at the river basin level are derived from county-level values (see Section 4.2). The remaining flux terms at the river basin scale are runoff (RO), $SW \Leftrightarrow GW$, recharge (R), and ET_{sw}. These values are aggregated from WPR-level data. Aggregating river basin values from counties or WPRs results in statewide values that are consistent when summing across any scale. For more information on how these values are calculated at the river basin level, see Sections 4.1.1 (RO), 4.1.2 (R), 4.1.3 ($SW \Leftrightarrow GW$), and 5.2.2 (ET_{sw}).

1.4.4 Statewide Scale

All estimates made at the statewide scale are aggregated from the river basin scale. Minor differences in statewide values result when aggregating WPRs and/or counties due to slight differences in boundary definitions and rounding errors; however, these differences are very small and are considered to be negligible.

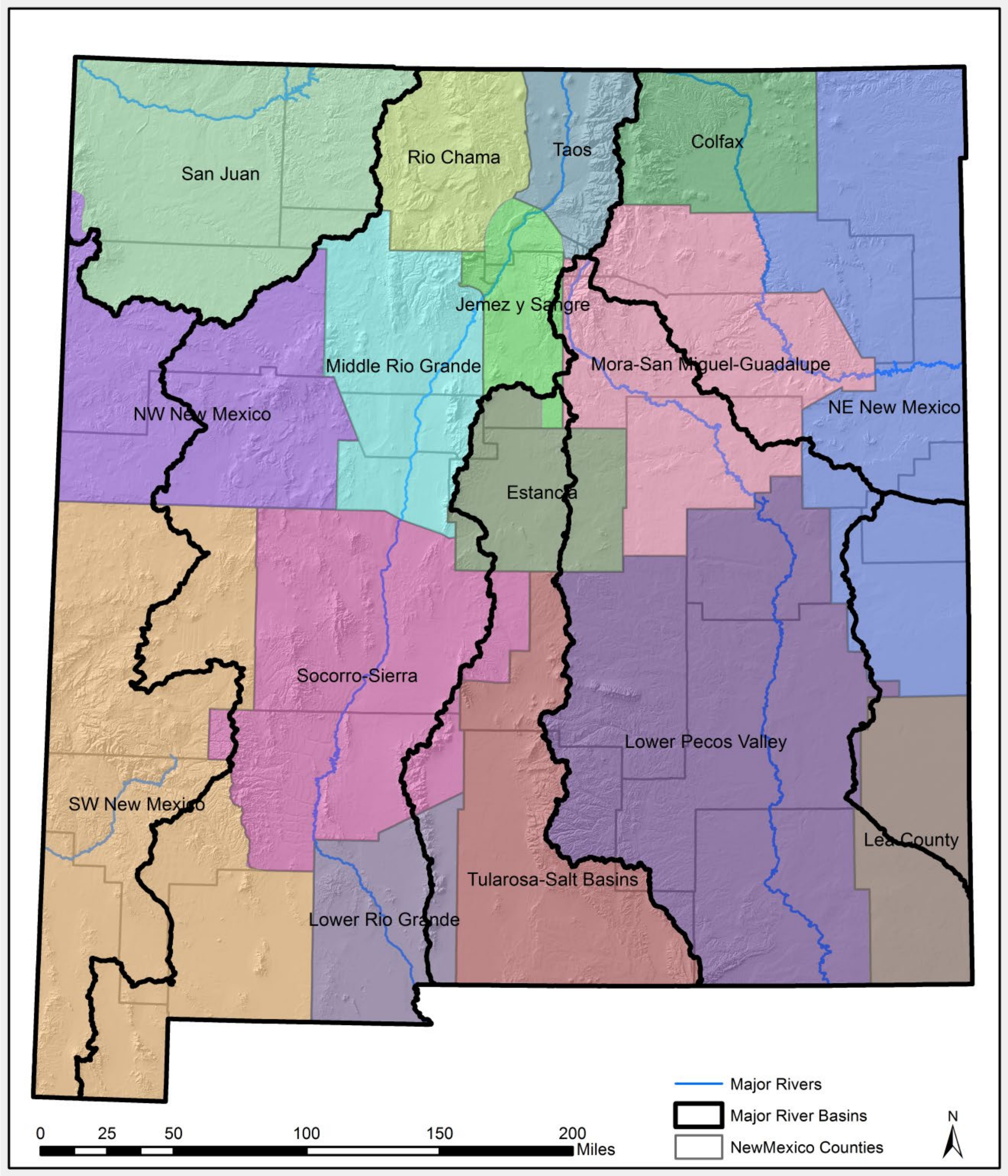

Figure 8. River basin, WPR, and county boundaries.

2 Stocks

In the terminology of system dynamics modeling, 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 certain location or water-bearing unit. The stocks of water in the NMDSWB are represented by the rectangular blocks in Figure 7 and include water stored in soil near the land surface, surface water bodies, human storage and distribution systems (HSDSs), and in groundwater aquifers. These stocks are each described in more detail below.

2.1 Land Surface Stock

For the purposes of the NMDSWB, the water in the land surface system consists of moisture stored in nonsaturated soils or geologic formations (the vadose zone), in vegetation, or in any other surface water source that cannot be practicably diverted for human use. The total water stored in this stock is a small volume of water compared to other stocks, is difficult to measure at large scales, and changes rapidly over short time periods. Because of these challenges, the NMDSWB does not calculate land surface water storage, and change in storage through time is set to zero for all timesteps. Thus, the land surface stock for purposes of this conceptual mass balance is a construct that allows P to be partitioned into R, ET, and RO at each timestep. RO is a closure term in the surface water stock as described in Section 4.1.1 and P is data driven, so ET_{ls} is calculated as the difference between these terms (Equation 1). The simplifying assumption of zero storage change through time in the land surface stock could be revisited in the future based on recent estimates of root zone soil moisture storage change (e.g., Ketchum et al., 2015) or remotely sensed estimates of large-scale soil moisture change.

$$ET_{ls} = P - RO - R \qquad \text{(Equation 1)}$$

Where:

ET_{ls} = ET from the land surface stock (Section 5.2.1)

P = Precipitation (Section 3.1)

RO = Runoff from the land surface to the surface water stock (Section 4.1.1)

R = Recharge (Section 4.1.2)

2.2 Surface Water Stock

In theory, the surface water stock represents the total amount of water in rivers, natural lakes (as opposed to reservoirs), and other natural waterways that could be diverted or impounded for human use. In practice and according to the methodology used in the NMDSWB, this total includes only surface water downstream of at least one stream gage as these gages define the quantity of all surface water in the model. Available water comes from streamflows across the boundaries of the MBAU in question, from RO to streams and rivers from rainfall, and from groundwater discharge (i.e., baseflow) within the MBAU. Because the volume of water stored in surface waterways (natural rivers, streams, and tributaries) is relatively constant and constitutes a small fraction of the state's total water inventory, the actual storage of water in this stock is not calculated and storage change through time is assumed to be zero. As with the land surface stock, this simplifying assumption means that fluxes into and out of the surface water stock are balanced at each timestep. Equation 2 shows this balance arranged such that the terms on the right side of the equal sign are solved based on data or data-based calculations, and the terms on the left side of the equal sign are solved subsequently to close the mass balance.

$$RO - SW \Leftrightarrow GW = SW_{in} - SW_{out} - SW_d + SW_r - ET_{sw} \qquad \text{(Equation 2)}$$

Where:

RO = Runoff (Section 3.2)

$SW \Leftrightarrow GW$ = Surface water-groundwater interaction (Section 4.1.3)

SW_{in} = Surface water inflow (Section 3.2)

SW_{out} = Surface water outflow (Section 5.3)

SW_d = Surface water diversions to human use (Section 4.2)

SW_r = Surface water returns from human use (Section 4.2.9)

ET_{sw} = Directly modeled ET from surface water system (Section 5.2.2)

2.3 Human Storage and Distribution System Stock

The HSDS stock conceptually represents water at any given time residing in man-made storage impoundments or distribution systems such as public water supplies, irrigation canals, and human-operated reservoirs. Because the net of human diversions, depletions, and returns sum to zero at every timestep, storage change in the HSDS stock only accounts for storage change within man made reservoirs. The HSDS storage change is calculated as the difference between inflows (diversions from surface water, P, and gains from groundwater) and outflows (returns to surface water, ET, and groundwater leakage) (Equation 3). For purposes of this mass balance, when water is added to a reservoir, it is considered a diversion of surface water to the HSDS, and when it is released, it is considered a return to the surface water system.

$$\Delta HSDS = \left(SW_d + GW_g + P_r\right) - \left(SW_r + GW_l + ET_h\right) \qquad \text{(Equation 3)}$$

Where:

$\Delta HSDS$ = HSDS storage change in a given period of time

SW_d= Surface water diversions to human use (Section 4.2)

GW_g= Groundwater gains (Section 2.3.1)

P_r = Precipitation falling directly into reservoirs (Section 2.3.1)

SW_r = Surface water returns from human use (Section 4.2.9)

GW_l= Groundwater leakage (reservoir water being lost to groundwater) (Section 2.3.1)

ET_h = Reservoir evaporation (Section 5.2.5)

2.3.1 Reservoirs

There are 19 reservoirs modeled in the NMDSWB (Appendix A.2). These reservoirs are significant to the hydrology of a given MBAU and historical operations data are available. Several small reservoirs in New Mexico are used primarily for public water supplies not included in the NMDSWB because of sparse or unavailable data such as Blue Water Lake in Cibola County and Black Rock Reservoir in McKinley County.

Each reservoir is modeled with a consistent framework, as described in this section. For detailed descriptions of individual reservoirs, including inflows, outflows, calibrations, sources of data, and reservoir rules used to drive future operations, refer to Appendix A.2. Each reservoir has SW_{in} and SW_{out} (releases). Flow data is most often provided by a U.S. Geological Survey (USGS) stream gage (USGS, 2015), although in some instances, inflows or outflows are obtained directly from the reservoir operator, often the United States Bureau of Reclamation (USBR) or the United States Army Corps of Engineers (USACE). In cases in which measured data are not available, modeled estimates are used.

P inflow to reservoirs is estimated from monthly PRISM (Prism Climate Group, 2018) P or from observed P data collected at a given reservoir. The P depth at a given timestep is multiplied by the reservoir surface area to determine P volume. Reservoir surface area is determined as a function of modeled reservoir volume from area-capacity look up tables specific to each reservoir.

Evaporation from the reservoirs is calculated from reservoir-specific pan evaporation data when and where it is available (URGWOM Technical Team, 2015) or using Hargreaves-Samani reference ET (Hargreaves and Samani, 1985) (Section 5.1.1). Pan evaporation is multiplied by a pan coefficient of 0.7 (URGWOM Technical Team, 2015), while the Hargreaves-Samani reference ET is multiplied by a monthly open water evaporation coefficient (Appendix A.4) (Roach, 2012). The resulting evaporation depth from either method is multiplied by the surface area of the reservoir.

In addition to the modeled inflows and outflows of the reservoir, there are additional unknown gains and losses and model error, which together account for the difference between observed storage change and modeled storage change during the historical period. To limit errors associated with modeled reservoir storage diverging from historical values, an error term is added to each reservoir during the historical period to force modeled reservoir storage at each timestep to be equal to observed storage. The reservoir is calibrated by adding a modeled inflow or leakage term so the cumulative net sum of the error term is approximately 0 kilo acre-feet (KAF) over the historical calibration period of 1975–2010. No error terms are applied to reservoirs during the future scenario period. Positive errors and modeled inflows are counted as surface water diversions (SW_d) in the HSDS stock. Negative errors and modeled losses are counted as returns from HSDS to either the surface water or groundwater stock, as determined on a reservoir-by-reservoir basis (Appendix A.2).

In the historical portion of the model, reservoir operations and behavior are entirely data driven. To model future projections, model reservoir rules are created to simulate reservoir operations. Factors such as flood control, available water, target storage, downstream demands, and compact agreements must be taken into consideration. Reservoir rules that control the operations of each individual reservoir are described in Appendix A.2.

2.4 Groundwater Storage Stock

The groundwater stock in the NMDSWB conceptually represents all water below the water table (saturated soil and rock). Total groundwater storage for the state of New Mexico is not known for most groundwater basins. For most major aquifers, however, estimates of groundwater storage change through time have been developed (Rinehart et al., 2015, 2016). Consistent with the availability of this information, the NMDSWB does not currently calculate total groundwater storage, but instead estimates groundwater storage change through time for each MBAU. Where groundwater storage change estimates are available, they are used in the NMDSWB as a calibration reference (Section 4.1.3 and Appendix A.6). Equation 4 illustrates how groundwater storage changes are calculated

$$\Delta GW = GW_i + \sum_i^n [(GW_{in} + R + GW_r) - (SW \Leftrightarrow GW + GW_d + ET_{gw} + GW_{out})] \text{ (Equation 4)}$$

Where:

ΔGW = Groundwater storage change (Section 2.4)

i = Time index for simulation

n = Number of timesteps in simulation

GW_i = Initial groundwater storage

GW_{in} = Groundwater flow into the MBAU (assumed zero) (Section 3.3)

R = Groundwater recharge (Section 4.1.2)

GW_r= Groundwater return flows (from human use) (Section 4.2)

$SW \Leftrightarrow GW$ = Surface water-groundwater interaction (Section 4.1.3)

GW_d = Groundwater diversions (to human use) (Section 4.2)

ET_{gw} = Groundwater evapotranspiration (Section 5.2.5)

GW_{out} = Groundwater outflows from the MBAU (assumed zero)

Groundwater storage change is reset to zero in 2015 at the start of the future scenario period to ease the direct comparison of the effects of different future scenarios on groundwater storage change (Section 5.4).

3 Inflows

3.1 Precipitation

The *P* (and temperature) data used in the historical NMDSWB scenario are from the Parameter-Elevation Relationship on Independent Slopes Model (PRISM) (PRISM, 2018). The PRISM data used include the monthly *P* totals for the PRISM-defined "historical past" years of 1971–1980 and the "recent years" of 1981–2013, as well as the daily *P* totals for 2014–2015 (PRISM 2018). The 1971–1980 and 1981–2013 *P* estimates in the NMDSWB are derived from the monthly 4x4-kilometer resolution PRISM product, and the 2014–2015 *P* estimates are derived from the daily 800x800-meter resolution PRISM product aggregated to monthly (PRISM 2018). The monthly *P* volume by county, WPR, or river basin is calculated from the mean depth of *P* at a given MBAU level in a given month multiplied by the area of the MBAU. PRISM-based statewide annual *P* and the 10-yr moving average volumes through time are shown in Figure 9 (PRISM ,2018). It is worth noting that the ten-year gaps in Figure 9B from 1975–1985 for the historical *P* data and from 2015–2025 for the future *P* data is due to the fact that it takes ten years to produce a 10-yr average.

Precipitation for modeling future projections is estimated from one of four potential climate models (Section 1.3.1; Appendix A.1). These four *P* estimates were clipped by each MBAU in the model to gain a total *P* depth for each MBAU for each month. The mean monthly depth over the given MBAU was multiplied by the area of the given MBAU to calculate a monthly *P* volume. Future statewide annual *P* volumes for two climate models and the 10-yr moving average *P* volumes for all four climate models through time are shown in Figure 9. There is considerable variability between climate models on what GHG emissions will mean for *P* in New Mexico (e.g., Llewellyn et al., 2013), and so it is not surprising that future *P* scenarios for the four models considered significantly overlap (Figure 9).

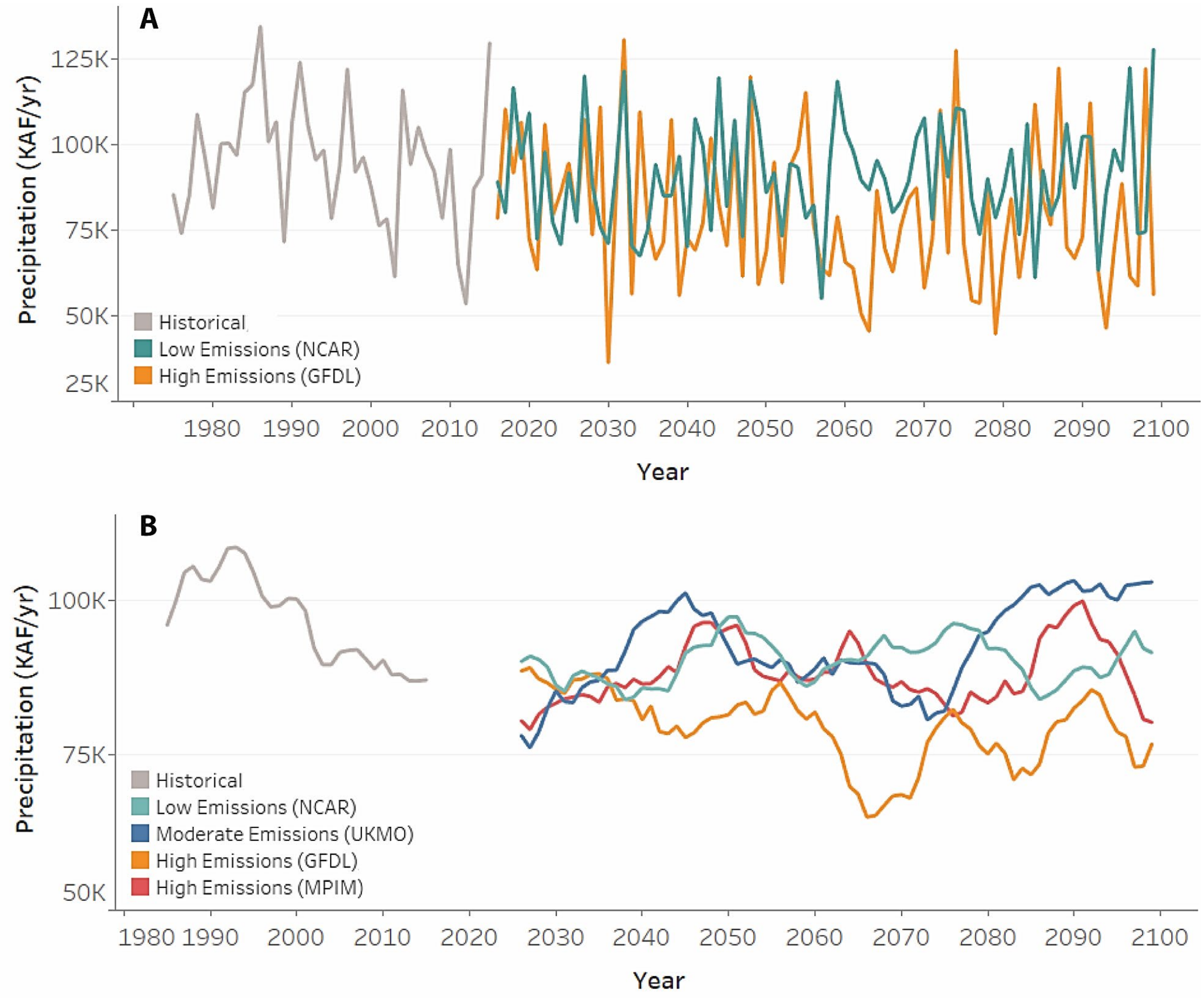

Figure 9. A) Annual statewide *P* estimates for the 1975–2015 historical period (PRISM 2018) and two climate models. B) Statewide *P* estimates shown as 10-yr moving averages for the 1975–2015 historical period (PRISM 2018) and all four climate models.

3.2 Surface Water Inflows

SW_{in} into a given MBAU in the NMDSWB consist of flows that cross its boundary. Thus, MBAUs that occur at the headwaters of a river (e.g., the Pecos and Central Closed river basins) do not have any SW_{in}. Where SW_{in} do occur, available USGS stream gages are used to represent inflow. Surface water gages used in the NMDSWB were selected based on their locations and periods of record. When a stream gage is not available near a county, WPR, or river basin boundary, streamflow is estimated from nearby stream gages (based on drainage area) or correlated to inactive stream gages (through linear relationships), which represent closer proximity to a given boundary. In counties such as Bernalillo, Sandoval, and Valencia (Middle Rio Grande WPR), a significant portion of surface water flows across county lines into irrigation canals and drainage ditches. Flow data for these irrigation diversions are used when available

(URGWOM Technical Team, 2015) or estimated when not available. Detailed information on SW_{in} by county, WPR, and river basin is provided in Appendix A.6.

Table 3. Future county inflows.

County	County Inflow(s)	Non-county Inflow(s)
Bernalillo	Sandoval	
Catron	No Inflow	
Chaves	De Baca, Lincoln	
Cibola	McKinley	
Colfax	No Inflow	
Curry	No Inflow	
De Baca	Guadalupe	
Dona Ana	Sierra	
Eddy	Chaves	DELAWARE RIVER NEAR RED BLUFF
Grant	Catron	
Guadalupe	San Miguel	
Harding	No Inflow	
Hidalgo	No Inflow	
Lea	No Inflow	
Lincoln	Otero	
Los Alamos	No Inflow	
Luna	Grant	
McKinley	No Inflow	
Mora	Colfax	
Otero	No Inflow	
Quay	Harding, San Miguel	
Rio Arriba	Taos	RIO CHAMA NEAR LA PUENTE, AZOTEA TUNNEL AT OUTLET NEAR RIO CHAMA
Roosevelt	No Inflow	
Sandoval	McKinley, Santa Fe	JEMEZ RIVER NEAR JEMEZ
San Juan		LOS PINOS RIVER AT LA BOCA, SAN JUAN RIVER NEAR CARRACAS, PIEDRA RIVER NEAR ARBOLES, ANIMAS RIVER NEAR CEDAR HILL, LA PLATA RIVER AT CO-NM STATE LINE, MANCOS RIVER NEAR TOWAOC
San Miguel	Mora	
Santa Fe	Rio Arriba	
Sierra	Socorro	
Socorro	Valencia	
Taos		RIO GRANDE NEAR LOBATOS
Torrance	No Inflow	
Union	No Inflow	
Valencia	Bernalillo, Cibola	

Projections of future MBAU SW_{in} depend on geographic location. Inflows for boundary conditions where flows originate outside of the state (e.g., the Rio Grande at Lobatos, Colorado) are estimated based on climate forecasts. More detailed information on how these flows are estimated is presented in Section 8.2A.1.5. Remaining MBAU SW_{in} is equal to the output or partial output (in instances of multiple river systems) of upstream MBAUs (Table 3).

3.3 Groundwater Inflows

As used in the NMDSWB, groundwater inflow (GW_{in}) from a given MBAU is groundwater flowing into MBAU boundaries. For purposes of the NMDSWB, basin scale groundwater divides are assumed to be the same as surface water divides. In other words, there is no groundwater flow between major river basins within New Mexico. Although GW_{in} into a given MBAU might occur, they are largely unquantified. Groundwater flow across a given boundary, especially a political boundary, cannot be directly measured and must be calculated based on observed groundwater gradients and inferred geologic information, or extracted from regional groundwater models based on that information. In the NMDSWB, groundwater flows between basins are largely unknown and assumed to be zero at all spatial scales for changes in groundwater storage to be calculated. While this assumption is reasonable at the river basin scale, it becomes less appropriate at WPR and especially county-level spatial scales. Although these flows are minor, especially when compared to surface water flows and groundwater withdrawals, it is important to recognize that these GW_{in} do exist. As NMDSWB model development continues, some attempt to estimate groundwater flows across WPR and county boundaries should be considered, particularly in areas in which important aquifers extend across MBAU boundaries.

4 Water Movement between Stocks

The NMDSWB conceptual mass balance includes seven fluxes of water between the four represented stocks (Figure 1). These include RO (land surface stock to surface water stock), R (land surface stock to groundwater stock), surface water-groundwater interaction ($SW \Leftrightarrow GW$) (surface water stock to groundwater stock and vice versa), and four fluxes representing human use (diversions from the surface water and groundwater stocks to the HSDS stock, and returns from the HSDS stock to the surface water and groundwater stocks). These fluxes are internal to each MBAU and are either incorporated into the NMDSWB based on actual data, calculated based on other relevant data, or calculated to close the water balance for a modeled stock. This section discusses methods of quantifying water movements internal to each MBAU.

4.1 Surface Water System Closure Terms

Within the surface water stock, the inflows (SW_{in}, surface water returns [SW_r]) and SW_{out}, SW_d, and ET_{sw}) are known (data-based) terms. RO and $SW \Leftrightarrow GW$ are unknown terms. The RO (Section 4.1.1) and $SW \Leftrightarrow GW$ (Section 4.1.3) fluxes are estimated as closure terms to maintain mass balance (Equation 2, Section 2.2).

When the data-based outflows are greater than data-based inflows in a given timestep, and additional water (surface water deficit, negative balance on right side of Equation 2) is needed to satisfy Equation 2, water is added as RO and baseflow (a negative value of $SW \Leftrightarrow GW$, representing the movement from groundwater to surface water). Alternatively, when the data-based inflows are greater than the data-based outflows, and less water (surface water surplus (SW_s), positive balance on the right side of Equation 2) is needed to satisfy Equation 2, water is removed from the surface water system as a closure term in the form of $SW \Leftrightarrow GW$ (losses from the river system into the groundwater system). For MBAUs with available estimates of groundwater storage change, the $SW \Leftrightarrow GW$ flux is calibrated. The calibration of the $SW \Leftrightarrow GW$ flux and groundwater storage change estimates is discussed in greater detail in Section 4.1.3. At the state level the RO is a sizeable component of the surface water system and equates to approximately 75% of the total SW_{in} flux but is less than 2% of the total P. The associated uncertainty (Section 0) on the RO term is nearly double that of the SW_{in} flux, which is to be expected based on the methodology used to calculate RO. The $SW \Leftrightarrow GW$ term represents an even smaller portion of the surface water system at less t han 20% of the SW_{in} flux and less than 0.5% of P.

In modeling future conditions, SW_{out} is the only calculated closure term. RO, R, and $SW \Leftrightarrow GW$ fluxes are all calculated based on ratios determined in the historical accounting model, and outflow is the only unknown term remaining to be solved in Equation 2.

4.1.1 Runoff

Runoff consists of water from P within a given MBAU that passes through the land surface stock and into the surface water system in the same MBAU, without moving through the groundwater system. Inflows from upstream MBAUs are counted as SW_{in} and not RO. Runoff for each MBAU in the NMDSWB is calculated as part of a closure term from the surface water system.

At timesteps at which the data-based outflows from the surface water system (SW_{out}, SW_d to the HSDS, and directly modeled ET_{sw}) are greater than data-based inflows to the surface water system (SW_{in} and SW_r flows from HSDS), the water needed to balance the system is added from internal *RO* (i.e., *RO* that originates within the MBAU) and baseflow.

Baseflow is part of the $SW \Leftrightarrow GW$ flux as described in Section 4.1.3. Baseflow is water that drains from the groundwater stock into the surface water stock and is represented in the model as a negative $SW \Leftrightarrow GW$ flux. The relative proportion of runoff and baseflow are determined using the USGS baseflow index (BFI) grid (Wolock, 2003) for each respective county or WPR. While *RO* varies temporally based on *P*, baseflow is moderated through the groundwater system and responds more slowly to *P* and snowmelt events. To capture this modulation, baseflow is calculated as the BFI multiplied by a running 10-yr average of the water needed to balance the system. Internal *RO* is then calculated as whatever remaining inflows are needed to satisfy Equation 2 (Section 2.2) for each timestep. For example, the BFI for Taos WPR (and Taos County) is 67.4%, meaning that over the long-term, an average of 67.4% of surface water gains between gages comes from baseflow. Thus, at each timestep, baseflow is equal to 67.4% of the 10-yr average of water gains needed to balance the surface water system and is added to the Taos WPR surface water stock. Additional water needed (if any) to close the mass balance for that timestep is attributed to internal *RO*. The BFI for each county and WPR is presented in Appendix A.8 on Table 25 and Table 26, respectively.

To maintain consistent values at the river basin scale, only the net value of $SW \Leftrightarrow GW$, which is based on aggregation from WPR baseflow values, is calculated (Section 4.1.3). Similarly, *RO* at the river basin level is scaled from *RO* at the WPR level. Because some WPRs are located within multiple river basins, *P* is used to divide WPR-based *RO* across river basins. Since *RO* is roughly proportional to *P*, the 30-yr (1981–2010) PRISM (2018) normal *P* dataset is used to determine the average percentage of WPR *P* volume within each river basin. For example, the Lower Rio Grande WPR (Dona Ana County) is primarily located in the Rio Grande river basin; however, the eastern portion of the county on the other side of the Organ Mountains is located in the Central Closed River basin. According to the gridded PRISM (2018) data, historically, 79% of the *P* within the Lower Rio Grande WRP fell in the Rio Grande river basin and 21% of the *P* fell in the eastern portion located in the Central Closed River basin. Thus 79% of the *RO* in the Lower Rio Grande WPR is attributed to the Rio Grande river basin and 21% of the *RO* to the Central Closed River basin.

To model future scenarios, *RO* is calculated as a percentage of *P* based on historical monthly ratios of *P* and calculated *RO* from 1975–2010 (Table 27).

Runoff in WPRs that consist of multiple counties is calculated as the sum of *RO* in those counties. Runoff for independently calculated WPRs is calculated in two parts. The first part uses the historical *P*-to-*RO* method as a base for the *RO* for the WPR to keep the calculations relatively consistent across the spatial extents in the future period. If there is a surface water surplus for a given independently calculated WPR after the historical *P*-to-*RO* based *RO* has been accounted for, additional *RO* is added to balance the system. Baseflow calculations are projected into the future using the same 10-yr running average as described earlier. River basin

RO is calculated as the product of WPR runoff and the percentage of WPR P that is located within a given river basin.

4.1.2 Recharge

Recharge in the NMDSWB is P that moves through the land surface and infiltrates into the underlying groundwater system. Recharge is calculated by assuming that, without human diversions and returns, the groundwater system would be in steady-state. Additionally, it is assumed that under steady-state conditions, $SW \Leftrightarrow GW$ is dominated by baseflow. Under this assumption, nonanthropogenic inflows (GW_{in} from another MBAU and R) are equal to nonhuman-related outflows (groundwater outflows [GW_{out}] to another MBAU, ET_{gw}, and baseflow). For each county and WPR at each timestep, R is set equal to the portion of the surface water system deficit (negative balance on the right side of Equation 2) at a given timestep not coming from RO (Wolock, 2003) plus ET_{gw} and GW_{out} (assumed to be zero) minus GW_{in} (assumed to be zero) (Equation 5). In the conceptual framework of the NMDSWB, irrigation seepage back to groundwater is counted not as R, but as either a groundwater return (GW_r) or $SW \Leftrightarrow GW$, depending on the nature of the irrigation system (Section 4.2.9).

$$R = SW_s \cdot \mathrm{BFI} + ET_{gw} + 0 \cdot GW_{out} - 0 \cdot GW_{in} \qquad \text{(Equation 5)}$$

Where:

R = Recharge (monthly timestep)

SW_s = Surface water surplus (positive balance on the right side of Equation 2)

BFI = Baseflow index

ET_{gw} = Groundwater evapotranspiration

GW_{out} = Groundwater outflow to adjacent MBAUs (assumed to be zero) (Section 5.4)

GW_{in} = Groundwater inflow from adjacent MBAUs (assumed to be zero) (Section 3.3)

The assumption that R is equal to baseflow plus ET_{gw} less net GW_{in} (assumed to be zero), and the assumption that nonhuman-related groundwater fluxes are in balance should be considered in future iterations of the model. Current assumptions provide the NMDSWB with a self-consistent way to estimate R, which results in state-level mass balance terms (especially groundwater storage change) that are reasonable, but, as will be seen, produce some results that are not intuitively satisfying. The assumptions are in principle less valid in regions of greater groundwater pumping, where connectivity between groundwater and surface water systems have been greatly altered, as well as in portions of the state that do not have any perennial surface water system. As part of the Statewide Water Assessment, a group of researchers are working to develop a statewide R and RO model that, in the future, will improve the accuracy of both RO and R estimates within the NMDSWB for all MBAUs (Ketchum et al., 2015).

R at the river basin level is scaled up from R at the WPR level. Because some WPRs are divided across river basins, average P patterns are used to divide WPR-based RO across river basins as described in Section 4.1.1.

To model future scenarios, R at all spatial scales is calculated as a percentage of P. The percentage of P as R is calibrated for each MBAU in the historical period of the model. P in the future is multiplied by this ratio to acquire the total R for each county, WPR, and river basin. While this is a valid approach in most locations, R in some groundwater basins such as the Hatch and Mesilla valleys increase as a result of declining water tables. That issue will be addressed in future model iterations.

4.1.3 Surface Water-Groundwater Interaction

Surface water-groundwater interaction consists of two components, baseflow and surface water losses to the groundwater system. A negative $SW \Leftrightarrow GW$ value indicates baseflow (groundwater moving to surface water), whereas a positive $SW \Leftrightarrow GW$ value indicates surface water losses to the groundwater system. Baseflow is calculated based on the BFI of each MBAU, as described in Section 4.1.1. Section 2.2 describes how data-based calculations of surplus surface water (a positive balance on the right side of Equation 2) result in removal of water from the surface water system at each timestep. In MBAUs with no published groundwater storage change estimates, this removal of water occurs entirely as a $SW \Leftrightarrow GW$ flow. The assumption is that the sum of outflows is less than the sum of inflows to the surface water stock because water is being lost from streams and rivers to the groundwater stock. In counties and independently calculated WPRs with published estimates of groundwater storage change (8.2A.6), the $SW \Leftrightarrow GW$ flux is calibrated to bring NMBDSWB estimates of groundwater storage change into line with the published estimates (Section 4.1.3.1).

At the river basin scale, all fluxes into and out of the surface water stock are aggregated from WPR-level data except for the $SW \Leftrightarrow GW$ flux. If the $SW \Leftrightarrow GW$ flux is aggregated similarly to the RO and R terms at the river basin scale, minor inconsistencies arise as a result of multiple overlapping boundaries between river basins and WPRs that result in an unbalanced surface water system. To avoid this, the river basin $SW \Leftrightarrow GW$ term is solved independently at the river basin scale as the final closure term to the surface water system. The $SW \Leftrightarrow GW$ term at the river basin scale is equal to the sum of surface water inflows (RO_{rb}, $SW_{in\,rb}$, and $SW_{r\,rb}$) minus the sum of surface water outflows ($ET_{sw\,rb}$, $SW_{d\,rb}$, and $SW_{out\,rb}$) (see Equation 6).

$$SW \Leftrightarrow GW_{rb} = (SW_{in\,rb} + RO_{rb} + SW_{r\,rb}) - (ET_{sw\,rb} + SW_{d\,rb} + SW_{out\,rb}) \quad \text{(Equation 6)}$$

where:

$SW \Leftrightarrow GW_{rb}$ = River basin surface water-groundwater interactions

$SW_{in\,rb}$ = Surface water inflows to river basin

RO_{rb} =River basin runoff

$SW_{r\,rb}$ = River basin surface water returns

$ET_{sw\,rb}$ = River basin surface water evapotranspiration

$SW_{d\,rb}$ = River basin surface water diversions

$SW_{out\,rb}$ = Surface water outflows from river basin

At the county level, the $SW \Leftrightarrow GW$ flux for counties with RO or SW_{in} is calculated in the future model period based on the historical ratio of $SW \Leftrightarrow GW$ to SW_{in} (A.10, Table 29). For counties without RO or SW_{in}, $SW \Leftrightarrow GW$ is not calculated and is assumed to be zero (Table 3, Table 30), which is consistent with historical calculations for those MBAUs. Due to the methodology used to calculate the $SW \Leftrightarrow GW$ flux, it is not possible to differentiate the individual contributions of baseflow or surface water to groundwater losses for a given MBAU at a given timestep. This method allows only for the net $SW \Leftrightarrow GW$ flux to be determined. Some MBAUs might have had positive $SW \Leftrightarrow GW$ fluxes in some timesteps and negative fluxes in others during the historical period, but in the future portion of the model, the $SW \Leftrightarrow GW$ flux for a given MBAU will be either net gaining or net losing in all timesteps.

WPR $SW \Leftrightarrow GW$ is calculated two different ways, depending on the geographical boundaries of the WPR. For WPRs calculated from counties, the term is summed from the $SW \Leftrightarrow GW$ terms of those counties, in historical and future time periods. For independently calculated WPRs, the $SW \Leftrightarrow GW$ is calculated with the same methodology as at the county level, for historical and future time periods.

River basin $SW \Leftrightarrow GW$ is calculated as a closure term using the same structure as the historical river basin closure terms (Equation 7). $SW \Leftrightarrow GW$ within each river basin is calculated as the sum of $SW_{in\,rb}$, $SW_{r\,rb}$, and RO_{rb} less the sum off $SW_{out\,rb}$, $SW_{d\,rb}$, and $ET_{sw\,rb}$.

4.1.3.1 Calibration of $SW \Leftrightarrow GW$ flux

Two time periods are used in the model for the calibration of the $SW \Leftrightarrow GW$ flux, 1975–1999 and 2000–2015. The earlier time period represents wetter climatic conditions while the later time period represents relatively drier conditions. In the majority of MBAUs with published estimates of groundwater storage change, the model initially underestimates the reduction in groundwater storage, perhaps because of an overestimate of the volume of water entering the groundwater system, either through R, $SW \Leftrightarrow GW$, or GW_r. To reduce the amount of water entering the groundwater system, a calibration constant is applied to the $SW \Leftrightarrow GW$ flux that partitions the excess water into additional ET_{sw}. As described in Section 4.1.3, a positive value of $SW \Leftrightarrow GW$ is derived from a surplus of water in the surface water system (Equation 2). In instances in which the model is returning too much water into the groundwater stock compared to the published estimates (Table 54 and Table 55), the additional water calculated as a surface water surplus is split accordingly between the default path of $SW \Leftrightarrow GW$ and additional ET_{sw}. The calibration constants for the two time periods can be seen in Appendix A.10, Table 33 and Table 34.

Conceptually, this ratio represents the portion of the SW_r that will eventually be gaged somewhere downstream. While very few return flows are immediately gaged, the assumption is that return flows that reenter the surface water system will ultimately appear downstream as additional gaged flows. The portions of the returns that do not reenter to the gaged surface water system are lost for accounting purposes and are added to NMDSWB ET_{sw}.

If regional changes in groundwater storage are available from other studies, this ratio is calibrated so that NMDSWB calculated groundwater storage change estimates reflect the value reported in these studies (Appendix A.6; Table 19). The calibration values by county and WPR can be seen in Table 33 and Table 34.

4.2 Human Diversions and Returns

Human water use data are derived mainly from the OSE water use by categories reports (e.g., Longworth et al., 2013), which are published every five years and report estimates of annual water use across nine water use sectors (Table 38) at both a county and river basin scale (the NMDSWB Central Closed River basin is part of the Rio Grande basin in these reports). Since the NMDSWB model runs on a monthly timestep, human water use from these reports is estimated through methodology consistent with the OSE to produce monthly values, as described in Sections 4.2.1 through 4.2.9.

Future human water use is calculated in the NMDSWB model from 2016 through 2099 using the same methodology as the historical period. Public and domestic water use estimates in the future are based on projected population growth rates by county (UNM BBER, 2014) and projected per-capita water use from the 2000 OSE Water Use by Categories report (Wilson and Lucero, 2003). Public and domestic water use can be adjusted up or down with the population growth and per-capita water use scenario options, as described in Section 1.3. Irrigated agricultural water use estimates in the future are based on temperature, P, and irrigated acreage by crop type projections. For a given future scenario, temperature and P projections are derived from one of four climate model options. Future irrigated acreages by crop type are held fixed from the 2015 CropScape Cropland Data Layer (USDA, 2015), which can be altered ± 25% with the agricultural acreage by crop type scenario option.

4.2.1 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 (UNM's) Bureau of Business and Economic Research (BBER) (UNM BBER, 2014). Historical population data by county are input into the model on a decadal basis, and historical growth rates are calculated (see Equation 7) using the compound rate formula shown.

$$r = \left(\frac{N_{10}}{N_0}\right)^{\frac{1}{t}} - 1 \qquad \text{(Equation 7)}$$

Where:

r = Population growth rate (/year)

t = Time (10 years)

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

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

Historical monthly populations are calculated by multiplying the county population during the previous month by the current growth rate for that time period. County growth rates are assumed to be constant during the decade between national census. 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 1981–1990 growth rate equal to the growth rate the following decade (1990–2000) yields a starting population in Cibola County of approximately 22,000 people. The population model adds 22,000 people in 1981 to an initial population of zero in Cibola County while subtracting 22,000 people from the Valencia County population. The model readjusts the calculated county population every decade to match the census data so that rounding errors in the growth model (Equation 7) are not propagated through time. Since population data is primarily available at the county level, a method was developed to transform county populations into WPR populations. This transformation uses data from the 2000 census (Alcantara and Lopez, 2003), in which 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. Historical population figures by county, WPR, and river basin used in the model from 1970 through 2010 are shown in Appendix A.12 on Table 35, Table 36, and Table 37. River basin population data are scaled up from counties similarly using county population data within a respective river basin from the 2010 OSE Water Use by Categories report (Longworth et al., 2013).

The UNM BBER (2014) population model provides population rate estimates until 2040 that are used in the historical period of the model from 2010 through 2015 and in the future scenario period. For population growth from 2041 through 2099, the model uses the 2040 growth rates, which like all future growth rates can be altered up or down by 20% with the population growth scenario option. The population model is used to determine the magnitude of many water uses (see Sections 4.2.2 through 4.2.9). The WPR and river basin populations are aggregated from the county level.

4.2.2 Water Use by Categories Data

Water use in New Mexico is estimated every five years by the New Mexico Office of the State Engineer (OSE) (Longworth et al., 2008, 2013; Sorensen, 1977; 1982; Wilson, 1986; Wilson and Lucero, 1992, 1997, 2003). The OSE's Water Use by Categories report represents an estimate of annual average water use for a specific year. Water use was presented by the OSE as withdrawals (i.e., diversions), depletions, and returns in reports up to and including 2000 and withdrawals only from 2005 forward. Withdrawals are defined as the total amount of water taken from a source to be used elsewhere, and depletions are defined as the quantity of water consumed (i.e., lost to ET and not available for use elsewhere). Return flows are the difference between withdrawals and depletions. The data are provided for each river basin and county. The NMDSWB starts with the 1975 OSE report (Sorensen, 1977). For report years from 1990 through 2010, the water use categories did not change and consisted 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 38). For more information on changes to OSE water use categories through time and depletion calculations, see Appendix A.13.

Future human surface water use at the county level is determined by calculating water demand for each water use category along with the monthly calculation of available water within a given MBAU. Surface water is considered available water for diversion for human use after reservoir operations and natural water processes (RO, ET_{sw}, and $SW \Leftrightarrow GW$; Sections 4.1.1, 5.2.2, and 4.1.3, respectively) have been calculated. If the expected withdrawals are less than the amount of available water, then the rates of withdrawals are used with no alteration. If the amount of available water is less than the expected withdrawals, then the expected withdrawals are reduced to equal the available water. Therefore, surface water withdrawals will not exceed available water in the system. Future depletions are calculated in a similar manner for each water use category and any reduction in withdrawals to available water will be reflected in the depletions. Returns are calculated as withdrawals less depletions. There are no restrictions placed on groundwater withdrawals as the total amount of groundwater storage in each basin is unknown in the NMDSWB.

Future WPR and river basin withdrawals are based on county model-calculated water use. The limited water is scaled up spatially. Summed WPRs are calculated based on the sum of the uses from the counties in the given WPR. Public water supply, domestic water supply, commercial, industrial, and power water withdrawal calculations for independently calculated WPRs and river basins are based on the population of each county within a given WPR and/or river basin. Irrigated agriculture and livestock water withdrawals are based on the percent of agricultural withdrawals from each county in a given WPR and/or river basin. Mining uses are based on the percent of mining districts from a county in the WPR or river basin.

4.2.3 Municipal and Self-Supplied Domestic

The OSE water use reports published every five years (Longworth et al., 2008, 2013; Sorensen, 1977; 1982; Wilson, 1986; Wilson and Lucero, 1992, 1997, 2003) include water use and population served for municipal and self-supplied domestic water uses. The water use for municipal and domestic sectors is divided by the respective populations to determine municipal and domestic per-capita water withdrawal and depletion rates every five years. For the NMDWSB model, the per-capita withdrawal and depletion rates for municipal and domestic uses are interpolated between the 5-year reports and multiplied by the current population (Section 4.2.1) at each timestep. Since depletions are not reported by the OSE after the year 2000 (Wilson and Lucero, 2003), the 2000 per-capita depletions are used through the model end date of 2099. County uses are scaled up to WPRs and river basins based on the percentage of a county’s population in each MBAU. For further information on these calculations, see Appendix A.14.

Future county municipal and self-supplied domestic water depletions are calculated as the population of a given MBAU times the 2000 OSE (Wilson and Lucero, 2003) reported per-capita depletions. The future scenario options allow the user to alter the population and per-capita water use estimates by ± 20%.

4.2.4 Irrigated Agriculture

The methods for calculating CIRs for counties are described in detail in Section 5.1.1. Surface water and groundwater withdrawals for irrigated agriculture in counties are calculated by multiplying the estimated CIR by appropriate surface water and groundwater irrigation efficiencies (Appendix A.15, Table 41). County surface water- and groundwater-specific irrigation efficiencies are determined by taking the ratio of historical OSE-reported depletions to withdrawals. The irrigation efficiencies are held constant for the five years corresponding to each OSE report. Since no depletions are reported by the OSE after the year 2000 (Wilson and Lucero, 2003), the 2000 irrigation efficiencies are used through 2099. This is currently a model limitation, as irrigation efficiencies improve through time with technological advances. Withdrawals and depletions are solved at the county level and then summed to give values for WPRs and river basins. The amount of agricultural land in a specific county located within a given WPR or river basin is determined from USGS National Land Cover Database (NLCD) data (Jin et al., 2013).

For calculating future projections, CIR estimates are made at the county level and then summed to give values for WPRs and river basins. The irrigation efficiencies for the future are held constant using values from the 2000 OSE data (Wilson and Lucero, 2003). The amount of agricultural land in a given MBAU for the future is held constant from the historical 2015 CropScape Cropland Data Layer (USDA, 2015). The water diverted and consumed by agriculture is a significant percentage of the total water use in the state of New Mexico, and the NMDSWB is highly sensitive to model inputs used in the calculation of agricultural water use. To allow for some variation in future agricultural water use, the agricultural acreage by crop type scenario option can be used to alter the U.S. Department of Agriculture (USDA, 2015) acreage estimates by ± 25%.

4.2.5 Livestock

Livestock withdrawals are estimated on a county level in the NMDSWB from 1975 to 2015 in the historical period. These estimates are made using 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, and the values for water use per animal used in the NMDSWB are the same values reportedly used by the New Mexico OSE (Table 42). In the NMDSWB, several different sources are used for historical animal population data at the county level: the USDA National Agricultural Statistics Service (NASS) Quick Stats Database (USDA, 2014a) is used for all animal populations for 1975–1999; the USDA NASS annual statistical bulletins are used for cattle, dairy cows, sheep, and lamb populations for 2000–2015 (e.g., USDA, 2014a); the USDA 2002 Census of Agriculture (USDA, 2004) was used for chicken, hog, and horse populations for 2000–2004; the USDA 2007 Census of Agriculture (USDA, 2009) was used for chicken, hog, and horse populations for 2005–2009; and the USDA 2012 Census of Agriculture (USDA, 2014a) was used for chicken, hog, and horse populations for 2010–2015. The OSE uses county assessor information in addition to information from the New Mexico Department of Agriculture when tabulating animal populations in the state, but the OSE does not provide this information at the county level (Table 43). Livestock depletions are assumed to be 100% of withdrawals as there is very little return flow (Wilson and Lucero, 2003). Withdrawals and depletions are determined at the county level, then scaled up to WPRs and river basins by multiplying the percentage of each county's agricultural area (e.g., Jin et al., 2013) within a given WPR/river basin, under the assumption that livestock areas are co-located proportionally with agricultural areas. See Appendix A.16 for livestock water use and population tables.

Future county livestock populations are based on values for a given county from 2015 and held constant through 2099. The 2015-based livestock populations and associated per-animal water uses are then used to determine withdrawals for each county. WPR and river basin livestock water uses are determined by the ratio of county agricultural land in the given WPR or river basin as a proxy for agriculture. County withdrawals are multiplied by these ratios and aggregated into a given WPR or river basin to get a total withdrawal for each MBAU.

4.2.6 Mining and Power

Values for water withdrawals and depletions from mines and power generation in the NMDSWB are taken directly from the water withdrawals and depletions (depletions when available) data provided by the OSE water use by categories reports (e.g., Longworth et al., 2013). The values published in those reports are held constant in the model for the five years preceding the respective published report. Depletions after the year 2000 are estimated by multiplying the ratio of the 2000 (Wilson and Lucero, 2003) reported withdrawals and depletions by the 2005 and 2010 withdrawals. County and river basin water use for mining and power come directly from the OSE reports. For WPR mining use, county-level data are multiplied by spatialized mining district data (McLemore et al., 2005) to determine the percentage of mining operations of each county within a given WPR. No spatialized dataset has been found to upscale county water use for power to the WPR level. Currently the proportion of county populations within WPRs is used to aggregate county water for power data to the WPR and river basin scale. Future efforts might consider use of power plant locations to move from county to WPR.

Future county mining and power uses are carried forward from the 2010 OSE reported uses (Longworth et al., 2013) and the 2000 withdrawal-depletion ratio (Wilson and Lucero, 2003). Mining water use in each WPR and river basin is determined using a ratio of county mining districts in the given WPR or river basin. County withdrawals are multiplied by these ratios and summed by the WPR or river basin to get a total withdrawal for each MBAU. Future power use at the county level is scaled up to WPRs and river basins by the proportion of county populations within WPRs and river basins.

One type of water use that has become significant in some regions of New Mexico in the last 10 years is fresh water used to support development of oil and gas resources. The hydraulic fracturing process to enhance production of oil and gas wells in particular uses a large volume of water, up to 3 acre-feet or more for a single well. Most of this water is purchased from owners of irrigation and domestic wells; however, little reliable data are available on the magnitude of this use and it is not reported by the OSE. Future development of the NMDSWB will include this use as information becomes available.

4.2.7 Commercial and Industrial

Values for water withdrawals and depletions by commercial and industrial water users in the NMDSWB are taken directly from the water withdrawals and depletions (depletions when available) data provided by the OSE water use by categories reports (e.g., Longworth et al., 2013). The values published are held constant in the model for the five years preceding the respective published report. Depletions after the year 2000 are estimated by multiplying the ratio of the 2000 reported withdrawals and depletions (Wilson and Lucero, 2003) by the 2005 and 2010 withdrawals. The WPR and river basin municipal and domestic withdrawals and depletions are calculated by multiplying county-level withdrawals and depletions by the respective percentage of a county's population within a given WPR/river basin.

The historical commercial and industrial withdrawals and depletions by county are carried forward through 2099. WPR and river basin commercial uses are determined using a ratio of county population in the given WPR or river basin. County withdrawals are multiplied by these ratios and aggregated into the appropriate WPRs and river basins to get a total withdrawal for each MBAU.

4.2.8 Reservoir Evaporation

Reservoir evaporation is calculated in the NMDSWB by multiplying reservoir surface area by Hargreaves-Samani reference ET and a monthly open water evaporation coefficient, or by using local pan evaporation data when available (Section 2.3.1). Hargreaves-Samani reference ET is described in detail in Section 5.1.1. Each reservoir's surface area varies with the volume of water in it and is determined from a volume-area rating relationship contained in a look-up table. Information on modeling individual reservoirs is provided in Appendix A.2. Reservoir evaporation is calculated using the same methods in both historical and future periods of the NMDSWB model.

4.2.9 Groundwater and Surface Water Returns

The water use by categories reports issued by the OSE (e.g., Longworth et al., 2013) provide information on the sources of water returns (i.e., water that was withdrawn but not consumed) before 2005. The information in these reports does not detail whether these returns are going back to the surface water or groundwater system (i.e., the destination of the return). The NMDSWB incorporates several assumptions to partition returned water to the appropriate groundwater or surface water stock. The default return options in the NMDSWB are as follows:

- 100% of public water supply returns go to surface water (with the assumption that only indoor water use has associated return flows, which are returned to a wastewater treatment plant, treated, and returned to a surface water body).
- Domestic water returns go to groundwater (with the assumption that only indoor water use has associated return flows, which are returned to a septic system, treated, and returned to the groundwater system).
- The ratio of agricultural returns to surface water/groundwater is dictated by the relative use of surface water or groundwater for agriculture in a given MBAU (Table 4).[1]
- Livestock water withdrawals produce no return flows.
- 100% of commercial water returns go to surface water (with the assumption that only indoor water use has associated return flows, which are returned to a wastewater treatment plant, treated, and returned to a surface water body).
- 100% of mining returns go to groundwater (with the assumption that any water applied to treatments ponds will be evaporated and have no returns). Water that is returned is likely injected back into the groundwater.
- 100% of power returns go to surface water. A substantial portion of the water used in the cooling process is evaporated. However, water used for other power plant operations will be discharged to a surface body of water and depending on the location of the power plant, the returned water may be lost before being gaged in a downstream portion of the model.

Table 4. Agricultural return flow destinations as estimated in the NMDSWB model.

Percentage of Agricultural Withdrawals from Surface Waters	Percentage of Agricultural Returns to Surface Waters
100–71	100
51–70	80
41–50	50
31–40	30
30–0	0

To calculate future return flow projections after available water has been determined, withdrawals are calculated, depletions are removed from the withdrawals, and the remaining water is considered a return and partitioned by the same ratios as the historical period (Table 33). SW_r are added to available water and ultimately leave the MBAU in the SW_{out}, and for counties without a SW_{out}, returns are added to the $SW \Leftrightarrow GW$ flux. Independently calculated WPRs and all river basin returns are calculated in the same way, where returns are the difference between depletions and withdrawals. The withdrawals and depletions are calculated from ratios of counties within the WPRs and river basins. Summed WPR surface water and groundwater returns are calculated as sums of the counties within the WPR.

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[1] The destination of irrigated agricultural returns can be the surface water or the groundwater. Returns to the groundwater via seepage through the root zone are often captured by drains, and thus ultimately return to the surface water system after some delay in the groundwater system. In irrigation districts that rely entirely on groundwater pumping, there may not be a surface water system for returns. In the NMDSWB, agricultural returns to surface water are calculated by the relative proportion of surface water/groundwater used for irrigation. The agricultural return flow ratio to surface water/groundwater by county can be seen in Appendix A.17, Table 44.

5 Outflows

5.1 Evapotranspiration

Evapotranspiration represents the phase change of water from the liquid phase to the vapor phase and constitutes water that is lost to the atmosphere either directly from open water (evaporation) or mediated by plants (transpiration). It is by far the largest loss term in New Mexico's water budget. This section of the report summarizes methods used to estimate ET rates, season lengths, the portion of ET that is met directly by P, and area data used to calculate volumetric flows.

Except for ET_{sw} (due to data availability), future ET projections are calculated using the same methods as in the historical period, and all areas of land are held constant from 2015 through 2099 (unless altered using the agricultural acreage by crop type scenario option). The temperature estimates for the future ET calculations are specific to each climate model.

5.1.1 Methods for Estimating ET

Evapotranspiration is calculated using three different methods: the Hargreaves-Samani reference ET (Hargreaves and Samani, 1985), the Original Blaney-Criddle (OBC) consumptive irrigation requirement (Blaney and Criddle, 1950), and the Modified Blaney-Criddle (MBC). Three methods are used because the Hargreaves-Samani method is widely used, particularly when reliable wind speed, humidity, and solar radiation data is not available, and the Blaney-Criddle method carries an important historical legacy in New Mexico, and both the OBC and MBC are used in the OSE reports (e.g. Longworth et al., 2013). Equation 8 provides the Hargreaves-Samani equation (Hargreaves and Samani, 1985).

$$ET_{oHS} = 0.0023Ra(T + 17.8)\sqrt{Tmax - Tmin} \qquad \text{(Equation 8)}$$

Where:

ET_{oHS} = Hargreaves-Samani-based reference ET (inches/month)

Ra = the water equivalent of extraterrestrial radiation (mm/day)
The Ra variable represents extraterrestrial solar radiation and is expressed in units of length/time, which means that a given amount of radiation (energy) is expressed as the depth of water it could evaporate. See Equation 14 in Appendix A.18.

T = mean temperature (degrees Celsius [°C])

$Tmax$ = maximum temperature (°C)

$Tmin$= minimum temperature (°C)

The temperature data are obtained from monthly PRISM (2018) data. The monthly mean, minimum, and maximum temperatures are all the spatial averages of the PRISM (2018) data for the agricultural area (determined from Jin et al., 2013) within a county or WPR. The reference ET is multiplied by seasonal varying reference crop coefficients to get crop-specific potential ET, which represents an upper estimate of ET losses and is the maximum amount of ET that could occur if a crop is not water limited. For conversion from Hargreaves-Samani reference ET to crop-specific ET, the reference crop coefficients shown in Table 5 are used (Brouwer and Heibloem, 1986).

Table 5. Reference crop coefficients (Brouwer & Heibloem, 1986) used with the Hargreaves-Samani method and the OBC method consumptive use coefficients (Longworth et al., 2013; Soil Conservation Service, 1970) used in the NMDSWB.

Vegetation Type	**Hargreaves-Samani (Reference Crop Coefficients)**		**OBC (Consumptive Use Coeffecients)**	
	$K_{growing}$	$K_{non\text{-}growing}$	$K_{growing}$	$K_{non\text{-}growing}$
Grains (irrigated cropland)	1.15	0.3	0.75	0.4
Alfalfa and Pasture (irrigated cropland)	0.95	0.4	0.8	0.5
Fruits and Vegetables (irrigated cropland)	1.05	0.7	0.7	0.4
Orchards (irrigated cropland)	0.96	0.45	0.65	0.4
Riparian	1.05	0.7	0.7	0.7

The Blaney-Criddle equation is used by the OSE to calculate the CIR for irrigated agriculture water withdrawals across the state (Blaney and Criddle, 1950). The OBC is used as the default calculation for estimating crop ET in the NMDSWB. Equation 9 provides the OBC method for calculating consumptive use.

$$ET_{BC} = TPK * \ [1 \text{ inch/°F}] \qquad \text{(Equation 9)}$$

Where:

ET_{BC} = Blaney-Criddle consumptive use (inch/mo)

T = Mean monthly temperature (degrees Fahrenheit [°F])

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

K = Unitless consumptive use coefficient, which is constant throughout the growing season in the OBC method values for K used in the NMDSWB are shown in Table 5 (Longworth et al., 2013; Soil Conservation Service, 1970).

The Modified Blaney-Criddle method (Soil Conservation Service, 1970), referred to as the MBC by Longworth et al. (2013) is used by the OSE in the San Juan (Upper Colorado) basin to compute CIR so that values reported by the state are consistent with New Mexico Interstate

Stream Commission (NMISC) compact accounting (Longworth et al., 2013). The NMDSWB also uses the MBC method to calculate CIR in the San Juan basin. With this method, *K* is defined as:

$k_t * k_c$

where:

$$k_t = 0.0173T - 0.314 \qquad \text{(Equation 10)}$$

k_c = an empirical crop stage coefficient that varies through the growing season

The k_c values used in the NMDSWB are shown in Table 6. The values for grains come from the U.S. Department of Agriculture's Technical Release 21 (TR-21) (Soil Conservation Service, 1970) crop growth stage coefficient curve for grain corn (Curve No. 1) assuming a five-month growing period (10%, 30%, 50%, 70%, and 90% growth stage). The values for alfalfa and 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 OSE (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 6. Crop stage coefficient (k_c) used in the MBC method in the NMDSWB. Values are from a combination of TR-21 curves (Soil Conservation Service, 1970) 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 and 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 and 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	0.9	0.78	0.66

The Blaney-Criddle equation (Equation 9) is given in its native U.S. units, which are its most familiar form; however, to be consistent with units in the NMDSWB, there is an implicit factor of 1.0 (inch/°F) included in the equation.

The Blaney-Criddle and Hargreaves-Samani approaches to estimating ET are both temperature- and location-driven methods, and thus lend themselves well to statewide use. Generally Hargreaves-Samani is the method of choice for monthly timestep situations in which only temperature and location are available; however, in the NMDSWB, Blaney-Criddle is used to estimate ET from irrigated agriculture due to a significant historical legacy of this approach in New Mexico, including in the OSE technical reports on water use by categories (Longworth et al., 2008; 2013; Sorensen, 1977; 1982; Wilson, 1986; Wilson and Lucero, 1992; 1997; 2003).

The Hargreaves-Samani approach is used in the NMDSWB to estimate reservoir evaporation and riparian ET_{gw}. The Hargreaves-Samani and Blaney-Criddle formulas both estimate ET as a function of temperature and 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

To capture spatial and temporal variability of the growing season, the NMDSWB calculates irrigation season based on monthly temperature data at all timesteps, as discussed in Appendix A.19. These temperature based irrigation season parameters resulted in Blaney-Criddle-based calculations of historical agricultural consumption comparable in magnitude to five-year average consumptions reported by OSE, as seen in Figure 10.

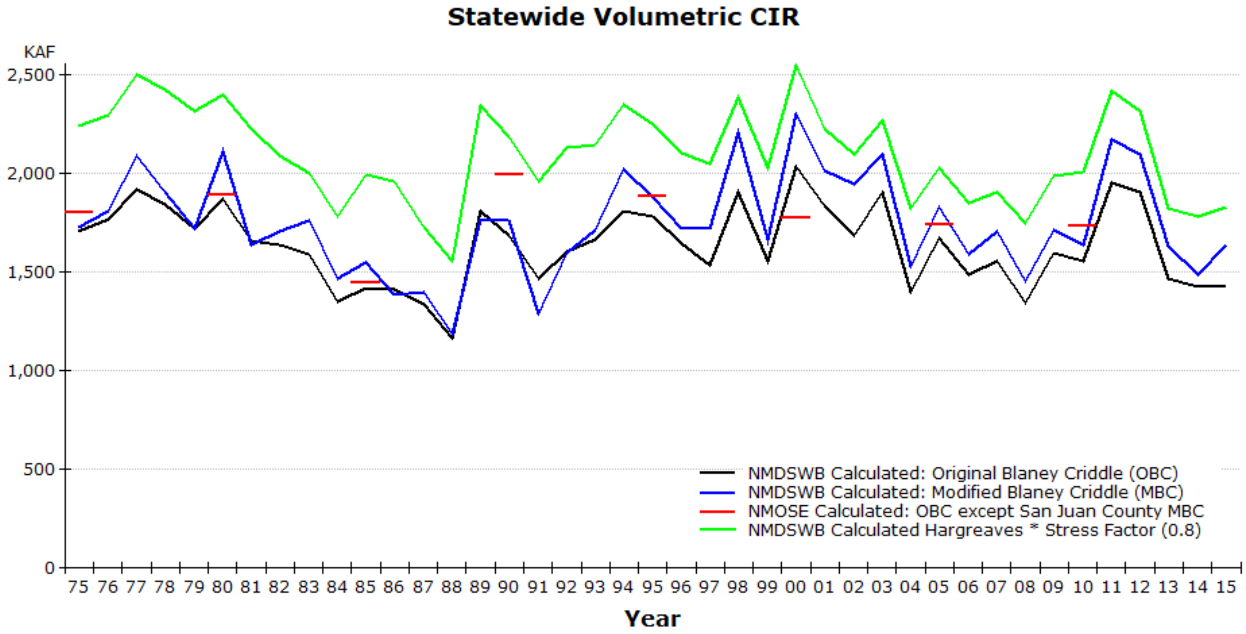

Figure 10. Statewide agricultural CIR calculated by the NMDSWB from 1975–2015 as compared to OSE reported values (e.g., Longworth et al. 2013).

5.1.3 Effective Precipitation

Effective *P* (i.e., *P* that can be used 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, respectively. By default, effective *P* is calculated with the Soil Conservation Service (1970) method, but the NMDSWB also can calculate effective *P* with a USBR method documented by Longworth et al. (2013). For detailed descriptions and equations on effective *P* methods, see Appendix A.18.

5.1.4 Area of Irrigated Agriculture

The volume of water consumed by irrigated agricultural activities is found by multiplying the consumption rate (i.e., ET rate) by the total irrigated acreage. The irrigated agricultural data necessary for this calculation was gathered from five sources: the OSE technical reports on water use by categories and irrigated acreages (Longworth et al., 2008; 2013; Sorensen, 1977; 1982; Wilson, 1986; Wilson and Lucero, 1992; 1997; 2003), the USDA NASS Quick Stats Database (USDA, 2014a), 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), the USGS's NLCD (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013; Price et al., 2003; Vogelmann et al., 2001), and the USDA CropScape Cropland Data Layer (USDA, 2015).

The OSE estimates 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; Wilson, 1986; Wilson and Lucero, 1992; 1997; 2003). Each report represents an estimate of the total irrigated acreage for the report year only. The OSE reports, however, do not include any information on the crop type, which is needed to calculate specific crop CIRs. Specific crop acreages are determined from the USDA NASS Quick Stats Database (USDA, 2014a), the NMSU Cooperative Extension Service's technical report on trends in irrigated and dryland acreages in New Mexico 1970–1994 (Lansford, 1997), and the USDA CropScape Cropland Data Layer (USDA, 2015). See Appendix A.21 for more information on determining agricultural areas. Statewide total crop acreages estimated in this manner are shown in Figure 11.

Modeled future projections of irrigated agricultural areas through 2099 are constant and are based on the 2015 USDA CropScape Cropland Data Layer estimate (USDA, 2015). These estimates, however, can be altered using the agricultural acreage by crop type scenario option.

5.1.5 Riparian Area and Spatial Transformations of Agriculture Area

Agricultural acreage is only reported at the county level by the sources used in NMDSWB. 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 and river basin. To account for this, the irrigated acreage at the county, WPR, and river basin scale is determined from remotely sensed land cover data from the USGS NLCD. For 1970–2003[2], agricultural acreage was measured from the 2001 USGS NLCD data (Homer et al., 2007); for 2004–2008, agricultural acreage was measured from the 2006 USGS NLCD data (Fry et al., 2011); and for 2009-2015, the agricultural acreage was measured from the 2011 USGS NLCD data (Jin et al., 2013). The percent of county agriculture acreage within a given WPR or river basin is then estimated from these data, which is multiplied by total agricultural acreage at the county level. Lansford (1997) is used for 1970–1994 and OSE data (e.g., Longworth et al., 2008) is used for 1995–2015 to determine total agricultural acreage. Although early land use datasets from the 1970s, 1980s (Price et al., 2003), and 1992 (Vogelmann et al., 2001) were explored, the total

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[2] The 2001 values are held constant through 2003, the half-way point between the next set of reported values for 2006. Similarly, the 2006 values are used through 2009 the half-way point between the next set of reported values for 2011.

riparian and agricultural areas from those datasets were inconsistent with later datasets, so they were not used in the NMDSWB. Because of difficulties with calibration of the model associated with abrupt changes in riparian area from the different USGS NLCD estimates, the riparian areas from the 2011 USGS NLCD data (Jin et al., 2013) are used directly for county, WPR, and river basin scales for all time periods in the model. Statewide total agriculture and riparian areas can be seen in Figure 12. It is apparent from this figure that there are large discrepancies in agricultural land areas reported by different sources.

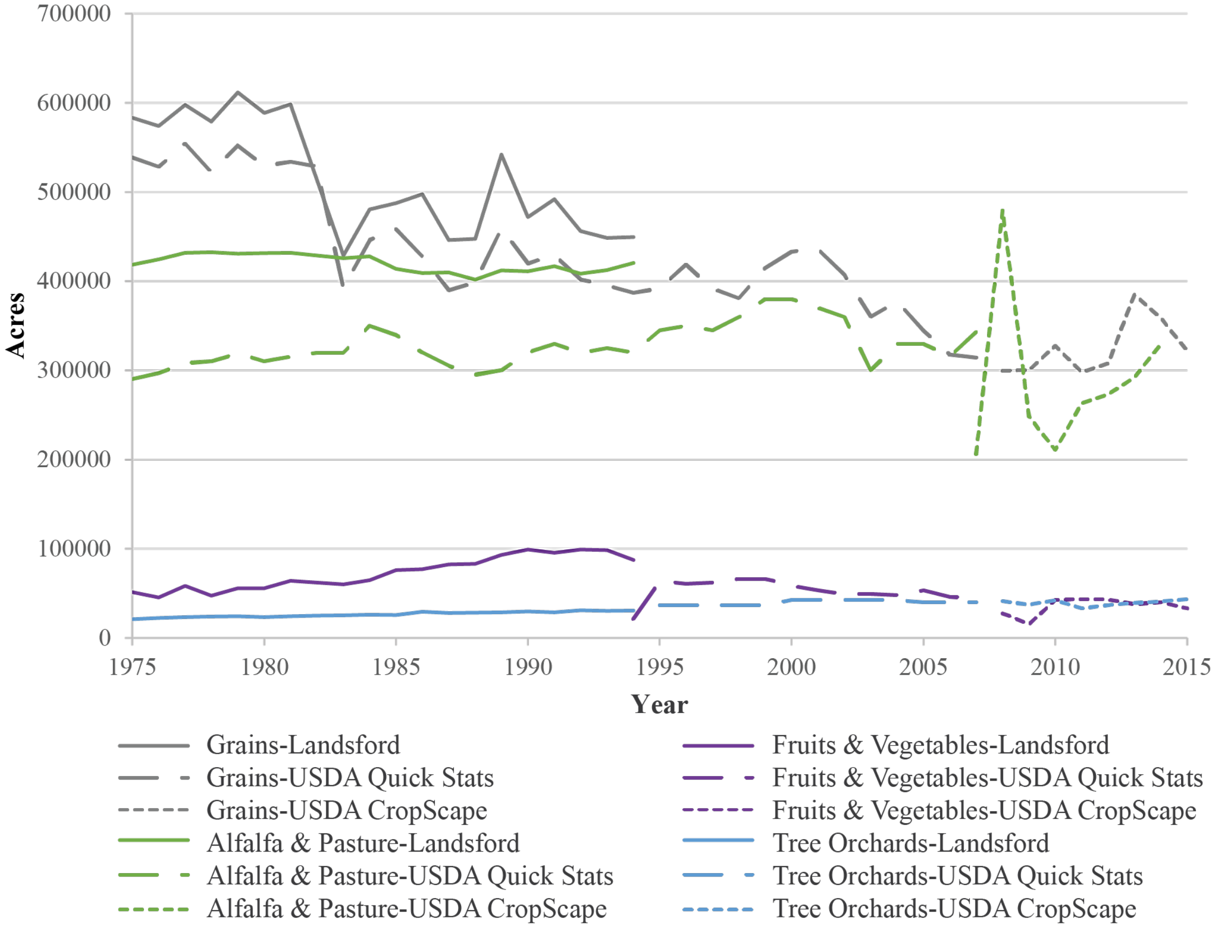

Figure 11. Estimated statewide agricultural acreages by crop type. In the historical period, the NMDSWB uses Lansford (1997) crop acreage estimates from 1975–1994, USDA (2014) Quick Stats crop acreage estimates from 1995–2007, and USDA (2015) CropScape crop acreage estimates from 2008–2015, where future estimates are based on the 2015 CropScape crop acreage estimates (USDA, 2015). See Appendix A.21 for more information.

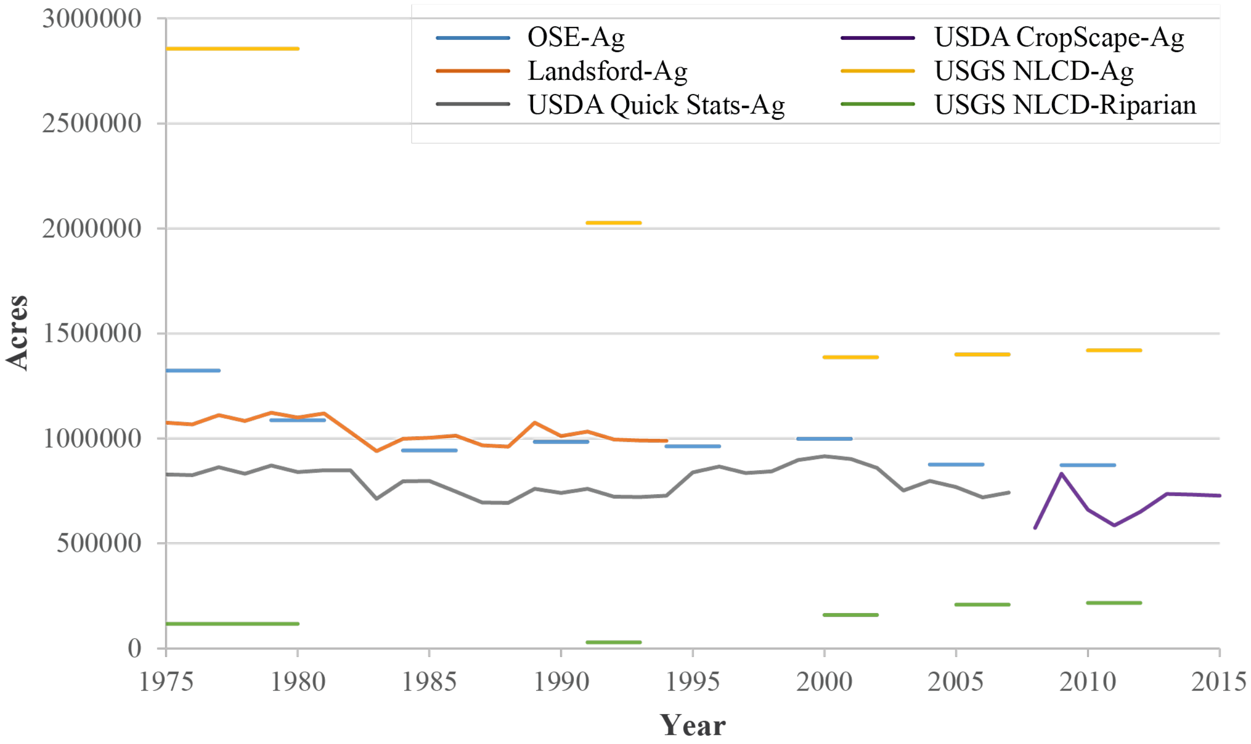

Figure 12. Statewide total agriculture and riparian land cover. In the historical period, the NMDSWB uses total agricultural acreage from Lansford (1997) for years 1975–1994 and from the OSE (e.g., Longworth et al., 2008) for years 1995–2015. The 2015 CropScape crop acreage estimates (USDA, 2015) are used for future years 2016–2099.

5.2 Water Budget ET Terms

5.2.1 Land Surface ET

Direct estimates of ET_{ls} are not used in the NMDSWB. Because changes in water storage in the land surface stock are not yet incorporated (Section 2.1), ET_{ls} is calculated by setting ET equal to *P* less surface water *RO* and *R*. In other words, rainfall that does not result in *RO* or *R* is assumed to evapotranspire into the atmosphere. This approach is used in both the historical and future model periods.

5.2.2 Surface Water Evapotranspiration

Surface water evapotranspiration[3] accounts for losses from rivers and streams (reservoir evaporation is counted as ET_h) and is calculated in two parts. There is a direct estimate of ET_{sw} and an additional closure component derived when there is a surplus in the surface water system (Section 4.1.3). The direct component is calculated by multiplying river area by Hargreaves-Samani reference ET and an open water evaporation coefficient for the respective basin (Appendix 8.2A.4). The river areas are dynamically calculated each month (of the historical

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[3] Conceptually these losses from open water surfaces are evaporative only, but for simplicity and consistency with other fluxes to the atmosphere, they are referred to as ET losses.

period) in the NMDSWB by comparing 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 each timestep is held constant for half of the distance to the upstream gage (or to the start of a river/tributary or to a MBAU boundary) and for half the distance to the downstream gauge (or to the basin border for river stretches between basin boundaries). All stream length segments were measured using ArcGIS. Refer to Appendix A.8 for county- and WPR-specific stream segment parameters used in the NMDSWB.

The additional closure component of ET_{sw} conceptually represents a portion of the SW_r, which are estimated to be nongaged. While very few return flows are gaged for most water use sectors, the assumption for gaged return flows made here is that return flows reentering the surface water system will ultimately be manifested along the river as increased flows at downstream gages. The portions of the returns that do not reenter the surface water system or for some other reason are not gaged are for accounting purposes lost and are added to NMDSWB surface water ET_{sw} (see Section 4.1.3.1).

In the future model, period stream gage data is not available for all of the gages used in the historical period of the NMDSWB, thus ET_{sw} needs to be calculated differently. Future county ET_{sw} is calculated based on its ratio to SW_{in}. The ratio is derived from the historical ratio of ET_{sw} to SW_{in}. ET_{sw} for the independently calculated WPRs is calculated in the same manner, and ET_{sw} for the summed WPRs is calculated as a sum of the ET_{sw} for all the counties within the WPR. $ET_{sw\ rb}$ is calculated as a sum of all the WPR (and/or percentage of the WPR) ET_{sw} values that are located within the river basin.

5.2.3 Human Consumption

In the NMDSWB model, ET_h (as defined as the difference between withdrawals and return flows) is calculated for public and domestic water supplies (Section 4.2.3), irrigated agriculture (Section 4.2.4), and livestock (Section 4.2.5). 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) and are used directly by the NMDSWB (see Sections 4.2.6 and 4.2.7). All consumptive uses are initially calculated at the county level and summed to give values for WPR and river basins accordingly, using identical methodologies as used for surface and groundwater withdrawals by use category. Reservoir evaporation is calculated based on modeled reservoir surface area as described in Section 4.2.8.

5.2.4 Human Return Flows

In the NMDSWB, return flows are calculated as the difference between withdrawals and consumption (depletions). Section 4.2.9 describes how return flows are partitioned to groundwater or surface water. The SW_r flux from human storage also includes releases from reservoir storage, which constitute inflows to the surface water stock.

5.2.5 Groundwater ET

Groundwater ET is calculated as a riparian ET rate multiplied by a remote sensing-based estimate of riparian area. Sections 5.1.1 and 5.1.5 describe how riparian ET rates and remotely sensed riparian areas are calculated.

5.3 Surface Water Outflows

As used in the NMDSWB, SW_{out} from a given MBAU consist of flows that cross its boundary. SW_{out}, if any, 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 outflow. Surface water gages used in the NMDSWB were selected based on their locations and periods of record. When a stream gage is not available near a county, WPR, or river basin boundary, streamflow is estimated from nearby stream gages or correlated to inactive stream gages, which represents a closer proximity to a given boundary. Detailed information on SW_{out} by county, WPR, and river basin are presented in Appendix A.6.

Future county SW_{out} represent the remaining surface water after all the diversions and use calculations have been removed from or added back to the SW_{in}. The calculation order is as follows: surface water in, reservoir diversions and returns, natural hydrological processes (RO, ET_{sw}, $SW \Leftrightarrow GW$), human use withdrawals, depletions, and returns. The remaining water is considered outflow to the next county. Some counties do not have SW_{out} as determined in the historical period (Table 20). In particular, some counties in eastern New Mexico do not have any streams that cross county boundaries. Since there is an ordered flow calculation for each county, there is often a small amount of water returned to the surface water system that would be considered SW_{out}. For MBAUs that do not have an SW_{out} in the historical period, to maintain the mass balance of the system, any remaining water that would be added to the SW_{out} variable is accounted for in the mass balance as $SW \Leftrightarrow GW$. The outflows of some MBAUs are split between multiple MBAUs to be consistent with the hydrologic system. These are determined by historical outflow ratios between the given MBAUs (Table 18).

For the independently calculated WPRs[4] (Table 2), outflows are set to equal the county of which the border is shared. For these independently calculated WPRs, future period SW_{out} is initially calculated identically to the methods described above detailing future period county outflows. Due to errors associated with the change of spatial resolution between counties and WPRs, the independent WPR SW_{out} calculations can result in slightly different values than the SW_{out} calculated at the corresponding county boundaries (Table 3). Since the WPR SW_{out} is set to equal

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[4] Rio Chama WPR is a unique case where the outflow of this WPR does not fall on a border. In the historic portion of the model, the nearest gages were used for the outflow. In the future the Rio Chama outflow is the combination of the flow out of Heron Reservoir and a synthetic gage on the Rio Chama at Ojo. The Rio Chama Ojo synthetic gage was developed by creating a historic multivariate regression equation with the Lobatos and La Puente gages. These two gages were selected because they are modeled gages used as future inflows.

that of the corresponding county mass balance is maintained by adding the differences that arise to the WPRs $SW \Leftrightarrow GW$ term. For example, if Santa Fe county had a calculated SW_{out} of 100 cfs in a given timestep in the future period of the model, and Jemez y Sangre WPR had a calculated SW_{out} of 105 cfs, the modeled outflow of Jemez y Sangre WPR would be set to 100 cfs and 5 cfs would be added to the Jemez y Sangre WPR $SW \Leftrightarrow GW$ term.

Future river basin SW_{out} is calculated the same as the WPR SW_{out} described above. The river basin SW_{out} is set to equal the county of which the border is shared. Any slight discrepancies that arise are added to the river basin $SW \Leftrightarrow GW$ term to maintain mass balance at all spatial scales.

5.4 Groundwater Outflows

In the NMDSWB, GW_{out} from a given MBAU consists of groundwater flowing across MBAU boundaries. For purposes of the NMDSWB, basin-scale groundwater divides are assumed to be the same as surface water divides. In other words, there is no groundwater flow between major river basins within New Mexico. Groundwater flows across MBAUs are largely unquantified except in a few basins that have been the subject of regional groundwater modeling.

Groundwater flow across a given boundary, especially a political boundary, must be calculated based on observed groundwater elevations and inferred geologic information, or extracted from regional groundwater models based on the same information. Due to this lack of information, in the NMDSWB, groundwater flows between MBAUs are assumed to be zero at all spatial scales. While this assumption is reasonable at the river basin scale, it becomes less appropriate at WPR and especially county-level scales. Although these flows are likely small when compared to surface water flows and groundwater withdrawals, it is important to understand that they may exist. In some MBAUs, particularly at smaller spatial scales and in areas where groundwater is a major source of supply, future model development should include efforts to quantify these flows.

6 Energy Water Nexus

The NMDSWB provides estimation of energy usage based on the water fluxes estimated in the model. Energy consumption for associated uses of water production, transportation, and treatment are calculated under the same set of assumptions/equations in both historical and future periods of the model. Many of the water fluxes represented in the NMDSWB are directly connected to associated generation or use of energy. Depending on the source and use of the water, energy might be required to produce, transport, and/or treat water in order to use or discharge water. Releases from certain reservoirs, or flows down certain conveyances might, on the other hand, result in generation of hydroelectricity. The NMDSWB tracks energy requirements associated with groundwater pumping for all uses; surface water pumping associated with five specific projects; surface water pumping for all uses; supply side treatment of all water used in the public water supply and domestic, commercial, or industrial sectors; and waste side treatment for all water returned from the public water supply and commercial, industrial, and mining sectors. The water consumed in the production of energy is accounted for in the ET_h flux, described in Section 4.2.6. All methods for calculating energy consumption are used in the historical and future periods of the model.

6.1 Surface Water Pumping

Energy use is estimated for five surface water pumping projects, two public water supply projects, and three irrigation projects. The public water supply projects, both from the Rio Grande are (1) the Albuquerque Bernalillo County Water Utility Authority (ABCWUA) San Juan-Chama Drinking Water Project (SJC DWP) (ABCWUA, 2016), and (2) the Buckman Direct Diversion (BDD) serving Santa Fe City and County (BDD, 2016). The irrigation projects are (3) the Ft. Sumner Project on the Pecos (USBR, 2016a), and the (4) Hammond (USBR, 2016b) and (5) Navajo Indian Irrigation Projects on the San Juan River (USBR, 2016d). Equation 11 shows the calculation of the power (energy per time) required to lift water in these projects.

$$p = \frac{Q\rho g h}{\eta_p} \qquad \text{(Equation 11)}$$

where:

p = Power ($m*l^2/t^3 = f*l/t$)

Q = Volumetric flow rate (l^3/t)

ρ = Density (m/l^3)

g = Acceleration due to gravity (l/t^2)

h = The hydraulic head, which includes elevation difference and pipe friction losses (l)

η_p = The unitless pump efficiency

If metric units of meters, kilograms, and seconds are used, power is calculated in units of watts. If U.S. units of pounds, feet, and seconds are used, then a unit conversion factor is required. A pump efficiency value of 50% is used based on a California Energy Commission report that found efficiencies ranging between 34% and 59% in over 980 irrigation district pump tests (Burt et al., 2003).

The height water is lifted is estimated to be 200 feet for ABCWUA SJC DWP and 1,530 feet for the BDD, based on elevation information in Google Earth©. The height the water is lifted in the Ft. Sumner Irrigation Project is 21 feet (USBR, 2016b). The Hammond Irrigation Project has two lift stations. The primary station is powered by energy generated from a drop in another part of the conveyance system, so it is not included in this analysis (USBR, 2014). The Hammond auxiliary pump station with a rise of 56 feet (USBR, 2016b), however, is powered by natural gas (USBR, 2014) and is included. The Navajo Indian Irrigation Project includes 81 pumping plants (USBR, 2016d) with a pump capacity weighted average lift of 275 feet.

The NMDSWB estimated flows are resolved by county and do not include flows pumped by each project, so the pumped flows are estimated. For the public water supply pumping, the ABCWUA SJC DWP is historically the only SW_d for public water supply in Bernalillo County, so county-level data should represent the project flows. BDD pumping is more complicated because the City of Santa Fe also diverts surface water from two small reservoirs on the Santa Fe River, which, due to their elevation above the city do not require power for pumping. BDD pumping is set to zero before 2012 (BDD, 2016), and to the smaller of the Santa Fe County SW_d for public water supply and the annual average consumptive water rights at BDD (5605 AF/yr of SJC plus 1.5 cubic feet per second [cfs] "native" rights) from 2012 forward (URGWOM Technical Team, 2015). Future work could improve on the representation of these public water systems.

Pumped irrigation flows are calculated by estimating the area irrigated with the pumped water, then calculating the fraction of total irrigated area in the county, and multiplying that fraction by the total SW_d in the county in a given timestep. Fort Sumner pumped project flows are estimated as one-fifth of project irrigated area based on a pump capacity of 20 cfs compared to a main canal capacity of 100 cfs (USBR, 2016a). The project area is 6,500 acres, so the irrigated area served by pumps is estimated to be 1,300 acres. The Hammond Auxiliary Pumping Plant has a 12-cfs capacity compared to a 90-cfs capacity of the main canal (USBR, 2016b), so 12/90 of the total 3,933 acres, or 525 acres, are estimated to be served by the auxiliary pumps. All 70,000 acres of the Navajo Indian Irrigation Project (USBR, 2016d) are assumed to be supplied by pumped water. Future work could include improved information on the timing and amount of water pumped by these projects.

6.2 Groundwater Pumping

Energy use associated with well pumping is also estimated with Equation 11 with the height of water lifted determined by average depth to groundwater in a given spatial area. Currently, depth to groundwater by county calculated by Tidwell et al. (2014) with USGS well record data is used for all timesteps. Future efforts will include incorporation of depth to groundwater data by county, WPR, and river basin by decade. This data is currently being developed by researchers at the New Mexico Bureau of Geology and Mineral Resources as part of the Statewide Water Assessment (Rinehart et al., 2015). Well pump efficiency is assumed to be 50% based on a California Energy Commission study that found a range of 40% to 57% in well pumps across the state (Burt et al., 2003).

6.3 Water Distribution System

Once water has been produced and transported, it is pumped into a distribution system. Power required for pumping to the distribution system is also calculated using Equation 11, where the hydraulic head is estimated to be the average elevation difference between the supply source and the middle of town. It is assumed that water is pressurized to 67 pounds per square inch (psi) for domestic and industrial use and 72 psi for public water supply based on a 2013 report by the Electric Power Research Institute (EPRI) and the Water Research Foundation (WRF) (EPRI-WRF, 2013). This is equal to a pump head of 155 feet (ft) and 166 ft, respectively. Operating pressure for irrigation wells is assumed to be 28 psi (h_p = 65 ft) based on the 2008 state average reported by the USDA Census of Agriculture (USDA, 2008). Surface water irrigation was assumed to require pressurization to 38 psi (h_p = 88 ft) for sprinkler and drip based on the average operating pressure for New Mexico pumps from ponds, lakes, reservoirs, and rivers, also as reported by the USDA Census of Agriculture (USDA, 2013). Flood irrigation is assumed to require no pressurization. The percentage of surface water applied to agriculture by sprinkler, drip, or flood is estimated by county for 1990, 1995, 2000, 2005, and 2010 by the OSE (e.g., Longworth et al. 2013) and these values were used in calculations of power requirements for water pressurization. In addition to pressurization, additional energy is required to overcome head losses due to pipe friction as water is moved through the systems. This component of energy use in water distribution systems is not currently included in the NMDSWB and may be considered for future inclusion.

6.4 Water Treatment

All surface water used for public water supply and domestic, commercial, or industrial purposes is assumed to be treated at an assumed energy cost of 1,400 kilowatt hours per million gallons (kWh/MG). EPRI-WFR (2013) estimate 1,600 kWh/MG for nationwide surface water treatment and 2,100 kWh/MG for nationwide groundwater treatment, including pumping costs. Based on these numbers, Tidwell et al. (2014) estimate 1,400 kWh/MG for surface water or groundwater treatment costs independent of pumping, in the western United States. According to a local water expert, groundwater in New Mexico requires no treatment other than chlorination, and thus energy for groundwater treatment is assumed to be zero in the NMDSWB (Thomson, 2018).This methodology is intended to give an order-of-magnitude initial estimate, and these values could be improved in future work using treatment plant-specific information from across the state.

6.5 Wastewater Treatment

All water returns from the public water supply and commercial and industrial sectors are assumed to receive secondary treatment at an energy cost of 2,080 kWh/MG, based on EPRI-

WFR (2013). As a nationwide average, mining returns are assumed to receive less than secondary treatment at an energy cost of 750 kWh/MG. In New Mexico, a local water expert states that mining returns are not treated, and thus energy required for mining wastewater returns is assumed to be zero in the NMDSWB (Thomson, 2018). Domestic, agricultural, livestock, and power return flows (Section 5.2.4) are not treated and, therefore, are assumed to have no associated energy cost.

6.6 Hydropower

There are four hydropower reservoirs modeled in the NMDSWB: El Vado, Abiquiu, and Elephant Butte Reservoirs in the Rio Grande basin, and Navajo Reservoir in the San Juan River basin. Hydropower generation is estimated using Equation 12.

$$p = Q\rho g h \eta_t \qquad \text{(Equation 12)}$$

where:

p = Power ($m*l^2/t^3 = f*l/t$)

Q = Volumetric flow rate (l^3/t)

ρ = Density (m/l^3)

g = Acceleration due to gravity (l/t^2)

h = Difference between the reservoir pool elevation and the tail water elevation (l)

η_t = Unitless turbine efficiency

The volumetric flow rate, Q, is a time-varying modeled value as is reservoir pool elevation, which is a function of modeled reservoir storage. Tail water elevations and turbine efficiencies are assumed to be constant. Average turbine efficiency at El Vado, Abiquiu, and Elephant Butte were estimated to be between 80% and 90% based on turbine performance information from the Upper Rio Grande Water Operations Model (URGWOM) (URGWOM Technical Team, 2015). A value of 85% was chosen for the Navajo turbines based on these values. Tail water elevations for El Vado, Abiquiu, and Elephant Butte were estimated from URGWOM, while the tail water elevation for Navajo was estimated from Google Earth as 5,723 ft. This value is consistent with a reported streambed elevation of 5,720 ft at the dam axis (USBR, 2016c). The datum for the tail water elevations is unknown, and potential datum corrections are assumed negligible within the context of head differences on the order of hundreds of feet and monthly timestep calculations. Tail water elevations and turbine efficiencies used are shown in Table 7.

Table 7. Tail water elevation and turbine efficiency values for hydropower calculations.

Reservoir	Tailwater Elevation (ft)	Turbine Efficiency	Source	Generating Capacity	Comments
El Vado	6,717.8	80%	URGWOM	8 MW (U.S. Bureau of Reclamation, 2009)	URGWOM parameters suggest head- and flow-dependent efficiency between 69% and 103% with an average of 78% if the 103% is ignored.
Abiquiu	6,050	88%	URGWOM	16 MW (Los Alamos County Department of Public Utilities, 2011)	URGWOM parameters suggest head- and flow-dependent efficiency between 86% and 99% with most values below 90%.
Elephant Butte	4,204	90%	URGWOM	27 MW (U.S. Bureau of Reclamation, 2005)	URGWOM parameters suggest head-dependent efficiency between 88% and 95% independent of flow rate.
Navajo	5,723	85%	Google Earth	32 MW (U.S Bureau of Reclamation, 2017)	Reasonable value for turbine efficiency based on Rio Grande reservoir values above.

7 Uncertainty Analysis

The NMDSWB model includes uncertainty information for all reported values in the mass balance framework in the historical period of the model. Many of the values displayed in the NMDSWB are estimated, and it is important that users understand the limitations and uncertainty of the reported values. To determine uncertainty for NMDSWB mass balance values, standard error data was obtained for all major NMDSWB input datasets and equations (PRISM *P* and temperature, USGS stream gages, NLCD land cover, Hargreaves-Samani reference ET, Original and Modified Blaney-Criddle ET, and crop coefficients). The standard error estimates were then transformed into probability distributions (see Appendix A.24 for detailed information on the distribution of error about each input dataset). Next, the NMDSWB was run 1,000 times with each run sampling randomly from the standard error-based probability distribution of all input data. The statistical distribution of model output was recorded as a standard deviation for all NMDSWB output values at every spatial scale and every month from 1975–2010. The uncertainty range displayed in the NMDSWB mass balance interface (Figure 1) is equal to the average of two standard deviations over the 1975–2010 period for each value, which for normally distributed parameters, would represent a 95% confidence interval. While the uncertainty range on the input datasets quantify the uncertainty in NMDSWB estimates of human uses such as irrigated agriculture and reservoir evaporation, uncertainty estimates in the remaining water use categories (public water supply, domestic, livestock, industrial, commercial, mining, and power) have not yet been quantified, and remain an area for future efforts.

Uncertainty values determined in the historical period of the model are currently used as the range of uncertainty in the future period of the model. Users of the NMDSWB model should note that any values displayed in the future period have a much higher degree of uncertainty than is represented in the model interface. Future values do not tend to represent or predict any actual future conditions, but are intended to help identify trends and patterns in regional water budgets moving into the future.

8 Next Steps and Conclusions

8.1 Next Steps

Through the development of the NMDSWB model, certain hydrologic variables have been identified as particularly uncertain. These include groundwater storage change and total groundwater storage, *R*, *RO*, and ET_{ls}. Incorporating concurrent research from the New Mexico Statewide Water Assessment toward improved estimates of these parameters is discussed in Section 8.1.1. Future enhancements to the NMDSWB model should include incorporation of better estimates of historical and current hydrologic conditions based on these new research efforts, as well as an attempt to include total groundwater availability within the NMDSWB framework and potential refinement of spatial MBAUs to include HUC-8 watersheds (USBR, USGS, and NRCS, 2013). This spatial unit would be consistent with efforts by the USGS (2015b) and would increase the spatial resolution of the NMDSWB from the current county level maximum to HUC-8 watershed based units. For the future period of the model, more detailed and regionally specific future scenario options are worth consideration. Interest has been expressed in scenario capabilities that incorporate water rights and interstate compacts. As explained in Appendix A.2.9 and A.2.20, interstate compact logic is already included in reservoir operations for the Canadian and Rio Grande rivers, but incorporating interstate compact logic for the Pecos and San Juan rivers would be an improvement to the model. The large scale spatial resolution and relatively low temporal (monthly) resolution of the NMDSWB will always limit the usefulness of the model for detailed water rights questions; however, general questions regarding water rights of larger entities or groups of users such as cities or irrigation districts may be addressed with some success with future versions of the NMDSWB.

Users can access the NMDSWB modeled results via the interactive visualization tool on the NMDSWB page on the NM WRRI website (New Mexico Water Resources Research Intitute, 2018). This online tool currently includes a predefined set of approximately 108 future scenarios, representing four climate model options, three population growth rate options (historically derived projection, 80% of the historically derived projection, and 120% of the historically derived projection), three per-capita use rate options (historically derived projection, 80% of the historically derived projection, and 120% of the historically derived projection), and three agricultural acreage by crop type options (historically derived projection for all crop types, 75% of the historically derived projection for all crop types, and 125% of the historically derived projection for all crop types). For the full Powersim version of the model, contact the New Mexico Water Resources Research Institute at (575) 646-4337.

8.1.1 Incorporation of Statewide Water Assessment Data

Concurrent with the development of the NMDSWB model, research groups from the New Mexico Institute of Mining and Technology, New Mexico Bureau of Geology and Mineral Resources, NM WRRI, NMSU, OSE, and USGS have been developing new statewide hydrologic data as part of the Statewide Water Assessment. A primary goal of these research efforts is to help inform the NMDSWB model with the most up-to-date and accurate data available and, in this way, better constrain the estimates of local and regional water budgets generated by the NMDSWB model. The work of the Statewide Water Assessment research groups to develop statewide estimates of aquifer *R*, *RO*, ET (Ketchum et al., 2015), and groundwater storage change (Rinehart et al., 2016) has proceeded in parallel with NMDSWB model development, and specific results from these efforts such as groundwater storage change for select MBAUs have been incorporated into the NMDSWB model as they became available, and will continue to be incorporated into the NMDSWB upon their completion.

To avoid duplicative calibration efforts, incorporation of additional groundwater storage change values from Rinehart et al. (2016) has been delayed pending development of stable statewide *R* and *RO* values. In the meantime, a comparative analysis was performed between groundwater storage change values in the Rio Grande and Central Closed river basins (Rinehart et al., 2016), preliminary statewide *R*, *RO*, and ET values (Ketchum et al., 2015), and corresponding NMDSWB model estimates of these terms. This comparison is summarized in Appendix A.25 and gives a sense of areas in which the gage-based mass balance approach (NMDSWB) is or is not consistent with the independent observation- (groundwater storage) and physical model-based (*R*, *RO*, and ET) efforts to arrive at the same mass balance terms.

8.2 Conclusions

Water has always been a critical resource in New Mexico. Long-term economic stability in the state depends on a thorough understanding of the extent and limits of these water resources. The NMDSWB aims to engage planners, policy makers, water users, scientists, and the interested public across New Mexico in an interactive exploration of historical and potential future water distribution throughout the state. As population growth and potential climate change drive increases in demand and potential impacts on future supplies, it is more important than ever that New Mexico's limited water resources are quantified as completely as possible. The NMDSWB is a novel effort to aggregate a variety of water-related observations and calculations into a single framework to account for historical water movement through the state from 1975 through 2015 and to then provide estimates of future water use and supply into the future through 2099.

By compiling existing relevant information into a single mass balance constrained framework, an overall picture of water resources, movement, and use at a variety of spatial scales is possible. Closing the mass balance around this data has resulted in mass balance-based or -influenced estimates of certain terms such as ET_{sw}, plant ET, and *R*, which are otherwise difficult to obtain. It enables quantitative estimates of other parameters such as *RO* and changes in storage for which measurements are non-available or sparse. The NMDSWB effort has shown that *P* data and surface water records are relatively robust, and estimates of human use, although temporally coarse, are also extensive. The understanding and quantification of *R*, $SW \Leftrightarrow GW$ interactions, and regional groundwater movement on the other hand are less developed, and the NMDSWB effort is bringing these data gaps to the forefront and helping to direct other research efforts.

Uncertainties of note in the NMDSWB include the closure-based calculation methods for *R* and the $SW \Leftrightarrow GW$ flux. The uncertainty analysis discussed in Section 7 aims to quantify the degree to which these assumptions may affect model output. Until the parallel work by other researchers in the Statewide Water Assessment begins to fill in data gaps, however, the uncertainty of fluxes and stocks calculated by the NMDSWB remains high, and users should be cautioned to use model output as draft values. As the work from groups in the Statewide Water Assessment becomes available, the uncertainty of fluxes and stocks represented in the NMDSWB model will decrease and the utility of the model for providing a high-level view of New Mexico's water resources for planning purposes will be enhanced. The scenario capability of the NMDSWB model allows a model user to interactively explore potential impacts of various assumptions on long-term trends in regional water budgets within New Mexico. Providing this capability in the face of an uncertain water future adds a compelling and critical capability to the quiver of tools available to water planners across the state.

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A Appendix

A.1 Climate Change

A.1.1 The CMIP3 GCM Runs

Phase 3 of the Coupled Model Intercomparison Project[5] (CMIP3) archived temperature and precipitation model output from 16 Global Climate Models (GCM) run from 1950 through 2099 for three different emission scenarios and a variety of boundary conditions. The result is 112 different GCM runs numbered according to the framework shown in Table 8. The 112 CMIP3 GCM runs were spatially downscaled to 1/8-degree resolution using statistical methods. The resulting "Bias Corrected Spatially Downscaled" projections are archived for public access.[6]

A.1.2 Selection of 4 GCM Runs for NMDSWB Scenarios

There is large uncertainty associated with GCM runs, and as a result it is typical to use a large set of GCMs to get a sense of the range of possible outcomes that might be expected. For the purposes of the NMDSWB, model usability considerations were for fewer climate change scenarios, while model value considerations were to capture a large range of future conditions. To accomplish both goals, four GCM runs were chosen to represent a wide range of potential climate change futures. This selection occurred as follows. First, two A2 scenario model runs by the MPI ECHAM5 and GFDL CM2.0 models (runs 48 and 59 in Table 8) were selected as runs because they had been dynamically downscaled (Hostetler et al., 2011) to generate high spatial resolution data that can be used by the recharge group of the New Mexico Statewide Water Assessment (Ketchum et al., 2015) to evaluate climate change impacts. Next, a run was selected from each of the A1b and B1 scenarios to represent relatively large and small long-term climate change impacts respectively. These impacts were determined by comparison of change to simulated average precipitation and average temperature in future periods with the simulated average values during the historical period as described in detail below. The intent of this selection was to capture a large range of potential climate change impacts in a small sample of runs. Analysis of individual GCM skill (ability to match historical observations), uncertainty, or biases in New Mexico were not considered, rather the behavior of the GCMs within the range of GCM behaviors was the key metric utilized. This selection was done based on visual inspection of figures developed for the Santa Fe Basin Study (Llewellyn et al., 2015) as described below and shown in Figure 15, Figure 16, and Figure 17.

A.1.3 GCM Ensembles

GCM runs can be grouped by comparing average temperature and precipitation simulated by each GCM over a given area during a historical period of 1950–1999 to averages over the same

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[5] http://www-pcmdi.llnl.gov/projects/cmip/index.php

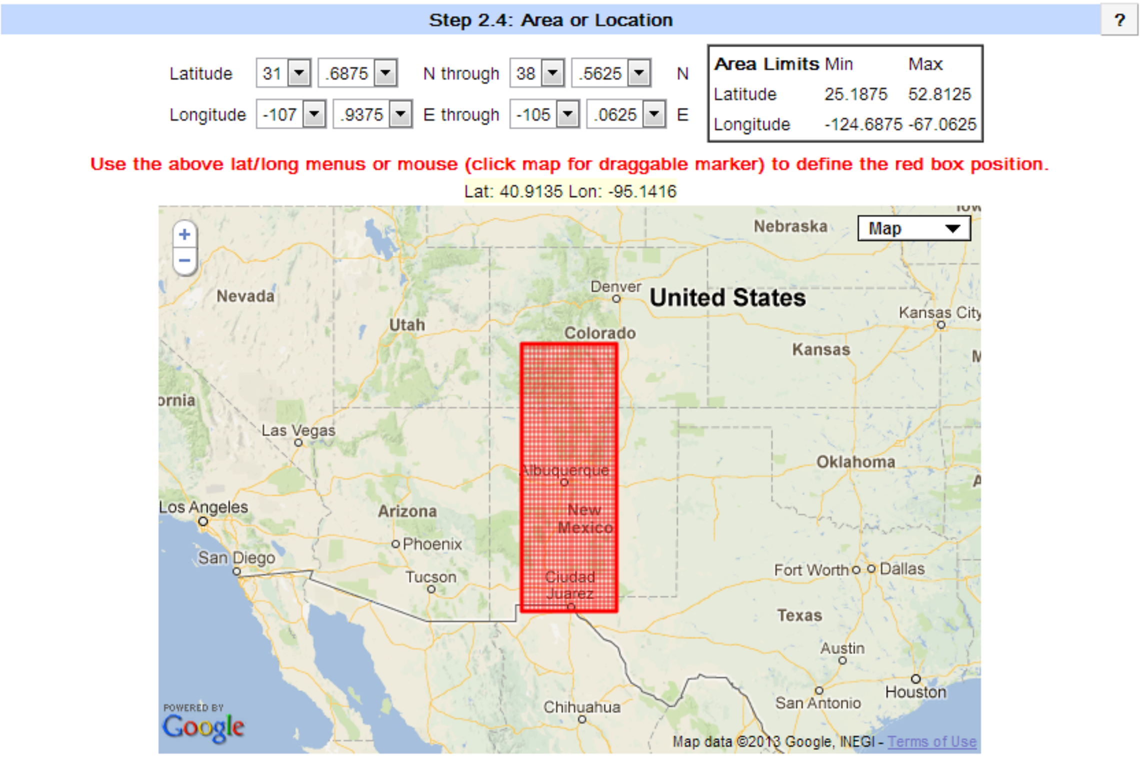
[6] http://gdo-dcp.ucllnl.org/

area for future simulation years. This was done for the Santa Fe Basin Study (Llewellyn et al., 2015), and that work is used here for relative comparisons of GCM runs in New Mexico. The steps used to develop Figure 15, Figure 16, and Figure 17 are listed below.

1. A representative area for the Upper Rio Grande basin was selected. This is a rectangle extending from 31.6875 through 38.5625 degrees of latitude, and -107.9375 through -105.0625 degrees of longitude as shown in Figure 13.
2. A single average temperature and average precipitation was calculated for each GCM for the spatial area chosen during the 1950–1999 historical simulation period (average of each month of data in each 1/8-degree pixel shown in Figure 13.)
3. Three more average temperature and average precipitation values were calculated for each GCM run for the spatial area chosen during the 2010–2039, 2040–2069, and 2070–2099 simulation periods.
4. The difference between these values was defined as the “delta” temperature and the “delta” precipitation for each model for the spatial extent and time periods selected.
5. The temperature deltas were plotted against the precipitation deltas, and for visual purposes the deltas were grouped according to rank as above or below the 50th percentile temperature delta, above or below the 50th percentile precipitation delta, or between the 25th and 75th percentile deltas for both.

Table 8. The index values of the 112 CMIP3 GCM runs and the associated model and emission scenario. Highlighted runs are used for climate model options by the NMDSWB model.

	Emissions Scenarios																		
Climate Models:	A1b							A2					B1						
bccr_bcm2_0	1							40					76						
cccma_cgcm3_1	2	3	4	5	6			41	42	43	44	45	77	78	79	80	81		
cnrm_cm3	7							46					82						
csiro_mk3_0	8							47					83						
gfdl_cm2_0	9							48					84						
gfdl_cm2_1	10							49					85						
giss_model_e_r		11		12				50					86						
inmcm3_0	13							51					87						
ipsl_cm4	14							52					88						
miroc3_2_medres	15	16	17					53	54	55			89	90	91				
miub_echo_g	18	19	20					56	57	58			92	93	94				
mpi_echam5	21	22	23					59	60	61			95	96	97				
mri_cgcm2_3_2a	24	25	26	27	28			62	63	64	65	66	98	99	100	101	102		
ncar_ccsm3_0	29	30	31		32	33	34	67	68	69	70		103	104	105	106	107	108	109
ncar_pcm1	35	36	37	38				71	72	73	74			110	111				
ukmo_hadcm3	39							75					112						



Step 2.4: Area or Location

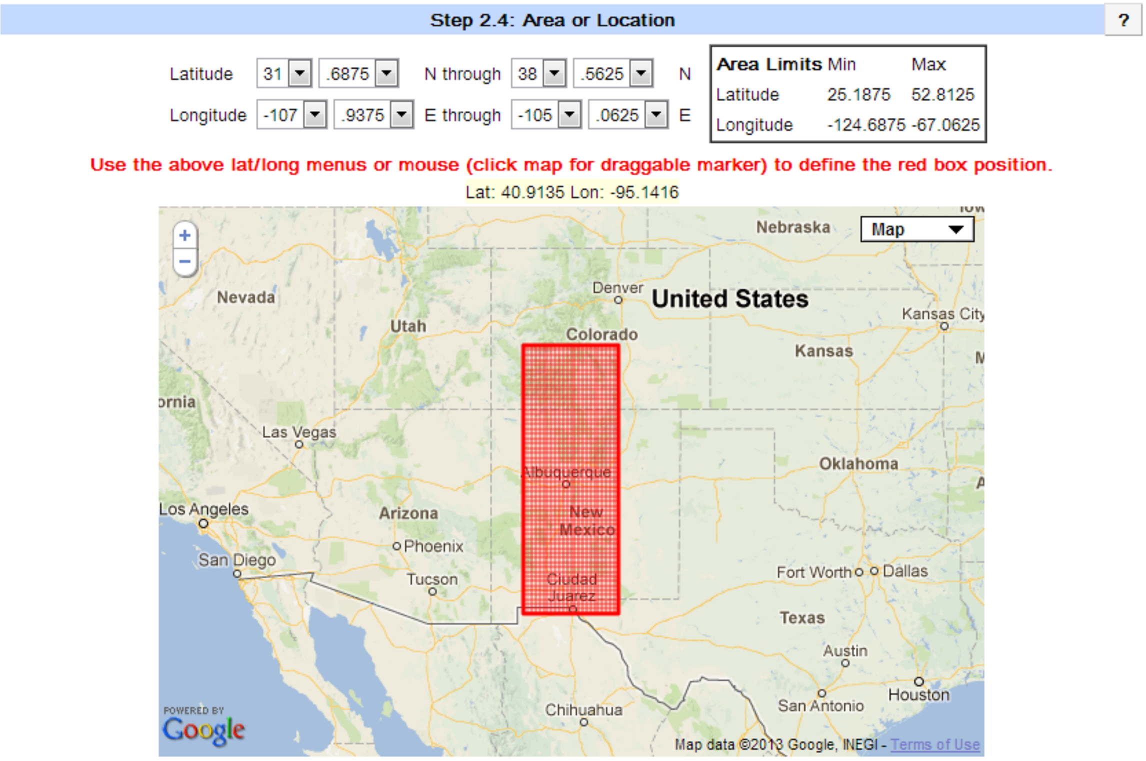
Latitude 31 .6875 N through 38 .5625 N

Longitude -107 .9375 E through -105 .0625 E

Area Limits	Min	Max
Latitude	25.1875	52.8125
Longitude	-124.6875	-67.0625

Use the above lat/long menus or mouse (click map for draggable marker) to define the red box position.

Lat: 40.9135 Lon: -95.1416



Step 2.4: Area or Location

Latitude 31 .6875 N through 38 .5625 N

Longitude -107 .9375 E through -105 .0625 E

Area Limits	Min	Max
Latitude	25.1875	52.8125
Longitude	-124.6875	-67.0625

Use the above lat/long menus or mouse (click map for draggable marker) to define the red box position.

Lat: 40.9135 Lon: -95.1416

Figure 13. Spatial area used to define the average temperature and precipitation value for each GCM for a given time period. Extents are 31.6875 through 38.5625 degrees of latitude, and -107.9375 through -105.0625 degrees of longitude. Screen capture from http://gdo-dcp.ucllnl.org/.

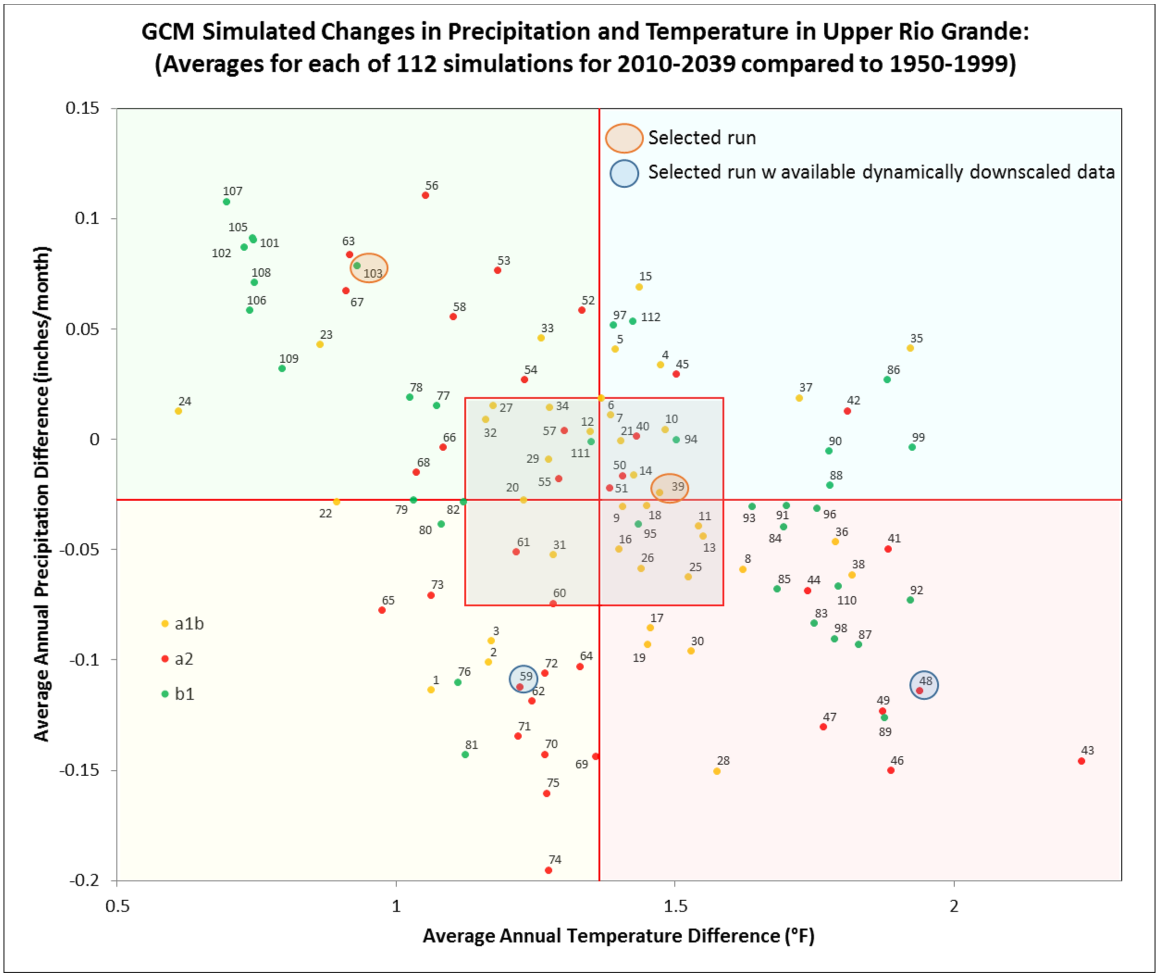


Figure 14. Plotting the temperature delta (X axis) against the precipitation delta (Y axis) to group the 112 GCMs based on the 2010–2039 simulation period. The red lines represent the 50% values for each, and the red bounding square encompasses the 25% to 75% values.

Figure 15. Plotting the temperature delta (X axis) against the precipitation delta (Y axis) to group the 112 GCMs based on the 2040–2069 simulation period. The red lines represent the 50% values for each, and the red bounding square encompasses the 25% to 75% values.

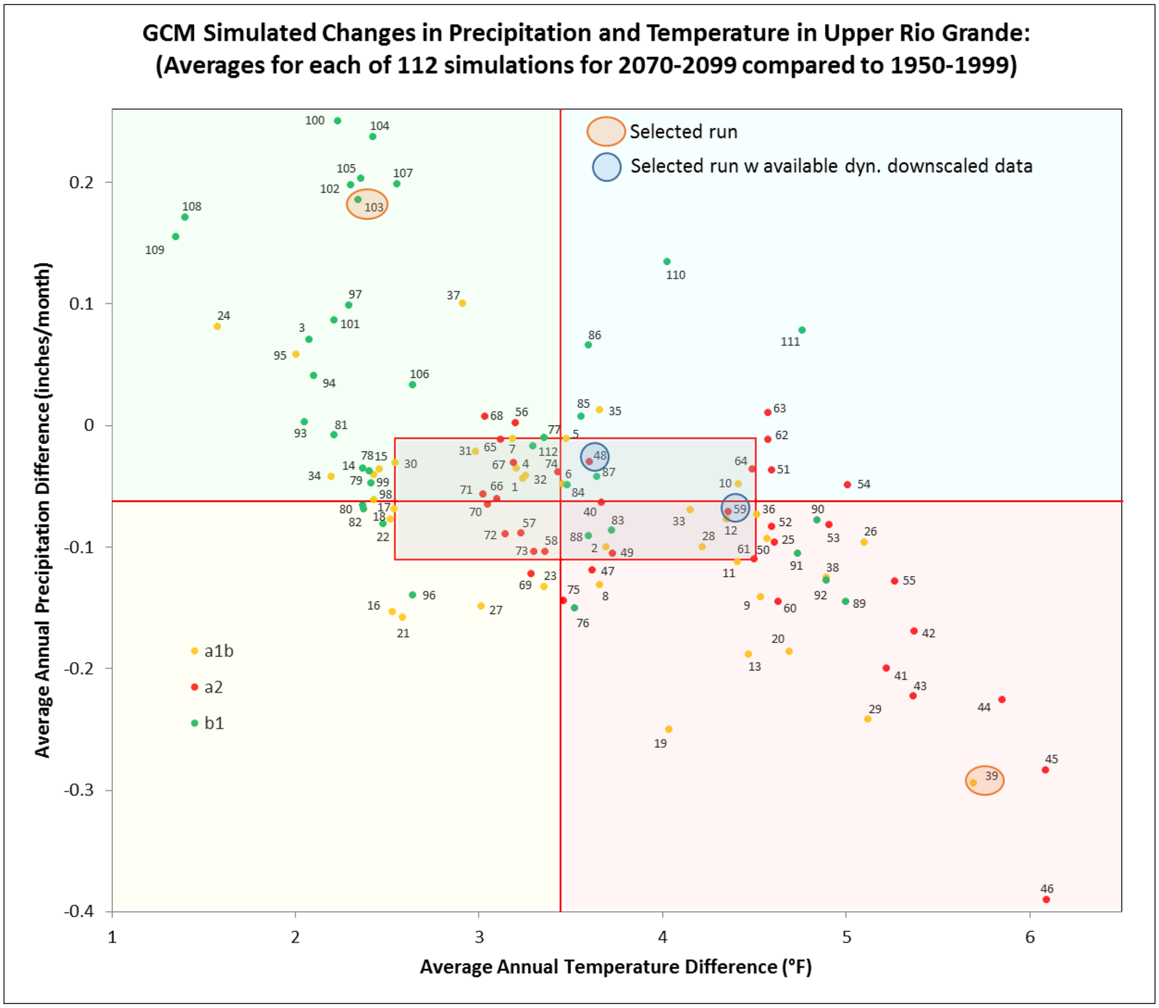
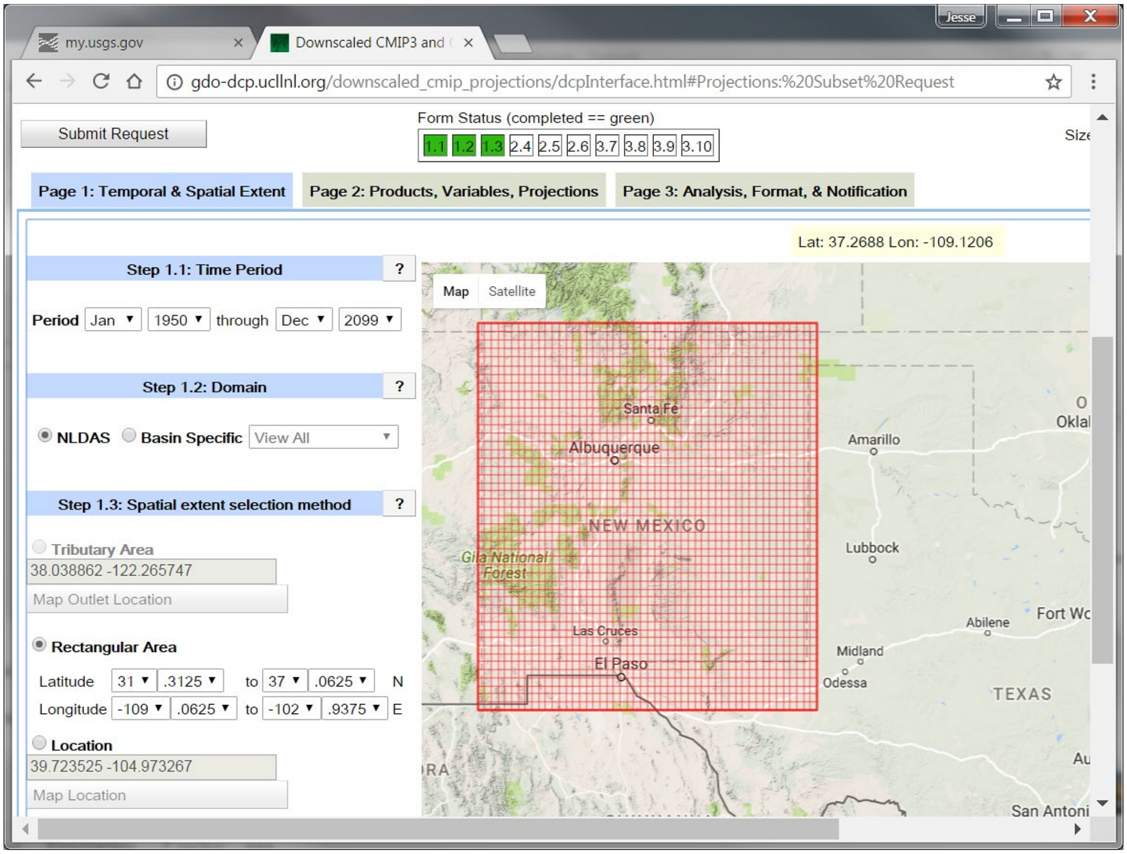


Figure 16. Plotting the temperature delta (X axis) against the precipitation delta (Y axis) to group the 112 GCMs based on the 2010–2019 simulation period. The red lines represent the 50% values for each, and the red bounding square encompasses the 25% to 75% values.

A.1.4 Input Data Generation

Once the four model runs to be used to generate different climate scenarios were selected, the temperature, precipitation, and inflow data associated with each was developed.

Monthly average, 1/8th degree average temperature and precipitation data simulated by each model from 1950 through 2099 was downloaded from ucllnl.org for the spatial extent of 31.3125° to 37.0625° North and -109.0625° to -102.9375° east for each of the selected GCMs as shown in Figure 17. This temperature and precipitation data were averaged across county, water planning region, and river basin for use as input to the NMDWSB. Maximum and minimum temperatures for each county were calculated using a historical ratio of historical mean to maximum temperature and historical mean to minimum temperature, as there was no maximum and minimum temperature available from the GCM outputs. These ratios were then used to project the maximum and minimum temperatures for the four model runs.



Form Status (completed == green)

Step 1.1: Time Period

Period Jan 1950 through Dec 2099

Step 1.2: Domain

● NLDAS ○ Basin Specific View All

Step 1.3: Spatial extent selection method

○ Tributary Area

38.038862 -122.265747

Map Outlet Location

● Rectangular Area

Latitude 31 .3125 to 37 .0625 N

Longitude -109 .0625 to -102 .9375 E

○ Location

39.723525 -104.973267

Map Location

Figure 17. Spatial data extent for downscaled GCM based precipitation and temperature data.

A.1.5 Projected Streamflow Inputs

Flows associated with each of the CMIP3 GCM runs were generated at a variety of locations as part of the Upper Rio Grande Impacts Assessment (URGIA) (Llewellyn et al., 2013). Flows were generated by using downscaled temperature and precipitation data to drive the Variable Infiltration Capacity (VIC) land surface model (Liang et al., 1994) to generate flows, which were in turn used to drive the Upper Rio Grande Simulation Model (URGSiM), a monthly timestep water operations model. There are 16 flow inputs required by the NMDSWB, and six of them are associated with watershed inflows from within New Mexico to modeled reservoirs, and eight are associated with flows into New Mexico across state lines. Of these 16, four were available as output from VIC (generally unregulated flows), two were available as output from URGSiM (flows regulated by human activity), and the remainder were generated by correlation to (generally unregulated) flows generated by VIC on the Rio Blanco above the San Juan Chama diversion, the Santa Fe River above McClure, and the Rio Puerco near Bernardo. As seen in Figure 18, historical flows on the Rio Blanco above the San Juan Chama diversion correlate well with historical flows on the Animas River near Cedar Hill, the San Juan River near Caraccas, and the Piedra River near Arboles. Correlations between the Blanco and the smaller La Plata River at the NM-CO state line, Los Pinos River at La Boca, and Mancos River near Towaoc were not as strong but considered sufficient for capturing the general climate change signal associated with the GCM runs. These correlations were used in conjunction with GCM-VIC based simulation of flows on the Rio Blanco above the San Juan Chama diversion to generate climate change based flows at these six inflows points to the NMDSWB. As seen in Figure 19, historical flows along three tributaries to Eagle Nest reservoir correlate reasonably to historical flows on the Santa Fe River above McClure reservoir. These correlations were used in conjunction with GCM-VIC based simulation of flows on the Santa Fe River above McClure reservoir to generate climate change based flows at these three inflows points to the NMDSWB.

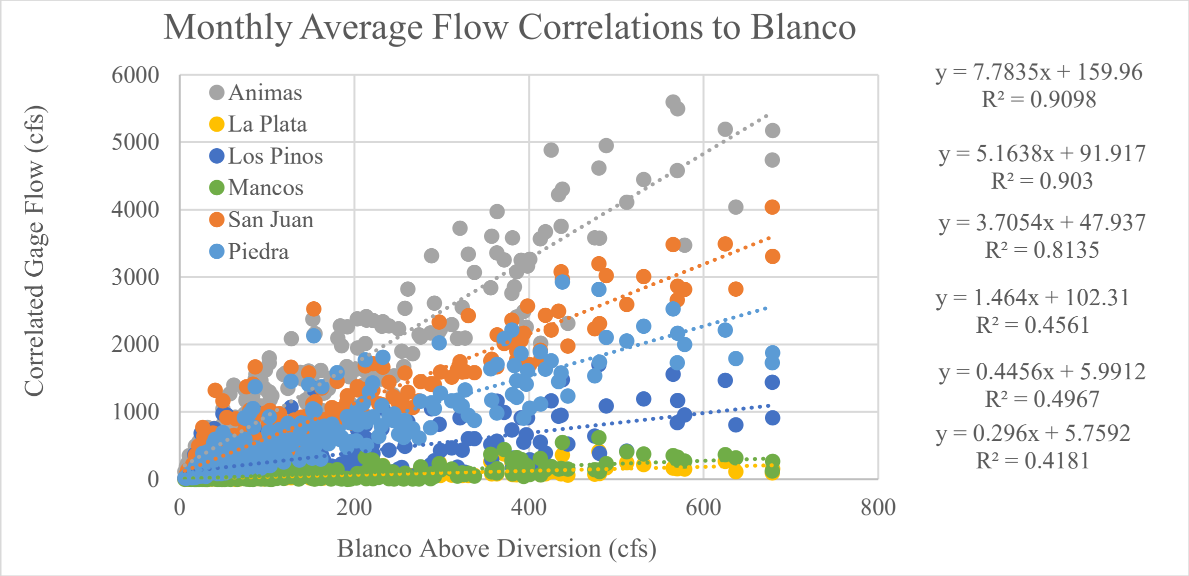


Figure 18. Correlations between historical flow on the Rio Blanco above the San Juan Chama diversion and the Animas River near Cedar Hill, the La Plata River at the NM-CO state line, the Los Pinos River at La Boca, the Mancos River near Towaoc, the San Juan River near Caraccas, and the Piedra River near Arboles.

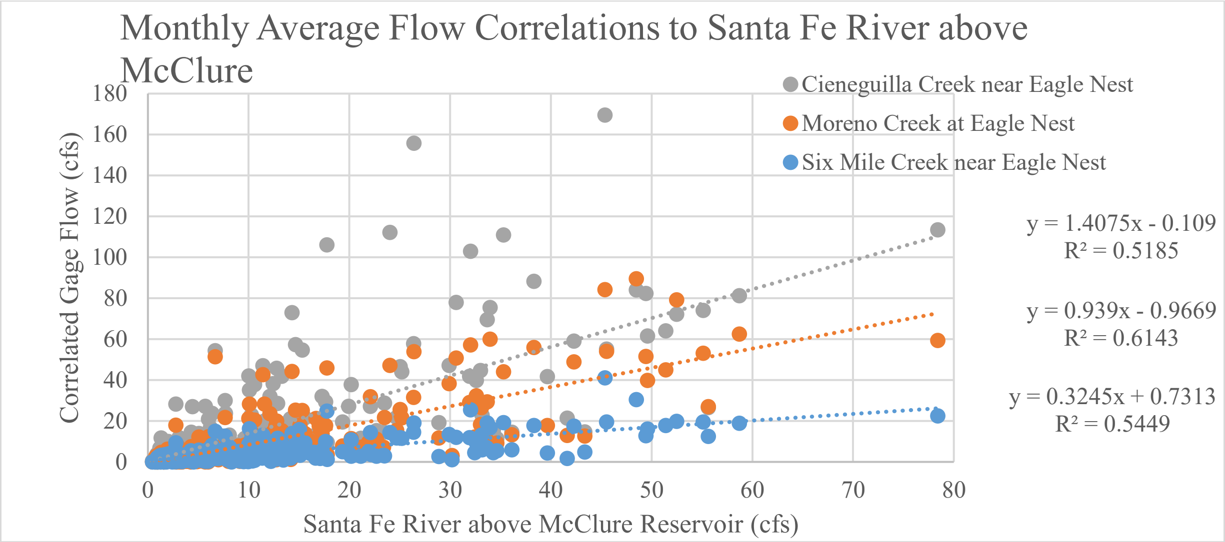


Figure 19. Correlations between historical flow on the Santa Fe River above McClure and three tributaries to Eagle Nest Reservoir.

The Delaware River near Red Bluff, New Mexico represents the only flow into New Mexico from a state other than Colorado in the NMDSWB. This inflow joins the Pecos River and then flows back into Texas, and so does not represent water that can be used by New Mexico. Historical flow at this location does not correlate to any meaningful degree with historical flow at any location for which climate change based flow information is available. Due to the lack of climate change information and the relative lack of impact of these flows on New Mexico water use, a very simple approach was taken to developing the climate change driven flows at the Delaware River near Red Bluff. The historical flows at this location were averaged by month from 1969 through 2014, and the average monthly values were used for all future months modified by the magnitude of change between historical and future time periods simulated by GCM and VIC model output at the Rio Puerco near Bernardo, the southernmost point for which climate change based flows were available through URGIA. The historical average monthly flows by month were multiplied by the factors shown in Table 9 depending on the future year to generate the climate change impacted flows at the Delaware River near Red Bluff.

Table 9. GCM-VIC simulated relative changes in flow volume at the Rio Puerco near Bernardo through time.

Rio Puerco near Bernardo Simulated Change vs 1950–2009				
GCM Run Index:	**39**	**48**	**59**	**103**
2010–2039	-20%	-55%	-40%	57%
2040–2069	-31%	-59%	-34%	28%
2070–2099	-63%	-77%	-38%	60%

Table 10. summarizes the NMDSWB inflow data required for scenario evaluation, and how each flow was generated based on some combination of GCM, VIC, and URGSiM model output. Table 17 summarizes which MBAUs these modeled inflows become inputs too.

Table 10. Inflow data summary for the NMDSWB.

NMDSWB Inflow Location	Climate Change Scenario Source
Rio Grande near Lobatos	URGSiM output, URGIA (Llewellyn et al. 2013)
Azotea tunnel flows	URGSiM output, URGIA (Llewellyn et al. 2013)
Rio Chama near La Puente	VIC output, URGIA (Llewellyn et al. 2013)
Nambe Reservoir inflow	VIC output, URGIA (Llewellyn et al. 2013)
Santa Fe River above McClure	VIC output, URGIA (Llewellyn et al. 2013)
Jemez River near Jemez	VIC output, URGIA (Llewellyn et al. 2013)
San Juan River near Caraccas	Scaled to VIC flows at Rio Blanco diversion with historical correlation
Piedra River near Arboles	Scaled to VIC flows at Rio Blanco diversion with historical correlation
Los Pinos River at La Boca	Scaled to VIC flows at Rio Blanco diversion with historical correlation
Animas River near Cedar Hill	Scaled to VIC flows at Rio Blanco diversion with historical correlation
La Plata River at state line	Scaled to VIC flows at Rio Blanco diversion with historical correlation
Mancos River near Towaoc	Scaled to VIC flows at Rio Blanco diversion with historical correlation
Eagle Nest Reservoir Inflows	Scaled to VIC flows at Santa Fe River above McClure Reservoir with historical correlation
Delaware River near Red Bluff	Historical monthly averages multiplied by relative changes simulated by GCMs and VIC at Rio Puerco near Bernardo

A.2 Reservoirs

There are 19 reservoirs that are modeled in the NMDSWB (Table 15). The reservoirs modeled here are of significant importance to the hydrologic regime of a given MBAU and have publicly available historical operations data. There are several smaller reservoirs in New Mexico used primarily for public water supplies that have not yet been included into the NMDSWB effort due to sparse or unavailable data.

A.2.1 Navajo Reservoir

Navajo reservoir, 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 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] (USGS, 2015; 2018). 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] (USGS, 2015; 2018).

Diversion information to the NIIP is provided as a single constant annual value of 126,263 acre feet from 1976 to 1997, and from 1998 through 2013 the diversion information is provided as annual volumes for each year (Beutler, 2014). Since no values were available for 2014 and 2015, the 2013 annual diversion (Beutler, 2014) was used. The annual diversion volume is disaggregated to a monthly timestep 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 (2018) 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 an area-capacity table provided by the USBR (2015).

Evaporation from the reservoir is calculated using the Hargreaves-Samani 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 (Table 16 (Appendix A.4) (Roach, 2012). Reservoir operations data: storage, pool elevation, and an area-elevation-capacity table is provided by the USBR (U.S Bureau of Reclamation et al., 2015).

In addition to the known inflows/outflows of the reservoir, there are additional unknown gains/losses. During the historical period, these are modeled to equal the difference between observed storage change and predicted storage change. In order to model reservoir storage into the future, a calibration inflow term of 6.22% has been added to the gaged inflow, such that cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010.

In the future portion of the model, Navajo reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Rules governing Navajo reservoir are currently oversimplified and do not fully reflect the provisions laid forth in the Upper Colorado River Basin Compact. However, the rules used in the future portion of the model accurately reflect how the reservoir operated historically. For each timestep in the model, the future reservoir rules aim to release a target release. If there is not enough water in the reservoir to meet the target release, then only the available water is released. For any given timestep, if there is too much inflow into the reservoir for the given storage capacity and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir. The target release for Navajo reservoir has been calibrated based on the historical period of 1975–2010 such that for each month, there is a ratio between reservoir inflow and outflow. These monthly ratios are used in the future so that for each month, a given portion of simulated inflow is set to equal the target release.

A.2.2 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), except for the February 2015 to January 2016 storage data, which is from the USBR (2018). 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 (USGS, 2015; 2018).

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 et al., 2015).

Evaporation from the reservoir is calculated from Hargreaves-Samani reference ET for Guadalupe county multiplied by the surface area of the reservoir as well as by monthly open water coefficients calibrated for Santa Rosa reservoir from USACE calculated reservoir evaporation depths (Young, 2015a) (Table 16) (Appendix A.4).

In addition to the known inflows/outflows of the reservoir, there are additional unknown gains/losses. During the historical period, these are modeled to equal the difference between observed storage change and predicted storage change. In order to model reservoir storage into the future, a calibration groundwater leakage term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The Groundwater leakage term is calculated as the product of the current pool elevation of Santa Rosa reservoir and a constant of 0.00745 ft^2/s.

In the future portion of the model, Santa Rosa reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Rules governing Santa Rosa reservoir are currently oversimplified and do not fully reflect the provisions laid forth in the Pecos River Basin Compact. However, the rules used in the future portion of the model accurately reflect how the reservoir operated historically. For each timestep in the model, the reservoir rules aim to release a target release. If there is not enough water in the reservoir to meet the target release, then only the available water is released. If there is too much inflow into the reservoir given the current storage and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir. The target release for Santa Rosa reservoir has been calibrated based on the historical period of 1975–2010 such that for each month, there is a ratio between reservoir inflow and outflow. These monthly ratios are used in the future so that at each month, a given portion of simulated inflow is set to equal the target release.

A.2.3 Sumner Reservoir

The Fort Sumner irrigation project was developed by private interests in the late 19th and early 20th centuries. In the early 1950s, Sumner Dam 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; 2018). 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 (USGS, 2015; 2018).

Precipitation falling on the reservoir is calculated using the PRISM (2018) 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-Samani 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 (Table 16) (Appendix A.4).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration inflow term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated inflow term is calculated as 0.1 % of gaged reservoir inflow.

In the future portion of the model, Sumner reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Rules governing Sumner reservoir are currently oversimplified and do not fully reflect the provisions laid forth in the Pecos River Basin Compact. However, the rules used in the future portion of the model accurately reflect how the reservoir operated historically. For each timestep in the model, the reservoir rules aim to release a target release. If there is not enough water in the reservoir to meet the target release, then only the available water is released. If there is too much inflow into the reservoir given the current storage and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir. The target release for Sumner reservoir has been calibrated based on the historical period of 1975–2010 such that for each month, there is a ratio between reservoir inflow and outflow. These monthly ratios are used in the future so that for each month, a given portion of simulated inflow is set to equal the target release.

A.2.4 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, whereas Rocky Dam is non-gated and drains at a maximum rate of 300 cfs. During large flood events, the two reservoirs breach the dike separating them and become one common pool. Reservoir storage data for Two Rivers reservoir is from USACE (Young, 2015b) and USACE (2018). 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] (USGS, 2015; 2018). 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 an area-capacity look up table provided by the USACE (Young, 2015b).

Evaporation from the reservoir is calculated using the Hargreaves-Samani 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, the nearest reservoir with pan evaporation data (Table 16) (Appendix A.4).

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. In order to model reservoir storage into the future, a calibration groundwater leakage term has been added, such that cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated groundwater leakage term is calculated as the product of the current reservoir pool elevation and a constant of 0.00211 ft^2/s.

Two Rivers reservoir is operated primarily for flood control and has no active storage. The reservoir inflow, outflow, and storage are still simulated in the future portion of the model. However, because inflows are aggregated to a monthly flow, the peak floodwaters that are slowed down by two rivers reservoir are not seen in this model as they would be on a daily timestep. The reservoirs only rule is to limit flow to the downstream channel capacity, if that is not exceeded, then all available water is released.

A.2.5 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] (USGS, 2015; 2018).

Reservoir evaporation rate is calculated using Hargreaves-Samani 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 that was calibrated for Brantley Reservoir, the nearest reservoir with pan evaporation data (Table 16) (Appendix A.4).

An area-capacity table was not available to convert storage to surface area, thus a simple linear relationship was developed assuming the shape 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 (2018) 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 that is less than or greater than observed storage change. In order to model reservoir storage into the future, a calibration groundwater leakage term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated groundwater leakage term is calculated as 33.2% of gaged reservoir inflow.

A.2.6 Brantley Reservoir

In the NMDSWB, Brantley reservoir begins to fill October of 1988. Area-capacity data for Brantley reservoir was provided by the U.S Bureau of Reclamation (Donnelly, 2015) and storage data is from the USBR (2018). 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] (USGS, 2015; 2018). The gaged outflow is represented by USGS gage, Pecos River below Brantley Dam near Carlsbad, NM [8401500] (USGS, 2015; 2018).

Precipitation falling on the reservoir is calculated using the PRISM (2018) 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 look-up table (Donnelly, 2015).

Reservoir evaporation is calculated using Hargreaves-Samani reference ET for Eddy County (Section 5.1.1) multiplied surface area at the given timestep and an open water evaporation coefficient that was calibrated for Brantley reservoir (Table 16) (Appendix A.4) 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 that is less than or greater than observed storage change. In order to model reservoir storage into the future, a calibration inflow term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated inflow term is calculated as 1.6% of gaged reservoir inflow.

In the future portion of the model, Brantley reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Rules governing Brantley reservoir are currently oversimplified and do not fully reflect the provisions laid forth in the Pecos River Basin Compact. However, the rules used in the future portion of the model accurately reflect how the reservoir operated historically. For each timestep in the model the reservoir rules aim to release a target release. If there is not enough water in the reservoir to meet the target release, then only the available water is released. If there is too much inflow into the reservoir given the current storage and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir. The target releases for Brantley reservoir have been calibrated based on the historical period of 1975–2010 such that for each month, there is a ratio between reservoir inflow and outflow. These monthly ratios are used in the future so that at each month, a given portion of simulated inflow is set to equal the target release.

A.2.7 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; USBR, 2018).

The gaged reservoir inflow is the USGS gage, Pecos River at Damsite 3 near Carlsbad, NM [USGS# 8402000] (USGS, 2015; 2018). The gaged outflows are USGS gages, Pecos River below Avalon Dam [USGS# 8404000] and Carlsbad Main Canal at Head near Carlsbad, NM [8403500] (USGS, 2015; 2018).

Precipitation falling on the reservoir is calculated using the PRISM (2018) 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 look-up table provided by the USBR (Donnelly, 2015).

Reservoir evaporation is calculated using Hargreaves-Samani reference ET for Eddy County (Section 5.1.1) multiplied by an open water evaporation coefficient (Table 16) (Appendix A.4) that was calibrated for Brantley reservoir using 1997–2011 reservoir evaporation data from the USBR (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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration groundwater leakage term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated groundwater leakage term is calculated as the product of current reservoir storage and a constant term of 0.34315 per month. Elevation-capacity data was unavailable for Avalon reservoir; hence storage was used in lieu of pool elevation for calculating groundwater leakage.

In the future portion of the model, Avalon reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Rules governing Avalon reservoir are currently oversimplified and do not fully reflect the provisions laid forth in the Pecos River Basin Compact. However, the rules used in the future portion of the model accurately reflect how the reservoir operated historically. For each given timestep in the model, the reservoir rules aim to release a target release. If there is not enough water in the reservoir to meet the target release, only the available water is released. If there is too much inflow into the reservoir given the current storage and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir. The target release for Avalon reservoir have been calibrated based on the historical period of 1975–2010 such that for each month, there is a ratio between reservoir inflow and outflow. These monthly ratios are used in the future so that for each month, a given portion of simulated inflow is set to equal the target release.

A.2.8 Eagle Nest Reservoir

Eagle Nest reservoir is located in Colfax County and is in the northwest portion of the Canadian river basin. Storage data from 1970–2013 is provided by the USGS Water Resources Data for New Mexico annual reports (*Water resources data for New Mexico, water year 1969–2013; Part 1. Surface water records*, n.d.) and storage data from 2014–January 2016 is from the USGS (2018).

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] (USGS, 2015). Outflow from the reservoir is measured from the USGS gage, Cimarron River below Eagle Nest Dam [USGS# 07206000] (USGS, 2015; 2018). Data for the three inflow stream gages are unavailable after 2010, at this point in the model reservoir inflow is estimated for the remaining historical years (2010–present) from the Cimarron River below Eagle Nest gage multiplied by monthly historical percentages of releases as inflow.

Surface area is estimated using a stage rating curve manual developed using four aerial images. See Table 11 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 0.99 and is written as:

$$A = -3E^{-7} * S^2 + 0.0575S - 7.5205 \qquad \text{(Equation 13)}$$

Where:

A = Area of reservoir

S = Storage of reservoir

Table 11. 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 (2018) 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-Samani reference ET for Colfax County and a monthly open water coefficient. The monthly open water coefficients used can be seen in Table 16, and are based on values for Heron and El Vado from URGSiM (Roach, 2007). Precipitation data are provided by the PRISM (2018) dataset.

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration inflow term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated inflow term is calculated as 37% of gaged reservoir inflow.

In the future portion of the model, Eagle Nest reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Target releases are designed to meet downstream demands for municipal and agricultural surface water uses in Colfax County. For a given calendar year, releases from Eagle Nest reservoir are set equal to the monthly demand for municipal and agricultural surface water uses until annual allocations have been met, at which time no additional water will be released until the following year. Annual municipal surface water allocations for Colfax County are set to 4,484 AF per year and annual agricultural surface water allocations are set to 6,113 AF per year in accordance to the *Agreement For Settlement of Pending Litigation and Other Disputes Concerning State Engineer Permit No. 71* (The State of New Mexico, 2006).

A.2.9 Conchas Reservoir

Conchas reservoir storage data were provided by the USACE for 1970–2014 (Ball, 2014) and by USACE (2018) for 2015–January 2016. Reservoir surface area is calculated from two area-capacity look up tables, one for 1970–1987 and one for 1988–2014 (Ball, 2014).

Inflow into Conchas reservoir is measured from the USGS gage, Canadian River near Sanchez, NM [USGS# 07221500] (USGS, 2015; 2018). 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 that all releases below 400 cfs and 1/3 of the releases above 400 cfs 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 1992–2014.

Precipitation falling on the reservoir is calculated using the PRISM (2018) monthly average precipitation depth for San Miguel County multiplied by the surface area of the reservoir (at the given timestep).

Hargreaves-Samani reference ET (Section 5.1.1) is used to calculate reservoir evaporation and is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16), which is calibrated for Conchas reservoir using monthly USACE pan-based reservoir evaporation estimates for 1970–2013 (Ball, 2014) (Appendix A.4).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration inflow term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated inflow term is calculated as 53.4 % of gaged reservoir inflow.

In the future portion of the model, Conchas reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Target releases are designed to meet downstream demands of Quay County, including agricultural demands for Bell Ranch and Arch Hurley Irrigation districts. If there is available water in storage, then releases will be made to meet those demands. If available water is less than the full demand, then only the portion of available water will be released.

A.2.10 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 (USGS, 2015; 2018).

Inflow into Ute reservoir is measured from the USGS stream gage, Ute Creek near Logan, NM [USGS# 07226500] (USGS, 2015; 2018), as well as the Canadian River mainstem releases from Conchas reservoir (Conchas reservoir is 55 miles upstream of Ute Reservoir). Since the Ute Creek near Logan, NM gage does not have streamflow data for July 2013–December 2014, the monthly historical average flows were used for those months. Data for Conchas reservoir mainstem releases were provided by the USACE for 1991 through 2014 (Ball, 2014), and estimated from total releases before 1991 (See Appendices A.2.9). Outflow from Ute reservoir is measured at the USGS gage, Canadian River at Logan, NM [USGS# 07227000] (USGS, 2015; 2018).

Surface area or the reservoir is calculated from five area-capacity look-up tables, each starting in the following years: 1963, 1976, 1984, 1992, and 2002. The precipitation falling on the reservoir is calculated using the PRISM (2018) monthly average precipitation depth for Quay County multiplied by the surface area of the reservoir (at the given timestep).

Hargreaves-Samani reference ET for Quay County is used to calculate reservoir evaporation and is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Section 5.1.1), 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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration groundwater leakage term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated groundwater leakage term is calculated as the product of the current pool elevation at a given timestep and a constant of 0.004 ft^2/s.

In the future portion of the model, Ute reservoir is operated under a set of rules in accordance to the *Canadian River Compact* (Bliss et al., 1950) to try to maximize storage while meeting downstream demands and avoiding overtopping. Article IV of the *Canadian River Compact* states that New Mexico has free and unrestricted use of waters in the Canadian River basin so long as storage below Conchas dam remains below 200,000 AF. Therefore, Ute reservoir is set up in the future portion of the NMDSWB with operational guidelines that aim to maximize reservoir storage while limiting that amount to 200,000 AF.

A.2.11 Heron Reservoir

Heron reservoir is located in Rio Arriba County and the Rio Chama WPR. Historical storage data is provided by the Upper Rio Grande Water Operation Model team (URGWOM) ((URGWOM Technical Team, 2015).

Inflow into Heron reservoir is measured by the USGS stream gage Azotea Tunnel at outlet near Chama, NM [USGS# 08284160] (USGS, 2015; 2018). The 2015 Azotea Tunnel flows are from Wolfe et al. (2016). Releases from Heron reservoir are measured by the USGS stream gage Willow Creek below Heron Dam, NM [USGS #08284520] (USGS, 2015) and from URGWOM (URGWOM Technical Team, 2015) (when there are no estimates for the Willow Creek below Heron Dam, NM gage.

Surface area and pool elevation of the reservoir are calculated from an area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015).

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Rio Arriba County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET, which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Section 5.1) (Roach, 2007).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration inflow term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975-2010. The calibrated inflow term is calculated as 5.95% of the gaged Rio Chama near La Puente, NM [USGS# 08284100] streamflow.

In the future portion of the model, Heron reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. For a given calendar year, target releases are designed to meet downstream demands for municipal uses in Santa Fe and Albuquerque, as well as for agricultural surface water uses in the Middle Rio Grande. Annual surface water allocations for municipal uses in Santa Fe and Albuquerque are set to 53,805 AF per year based on an combined annual allocation of San-Juan Chama (SJC) Project water to the city of Albuquerque of 48,200 AF and 5,605 AF to the city and county of Santa Fe (Glaser, n.d.) Once annual allocations have been met, no more releases are made from Heron reservoir to meet the downstream municipal demands. Based on an annual allocation of SJC Project water to Middle Rio Grande agriculture (Glaser, n.d.), annual surface water allocations for the Middle Rio Grande agriculture demand is set to 42,395 AF per year. The Middle Rio Grande agriculture demand at any given timestep is set equal to the calculated surface water withdrawal demand in Sandoval, Valencia, Bernalillo, and Socorro Counties minus the simulated flow in the Rio Grande at Embudo, NM. In the future portion of the NMDSWB model, the simulated flow in the Rio Grande at Embudo, NM is represented by the surface water outflow from Taos County.

A.2.12 El Vado Reservoir

El Vado reservoir is located in Rio Arriba County and Rio Chama WPR, and is just downstream of Heron reservoir. Historical storage data is provided by the URGWOM Technical Team (2015).

Inflow into El Vado reservoir is gaged by the USGS stream gages Rio Chama near La Puente, NM [USGS# 08284100] and Willow Creek below Heron Dam, NM [USGS# 08284520] (USGS, 2015; 2018), as well as from URGSIM (Roach, 2007)when there are no estimates for the Willow

Creek below Heron Dam, NM gage. Reservoir releases are provided by the USGS stream gage Rio Chama below El Vado Dam, NM [USGS# 08285500] (USGS, 2015; 2018).

Surface area and pool elevation of the reservoir are calculated from an area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015).

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Rio Arriba County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET, which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Section 5.1) (Roach, 2007).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975-2010. The calibration term for El Vado reservoir is a peak flow reduction on the Rio Chama near La Puente stream gage. Analysis done by Roach (2007) suggests that gaged flows over 2000 cfs are overestimated. In order to calibrate the cumulative net sum of unknown inflows/outflows to zero over the historical calibration period, streamflows over 2000 cfs are reduced by 36.2%.

In the future portion of the model, El Vado reservoir is operated under a set of rules in accordance to Article VII of the *Rio Grande Compact Commission Report* (Hinderlider et al., 1952) while attempting to maximize storage, meet downstream demands, and avoid overtopping. If Article VII is in effect, then no native water can be stored in El Vado reservoir and all native water is passed through (for more information on Article VII see the section on Elephant Butte reservoir, Appendices A.2.8). Native water is considered to be any inflow to the reservoir that is not passing through the Azotea tunnel at the current timestep. At this juncture, no accounting sub-model has been created to track native and SJC Project water separately through the multiple spatial scales and storages of the NMDSWB. Thus, only SJC passing through the Azotea tunnel at a given timestep is considered non-native water. If Article VII is not in effect, then reservoir operations aim to meet the target releases. For a given calendar year, target releases for El Vado are designed to meet downstream demands for municipal uses in Santa Fe and Albuquerque, as well as for agricultural surface water uses in the Middle Rio Grande. Based on an annual allocation of SJC Project water to the city of Albuquerque of 48,200 AF and of 5,605 AF to the county of Santa Fe (Glaser, n.d.), annual surface water allocations for municipal uses in Santa Fe and Albuquerque are set to 53,805 AF per year. Once annual allocations have been met, no more releases are made from El Vado reservoir to meet the downstream municipal demands. Based on an annual allocation SJC Project water to Middle Rio Grande agriculture (Glaser, n.d.), annual surface water allocations for the Middle Rio Grande agriculture demand is set to 42,395 AF per year. The Middle Rio Grande agriculture demand at any given timestep is set equal to the calculated surface water withdrawal demand in Sandoval, Valencia, Bernalillo, and Socorro counties minus the simulated flow in the Rio Grande at Embudo, NM. In the future portion of the NMDSWB model, the simulated flow in the Rio Grande at Embudo, NM is represented by the SW_{out} from Taos County.

A.2.13 Abiquiu Reservoir

Abiquiu reservoir is located in Rio Arriba County and the Rio Chama WPR. Historical storage data are provided by the URGWOM Technical Team (2015).

Inflow into Abiquiu reservoir is measured by the USGS stream gage Rio Chama above Abiquiu reservoir, NM [08286500] (USGS, 2015; 2018). Releases from Abiquiu reservoir are measured by the USGS stream gage Rio Chama below Abiquiu Dam, NM [USGS# 0828700] (USGS, 2015; 2018). Surface area, and pool elevation of the reservoir are calculated from an area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015).

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Rio Arriba County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area ((URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Roach, 2007).

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. In order to model reservoir storage into the future a calibration inflow term has been added, such that cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated inflow term is calculated as 59% of the Jemez River near Jemez, NM [USGS# 08324000] streamflow, as ungaged flows to Abiquiu reservoir are largely from the north side of the Jemez Mountains.

In the future portion of the model, Abiquiu reservoir is operated under a set of rules in accordance to Article VII of the *Rio Grande Compact Commission Report* (Hinderlider et al., 1952) while attempting to maximize storage, meet downstream demands, and avoid overtopping. If Article VII is in effect, then no native water can be stored in Abiquiu reservoir and all native water is passed through (for more information on Article VII see the section on Elephant Butte reservoir, Appendices A.2.8). Native water is consider any inflow to the reservoir that is not passing through the Azotea tunnel at the current timestep. At this juncture, no accounting sub-model has been created to track native and SJC Project water separately through the multiple spatial scales and storages of the NMDSWB. Thus, only SJC water passing through the Azotea tunnel at a given timestep is considered non-native water. If Article VII is not in effect, then reservoir operations aim to meet the target releases. For a given calendar year, target releases for Abiquiu are designed to meet downstream demands for municipal uses in Santa Fe and Albuquerque, as well as for agricultural surface water uses in the Middle Rio Grande. Based on an annual allocation of SJC Project water to the city of Albuquerque of 48,200 AF and of 5,605 AF to the county of Santa Fe (Glaser, n.d.), annual surface water allocations for municipal uses in Santa Fe and Albuquerque are set to 53,805 AF per year. Once annual allocations have been met, no more releases are made from Abiquiu reservoir to meet the downstream municipal demands. Based on an annual allocation SJC Project water to Middle Rio Grande agriculture (Glaser, n.d.), annual surface water allocations for the Middle Rio Grande agriculture demand is set to 42,395 AF per year. The Middle Rio Grande agriculture demand at any given timestep is set equal to the calculated surface water withdrawal demand in Sandoval, Valencia, Bernalillo, and Socorro counties minus the simulated flow in the Rio Grande at Embudo, NM. In the future portion of the NMDSWB model, the simulated flow in the Rio Grande at Embudo, NM is represented by the SW_{out} from Taos County. Additionally, Abiquiu reservoir is operated for flood control and the reservoir rules limit releases to the downstream channel capacity of 1,800 cfs.

A.2.14 Nambe Falls Reservoir

Nambe Falls reservoir is located in Santa Fe County and the Jemez y Sangre WPR. Historical storage data is provided by the USGS (2015) and the USBR (2018).

Inflow into Nambe Falls reservoir is measured by the USGS stream gage Rio Nambe above, NM [08294195] from October, 2001 through December, 2011 (USGS, 2015). For the remaining years in the historical period of the model, estimated reservoir inflows are made available from the URGWOM Technical Team (2015). Releases from Nambe Falls reservoir are measured by the USGS stream gage Rio Nambe below Nambe Falls Dam, NM [08294210] (USGS, 2015; 2018).

Surface area and pool elevation of the reservoir are calculated from three area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015). The reservoir surveys providing updated area-capacity-elevation data are from 1967, 2004, and 2013.

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Santa Fe County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Roach, 2007).

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 that is less than or greater than the observed storage change. Because the cumulative net sum of unknown gains/losses over the historical calibration period (1975–2010) is less than zero KAF, no calibration flow was added to the Nambe Falls reservoir.

In the future portion of the model, the Nambe Falls reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Target releases are designed to meet downstream demands for Pojoaque Valley Irrigation District (PVID), which serves the Pueblos of San Ildefonso, Nambe, and Pojoaque. The irrigated area of PVID is estimated at 2,786 acres (The State of New Mexico, 2012), which comprises roughly 37% of the Santa Fe County surface water irrigated acreage (based on 2010 OSE values) (Longworth et al., 2013). The PVID also relies on water supplies not only from the Rio Nambe, but also from the Rio en Medio. No gage data are available on the Rio en Medio, but it is estimated that this river delivers about one-third of the water supplies delivered by Rio Nambe (Brainard and Veehius, n.d.). In the future portion of the model, the Rio en Medio supply is set to equal 1/3rd of the Nambe Falls inflow. The target releases for the Nambe Falls reservoir are set to equal 37% of demand for surface water withdrawals in Santa Fe County at any given timestep minus the estimated available water from the Rio en Medio. When there is available water in the reservoir to meet the target releases, the full target release is made. If there is not enough available water to meet the target demand, then all available water is released even though the full demand will not be met.

A.2.15 Santa Fe Reservoirs

The Santa Fe reservoirs (located in Santa Fe County and the Jemez y Sangre WPR) are comprised of McClure and Nichols reservoirs. Due to sparse reservoir operations data, these two reservoirs are modeled as one reservoir in the NMDSWB. Historical storage data is obtained from URGSiM (Roach, 2007) and the USGS (2018).

Inflow into the Santa Fe reservoirs is measured by the USGS stream gage Santa Fe River above McClure reservoir [USGS# 08315480] (USGS, 2015; 2018). Releases from the Santa Fe reservoirs are modeled as diversions to the Santa Fe water treatment plant and releases to the Santa Fe River. Diversions to the Santa Fe water treatment plant are estimated from calculated surface water withdrawals for public water supply within Santa Fe County (Section 4.2.3). Releases to the Santa Fe River are calculated as water available for release minus the diversions to the water treatment plant. Water available for release is set equal to the storage at the start of a given timestep plus the gaged inflows and precipitation minus the evaporation over the given timestep.

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Santa Fe County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET, which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Section 5.1) (Roach, 2007).

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 that is less than or greater than the observed storage change. Observed storage is unavailable from October 1989 to September 1990 and from October 1991to September 2006. During these periods, storage values for the Santa Fe reservoirs are modeled estimates.

In the future portion of the model, the Santa Fe reservoirs are operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Target releases are designed to meet the downstream demands for municipal uses in Santa Fe, which are not meet by SJC water released out of Abiquiu reservoir for the given timestep. If there is available water in storage, then releases will be made to meet those demands. If available water is less than the full demand, only the portion of available water will be released.

A.2.16 Cochiti Reservoir

Cochiti reservoir is located in Sandoval County and the Rio Chama WPR. Historical storage data is provided by the URGWOM Technical Team (2015).

Inflow into Cochiti reservoir is measured by the USGS stream gage Rio Grande at Otowi, NM [USGS# 08313000] (USGS, 2015; 2018). Releases from Cochiti reservoir are measured by the USGS stream gage Rio Grande below Cochiti dam, NM [USGS# 08317400] (USGS, 2015), as well as from diversions to the East Side Main Canal and the Sili Canal (URGWOM Technical Team, 2015).

Surface area and pool elevation of the reservoir are calculated from six area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015). The date ranges for the area-capacity-elevation tables are from: 1973–1978, 1979–1981, 1982–1987, 1988–1991, 1992–1998, and 1999–forward.

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Sandoval County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET, which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Section 5.1) (Roach, 2007).

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 that is less than or greater than the observed storage change. To model reservoir storage into the future, a calibration groundwater leakage term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated groundwater leakage term is calculated as the product of the current pool elevation and a constant of 0.0019 ft^2/s.

In the future portion of the model, Cochiti reservoir is operated under a set of rules in accordance to Article VII of the *Rio Grande Compact Commission Report* (Hinderlider et al., 1952) while attempting to maximize storage, meet downstream demands, and avoid overtopping. If Article VII is in effect, then no native water can be stored in Cochiti reservoir and all native water is passed through (for more information on Article VII see the section on Elephant Butte Reservoir, Appendices A.2.8). Native water is considered any inflow to the reservoir that is not passing through the Azotea tunnel at the current timestep. At this juncture, no accounting sub-model has been created to track native and SJC Project water separately through the multiple spatial scales and storages of the NMDSWB. Thus, only SJC water passing through the Azotea tunnel at a given timestep is considered non-native water. If Article VII is not in effect, then reservoir operations aim to meet the target releases. For a given calendar year, target releases for Cochiti are designed to meet downstream demands for municipal uses in Albuquerque and agricultural surface water uses in the Middle Rio Grande. Based on an annual allocation of SJC Project water (Glaser, n.d.), annual surface water allocations for municipal uses in Albuquerque are set to 48,200 AF per year. Once annual allocations have been met, no more releases are made from Cochiti reservoir to meet the downstream municipal demands. Based on an annual allocation SJC Project water to Middle Rio Grande agriculture (Glaser, n.d.), annual surface water allocations for the Middle Rio Grande agriculture demand is set to 42,395 AF per year. The Middle Rio Grande agriculture demand at any given timestep is set equal to the calculated surface water withdrawal demand in Sandoval, Valencia, Bernalillo, and Socorro counties minus the simulated flow in the Rio Grande at Embudo, NM. In the future portion of the NMDSWB model, the simulated flow in the Rio Grande at Embudo, NM is represented by the surface water outflow from Taos County. Additionally, Cochiti reservoir is operated for flood control and the reservoir rules limit releases to the downstream channel capacity at the junction with the Jemez river dam to 5,000 cfs. The flood control operations are solved for at Cochiti first, and then they are solved for downstream at the Jemez Canyon dam.

A.2.17 Jemez Reservoir

Jemez reservoir is located in Sandoval County and the Middle Rio Grande WPR. Historical storage data is provided by the URGWOM Technical Team (2015).

Inflow into Jemez reservoir is measured by the USGS stream gage Jemez River near Jemez, NM [USGS# 08324000] (USGS, 2015; 2018). Releases from Jemez reservoir are measured by the USGS stream gage Jemez River below Jemez Canyon Dam, NM [USGS# 08329000] (USGS, 2015; 2018). Surface area and pool elevation of the reservoir are calculated from area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015).

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015).

Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Sandoval County multiplied by the surface area of the reservoir (at the given timestep). Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Roach, 2007).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration groundwater leakage term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated groundwater leakage term is calculated as the product of the current pool elevation and current surface area divided by a calibration constant of 0.000183 per day, which represents the hydraulic conductivity (*k*) of reservoir bed sediments divided by an undetermined bed thickness.

In the future portion of the model, Jemez reservoir is operated only as a flood control pool. At any given timestep, all available water is released downstream unless the combined flow at the junction of the Jemez River below the Jemez Canyon dam and the Rio Grande will be over 5,000 cfs. If that is the case, water is stored in Jemez reservoir until the downstream channel capacity is less than 5,000 cfs.

A.2.18 Elephant Butte Reservoir

Elephant Butte reservoir is located in Sierra County and the Socorro-Sierra WPR. Historical storage data is provided by the URGWOM Technical Team (2015).

Inflow into Elephant Butte reservoir is measured by the USGS stream gages Rio Grande Conveyance channel at San Marcial, NM [USGS# 08358300] and Rio Grande Floodway at San Marcial, NM [USGS# 08358400] (USGS, 2015; 2018). Releases from Elephant Butte reservoir are measured by the USGS stream gage Rio Grande below Elephant Butte Dam, NM [USGS# 08361000] (USGS, 2015; 2018).

Surface area and pool elevation of the reservoir are calculated from five area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015). The date ranges for these area-capacity-elevation tables are: 1969–1979, 1980–1987, 1988–1999, 2000–2006, and 2007–forward.

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Sierra County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET, which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Roach, 2007).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, calibration inflow terms have been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. There are two sources of unknown gains into Elephant Butte Reservoir, surface water gains and groundwater gains. The surface water calibration inflow component is set equal to 20% of the gaged flow in the Rio Puerco near Bernardo, which is a good proxy for non-gaged tributaries in the surrounding area. The groundwater calibration inflow is set equal to the reservoir pool elevation times a constant of 0.137 ft^2/s (Roach, 2013; Roach and Shour, 2014). Groundwater gains to Elephant Butte Reservoir are considered a negative GW_r flow from the HSDS stock.

In the future portion of the model, Elephant Butte reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. Upstream reservoir rules at El Vado, Abiquiu, and Cochiti are governed by Article VII of the *Rio Grande Compact Commission Report* (Hinderlider et al., 1952). In the NMDSWB, Article VII is triggered when the combined storage of Elephant Butte and Caballo reservoirs less the cumulative Rio Grande compact balance (Appendix A.2.20) are below 400,000 AF. This effectively allows no additional native water to be stored in the upstream reservoirs (while Article VII is in effect). For each timestep in the model, the reservoir rules aim to release a target release. Target releases for Elephant Butte reservoir are based on average downstream demand as reported by the URGWOM Technical Team (2015) (Table 12).

Table 12. Elephant Butte Reservoir Monthly Target Releases.

Month	Target Release AF/mo
January	23,600
February	52,100
March	82,700
April	102,700
May	122,800
June	133,000
July	117,500
August	81,000
September	42,100
October	14,600
November	6,600
December	18,300

If there is not enough water in the reservoir to meet the target release, then only the available water is released. If there is too much inflow into the reservoir given the current storage and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir.

A.2.19 Caballo Reservoir

Caballo reservoir is located in Sierra County and Socorro-Sierra WPR. Historical storage data are provided by the URGWOM Technical Team (2015).

Inflow into Caballo reservoir is measured by the USGS stream gage Rio Grande below Elephant Butte Dam, NM [08361000] (USGS, 2015; 2018). Releases from Caballo reservoir are measured by the USGS stream gage Rio Grande below Caballo Dam, NM [08362500] (USGS, 2015; URGWOM, 2015). Surface area and pool elevation of the reservoir are calculated from area-capacity-elevation look-up tables provided by the URGWOM Technical Team (2015).

The precipitation falling on the reservoir can be determined via two methods. The default method is observed reservoir station data available from the URGWOM Technical Team (2015). Precipitation can also be calculated using the PRISM (2018) monthly average precipitation depth for Sierra County multiplied by the surface area of the reservoir (at the given timestep).

Reservoir evaporation can also be determined via two methods. The default is from observed reservoir pan evaporation data available from URGWOM multiplied by a pan coefficient of 0.7 and by reservoir surface area (URGWOM Technical Team, 2015). Evaporation can also be calculated from Hargreaves-Samani reference ET, which is multiplied by surface area at a given timestep and a monthly open water coefficient (Table 16) (Roach, 2007).

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 that is less than or greater than the observed storage change. In order to model reservoir storage into the future, a calibration inflow term has been added such that the cumulative net sum of unknown gains/losses is approximately 0 KAF over the historical calibration period of 1975–2010. The calibrated inflow term is the product of precipitation depth measured at Caballo reservoir for the current timestep and a constant effective precipitation area of 1,984 acres (value found through calibration).

In the future portion of the model, Caballo reservoir is operated under a set of rules to try to maximize storage while meeting downstream demands and avoiding overtopping. For each timestep in the model, the reservoir rules aim to release a target release. Target releases for Caballo reservoir are based on average downstream demand as reported by the URGWOM Technical Team (2015) (Table 13).

If there is not enough water in the reservoir to meet the target release, then only the available water is released. If there is too much inflow into the reservoir given the current storage and the reservoir is at risk of spilling, a maximum flood control release is made that is larger than the target release to avoid overtopping the reservoir.

Table 13. Caballo reservoir monthly target releases.

Month	Target Release AF/mo
January	7,500
February	28,100
March	109,100
April	89,500
May	101,800
June	128,900
July	135,100
August	107,400
September	67,100
October	15,500
November	0
December	0

A.2.20 Rio Grande Compact

In the future period of the NMDSWB model, New Mexico's delivery of Rio Grande water with regards to the Rio Grande Compact is tracked. In the current version of the NMDSWB model, the compact balance is tracked, but rules governing water use and reservoir operations have not yet been implemented to ensure compliance with the compact agreement. The Rio Grande Compact balance is calculated as follows:

1. The Otowi Index Supply is calculated for a given calendar year in the future as the estimated native water passing the Otowi gage. This flow is estimated as the annual flow in the Rio Grande exiting Santa Fe County minus the annual flow of San Juan Chama water passing through Azotea tunnel. Based on the calculated annual Otowi Index Supply, New Mexico's effective deliveries to Elephant Butte are calculated in accordance to the Rio Grande Compact Commission, 1948 (RGCC, 1948), as seen in Table 14.

Table 14. Discharge of Rio Grande at Otowi Bridge and Elephant Butte Effective Delivery Supply

Otowi Index Supply (KAF)	Elephant Butte Effective Delivery Supply (KAF)
100	57
200	114
300	171
400	228
500	286
600	345
700	406
800	471
900	542
1,000	621
1,100	707
1,200	800
1,300	897
1,400	996
1,500	1,095
1,600	1,195
1,700	1,295
1,800	1,395
1,900	1,495
2,000	1,595
2,100	1,695
2,200	1,795
2,300	1,895
2,400	1,995
2,500	2,095
2,600	2,195
2,700	2,295
2,800	2,395
2,900	2,495
3,000	2,595

2. The Elephant Butte Effective Index Supply is calculated based on the outflow from Elephant Butte Reservoir for the given year plus the net change in Elephant Butte Storage for that year (Rio Grande Compact Comission, 1948).
3. In accordance with Article VI of the Rio Grande Compact, 1948 evaporation adjustments are made to reduce compact debit by annual native water evaporation in El Vado reservoir storage and to reduce compact debt by annual Elephant Butte evaporation.
4. Spill adjustments are calculated such that any spilled water from Elephant Butte Reservoir will reset the Rio Grande Compact balance to zero.
5. The cumulative Rio Grande Compact balance is calculated as the sum of the Effective Elephant Butte Supply (2) minus the Effective Elephant Butte Delivery Supply (1) and is then corrected for annual evaporative adjustments (3) and spill (4) adjustments.

A.3 Reservoir Locations

Table 15. Reservoir locations, capacity, and acreage. Unless noted otherwise, storage capacity is from URGWOM (URGWOM Technical Team, 2015) and acreage is from NMEMNRD (New Mexico Energy, Mineral and Natural Resources Department) (2012).

Reservoir	River Basin	WPR	County	Capacity (AF)	Acreage (A)
Navajo	San Juan	San Juan	Rio Arriba	1,708,600	15,610
Two Rivers	Pecos	Lower Pecos Valley	Chavez	168,000	Dry Pool
Sumner	Pecos	Lower Pecos Valley	De Baca	43,768	2,800
Brantley	Pecos	Lower Pecos Valley	Eddy	352,000	3,000
Avalon	Pecos	Lower Pecos Valley	Eddy	4,466	66
McMillan	Pecos	Lower Pecos Valley	Eddy	33,600	1,000
Santa Rosa	Pecos	Mora-San Miguel-Guadalupe	Guadalupe	717,000	3,500
Eagle Nest	Canadian	Colfax	Colfax	79,000	2,000
Ute	Canadian	Northeast	Quay	403,000	8,200
Conchas	Canadian	Mora-San Miguel-Guadalupe	San Miguel	315,700	16,030
Heron	Rio Grande	Rio Chama	Rio Arriba	401,300	6,000
El Vado	Rio Grande	Rio Chama	Rio Arriba	195,440	3,200
Abiquiu	Rio Grande	Rio Chama	Rio Arriba	1,198,500	5,200[1]
Cochiti	Rio Grande	Middle Rio Grande	Sandoval	589,159	1,200[2]
Jemez Canyon	Rio Grande	Middle Rio Grande	Sandoval	262,473	2,890[3]
Santa Fe	Rio Grande	Jemez y Sangre	Santa Fe	3,940[4]	118
Nambe Falls	Rio Grande	Jemez y Sangre	Santa Fe	2,023	54
Elephant Butte	Rio Grande	Jemez y Sangre	Sierra	2,023,400	36,640[5]
Caballo	Rio Grande	Jemez y Sangre	Sierra	326,670	11,000

[1] USACE (2013)
[2] West (1971)
[3] USACE (1975)
[4] City of Santa Fe (2014)
[5] Orvis (1989)

A.4 Reservoir open water evaporation coefficients

Table 16. Reservoir open water evaporation coefficients.

RESERVOIRS	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Navajo[2]	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Heron[2]	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
El Vado[1]	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Abiquiu[1]	1.2	1.2	1.2	1.2	1.2	1.1	1	1	1	1.2	1.2	1.2
Nambe[2]	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Santa Fe[2]	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Cochiti[1]	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.2	1.3	1.3	1.3
Jemez[3]	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.2	1.3	1.3	1.3
Elephant Butte[1]	1.3	1.3	1.6	1.6	1.6	1.4	1.3	1.2	1.3	1.4	1.5	1.3
Caballo[1]	1.4	1.2	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.3	1.3	1.3
Santa Rosa[4]	1.5	1.5	1.7	1.2	1.1	1.1	1.1	1.0	1.1	1.2	1.5	1.8
Sumner[4]	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[5]	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8
McMillan[5]	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[4]	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[5]	1.7	1.5	1.6	1.5	1.4	1.3	1.4	1.3	1.3	1.3	1.4	1.8
Ute[4]	2	1.5	1.4	1	0.9	0.7	0.8	0.8	0.9	1.2	1.6	1.5
Conchas[4]	1.6	1.5	1.5	1.3	1.2	1.1	1.1	1	1.1	1.2	1.4	1.6

[1] Correlation between Hargreaves Reference ET and 70% of observed pan evaporation at reservoir locations where both pan evaporation and temperature records overlap. Separate values used for each reservoir because of a clear increase in coefficient value going down stream. For reservoirs above Elephant Butte where pan evaporation not recorded from November through March (due to ice), used April value for Jan-Mar, and October value for Nov and Dec (Roach, 2007, 2012).

[2] Used calibrated values from El Vado reservoir (Roach, 2007, 2012).

[3] Used calibrated values from Cochiti reservoir (Roach, 2007, 2012).

[4] NMDSWB correlation between Hargreaves Reference ET and 70% of observed pan evaporation at reservoir locations where both pan evaporation and temperature records overlap.

[5] Used NMDSWB calibrated values from Brantley Reservoir.

A.5 County Connection Inflows and Outflows

Table 17. Inflows used for the county, WPR, and river basin MBAUs in the future portion of the model.

Modeled Inflows	County	WPR	River Basin
SAN JUAN RIVER NEAR CARRACAS	Rio Arriba	San Juan	San Juan
PEIDRA RIVER NEAR ARBOLES	Rio Arriba	San Juan	San Juan
LOS PINOS RIVER AT LA BOCA	Rio Arriba	San Juan	San Juan
ANIMAS RIVER NEAR CEDAR HILL	San Juan	San Juan	San Juan
MANCOS RIVER NEAR TOWAOC	San Juan	San Juan	San Juan
LA PLATA RIVER AT CO-NM STATE LINE	San Juan	San Juan	San Juan
MORENO CREEK AT EAGLE NEST	Colfax	Colfax	Canadian
CIENEGUILLA CREEK NEAR EAGLE NEST	Colfax	Colfax	Canadian
SIX MILE CREEK NEAR EAGLE NEST	Colfax	Colfax	Canadian
DELAWARE RIVER NEAR RED BLUFF	Eddy	Lower Pecos Valley	Pecos
RIO GRANDE NEAR LOBATOS	Taos	Taos	Rio Grande
AZOTEA TUNNEL AT OUTLET NEAR RIO CHAMA	Rio Arriba	Rio Chama	Rio Grande
RIO CHAMA NEAR LA PUENTE	Rio Arriba	Rio Chama	Rio Grande
RIO NAMBE FALLS	Santa Fe	Jemez y Sangre	Rio Grande
SANTA FE RIVER ABOVE MCCLURE	Santa Fe	Jemez y Sangre	Rio Grande
JEMEZ RIVER NEAR JEMEZ	Sandoval	Middle Rio Grande	Rio Grande

Table 18. Future County split outflows.

From	To	Note
Rio Arriba County	Santa Fe County, Colorado	Based on a monthly historic ratio of gaged Rio Arriba County outflows to Colorado and the total outflow of Rio Arriba County.
McKinley County	Cibola County, Sandoval County	Based on a monthly historic ratio of gaged McKinley County outflows to Cibola and the total outflow of McKinley County.
Catron County	Grant County, Arizona	Based on a calibrated ratio constant of 30% of Catron County outflows going to Grant County and the remainder going to Arizona.
Grant County	Luna County, Hidalgo County	Based on a monthly historic ratio of gaged Grant County outflows to Hidalgo and the total outflow of Grant County.
San Miguel County	Guadalupe County, Quay County	Based on a monthly historic ratio of gaged inflow to Guadalupe and Quay Counties. All Conchas Reservoir outflow goes to Quay County. Remaining surface water balance in San Miguel County is split 60/40 to Guadalupe/Quay Counties.

A.6 Published groundwater storage change estimates

Table 19. Published groundwater storage change estimates.

REGION	Region or Sub-region R/SR	Basin	Estimate of GW storage change (AF/yr)	Time Period	Title	AUTHOR
Northeast	SR	Union County	-500	1975-2000	Northeast New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2007)
Northeast	SR	Harding County	20,600	1975-2000	Northeast New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2007)
Northeast	SR	Quay County	54,800	1975-2000	Northeast New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2007)
Northeast	SR	Curry County	-136,500	1975-2000	Northeast New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2007)
Northeast	SR	Roosevelt County	-115,200	1975-2000	Northeast New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2007)
Northeast	R	Northeast WPR	-176,800	1975-2000	Northeast New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2007)
Northeast	R	High Plains Aquifer (NM)	-375,360	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)
Jemez Y Sangre	SR	Velarde	35	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Santa Cruz River	-995	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Santa Clara	10	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Los Alamos	-2,210	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Pojoaque-Nambe	-205	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Tesuque	-115	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Caja del Rio	-3,945	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	Santa Fe River	3,585	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	SR	North Galisteo Creek	-1,060	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)

REGION	Region or Sub-region R/SR	Basin	Estimate of GW storage change (AF/yr)	Time Period	Title	AUTHOR
Jemez Y Sangre	SR	South Galisteo Creek	-460	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Jemez Y Sangre	R	Total	-5,360	n/a	Jemez y Sangre Regional Water Plan	Jemez y Sangre Water Planning Council (2003)
Southwest	SR	San Simon	-10	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Playas-San Basilio	0	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Animas	-3,510	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Hachita-Moscos	0	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Mimbres	-33,680	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Nutt-Hockett	-10,680	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Gila	40	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	San Francisco	-10	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Little Colorado	10	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	San Agustin	0	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Rio Salado	0	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	North Plains	0	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	R	Total	-47,840	n/a	Southwest New Mexico Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Southwest	SR	Mimbres	0	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)
Southwest	SR	Mimbres	0	Steady State	Groundwater Model of the Mimbres Basin, Luna, Grant, Sierra and Doña Ana Counties, New Mexico	Cuddy, A.S. (2011)

REGION	Region or Sub-region R/SR	Basin	Estimate of GW storage change (AF/yr)	Time Period	Title	AUTHOR
Southwest	SR	Mimbres	-21	Model year 2005	Groundwater Model of the Mimbres Basin, Luna, Grant, Sierra and Doña Ana Counties, New Mexico	Cuddy, A.S. (2011)
Southwest	SR	Mimbres	-187,000	1970-2009	Groundwater Level and Storage Changes - Regions of New Mexico	Rinehart, A. et al. (2015)
Tularosa	R	Tularosa	-40,536	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)
Taos	SR	North	0	2000	Taos Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2008)
Taos	SR	Central	0	2000	Taos Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2008)
Taos	SR	South	0	2000	Taos Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2008)
Taos	SR	West	0	2000	Taos Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2008)
Mora-San Miguel	SR	Canadian	-8,825	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Estancia	320	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Ft. Sumner	11,410	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Not Declared	17,755	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Rio Grande	3,560	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Roswell	2,460	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Tucumcari	11,365	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	SR	Upper Pecos	79,185	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Mora-San Miguel	R	Total	117,230	2000	Mora-San Miguel-Guadalupe Regional Water Plan	Daniel B. Stephens & Associates, Inc. (2005)
Lower Rio Grande	SR	Hueco Bolson	-109,446	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)
Lower Rio Grande	SR	Mesilla	-8,107	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)

REGION	Region or Sub-region R/SR	Basin	Estimate of GW storage change (AF/yr)	Time Period	Title	AUTHOR
Middle Rio Grande	R	Middle Rio Grande	-34,050	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)
Middle Rio Grande	R	Middle Rio Grande	-1,000	Steady State	Simulation of Groundwater Flow in the Middle Rio Grande Basin Between Cochiti and San Acacia, New Mexico	McAda, D.P. and Barroll, P. (2002)
Middle Rio Grande	R	Middle Rio Grande	-1,000	October 1999 year end	Simulation of Groundwater Flow in the Middle Rio Grande Basin Between Cochiti and San Acacia, New Mexico	McAda, D.P. and Barroll, P. (2002)
Middle Rio Grande	SR	Albuquerque	-500	Steady State(predevelopment)	Simulation of Ground-water Flow in the Albuquerque Basin, Central New Mexico, 1901-1994, with Projections to 2020	Kernodle et al. (1994)
Middle Rio Grande	SR	Albuquerque	-700	1960	Simulation of Ground-water Flow in the Albuquerque Basin, Central New Mexico, 1901-1994, with Projections to 2020	Kernodle et al. (1994)
Middle Rio Grande	SR	Albuquerque	920	1994	Simulation of Ground-water Flow in the Albuquerque Basin, Central New Mexico, 1901-1994, with Projections to 2020	Kernodle et al. (1994)
Middle Rio Grande	SR	Albuquerque	-31,000	1974-1992	Geohydrologic Framework and Hydrologic Conditions in the Albuquerque Basin, Central New Mexico	Thorn, C.R., McAda, D.P., and Kernodle, J.M. (1993)
Estancia	R	Estancia	-22,700	2001-2008	Groundwater Depletion in the United States (1900-2008)	Konikow, L.F. (2013)
Estancia	R	Estancia	-50,800	1970-2009	Groundwater Level and Storage Changes - Regions of New Mexico	Rinehart, A. et al. (2015)
Rio Chama	R	Total	0		Rio Chama Regional Water Plan	La Calandria Associates, Inc. (1995)

A.7 Surface Water Inflows/Outflows by MBAU

Table 20. Surface water inflows and outflows for counties.

	Inflow		Outflow	
COUNTY	**Site Name**	**Site Number**	**Site Name**	**Site Number**
Bernalillo	RIO GRANDE AT ALAMEDA BRIDGE SANDOVAL BERNALILLO[a]	8329918	RIO SAN JOSE AT CORREO[a]	8351500
	RIO SAN JOSE AT CORREO, NM[a]	8351500	RIO PUERCO AT RIO PUERCO[a]	8352500
	RIO PUERCO AT RIO PUERCO, NM[a]	8352500	RIO GRANDE NEAR BOSQUE FARMS BERNALILLO VALENCIA[a]	8331160
	ARROYO CHICO NEAR GUADALUPE, NM[a]	8340500	Isleta Peralta Diversions	URGWOM
	RIO PUERCO ABOVE ARROYO CHICO NEAR GUADALUPE, NM	8334000	Isleta Cacique Acequia Diversions	URGWOM
			Isleta Chic Lateral Diversions	URGWOM
			Isleta Chic Acequia Diversions	URGWOM
Catron	N/A		SYNTHETIC GILA RIVER AT GRANT CATRON LINE[b]	
			SAN FRANCISCO RIVER NEAR GLENWOOD, NM	9444000
Chaves	PECOS RIVER NEAR DUNLAP, NM[a]	8385630	PECOS RIVER NEAR LAKE ARTHUR, NM	8395500
	RIO HONDO AT DIAMOND A RANCH NEAR ROSWELL, NM	8390500		
Cibola	ZUNI RIVER NEAR NM-AZ STATELINE[a]	9387300	RIO SAN JOSE AT CORREO, NM[a]	8351500
			ZUNI RIVER NEAR NM-AZ STATELINE[a]	9387300
Colfax	N/A		CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	7211500
Curry	N/A		N/A	
De Baca	PECOS RIVER NEAR PUERTO DE LUNA, NM	8383500	PECOS RIVER NEAR DUNLAP, NM[a]	8385630
Doña Ana	RIO GRANDE BELOW CABALLO DAM, NM	8362500	RIO GRANDE AT EL PASO, TX	8364000
Eddy	PECOS RIVER NEAR LAKE ARTHUR, NM	8395500	PECOS RIVER NEAR LAKE ARTHUR, NM	8395500
	DELEWARE RIVER NEAR RED BLUFF, NM	8408500	DELEWARE RIVER NEAR RED BLUFF, NM	8408500
Grant	SYNTHETIC GILA RIVER AT GRANT CATRON LINE[b]		MIMBRES RIVER AT FAYWOOD NM[a]	8477500
			GILA RIVER BELOW BLUE CREEK NEAR VIRDEN, NM[a]	9432000

	Inflow		Outflow	
COUNTY	Site Name	Site Number	Site Name	Site Number
Guadalupe	PECOS RIVER NEAR ANTON CHICO, NM	8379500	PECOS RIVER NEAR PUERTO DE LUNA	8383500
Guadalupe	GALLINAS RIVER NEAR COLONIAS, NM	8382500		
Harding	N/A		UTE CREEK NEAR LOGAN, NM	7226500
Hidalgo	GILA RIVER BELOW BLUE CREEK NEAR VIRDEN, NM[a]	9432000	GILA RIVER AT DUNCAN, NM[a]	9439000
Lea	N/A		N/A	
Lincoln	SYNTHETIC OTERO LINCOLN COUNTY LINE[b]	8387000	RIO HONDO AT DIAMOND A RANCH NEAR ROSWELL, NM	8390500
Los Alamos	N/A		N/A	
Luna	MIMBRES RIVER AT FAYWOOD NM[a]	8477500	N/A	
McKinley	N/A		ZUNI RIVER NEAR NM-AZ STATELINE[a]	9387300
			ARROYO CHICO NEAR GUADALUPE[a]	8340500
Mora	CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	7211500	CANADIAN RIVER NEAR SANCHEZ, NM	7221500
Otero	N/A		SYNTHETIC OTERO LINCOLN COUNTY LINE[b]	
Quay	RES CONCHAS MAINSTEM RELEASES[a]		CANADIAN RIVER AT LOGAN, NM	7227000
	RES CONCHAS IRRIGATION RELEASES ARCH HURLEY[a]		REVUELTO CREEK NEAR LOGAN, NM	7227100
	RES CONCHAS IRRIGATION RELEASES BELL RANCH[a]			
	UTE CREEK NEAR LOGAN, NM	7226500		
Rio Arriba	LOS PINOS AT LA BOCA, CO	9354500	LOS PINOS RIVER NEAR ORTIZ	8248000
	PIEDRA RIVER NEAR ARBOLES, CO	9349800	SAN ANTONIO RIVER AT ORTIZ	8247500
	SAN JUAN RIVER NEAR CARRACAS, CO	9346400	SAN JUAN RIVER NEAR ARCHULETA	9355500
	AZOTEA TUNNEL AT OUTLET NEAR CHAMA, NM	8284160	RIO GRANDE AT OTOWI	8313000
	RIO GRANDE AT EMBUDO, NM	8279500	RIO NAMBE BELOW NAMBE FALLS	8294210
Roosevelt	N/A		N/A	
Sandoval	RIO GRANDE AT OTOWI BRIDGE, NM	8313000	RIO GRANDE AT ALAMEDA BRIDGE SANDOVAL BERNALILLO[a]	8329918
	GALISTEO CREEK BELOW GALISTEO DAM, NM	8317950	RIO SAN JOSE AT CORREO[a]	8351500
	SANTA FE RIVER ABOVE COCHITI LAKE, NM[a]	8317200	RIO PUERCO AT RIO PUERCO[a]	8352500
	ARROYO CHICO NEAR GUADALUPE, NM[a]	8340500	ARROYO CHICO NEAR GUADALUPE[a]	8340500

COUNTY	Inflow		Outflow	
	Site Name	Site Number	Site Name	Site Number
			RIO PUERCO ABOVE ARROYO CHICO NEAR GUADALUPE	8334000
San Juan	ANIMAS RIVER NEAR CEDAR HILL, NM	9363500	SAN JUAN RIVER AT FOUR CORNERS, CO[a]	9371010
	LA PLATA RIVER AT CO-NM	9366500		
	SAN JUAN RIVER NEAR ARCHULETA, NM	9355500		
	MANCOS RIVER NEAR TOWAOC, CO	9371000		
San Miguel	CANADIAN RIVER NEAR SANCHEZ, NM	7221500	PECOS RIVER NEAR ANTON CHICO, NM	8379500
			GALLINAS RIVER NEAR COLONIAS, NM	8382500
			RES CONCHAS CANADIAN MAINSTEM RELEASES[a]	USACE
			RES CONCHAS IRRIGATION RELEASES ARCH HURLEY[a]	USACE
			RES CONCHAS IRRIGATION RELEASES BELL RANCH[a]	USACE
Santa Fe	RIO GRANDE AT OTOWI BRIDGE, NM	8313000	RIO GRANDE AT OTOWI BRIDGE, NM	8313000
	RIO NAMBE BELOW NAMBE FALLS	8294210	GALISTEO CREEK BELOW GALISTEO DAM, NM	8317950
			SANTA FE RIVER ABOVE COCHITI LAKE, NM[a]	8317200
Sierra	RIO GRANDE CONVEYANCE CHANNEL AT SAN MARCIAL, NM	8358300	RIO GRANDE BELOW CABALLO DAM	8362500
	RIO GRANDE FLOODWAY AT SAN MARCIAL, NM	8358400		
Socorro	RIO PUERCO NEAR BERNARDO, NM	8353000	RIO GRANDE CONVEYANCE CHANNEL AT SAN MARCIAL, NM	8358300
	RIO GRANDE AT BERNARDO	8332010	RIO GRANDE FLOODWAY AT SAN MARCIAL	8358400
Taos	RIO GRANDE NEAR LOBATOS, CO	8251500	RIO GRANDE AT EMBUDO	8279500
			COSTILLA CREEK NEAR COSTILLA, NM	8255500
Torrance	N/A		N/A	
Union	N/A		CIMARRON RIVER NEAR KENTON, OK	7154500
Valencia	RIO GRANDE NEAR BOSQUE FARMS BERNALILLO VALENCIA[a]	8331160	RIO PUERCO NEAR BERNARDO	8353000
	RIO PUERCO AT RIO PUERCO, NM[a]	8352500	Rio GRANDE AT BERNARDO	8332010
	RIO SAN JOSE AT CORREO, NM[a]	8351500	Valencia County all Surface Water Return Flows[a]	NMDSWB
	Isleta Peralta Diversions	URGWOM		

	Inflow		Outflow	
COUNTY	Site Name	Site Number	Site Name	Site Number
Valencia	Isleta Cacique Acequia Diversions	URGWOM		
	Isleta Chic Lateral Diversions	URGWOM		
	Isleta Chic Acequia Diversions	URGWOM		

[a] Contains portion of partially estimated streamflow due to missing or unavailable data.

[b] Sythetic streamflow. Streamflow estimated from nearby stream gages to better approximate streamflow at MBAU boundaries.

Table 21. Surface water inflows and outflows for WPRs.

	Inflow		Outflow	
WPR	**Site Name**	**Site Number**	**Site Name**	**Site Number**
Northeast-1	CONCHAS IRRIGATION RELEASAE BELL RANCH[a]		REVUELTO CREEK NEAR LOGAN, NM	7227100
	CONCHAS IRRIGATION RELEASE ARCH HURLEY[a]		CANADIAN RIVER AT LOGAN, NM	7227000
	CONCHAS MAINSTEM RELEASE[a]		CIMARRON RIVER NEAR KENTON, OK	7154500
San Juan-2	SAN JUAN RIVER NEAR CARRACAS	9346400	SAN JUAN RIVER AT FOUR CORNERS, CO[a]	9371010
	PIERDA RIVER NEAR ARBOLES	9349800		
	LOS PINOS AT LA BOCA, CO	9354500		
	ANIMAS RIVER NEAR CEDAR HILL	9363500		
	LA PLATA RIVER AT CO-NM	9366500		
	MANCOS RIVER NEAR TOWAOC	9371000		
Jemez y Sangre-3	RIO GRANDE AT EMBUDO, NM	8279500	RIO GRANDE AT OTOWI BRIDGE, NM	8313000
	RIO CHAMA BELOW ABIQUIU DAM, NM	8287000	GALISTEO CREEK BELOW GALISTEO DAM, NM	8317950
	RIO OJO CALIENTE AT LA MADERA, NM	8289000	SANTA FE RIVER ABOVE COCHITI LAKE, NM[a]	8317200
Southwest-4	N/A		GILA RIVER AT DUNCAN, AZ[a]	9439000
			SAN FRANCISCO RIVER NEAR GLENWOOD, NM	9444000
Tularosa-Salt basins-5	N/A		N/A	
Northwest-6	N/A		ZUNI RIVER NEAR NM-AZ STATELINE[a]	9387300
			RIO SAN JOSE AT ACOMA PUEBLO, NM[a]	8343500
			ARROYO CHICO NEAR GUADALUPE, NM[a]	8340500
Taos-7	RIO GRANDE NEAR LOBATOS	8251500	RIO GRANDE AT EMBUDO, NM	8279500
			COSTILLA CREEK NEAR COSTILLA, NM	8255500
Mora-San Miguel-Guadalupe-8	CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	7211500	CONCHAS IRRIGATION RELEASE BELL RANCH[a]	
			CONCHAS IRRIGATION RELEASE ARCH HURLEY[a]	

WPR	Inflow		Outflow	
	Site Name	Site Number	Site Name	Site Number
			CONCHAS CANADIAN MAINSTEM RELEASE[a]	
			PECOS RIVER NEAR PUERTO DE LUNA, NM	8383500
Colfax-9	N/A		CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	7211500
Lower Pecos Valley-10	PECOS RIVER NEAR PUERTO DE LUNA, NM	8383500	DELEWARE RIVER NEAR RED BLUFF, NM	8408500
	DELEWARE RIVER NEAR RED BLUFF, NM	8408500	PECOS RIVER AT RED BLUFF, NM	8407500
Lower Rio Grande-11	RIO GRANDE BELOW CABALLO DAM, NM	8362500	RIO GRANDE AT EL PASO, TX	8364000
Middle Rio Grande-12	RIO GRANDE AT OTOWI BRIDGE, NM	8313000	RIO PUERCO NEAR BERNARDO, NM	8353000
	GALISTEO CREEK BELOW GALISTEO DAM, NM	8317950	RIO GRANDE FLOODWAY NEAR BERNARDO, NM[a]	8332010
	SANTA FE RIVER ABOVE COCHITI LAKE, NM[a]	8317200	Valencia County all Surface Water Return Flows[a]	NMDSWB
	ARROYYO CHICO NEAR GUADALUPE, NM[a]	8340500		
	RIO SAN JOSE AT CORREO, NM[a]	8351500		
Estancia-13	N/A		N/A	
Rio Chama-14	AZOTEA TUNNEL AT OUTLET NEAR CHAMA, NM	8284160	RIO CHAMA BELOW ABIQUIU DAM, NM	8287000
			RIO OJO CALIENTE AT LA MADERA, NM	8289000
			LOS PINOS RIVER NEAR ORTIZ, CO	8248000
			SAN ANTONIO RIVER AT ORTIZ, CO	8247500
Socorro-Sierra-15	RIO PUERCO NEAR BERNARDO, NM	8353000	RIO GRANDE BELOW CABALLO DAM, NM	8362500
	RIO GRANDE FLOODWAY NEAR BERNARDO, NM[a]	8332010		
	Valencia County all Surface Water Return Flows[a]	NMDSWB		
Lea County-16	N/A		N/A	

[a] Contains portion of partially estimated streamflow due to missing or unavailable data.

[b] Synthetic streamflow. Streamflow estimated from nearby stream gages to better approximate streamflow at MBAU boundaries.

Table 22. Surface water inflows and outflows for river basins.

	Inflow		Outflow	
river basin	Site Name	Site Number	Site Name	gage #
Rio Grande	RIO GRANDE NEAR LOBATOS	8251500	RIO GRANDE AT EL PASO, TX	8364000
	AZOTEA TUNNEL AT OUTLET NEAR CHAMA	8284160	SAN ANTONIO RIVER AT ORTIZ, CO	8247500
			LOS PINOS RIVER NEAR ORTIZ, CO	8248000
			COSTILLA CREEK NEAR COSTILLA, NM	8255500
Pecos	N/A		DELEWARE RIVER NEAR RED BLUFF, NM	8408500
			PECOS RIVER AT RED BLUFF, NM	8407500
Canadian	N/A		REVUELTO CREEK NEAR LOGAN, NM	7227100
			CANADIAN RIVER AT LOGAN, NM	7227000
			CIMARRON RIVER NEAR KENTON, OK	7154500
Texas Gulf	N/A		N/A	
Lower Colorado	N/A		ZUNI RIVER NEAR NM-AZ STATELINE[a]	9387300
			GILA RIVER AT DUNCAN, AZ[a]	9439000
			SAN FRANCISCO RIVER NEAR GLENWOOD, NM	9444000
San Juan	SAN JUAN RIVER NEAR CARRACAS, CO	9346400	SAN JUAN RIVER AT FOUR CORNERS[a]	9371010
	PIERDA RIVER NEAR ARBOLES, CO	9349800		
	LOS PINOS AT LA BOCA, CO	9354500		
	ANIMAS RIVER NEAR CEDAR HILL, NM	9363500		
	LA PLATA RIVER AT CO-NM	9366500		
	MANCOS RIVER NEAR TOWAOC, CO	9371000		
Central Closed	N/A		N/A	

[a] Contains portion of partially estimated streamflow due to missing or unavailable data.
[b] Synthetic streamflow. Streamflow estimated from nearby stream gages to better approximate streamflow at MBAU boundaries.

Table 23. Estimated and synthetic gage flows.

Site Name (y)	Estimated Dates	Site Used for Estimate (x)	Number of Observations (n)	R^2	Equation
ARROYO CHICO NEAR GUADALUPE	October 1986–October 2005	PRISM precipitation for Middle Rio Grande WPR (mm/mo)	300	0.4311	$y = 0.0082x^2 + 0.1156x + 0.9913$
GILA RIVER AT DUNCAN, AZ	2003–2014	GILA RIVER BLUE CREEK NEAR VIRDEN, NM	120	0.987	$y = 0.947x - 11.056$
GILA RIVER AT GRANT CATRON LINE	1975–Present	GILA RIVER NEAR GILA, NM	N/A	N/A	28% of Grant County drainage is rounded to 25%
GILA RIVER BELOW BLUE CREEK VIRDEN, NM	October 1977–September 1978, March 1979–June 1978, and March 1980	GILA RIVER NEAR REDROCK, NM	537	0.9521	$y = 1.0867x - 12.676$
MIMBRES RIVER NEAR FAYWOOD, NM	1975–Present	MIMBRES RIVER NEAR MIMBRES, NM	129	0.7522	$y = 1.5019x - 2.9518$
OTERO LINCOLN COUNTY LINE	1975–Present	RIO RUIDOSO AT HOLLYWOOD, NM	N/A	N/A	Estimated flow at county line is 75% of flow at gage
PECOS RIVER NEAR DUNLAP, NM	October 2004–September 2005	PECOS RIVER NEAR ACME, NM	244	0.8007	$y = 0.9572x + 12.748$
RIO GRANDE AT ALAMEDA BRIDGE SANDOVAL BERNALILLO	1975–July 2003 and October 2004–September 2005	RIO GRANDE AT ALBUQUERQUE	123	0.9909	$y = 1.0085x + 63.708$
RIO GRANDE AT HWY 364 NEAR BOSQUE	October 2011–October 2014	RIO GRNADE FLOODWAY NEAR BERNARDO	37	0.9914	$y = 1.0335x + 3.9849$
RIO GRANDE FLOODWAY NEAR BERNARDO	August 2005–August 2011	RIO GRANDE FLOODWAY AT SAN ACACIA	419	0.8646	$y = 0.9869x + 106.53$
RIO GRANDE NEAR BOSQUE FARMS BERNALILLO VALENCIA	1975–April 2006 and October 2006–September 2007	RIO GRANDE AT ALBUQUERQUE	91	0.9219	$y = 0.805x - 116.95$
RIO GRANDE NEAR WHITE ROCK	1975–June 2000 and October 2003–Present	RIO GRANDE NEAR OTOWI	1,194	0.9874	$y = -0.00007x^2 + 1.2486x - 115.1$
RIO PUERCO AT RIO PUERCO	1977–Present	RIO PUERCO NEAR BERNARDO	446	0.9789	$y = 0.9979x + 3.0746$
RIO SAN JOSE AT CORREO	January 1969–September 1994	RIO SAN JOSE AT ACOMA PUEBLO (x), RIO PEURCO NEAR BERNARDO (z)	309	0.6002	$y = 0.536653x + 0.207901z + 0.121706$
SAN JUAN RIVER AT FOUR CORNERS	October 1975–December 1977	SAN JUAN RIVER AT SHIPROCK + estimated agricultural returns below Shiprock	N/A	N/A	(San Juan County agricultural surface water returns) * (% of agricultural area between Shiprock and Four Corners)
SANTA FE RIVER ABOVE COCHITI LAKE	October 1999–September 2004	N/A	N/A	N/A	Zero flow is assumed for years without data
ZUNI RIVER NEAR NM-AZ STATELINE	1975–1984 and 1994–Present	ZUNI RIVER ABOVE BLACK ROCK RESERVOIR, NM	8	0.984	$y = 0.7085x - 0.8569$
RES CONCHAS CANADIAN MAINSTEM RELEASES	1975–1991	N/A	N/A	N/A	If releases out of Conchas > 400 cfs, then 2/3 to Canadian Mainstream Release; else, none

Site Name (y)	Estimated Dates	Site Used for Estimate (x)	Number of Observations (n)	R^2	Equation
RES CONCHAS IRRIGATION RELEASES ARCH HURLEY	1975–1991	N/A	N/A	N/A	If releases out of Conchas > 400 cfs, then 2/3 to Canadian Mainstream Release and 97% of the remainder to Arch Hurley; else, 97% of Conchas releases to Arch Hurley
RES CONCHAS IRRIGATION RELEASES BELL RANCH	1975–1991	N/A	N/A	N/A	If releases out of Conchas > 400 cfs, then 2/3 to Canadian Mainstream Release and 3% of the remainder to Bell Ranch; else, 3% of Conchas releases to Bell Ranch
VALENCIA COUNTY ALL SURFACE WATER RETURN FLOWS	1975–Present	N/A	N/A	N/A	Sum of Valencia County surface water returns

A.8 USGS Stream Gage Quality Ratings

Table 24. USGS Stream Gage Quality Ratings for Uncertainty Assessment. The USGS, in its annual water data reports (e.g., Miller and Stiles, 2006) rates each gage during a given water year as excellent, good, fair, or poor when 95% of gage estimates are thought to be within 5%, 10%, 15%, or more than 15% of the true value respectively. Discussion of how the quality ratings are used to determine gage uncertainty can be found in Appendices A.24.2.

River basin	**QUALITY**
CANADIAN river basin	
07204000 MORENO CREEK AT EAGLE NEST, N. MEX.	GOOD
07154500 CIMARRON RIVER NEAR KENTON, OK	FAIR
07204500 CIENEGUILLA CR NR EAGLE NEST, NM	GOOD
07205000 SIXMILE CREEK NEAR EAGLE NEST, NM	GOOD
07206000 CIMARRON RIVER BELOW EAGLE NEST DAM, NM	GOOD
07211500 CANADIAN RIVER NEAR TAYLOR SPRINGS, NM	FAIR
07221500 CANADIAN RIVER NEAR SANCHEZ, NM	FAIR
07226500 UTE CREEK NEAR LOGAN, NM	POOR
07227000 CANADIAN RIVER AT LOGAN, NM	FAIR
07227100 REVUELTO CREEK NEAR LOGAN, NM	POOR
RIO GRANDE river basin	
08284520 WILLOW CREEK BELOW HERON DAM, NM	
08285500 RIO CHAMA BELOW EL VADO DAM, NM	GOOD
08286500 RIO CHAMA ABOVE ABIQUIU RESERVOIR, NM	GOOD
08294195 RIO NAMBE ABOVE NAMBE FALLS DAM NEAR NAMBE, NM	POOR
08317400 RIO GRANDE BELOW COCHITI DAM, NM	GOOD
08324000 JEMEZ RIVER NEAR JEMEZ, NM	GOOD
08329000 JEMEZ RIVER BELOW JEMEZ CANYON DAM, NM	FAIR
08361000 RIO GRANDE BELOW ELEPHANT BUTTE DAM, NM	GOOD
08315480 SANTA FE RIVER ABOVE MCCLURE RES, NR SANTA FE, NM	FAIR
08284100 RIO CHAMA NEAR LA PUENTE, NM	GOOD
PECOS river basin	
08382650 PECOS RIVER ABOVE SANTA ROSA LAKE, NM	FAIR
08382830 PECOS RIVER BELOW SANTA ROSA DAM, NM	GOOD
08384500 PECOS RIVER BELOW SUMNER DAM, NM	GOOD
08390800 RIO HONDO BLW DIAMOND A DAM NR ROSWELL, NM	GOOD
08399500 PECOS RIVER (KAISER CHANNEL) NEAR LAKEWOOD, NM	GOOD
08400000 FOURMILE DRAW NR LAKEWOOD, NM	GOOD
08401000 PECOS RIVER BELOW MCMILLAN DAM, NM	GOOD
08401200 SOUTH SEVEN RIVERS NR LAKEWOOD, NM	GOOD
08401500 PECOS RIVER BELOW BRANTLEY DAM NEAR CARLSBAD, NM	GOOD
08404000 PECOS RIVER BELOW AVALON DAM, NM	GOOD
08402000 PECOS R AT DAMSITE 3 NR CARLSBAD, NM	GOOD

RIO GRANDE river basin	**QUALITY**
08247500 SAN ANTONIO RIVER AT ORTIZ, CO	FAIR
08248000 LOS PINOS RIVER NEAR ORTIZ, CO	FAIR
08251500 RIO GRANDE NEAR LOBATOS, CO	GOOD
08279500 RIO GRANDE AT EMBUDO, NM	GOOD
08284160 AZOTEA TUNNEL AT OUTLET NEAR CHAMA, NM	GOOD
08287000 RIO CHAMA BELOW ABIQUIU DAM, NM	GOOD
08289000 RIO OJO CALIENTE AT LA MADERA, NM	GOOD
08294210 RIO NAMBE BELOW NAMBE FALLS DAM, NEAR NAMBE, NM	GOOD
08313000 RIO GRANDE AT OTOWI BRIDGE, NM	GOOD
08317200 SANTA FE RIVER ABOVE COCHITI LAKE, NM	GOOD
08317950 GALISTEO CREEK BELOW GALISTEO DAM, NM	POOR
08329900 NORTH FLOODWAY CHANNEL NEAR ALAMEDA, NM	GOOD
08329918 RIO GRANDE AT ALAMEDA BRIDGE AT ALAMEDA, NM	POOR
08331160 RIO GRANDE NEAR BOSQUE FARMS, NM	POOR
08331510 RIO GRANDE AT HWY 346 NEAR BOSQUE, NM	POOR
08332010 RIO GRANDE FLOODWAY NEAR BERNARDO, NM	FAIR
08334000 RIO PUERCO ABOVE ARROYO CHICO NEAR GUADALUPE, NM	FAIR
08340500 ARROYO CHICO NR GUADALUPE, NM	POOR
08343500 RIO SAN JOSE AT ACOMA PUEBLO, NM/08343500 RIO SAN JOSE NEAR GRANTS, NM	FAIR
08351500 RIO SAN JOSE AT CORREO, NM	FAIR
08352500 RIO PUERCO AT RIO PUERCO, NM	POOR
08353000 RIO PUERCO NEAR BERNARDO, NM	FAIR
08362500 RIO GRANDE BLW CABALLO DAM, NM	GOOD
08364000 RIO GRANDE AT EL PASO, TX	FAIR
08379500 PECOS RIVER NEAR ANTON CHICO, NM	GOOD
08382500 GALLINAS RIVER NEAR COLONIAS, NM	FAIR
08383500 PECOS RIVER NEAR PUERTO DE LUNA, NM	GOOD
08385500 PECOS RIVER NEAR FORT SUMNER, NM	POOR
08385630 PECOS RIVER NEAR DUNLAP, NM	FAIR
08387000 RIO RUIDOSO AT HOLLYWOOD, NM	GOOD
08390500 RIO HONDO AT DIAMOND A RANCH, NEAR ROSWELL, NM	FAIR
08395500 PECOS RIVER NEAR LAKE ARTHUR, NM	GOOD
08407500 PECOS RIVER AT RED BLUFF, NM	GOOD
08408500 DELAWARE RIVER NR RED BLUFF, NM	GOOD

San Juan river basin	QUALITY
09346400 SAN JUAN RIVER NEAR CARRACAS, CO.	GOOD
09349800 PIEDRA RIVER NEAR ARBOLES, CO.	GOOD
09354500 LOS PINOS RIVER AT LA BOCA, CO.	GOOD
09355500 SAN JUAN RIVER NEAR ARCHULETA, NM	GOOD
09363500 ANIMAS RIVER NEAR CEDAR HILL, NM	GOOD
09366500 LA PLATA RIVER AT CO-NM	GOOD
09371000 MANCOS RIVER NEAR TOWAOC, CO.	FAIR
09371010 SAN JUAN RIVER AT FOUR CORNERS, CO	FAIR
Lower Colorado river basin	
09387300 ZUNI RIVER NR NM-AZ STATE LINE, NM	POOR
09430500 GILA RIVER NEAR GILA, NM	GOOD
09432000 GILA RIVER BELOW BLUE CREEK, NEAR VIRDEN, NM	FAIR
09439000 GILA RIVER AT DUNCAN, AZ	POOR
09444000 SAN FRANCISCO RIVER NEAR GLENWOOD, NM	GOOD

A.9 BFI Values by MBAU

Table 25. Base Flow Index by county (Wolock, 2003).

County	BFI (%)
Bernalillo County	2.7
Catron County	53.8
Chaves County	18.3
Cibola County	31.9
Colfax County	45.8
Curry County	10.8
De Baca County	13.4
Dona Ana County	39.4
Eddy County	16.3
Grant County	45.6
Guadalupe County	26.4
Harding County	30.2
Hidalgo County	34.4
Lea County	15.9
Lincoln County	29.6
Los Alamos County	65.7
Luna County	38.2
McKinley County	36
Mora County	53.4
Otero County	29.6
Quay County	20
Rio Arriba County	54.9
Roosevelt County	12.1
Sandoval County	32.9
San Juan County	47.9
San Miguel County	38.7
Santa Fe County	49.8
Sierra County	50.3
Socorro County	30.8
Taos County	67.4
Torrance County	10.3
Union County	18.5
Valencia County	3.1

Table 26. Baseflow Index 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

A.10 Historical County Ratios

Table 27. County historical runoff to precipitation ratios (calibration values calculated with in the NMDSWB model).

County	Ratio (runoff/p)
Bernalillo County	0.041
Catron County	0.011
Chaves County	0.008
Cibola County	0.002
Colfax County	0.012
Curry County	0.000
De Baca County	0.015
Dona Ana County	0.015
Eddy County	0.023
Grant County	0.034
Guadalupe County	0.026
Harding County	0.005
Hidalgo County	0.001
Lea County	0.000
Lincoln County	0.002
Los Alamos County	0.000
Luna County	0.002
McKinley County	0.003
Mora County	0.017
Otero County	0.003
Quay County	0.017
Rio Arriba County	0.057
Roosevelt County	0.000
Sandoval County	0.013
San Juan County	0.040
San Miguel County	0.025
Santa Fe County	0.012
Sierra County	0.021
Socorro County	0.005
Taos County	0.058
Torrance County	0.00001
Union County	0.003
Valencia County	0.194

Table 28. County historical recharge to precipitation ratios (calibration values calculated with in the NMDSWB model).

County	Ratio (recharge/p)
Bernalillo County	0.030
Catron County	0.011
Chaves County	0.008
Cibola County	0.002
Colfax County	0.016
Curry County	0.0002
De Baca County	0.010
Dona Ana County	0.008
Eddy County	0.034
Grant County	0.029
Guadalupe County	0.016
Harding County	0.002
Hidalgo County	0.001
Lea County	0.00004
Lincoln County	0.002
Los Alamos County	0.0003
Luna County	0.001
McKinley County	0.002
Mora County	0.022
Otero County	0.003
Quay County	0.007
Rio Arriba County	0.060
Roosevelt County	0.0003
Sandoval County	0.018
San Juan County	0.043
San Miguel County	0.022
Santa Fe County	0.011
Sierra County	0.031
Socorro County	0.030
Taos County	0.104
Torrance County	0.005
Union County	0.006
Valencia County	0.040

Table 29. County historical *SW* ⇔ *GW* to surface water in ratios (calibration values calculated with in the NMDSWB model).

County	Ratio ($SW \Leftrightarrow GW/SW_{in}$)
Bernalillo County	0.055
Catron County	NA
Chaves County	-0.020
Cibola County	-0.606
Colfax County	NA
Curry County	NA
De Baca County	0.220
Dona Ana County	0.068
Eddy County	0.225
Grant County	-2.163
Guadalupe County	0.024
Harding County	NA
Hidalgo County	0.065
Lea County	NA
Lincoln County	-0.007
Los Alamos County	NA
Luna County	2.519
McKinley County	NA
Mora County	-0.534
Otero County	NA
Quay County	0.095
Rio Arriba County	-0.392
Roosevelt County	NA
Sandoval County	-0.009
San Juan County	0.096
San Miguel County	-0.428
Santa Fe County	-0.015
Sierra County	-0.023
Socorro County	0.005
Taos County	-0.669
Torrance County	NA
Union County	NA
Valencia County	0.0001

Table 30. County historical $SW \Leftrightarrow GW$ to runoff ratios for counties with no SW_{in}. Curry, Lea, and Roosevelt have no calculated $SW \Leftrightarrow GW$ in the future (calibration values calculated with in the NMDSWB model).

County	Ratio ($SW \Leftrightarrow GW$/Runoff)
Catron County	-0.742
Colfax County	-0.571
Curry County	NA
Harding County	-0.157
Lea County	NA
Los Alamos County	0.000
McKinley County	-0.341
Otero County	-0.448
Roosevelt County	NA
Torrance County	245.504
Union County	-0.177

Table 31. County historical ET_{sw} to surface water in ratios (calibration values calculated with in the NMDSWB model).

County	Ratio (ET_{sw}/SW_{in})
Bernalillo County	0.089
Catron County	NA
Chaves County	0.044
Cibola County	0.244
Colfax County	NA
Curry County	NA
De Baca County	0.023
Dona Ana County	0.196
Eddy County	0.023
Grant County	0.163
Guadalupe County	0.027
Harding County	NA
Hidalgo County	0.006
Lea County	NA
Lincoln County	0.106
Los Alamos County	NA
Luna County	0.000
McKinley County	NA
Mora County	0.027
Otero County	NA
Quay County	0.012
Rio Arriba County	0.100
Roosevelt County	NA
Sandoval County	0.092
San Juan County	0.005
San Miguel County	0.049
Santa Fe County	0.004
Sierra County	0.039
Socorro County	0.119
Taos County	0.074
Torrance County	NA
Union County	NA
Valencia County	0.072

Table 32. County historical ET_{sw} to runoff ratios for counties with no SW_{in}. Curry, Lea, and Roosevelt have no calculated ET_{sw} in the future (calibration values calculated with in the NMDSWB model).

County	**Ratio (ET_{sw}/Runoff)**
Catron County	0.020
Colfax County	0.053
Curry County	NA
Harding County	0.050
Lea County	NA
Los Alamos County	0.000
McKinley County	0.014
Otero County	0.012
Roosevelt County	NA
Torrance County	99.681
Union County	0.017

A.11 *SW* ⇔ *GW* calibration parameters by county and WPR

Table 33. *SW* ⇔ *GW* calibration parameter by county. Values represent percentage of surface water surplus at a given timestep partitioned into *SW* ⇔ *GW* flux (and returned to the groundwater system). The remaining portion of the surface water surplus is distributed into additional surface water evapotranspiration. Values are shown for the respective calibration periods of 1975 through 1999 and 2000 through 2015. Only the counties shown below have been calibrated based on published groundwater storage change estimates. Calibrations are based on data from (Rinehart et al., 2016), unless noted by a * in which calibrations are based on data from (Daniel B. Stephens & Associate INC., 2007). Counties not shown below have a *SW* ⇔ *GW* calibration parameter of 100, such that the full surface water surplus is partitioned into the *SW* ⇔ *GW* flux (i.e., water moves from surface water to groundwater storage).

County	**Percent of surface water system surplus returned to groundwater via the *SW* ⇔ *GW* flux**	
	1975–1999	**2000–2015**
Bernalillo County	26	100
Cibola County	0	100
Curry County*	100	100
Dona Ana County	11	77
Grant County	100	100
Harding County*	100	100
Hidalgo County	100	100
Lincoln County	100	0
Luna County	100	100
McKinley County	100	100
Otero County	0	100
Quay County*	100	100
Rio Arriba County	23	50
Roosevelt County*	100	100
Sandoval County	8	9
Santa Fe County	19	100
Sierra County	41	61
Socorro County	18	0
Taos County	0	0
Union County*	100	100
Valencia County	0	18

Table 34. *SW* ⬄ *GW* calibration parameter by Water Planning Regions. Values represent percentage of surface water surplus at a given timestep partitioned into *SW* ⬄ *GW* flux (and returned to the groundwater system). The remaining portion of the surface water surplus is distributed into additional surface water evapotranspiration. Values are shown for the respective calibration periods of 1975 through 1999 and 2000 through 2015. Only the WPRs shown below have been calibrated based on published groundwater storage change estimates. Calibrations are based on data from (Rinehart et al., 2016). WPRs not shown below have a *SW* ⬄ *GW* calibration parameter of 100, such that the full surface water surplus is partitioned into the *SW* ⬄ *GW* flux (i.e., water moves from surface water to groundwater storage).

WPR	Percent of surface water system surplus returned to groundwater via the *SW* ⬄ *GW* flux	
	1975–1999	2000–2015
San Juan WPR	100	100
Jemez y Sangre WPR	100	100
Tularosa-Salt-Sacramento WPR	0	0
Northwest WPR	100	100
Lower Pecos WPR	100	100
Estancia WPR	100	100
Rio Chama WPR	0	17

A.12 Historical Population Tables

Table 35. Historical decadal human populations 1970–2010 by county (UNM BBER, 2014).

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 36. Historical 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	31,590	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	**1,016,000**	**1,302,894**	**1,515,069**	**1,819,046**	**2,059,179**

Table 37. Historical decadal human populations 1970–2010 by river basin.

River Basin	1970	1980	1990	2000	2010
Rio Grande	598,770	807,156	980,710	1,203,317	1,407,911
Pecos	127,823	146,889	158,690	177,485	185,300
Canadian	36,273	36,596	35,605	37,349	35,812
Texas Gulf	99,488	106,948	107,924	111,774	125,121
San Juan	62,199	93,712	105,485	130,914	146,952
Lower Colorado	39,650	51,397	54,430	66,082	62,820
Central Closed	51,797	60,196	72,225	92,125	95,263
New Mexico	**1,016,000**	**1,302,894**	**1,515,069**	**1,819,046**	**2,059,179**

A.13 Water Use Categories

The 1975, 1980, and 1985 reports used slightly different water use categories; the earlier categories are either aggregated or separated within the NMDSWB values into the latter categories in order to maintain consistency throughout time (Table 38). In the 1975 report, the categories of commercial and industrial water use do not exist; instead, there is a single category dubbed manufacturing, which is split 50/50 within the NMDSWB values 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. Within the NMDSWB values 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. Implicit in this method is the assumption that water uses, delivery methods, and conservation practices have not changed. This is likely not true as in many locations throughout the state agricultural users have lined canals and laterals, leveled fields, changed to more efficient irrigation methods such as center pivot sprinklers, and changes in crops. Municipal and industrial users have also made significant improvements in water conservation as described in the Appendix A.14.

Table 38. OSE water use categories from 1975 to 2010 (Longworth et al., 2008, 2013; Sorensen, 1977; 1982; Wilson, 1986; Wilson and Lucero, 1992, 1997, 2003).Strikethrough text refers to water use categories that were quantified in early reports but not included in the most up to date reports. For consistency these categories were ignored and not included in the NMDSWB values.

2010	2005	2000	1995	1990	1985	1980	1975
Withdrawals only	Withdrawals only	Depletions, Withdrawals and Return Flows	Depletions, Withdrawals and Return Flows	Depletions, Withdrawals and Return Flows	Depletions, Withdrawals and Return Flows	Depletions, Withdrawals and Return Flows	Depletions, Withdrawals and 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~~

A.14 Domestic and Public Water Calculations

The water withdrawals and depletions by the public water supplier are divided by the population served to get per-capita water withdrawals and depletions by county for public water supply users. The reported water withdrawals and depletions for domestic self-supplied users are divided by the remaining population in the county to estimate per-capita water withdrawals and 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 five years. This percentage is multiplied by the monthly average population from the population model to calculate the publicly and domestically served populations at any given timestep. The publicly and domestically served populations are multiplied by the respective per-capita withdrawals and depletions to calculate public and domestic water use for any given timestep. In the 1975, 1980, and 1985 reports, the domestic and public water supply categories are separated into 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 are shown for each of the five-year periods from 1971 through 2010 in Table 39 and Table 40. Return flows as a ratio of withdrawals can be seen in Figure 20 and Figure 21. WPR and river basin municipal and domestic withdrawals/depletions are calculated by multiplying county level withdrawals and depletions by the respective percentage of a counties population within a given WPR or river basin. In the past 15 years, municipal and industrial users have made remarkable efforts at conserving water for per-capita usage. For example, urban Albuquerque water customers have decreased per-capita use from 250 GPCD to 135 GPCD since 2000 (ABCWUA, 2016). These changes have resulted in approximately 30% reduction in surface and groundwater diversions. Since return flows have remained essentially constant, the ratio of return flows to withdrawals has substantially increased. It is likely that similar results have been obtained from conservations programs in other NM cities.

Table 39. Public water supply per-capita withdrawals (e.g., Longworth et al., 2013).

	Public Water Supply Withdrawals Per-Capita (Gallons/Person*day)							
Counties	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010–2099**
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 40. Domestic self-supplied per-capita withdrawals (e.g., Longworth et al., 2013).

	Domestic Self-Supplied Withdrawals Per-Capita (Gallons/Person*day)							
Counties	**1975**	**1980**	**1985**	**1990**	**1995**	**2000**	**2005**	**2010–2099**
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**

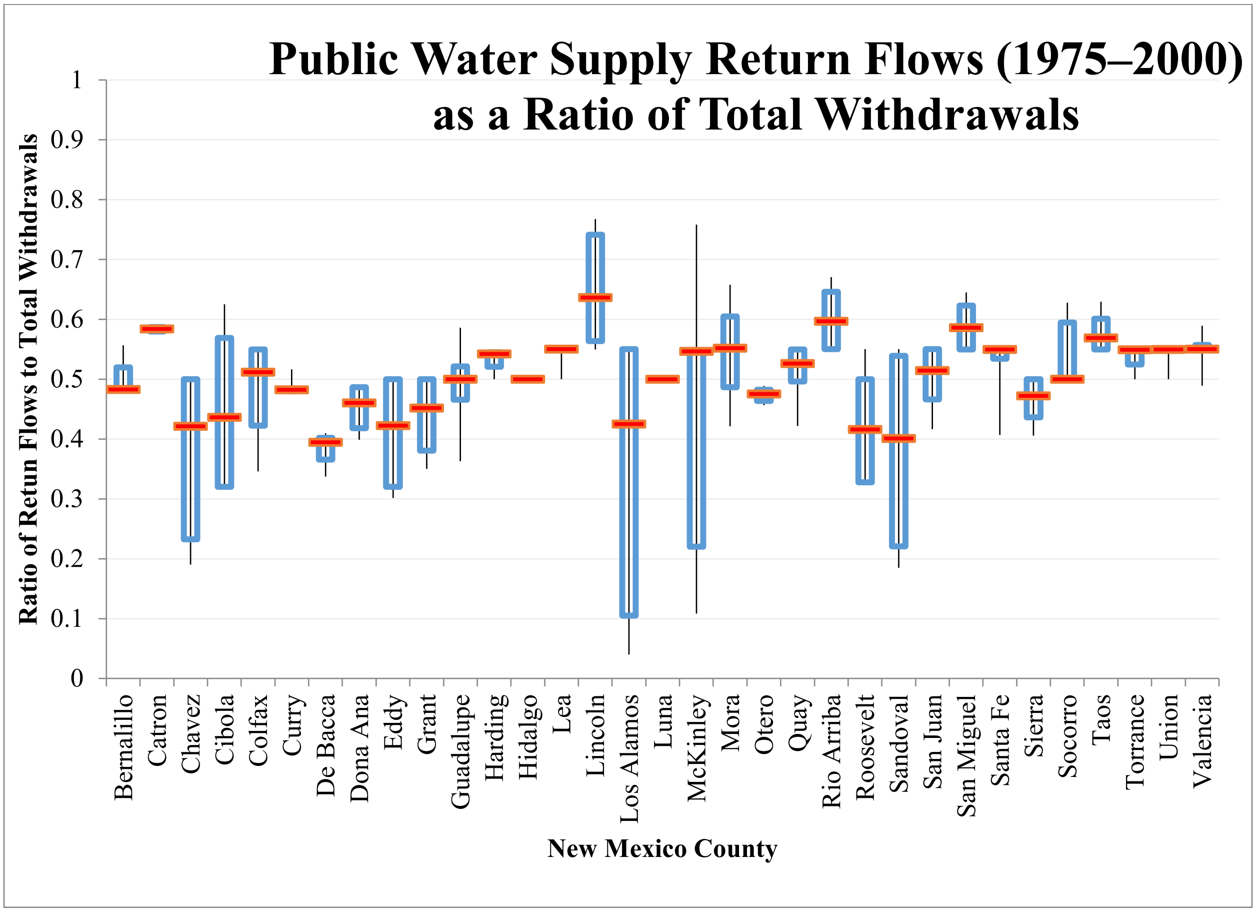


Figure 20. Public water supply return flows as a ratio of total public withdrawals. Median values are the solid red dashes, and the middle 50% of values are within the boxes. If there is not a visible box, the middle 50% of values are equal to the median value. Whiskers represent the maximum and minimum values. Catron, De Baca, Guadalupe, Harding, Mora, and Torrance counties report zero public water use until 1990, these zero values are excluded from the calculation (e.g., Longworth et al., 2013).

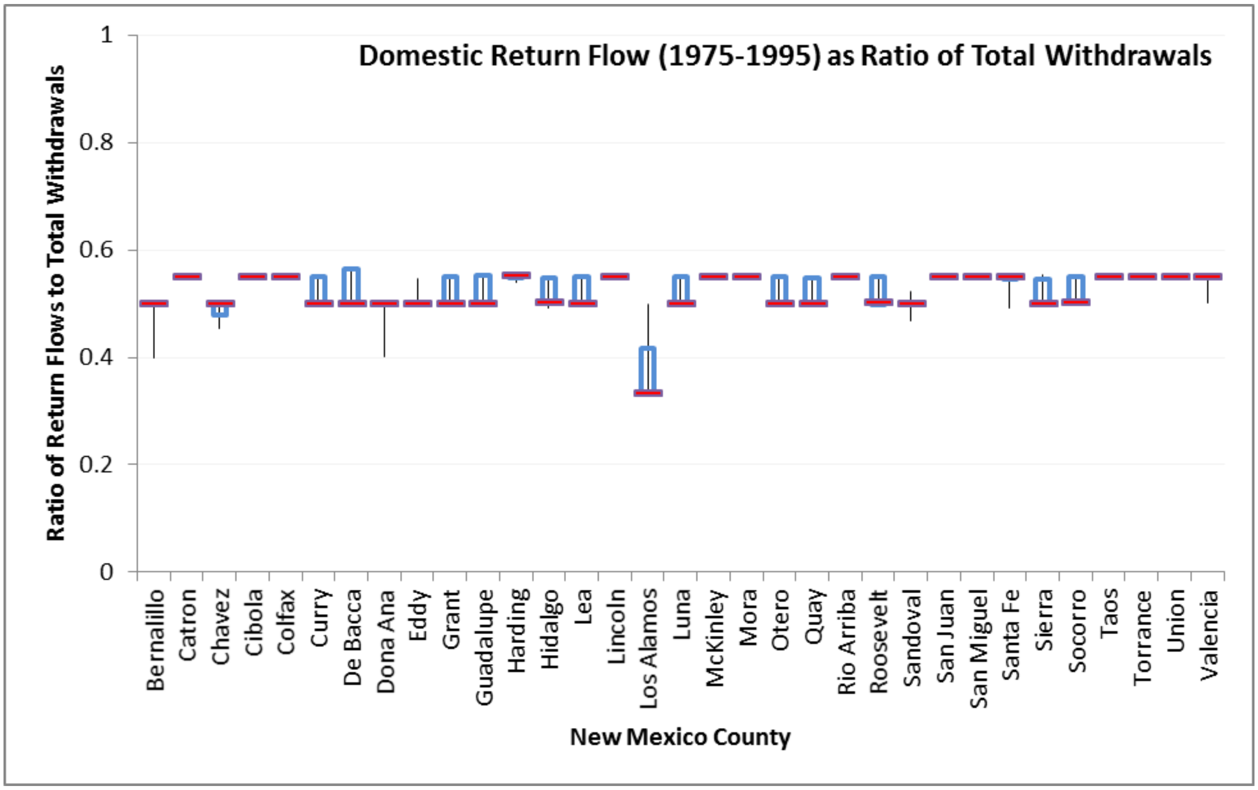


Figure 21. Domestic water use return flows as a ratio to total domestic withdrawals. Median values are the solid red dashes, and the middle 50% of values are within the boxes. If there is not a visible box, the middle 50% of values are equal to the median value. Whiskers represent the maximum and minimum values (e.g., Longworth et al., 2013).

A.15 Surface water and groundwater irrigation efficiencies by county

Table 41. Surface Water and groundwater irrigation efficiencies by county. These values represent the average on on-farm and off-farm irrigation efficiencies. Counties with surface water irrigation efficiencies of 1.00 have very minor uses of surface water irrigation for agriculture, but result from published pre-1985 OSE water use reports where surface water withdrawals are equal to surface water depletions for agricultural use.

County	SW irrigation efficiency	GW irrigation efficiency
Bernalillo County	0.26	0.56
Catron County	0.16	0.63
Chaves County	0.56	0.68
Cibola County	0.35	0.67
Colfax County	0.46	0.62
Curry County	1.00	0.71
De Baca County	0.34	0.67
Dona Ana County	0.40	0.66
Eddy County	0.50	0.71
Grant County	0.17	0.57
Guadalupe County	0.45	0.57
Harding County	1.00	0.69
Hidalgo County	0.48	0.60
Lea County	1.00	0.71
Lincoln County	0.40	0.54
Los Alamos County	1.00	0.00
Luna County	0.41	0.58
McKinley County	0.41	0.00
Mora County	0.46	0.84
Otero County	0.38	0.69
Quay County	0.39	0.66
Rio Arriba County	0.39	0.53
Roosevelt County	1.00	0.73
Sandoval County	0.29	0.56
San Juan County	0.57	0.00
San Miguel County	0.42	0.65
Santa Fe County	0.44	0.67
Sierra County	0.44	0.62
Socorro County	0.31	0.60
Taos County	0.39	0.65
Torrance County	1.00	0.67
Union County	0.47	0.72
Valencia County	0.28	0.59

A.16 Animal Use and Population Tables

Table 42. Daily per-capita water use by animal represented as gallons per-capita per day (GPCD). These data came from the following sources: Non-Dairy Cattle (Sweeten et al., 1990), Horses (Van der Leeden et al., 1990), Dairy Cows (Hagevoort, 2012; Wiersma, 1988), and all others (Soil Conservation Service, 1975; Sykes, 1955).

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 forward)[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 43. Total New Mexico animal populations from the OSE, USDA, and the populations used in the NMDSWB. The USDA animal populations from 1975–1999 are from the NASS Quick Stats Service (USDA, 2014a) and the USDA animal populations from 2000–2015 are from the NASS annual statistical bulletins (e.g., USDA, 2000) and the 2002, 2007, and 2012 Census of Agriculture (e.g., USDA, 2004, 2105).

		All Cattle (non-dairy)	Dairy Cattle	Sheep/ Lambs	Hogs/ Pigs[b]	Chickens[b]	Horses[c]
1990	OSE	571,000[a]	89,000	462,000	27,000	1,430,000	24,870
	USDA	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
1995	OSE	560,000[a]	170,000	265,000	5,000	1,400,000	24,870
	USDA	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
2000	OSE	564,000[a]	236,000	290,000	5,000	1,400,000	24,870
	USDA	1,404,000	236,000	289,250	4,047	32,758	46,686
	NMDSWB	1,404,000	236,000	289,250	4,047	32,758	46,686
2005	OSE	1,307,703	379,472	160,555	2,551	1,400,852	31,799
	USDA	1,182,000	316,000	143,600	2,077	32,749	53,616
	NMDSWB	1,182,000	316,000	143,600	2,077	32,749	53,616
2010	OSE	1,327,584	319,552	123,679	801	807,660	34,287
	USDA	1,253,100	307,700	119,200	1,547	28,268	50,723
	NMDSWB	1,253,100	307,700	119,200	1,547	28,268	50,723
2015	OSE	n/a	n/a	n/a	n/a	n/a	n/a
	USDA	1,014,200	316,200	89,700	1,547	28,268	50,723
	NMDSWB	1,014,200	316,200	89,700	1,547	28,268	50,723

[a] non-dairy cattle populations in OSE reports prior to 2005 are exclusive of heifers.

[b] In 1999 the USDA stops reporting annual populations of chickens and hogs/pigs. The USDA 2002 Census of Agriculture (USDA, 2004) is used for chicken and hog/pig populations from 2000–2004, the USDA 2007 Census of Agriculture (USDA, 2009) is used for chicken and hog/pig populations from 2005–2009, and the USDA 2012 Census of Agriculture (USDA, 2014b) is used for chicken and hog/pig populations from 2010–2015.

[c] Horse population data at the county level is not available until the USDA 2002 Census of Agriculture (USDA, 2004), the NMDSWB uses those values from 1975–2004. The USDA 2007 Census of Agriculture (USDA, 2009) is used for horse populations from 2005–2009, and the USDA 2012 Census of Agriculture (USDA, 2014b) is used for horse populations from 2010–2015.

A.17 Ratio of Agricultural Return Flows to Surface Water/Groundwater

Table 44. Ratio of agricultural return flows to surface water as used in the NMDSWB model. These percentages do not determine the resulting return flows of agricultural use, they are used to partition the total agricultural return flow into returns to surface water and returns to groundwater. For example, in counties with 80% returns to surface water, if the total agricultural return flow was calculated to be 100 AF, 80 AF would return to the surface water system and 20 AF would return to the groundwater system.

County	% of agricultural returns to surface water
Bernalillo County	100
Catron County	100
Chaves County	0
Cibola County	80
Colfax County	100
Curry County	0
De Baca County	80
Dona Ana County	80
Eddy County	30
Grant County	80
Guadalupe County	100
Harding County	0
Hidalgo County	0
Lea County	0
Lincoln County	80
Los Alamos County	0
Luna County	80
McKinley County	100
Mora County	100
Otero County	0
Quay County	100
Rio Arriba County	100
Roosevelt County	0
Sandoval County	100
San Juan County	100
San Miguel County	100
Santa Fe County	30
Sierra County	80
Socorro County	80
Taos County	100
Torrance County	80
Union County	0
Valencia County	100

A.18 Extra Terrestrial Radiation

The R_a variable represents extraterrestrial solar radiation, and is expressed in units of length/time, which means that a given amount of radiation (energy) is expressed as the depth of water it could evaporate (mm/da) (Equation 14).

$$R_a = 15.392 * E_{sd} * (S_{ha} * Sin(C_l) * Sin(S_d) + Cos(C_l) * Cos(S_d) * \mathrm{Sin}(S_{ha})) \quad \text{(Equation 14)}$$

E_{sd} = Earth Sun Distance (by month)

$= 1 + 0.033 * Cos(\frac{2\pi * Middle\ Julian\ Day\ of\ each\ month}{365})$

S_{ha} = Sunset Hour angle (by month and county)

$= ArcCos(-Tan(C_l) * Tan(S_d)$

C_l = Mean County Latitude

S_d = Solar Declination (by month)

$= 0.4093 * Sin(\frac{2\pi * Middle\ Julian\ Day\ of\ each\ month}{365 - 1.405})$

A.19 Irrigation Season Length Calculations

Table 3 in the U.S. Department of Agriculture's Technical Release 21 (TR-21) (Soil Conservation Service, 1970) provides some guidance for the U.S. 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 growing season is expected to be controlled more by minimum temperatures than mean temperatures, and climate change may impact minimum temperatures more than mean temperatures (Llewellyn et al., 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 22 and defined below:

$$P_f = \frac{[1+\cos(\pi * \left(\frac{T_{min}-T_1}{T_2-T_1}\right)}{2} \qquad \text{(Equation 15)}$$

where P_f is the probability of a freeze occurring during the month, T_{min} is the monthly average minimum temperature (°F), 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 $R^2 = 0.96$ (n = 30). 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% (and greater than 0%) is 75%, then it is assumed that irrigation occurs during 25% of the month. The switch from probabilistic to deterministic estimation of irrigation season resulted in a calibration based adjustment of the T_1 and T_2 parameters to 32°F and 46°F[7]. 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. The distribution of beginning and end months and the season lengths based on these parameters are shown in Table 45 and Figure 23.

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[7] Best fit to season length at the eight weather stations was 34°F and 48 °F, but T_1 and T_2 were reduced to get a better match to statewide five-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.

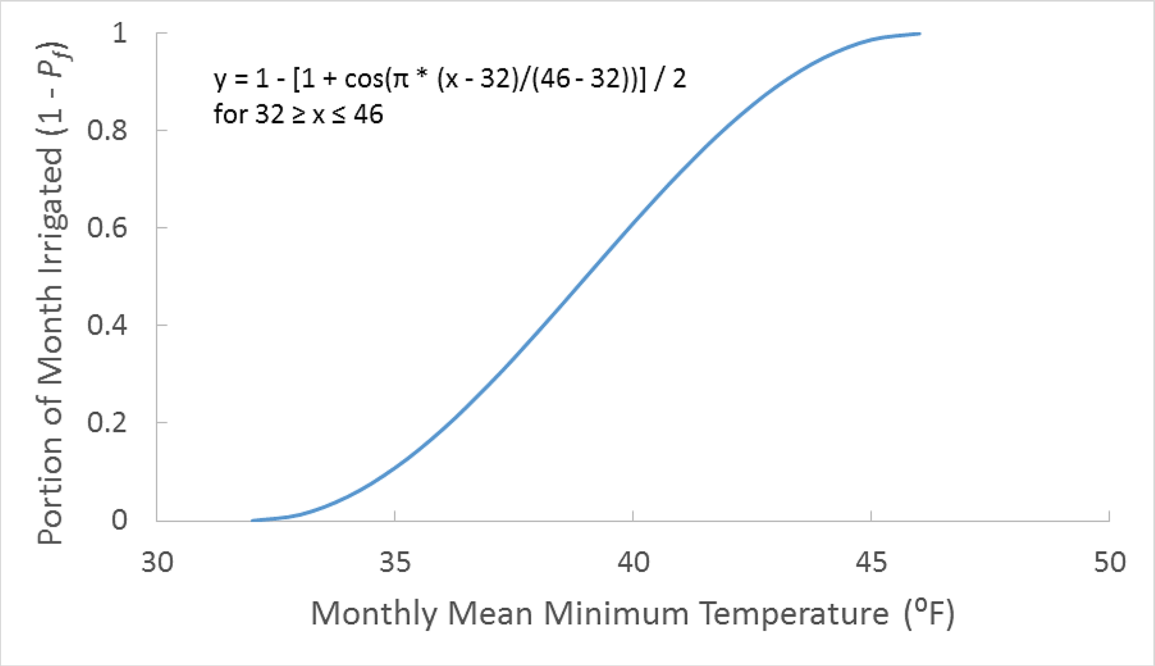

Figure 22. Functional relationship between monthly average minimum flow, and irrigation season start and end. The first month where T_{min} goes above 25^0F, a calculated portion of that month starts the irrigation season, which then continues until the first month T_{min} goes below 40^0F and a calculated portion of that month ends the irrigation season.

Table 45. Irrigation start and end months (end month is the last month irrigation occurs) and season length calculated from 1971 through 2009 using PRISM (2018) mean minimum monthly temperatures between 32°F and 46°F to start and end the season following the relationship shown in Figure 22.

	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%			

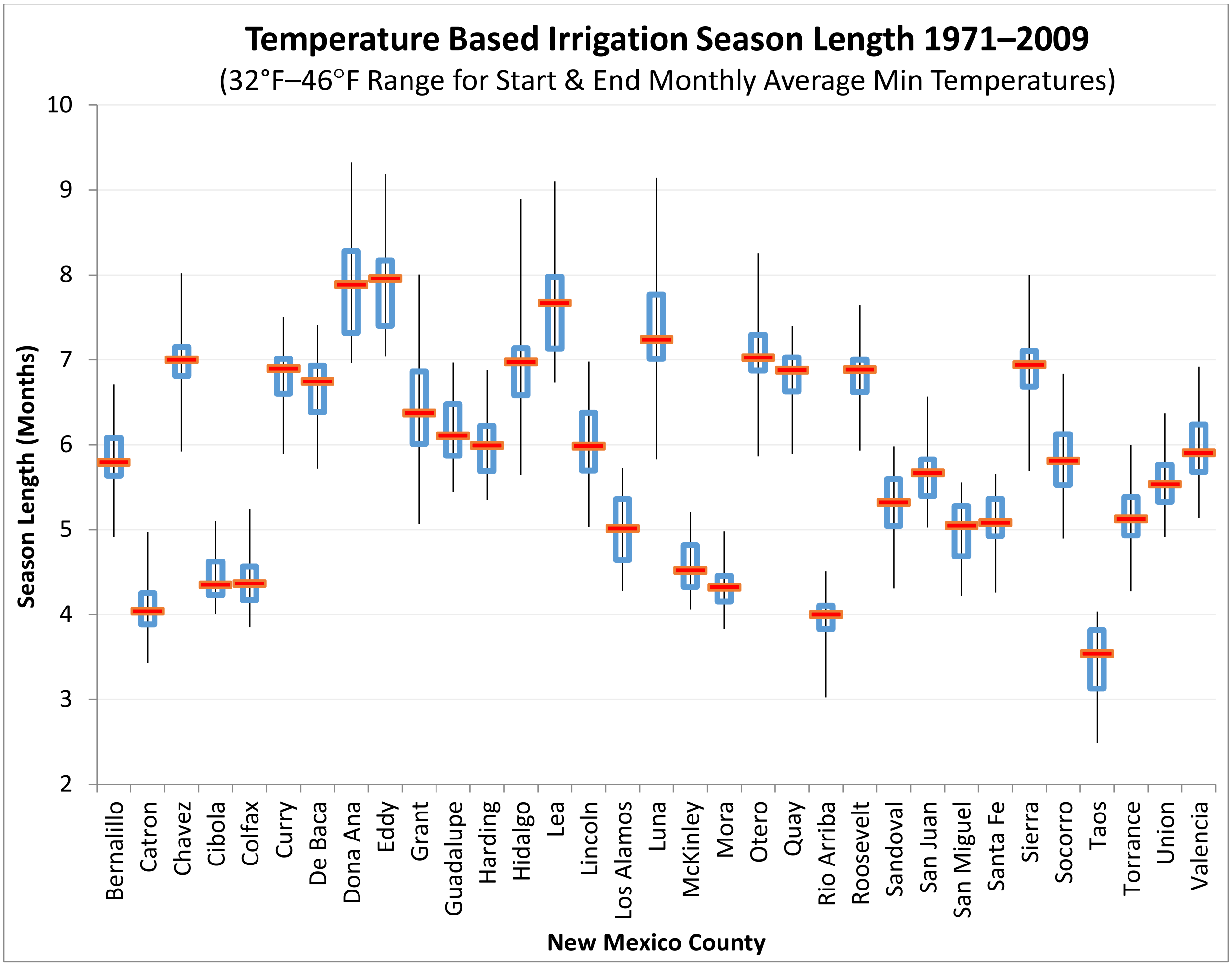

Figure 23. Calculated irrigation season lengths by county for historical years 1971 through 2009 if the irrigation season starts during the first month the county average PRISM (2018) mean minimum monthly temperature is more than 32°F, and ends during the month when the same is less than 46°F. Median values are the solid red dashes, and the middle 50% of values are within the boxes. Whiskers represent the maximum and minimum values.

A.20 Effective Precipitation

The Soil Conservation Service (1970) method is calculated as follows in the NMDSWB, and is used to estimate consumptive irrigation requirement from ET estimates done with both Hargreaves-Samani (Hargreaves and Samani, 1985) and Modified Blaney-Criddle ET (New Mexico Office of the State Engineer, 2015) methods:

$$P_e = SF(0.70917P_t^{0.82416} - 0.11556)(10^{0.002426ET_c}) \quad \text{(Equation 16)}$$

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 (unitless)

The soil water storage factor is defined as:

$$SF = (0.531747 + 0.295164\,D - 0.057697\,D^2 + 0.003804\,D^3) \qquad \text{(Equation 17)}$$

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 (Soil Conservation Service, 1970). The NMDSWB assumes an average irrigation application depth 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 effective rainfall (Table 46) (Stamm, 1967). This method for calculating effective rainfall is used in in conjunction with the Blaney-Criddle ET calculation (Blaney and Criddle, 1950).

Table 46. USBR effective rainfall.

Monthly Rainfall (R) (inches)	Effective Rainfall (R_e) (inches)
$1 \leq R$	$R_e = 0.95R$
$1 \leq R \leq 2$	$R_e = 0.95 + 0.90(R - 1)$
$2 \leq R \leq 3$	$R_e = 1.85 + 0.82(R - 2)$
$3 \leq R \leq 4$	$R_e = 2.67 + 0.65(R - 3)$
$4 \leq R \leq 5$	$R_e = 3.32 + 0.45(R - 4)$
$5 \leq R \leq 6$	$R_e = 3.77 + 0.25(R - 5)$
$R > 6$	$R_e = 4\ .02 + 0.0.5(R - 6)$

A.21 Irrigated Agriculture Areas

Total irrigated agricultural acreage in the historical period of the NMDSWB comes from Lansford (1997) for years 1975–1994 and from the 5-year OSE Water Use by Category reports (e.g., Longworth et al., 2013) for years 1995–2015. Since, the OSE reports do not include information regarding crop type, the percentages of crop types from other sources for years 1995–2015 are multiplied by the OSE reported acreages to determine crop type acreage at the county scale. The USDA/NASS reports (USDA, 2014a) are used from 1995–2007, and the USDA CropScape Cropland Data Layer (USDA, 2015) is used from 2008–2015, where the 2015 estimate is used for crop type and total acreage in the future period of the model. A summary of information available from these four sources is shown in Table 47.

Table 47. Information summary for irrigated agriculture reports.

	OSE	NMSU	USDA Reports	USDA CropScape
Spatial resolution	County	County	County	State
Temporal resolution	Every five years	Annual	Annual[a]	Annual
Temporal extent	1970–2010	1970–1994	1970–2007[b]	2008–2015
Crop type information	No	Yes	Yes	Yes
Multiple-cropped information	No	Yes	No	Yes

[a] Information for vegetable totals and orchards are is only available every five years.

[b] Data included in these reports after 2007 are incomplete and less reliable.

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 that are planted but not irrigated, but does not include this data by crop type. Because Lansford (1997) does not make the distinction between fields that are planted but not irrigated or fields that are multiple cropped, the adjusted acreage of each crop is calculated by multiplying the crop's percentage of total area in a given county by the sub-total irrigated acreage (sub-total acreage is the total irrigated acreage minus the planted but not irrigated and multiple cropped acreage). The model uses the sub-total acreage reported by Lansford (1997) for 1971 to 1994.

The USDA/NASS has an annual survey that 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 begin in 1971 for most crops and end in 2007 (the dataset is incomplete and less reliable after 2007). 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 are available from 1972 to 1989 and only include acres planted; the assumption is made that all barley planted during this time is irrigated. For cotton, data are available for irrigated acres planted from 1972 to 2007 and include acreage for both Upland and Pima cotton varieties. The data availability for hay on the county level are reported only as acres harvested, so the assumption is made that all hay harvested from 1971 to 2007 is irrigated. For sorghum and peanuts, data are available for irrigated acreage from 1971 to 2007 and for wheat, irrigated acreage data are available from 1972 to 2007. Annual crop acreage are 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 2007.

The USDA CropScape Cropland Data Layer (USDA, 2015) is available as annual spatial rasters starting in 2008. These rasters have a 30 m resolution and categorize all land uses. Zonal stats were ran on the annual rasters to determine crop type acreages for NM counties. This data source does not indicate whether crops are irrigated or non-irrigated, so it is assumed that all crops are irrigated; however, winter wheat and minor occurrences of double crops that would have to be arbitrarily split between two of the four crop-type categories used in the model are excluded from the acreage used in the NMDSWB.

The previously described NMSU crops (Lansford, 1997), USDA annually reported field crops (USDA, 2014a), and USDA CropScape crops (USDA, 2015) are aggregated into four categories that are used in the model, which include: grains, alfalfa and pasture grass, fruits and vegetables, and tree orchards (Table 48). The county acreages by combined crop type for 2010 used in the NMDSWB can be seen in Table 49.

Table 48. Crop type and aggregation.

NMSU Crops	USDA Quick Stats Crops	USDA CropScape Crops	Model Combined Crops
Barley	Barley	Barley	
Corn	Corn	Corn	
		Pop/Orn Corn	
Cotton-Upland	Cotton	Cotton	
Cotton-Pima			
Sorghum-Grain	Sorghum	Sorghum	
Sorghum-All other			Grains
Wheat	Wheat	Durum Wheat	
		Spring Wheat	
Other Small Grains		Rye	
		Oats	
		Millet	
		Triticale	
		Double Crop (Grains)	
Alfalfa		Alfalfa	
Planted Pasture	Hay	Other Hay/Non Alfalfa	Alfalfa and Pasture
Native Pasture			
Peanuts	Peanuts	Peanuts	
Sugar Beets			
Dry Beans		Dry Beans	
Potatoes		Potatoes	
Lettuce		Lettuce	
Onions		Onions	
Chile		Peppers	
All other vegetable	Vegetable Totals[a]	Soybeans	
All other field		Peas	Fruits and Vegetables
		Tomatoes	
		Carrots	
		Cabbage	
		Squash	
		Pumpkins	
		Watermelons	
		Cantaloupes	
Vineyards		Grapes	
		Cherries	
Orchards	Orchards[a]	Apples	
		Apricots	
		Peaches	Orchards
		Pecans	
		Pistachios	

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

Table 49. NMDSWB county acreages by combined crop type for 2010.

Counties	Grains	Alfalfa and Pasture	Fruits and Vegetables	Tree Orchards
Bernalillo	460	4,400	280	640
Catron	600	360	370	20
Chaves	33,400	43,760	150	4,690
Cibola	1,800	420	650	140
Colfax	230	15,930	0	20
Curry	98,190	7,870	750	180
De Baca	2,350	9,260	0	20
Dona Ana	21,860	19,380	1,910	21,900
Eddy	11,490	27,110	1,140	5,270
Grant	570	2,370	150	1,030
Guadalupe	440	2,990	0	280
Harding	290	1,070	0	0
Hidalgo	8,940	7,860	530	80
Lea	37,080	10,380	740	760
Lincoln	250	2,360	0	1,270
Los Alamos	0	0	0	0
Luna	15,230	9,620	4,830	1,280
McKinley	280	110	500	20
Mora	70	4,130	0	90
Otero	1,220	4,650	160	2,330
Quay	9,630	1,670	0	20
Rio Arriba	260	31,040	120	40
Roosevelt	86,020	13,860	4,170	170
Sandoval	170	7,620	260	130
San Juan	32,030	23,990	28,590	440
San Miguel	1,460	9,640	0	130
Santa Fe	9,020	7,920	10	80
Sierra	2,240	3,490	520	780
Socorro	780	10,960	6,640	520
Taos	150	26,790	10	10
Torrance	7,800	14,690	10	60
Union	41,330	2,180	0	40
Valencia	1,000	18,720	3,770	680

A.22 USGS NLCD Detailed Data Information

Table 50. 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)

A.23 Surface Water Evapotranspiration

Table 51. Stream segment parameters for surface water evapotranspiration by counties calculations.

Bernalillo County

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 Grande at Albuquerque	10	45	800	275	7000	400	27
Rio Puerco near Bernardo	0.2	1	30	30	7000	500	25

Catron County

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 Francisco River near Reserve NM	9	2	15	9	70	470	50
San Francisco River near Glenwood NM	25	11	30	36	105	2600	30

Chaves County

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)	
Pecos River near Acme NM	8	14	85	74	1250	125	59
Rio Hondo at Diamond Ranch near Roswell NM	1	8	100	120	16100	195	26
Rio Hondo below Diamond A Dam near Roswell NM	0.5	5.5	46	17	217	26	30
Pecos River near Arthur	1.7	10.7	47.9	16	90.6	22.6	7

Cibola County

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)	
Zuni River near NM-AZ Stateline	2.3	6.7	4.6	7.5	34	16	70
Rio San Jose at Acoma Pueblo	0.085	1.75	1.5	6	550	60	7

Colfax County

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)	
Cimarron River below Eagle Nest Dam NM	0.4	8	18	150	165	307	10
Cimarron River near Cimarron NM	1.5	10	15	20	215	27	40
Vermejo River near Dawson NM	3.3	16	10	20	100	27	55
Rayado Creek near Cimarron NM	1.5	11	5.5	27	160	33	30
Ponil Creek near Cimarron NM	0.08	3	3.5	12	240	23	25
Canadian River near Taylor Springs NM	0.25	5	13	28	2920	120	75

Curry County

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)	
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

De Baca County

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)	
Pecos River below Sumner Dam	17.5	1.05	17.6	100	161	1274	25.5
Pecos River near Dunlap NM	27	11	48	45	243	504	30.5

Dona Ana County

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 Grande below Caballo Dam	1	10	300	140	1990	170	34.5
Rio Grande at El Paso	7	20	375	145	1240	180	42.5

Eddy County

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 Panasco at Dayton NM	5	10	25	26	190	65	33
Kaiser Channel near Lakewood NM	1.5	15	88	40	1860	72	17.5
Pecos River below Dark County at Carlsbad NM	1.5	10	145	35	1280	325	25
Pecos River at Pierce County Crossing NM	3	6	80	35	700	335	20
Pecos River at Red Bluff NM	2	8.5	350	100	52600	750	14
Deleware River near Red Bluff NM	0.2	2	40	28	34600	380	8
Pecos River near Artesia NM	8.5	40	270	59	1590	98	20.5

Grant County

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)	
Mimbres River at Mimbres	5	15	90	30	1160	74	43
Mogollon Creek near Cliff NM	0.2	4	8	20	210	45	25
Gila River near Gila NM	19	30	85	60	3000	140	75
Gila River near Red Rock	12	20	105	60	210	130	20
Gila River below Blue Creek near Virden NM	3.5	15	130	50	6250	255	15

Guadalupe County

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)	
Gallinas River near Colonias NM	1	5	42	32	267	52	4.5
Pecos River near Anton Chico NM	1	11	125	36	670	135	35
Pecos River near Puerto de Luna Sumner Reservoir Inflow	55	55	110	75	1560	117	34

Harding County

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)	
Ute Creek near Logan NM	0.6	6	9	22	630	57	65

Hidalgo County

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)	
Gila River below Blue Creek near Virden NM	3.5	15	130	50	6250	255	7.5
Gila River at Duncan AZ	1	10	60	45	2800	1230	10

Lea County

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)	
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Lincoln County

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 Ruidoso at Hollywood NM	2.5	9	118	26	411	56	27
Rio Hondo at Diamond A Ranch near Roswell NM	1.7	10.7	47.9	16	90.6	22.6	25

Los Alamos County

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)	
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Luna County

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)	
Mimbres River at Mimbres	5	15	90	30	1160	74	43

McKinley County

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 NM	0.02	1	0.2	2	230	75	24
Zuni River abv. Black Rock Resevoir NM	0.085	1.75	1.5	6	550	60	38

Mora County

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)	
Coyote Creek near Golondrinas NM	0.4	4	5	12	180	30	27
Mora River at La Cueva NM	0.4	6	13	22	405	44	29
Mora River near Golondrinas NM	0.75	6	12	30	270	39	44

Otero County

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)	
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Quay County

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)	
Canadian River at Logan NM	1.5	10	3	13	22147	375	36
Revuelto Creek near Logan NM	0.03	1	9	25	3120	137	50

Rio Arriba County

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 Antonio River at Ortiz, CO	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Los Pinos River near Ortiz, CO	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rio Chama near La Puente	3	15	100	100	5000	140	14.5
Rio Chama below El Vado Dam	1	8	300	100	6000	175	28.5
Rio Chama above Abiquiu Reservoir	20	40	250	90	5000	120	12.5
Rio Chama below Abiquiu Reservoir	1	10	300	100	2500	180	13
Rio Chama near Chamita	2	5	300	120	4900	160	14.5
Rio Ojo Caliente at la Madera	3	10	20	20	1300	80	21
Rio Grande at Embudo	3	120	400	100	10000	130	29

Roosevelt County

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)	
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Sandoval County

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 Grande below Cochiti Dam	10	40	750	180	7000	220	41
Jemez River near Jemez	5	12	40	30	1000	60	38
Jemez River below Jemez Canyon Dam	1	8	30	30	1500	100	15
Arroyo Chico near Guadalupe	0.3	3	7	15	200	60	9
Rio Puerco above Arroyo Chico nr Guadalupe	0.3	5	10	15	2000	100	46

San Juan County

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

San Miguel County

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)	
Gallinas Creek near Montezuma NM	5.5	11	105	24	380	27	39.5
Pecos River near Pecos NM	8.5	26	244	46	493	84	43
Canadian River near Sanchez NM	0.3	6	30	36	2610	129	73
Gallinas River near Colonias NM	1	1	42	125	267	670	30
Pecos River near Anton Chico NM	0.2	11	40	36	34600	135	24.5

Santa Fe County

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 Nambe below Nambe Falls Dam	1	8	6	12	60	22	21
Rio Grande at Otowi Bridge	270	100	900	120	10000	150	16
Santa Fe River near Santa Fe	0.1	2	5	10	80	20	13.5
Santa Fe River above McClure Reservoir	1	5	5	12	30	22	4.5
Santa Fe River above Cochiti Lake	1	5	7	15	200	35	14
Galisteo Creek below Galisteo Dam	0.2	2	5	10	2000	50	33

Sierra County

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 Grande below Elephant Butte Dam	1	15	150	80	4500	125	34.5
Rio Grande below Caballo Dam	1	10	300	140	1990	170	42.5

Socorro County

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 Grande Floodway at Bernardo	1	10	600	150	7800	500	16
Rio Puerco near Bernardo	0.2	1	30	30	7000	500	14
Rio Grande Floodway at San Acacia	2	10	300	100	8000	200	28
Rio Grande Floodway at San Marcial	5	20	500	200	9000	350	38

Taos County

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)	
Costilla Creek near Costilla	3	9	75	30	400	45	29
Rio Grande near Lobatos, CO	25	75	160	140	500	160	6
Rio Grande near Cerro	50	50	300	90	9200	140	28
Red River near Questa	3	7	20	20	290	40	27
Rio Hondo near Valdez	3	10	25	18	200	45	17
Rio Lucero near Arroyo Seco	3	10	12	15	175	40	21
Rio Pueblo de Taos near Taos	3	10	12	18	400	30	17
Rio Pueblo de Taos below Los Cordovas	2	15	30	25	1500	75	10
Rio Grande del Ranch near Talpa	1	10	8	15	400	25	23.5
Rio Grande blw Taos Junction Bridge nr Taos	160	100	500	120	9500	200	23
Embudo Creek at Dixon	1	10	40	30	1300	50	4

Torrance County

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)	
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Union County

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)	
Cimarron River near Kenton OK	0.04	1	40	20	3070	196	64

Valencia County

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 Grande at Albuquerque	10	45	800	275	7000	400	11
Rio Grande Floodway at Bernardo	1	10	600	150	7800	500	17
Rio Puerco near Bernardo	0.2	1	30	30	7000	500	24

A.24 Uncertainty Analysis

A.24.1 ET Uncertainty

ET uncertainty is the total combined uncertainty from; the Hargreaves-Samani (Appendices A.24.1.1) and Blaney-Criddle (Appendices A.24.1.2) ET equations, crop coefficients (Appendices A.24.1.3) and PRSIM data (Appendices A.24.1.4)

A.24.1.1 Hargreaves-Samani Uncertainty

Hargreaves and Allen (Hargreaves and Allen, 2003) show daily timestep comparisons of Hargreaves-Samani reference ET versus lysimeter measured values for an eight-year period in Davis, California (Hargreaves and Allen, 2003). Visual inspection of the comparison in Hargreaves and Allen (2003) suggests that the standard error of estimate of approximately 1 mm/day, which is roughly 25% of the average daily ET value, captures 50–70% of the data. The daily timestep error (estimated values within 25% of actual 50–70% of the time) is consistent with a shorter timestep and improves with increases in length of the timestep. Jensen et al. (1997) compare Hargreaves-Samani and Penman-Monteith reference ET calculations at a monthly timestep to lysimeter measurements at six locations and find a standard error of estimate of 0.34 mm/day for the Hargreaves-Samani equation and 0.32 mm/day for the Penman-Monteith (Jensen et al., 1997). For a mean monthly reference ET of approximately 150 mm/month, these values suggest standard errors of estimate of approximately 10 mm/month, or roughly 7%, with no significant difference between Penman-Monteith and Hargreaves-Samani at a monthly timestep. Standard error of estimate does not give information on distribution of errors, but a set of numbers between 1–20 multiplied by an error distribution that is normal about 1.00 with a standard deviation of 0.07 results in a standard error of estimate of approximately 7–10%, so using the standard error of estimate as a proxy for the standard deviation of normally distributed error is reasonable. Thus, the Jensen et al. (1997) data can be used to approximate the accuracy of the Hargreaves-Samani method using monthly timestep of within 10% of actual ET rate for approximately 70% of the time (based on the approximation that 70% of values in a normal distribution are within one standard deviation of the mean), and within 30% 99% of the time. Gavilan et al. (2006) compare Hargreaves-Samani to Penman-Monteith over several years at 86 climate stations in southern Spain. They use 2–3 years of daily average data and accumulate reference ET estimates over the period of record. They find that at 35 stations (41%) Hargreaves-Samani underestimated Penman-Monteith reference ET with a mean underestimate of 10% Gavilán et al. (2006). At 21 stations (24%), Hargreaves-Samani overestimates Penman-Monteith reference ET with a mean overestimate of 9%. The remaining 30 stations average errors between ± 5%. Assuming the mean over/under estimates of 10% and 9% are close to the median values, roughly 17 station's underestimates are more than 10% off, and roughly 10 station's overestimates are more than 9% off. Thus, approximately 59 stations (69%) are within 10% of the Penman Monteith estimate.

Therefore, based on the literature, monthly estimates of ET_o using Hargreaves-Samani in a semi-arid environment will be assumed to be within 10% of actual ET rates about 70% of the time. This conceptual Hargreaves-Samani ET_o calculation error factor distribution is represented in the NMDSWB as normally distributed about 1.0 (no error) with a standard deviation of 0.1.

A.24.1.2 Blaney-Criddle Uncertainty

For consistency with New Mexico OSE water use reports prior to 2005, the NMDSWB calculates actual crop ET with the Blaney-Criddle method by default (though alternatively the user can select the Hargreaves-Samani method). As pointed out by Sammis et al. (2011), water managers are moving away from the Blaney-Criddle representation towards a reference ET based approach. In reflection of the general trend away from Blaney-Criddle, it is assumed that Blaney-Criddle ET estimates are less accurate than Hargreaves-Samani based calculations and the NMDSWB arbitrarily adds an additional 10% uncertainty such that Blaney-Criddle calculations are assumed to be within 20% of actual ET rates approximately 70% of the time. This conceptual Blaney-Criddle ET calculation error factor distribution is represented in the NMDSWB as normally distributed about 1.0 (no error) with a standard deviation of 0.2.

A.24.1.3 Crop Coefficient Uncertainty

There is also considerable variation and uncertainty in reference ET crop coefficients (used with Hargreaves-Samani) and Blaney-Criddle season crop coefficients. There is also large uncertainty in stress factors (affected by irrigation practices, soil quality, lack of water availability) that may reduce the reference ET calculated by Hargreaves-Samani. For purposes of this uncertainty analysis, the crop coefficients utilized by the Hargreaves-Samani method are assumed to be within 10% of actual 70% of the time (within 30%, 99% of the time). Those used with the Blaney-Criddle method within 20% of actual ET rates 70% of the time (within 60%, 99% of time). The conceptual crop coefficient calculation error factor distribution is represented in the NMDSWB as normally distributed about 1.0 (no error) with a standard deviation of 0.1 for Hargreaves-Samani and 0.2 for Blaney-Criddle.

A.24.1.4 PRISM Precipitation and Temperature Uncertainty

PRISM (2018) interpolation uncertainties were estimated with cross-validation (C-V) mean absolute error (MAE) and the 70% prediction interval (PI70) of the climate-elevation regression function (Daly et al., 2008). While the two measures did not correlate strongly at the point level, they did provide similar estimates when averaged over large regions. The C-V error is a measure of the difference between one or more station values and the model's estimates for those stations when the stations have been removed from the data set (Daly et al., 2008). The average monthly C-V MAE for western United States was 8.18 mm, 1.17° C, 0.73° C, and 0.95° C for precipitation, minimum, maximum, and mean temperatures, respectively. The C-V error estimates have no associated distribution and thus cannot be directly incorporated into a Monte-Carlo simulation.

While the C-V gives a good sense of error at station locations, the PI70 method gives a relative sense of modeled errors at all grid cells. For the PI70 method a (1-α) of 0.70 was chosen for the prediction interval because it approximated one standard deviation (where (1-α)=0.67) around the model prediction (Daly et al., 2008). This standard deviation is used to develop the calculated error factor distribution in the NMDSWB. The average monthly PI70 for the western United States was 6.10 mm, 1.15° C, 0.74° C, and 0.95° C for precipitation, minimum, maximum, and mean temperatures, respectively. In the western United States from 1981 to 2010 the mean monthly precipitation equals 44.02 mm, with a 70% prediction interval around this value equal to

37.92 mm to 50.12 mm. If the stated interval is assumed to be normally distributed, this represents a standard deviation of 14%. The conceptual PRISM (2018) precipitation calculation error factor distribution is represented in the NMDSWB as normally distributed about 1 (no error) with a standard deviation of 0.14.

For the PRISM (2018) temperature data, the minimum, maximum, and mean temperatures are assumed to be highly correlated; thus, the distribution error factor is only calculated for mean temperature and applied accordingly to minimum, maximum, and mean temperatures. This also avoids the potential conflict in Monte-Carlo simulation of minimum-maximum temperature swaps. In the western United States from 1981 to 2010, the mean monthly temperature equals 9.48°C, with a 70% prediction interval around this value equal to 8.53° C to 10.43°C. If the stated interval is assumed to be normally distributed, this represents a standard deviation of 9%. The conceptual PRISM (2018) temperature calculation error factor distribution is represented in the NMDSWB as normal about 1.0 (no error) with a standard deviation of 0.09.

A.24.2 USGS Stream Gage Uncertainty

A.24.2.1 Observations Uncertainty in Theory

One way to evaluate model performance is to look at differences between modeled and actual values (i.e., residuals) of selected parameters at points of historical observation. The points of observation for evaluation of surface water model performance during the calibration period include reservoir storage estimates and streamflows at gages interior to the model and not immediately below a reservoir (the reservoir is calibrated and measured reservoir releases are assumed to be without error). However, the observations themselves are not without error. As documented by the United States Geological Survey (USGS) (e.g., Miller and Stiles, 2006), the historical observations of streamflow contain errors and uncertainties from two main sources:

1. The stability of the stage-flow relationship at the gage location. The gage measures stream stage, and uses a relationship between stage and flow, derived from field measurements of flow at various stages, to estimate streamflow. However, this relationship can change as the stream bed changes due to sediment or vegetation build up. This is a particularly important source of uncertainty in moving sand bottom river channels such as the Rio Grande south of Cochiti reservoir and the Pecos River south of Sumner reservoir.

2. The accuracy of the direct measurement of the flow rate. Direct measurement of streamflow is done with velocity and depth measurements, and a myriad of assumptions as to the velocity profile through the two-dimensional profile through which flow occurs (e.g., Carter and Davidian, 1968). Ideally, the model residuals during calibration will be normally distributed about zero, and comparable to the distribution of uncertainty associated.

A.24.2.2 Quantification of Observation Uncertainty

The accuracy of the stream gages is evaluated according to USGS ratings of the gages. The USGS, in its annual water data reports (e.g., Miller and Stiles, 2006) rates each gage during a given water year as excellent, good, fair, or poor when 95% of gage estimates are thought to be within 5%, 10%, 15%, or more than 15% of the true value respectively. Assuming that when a gage is rated as poor, 95% of the gage estimates are within 50% of the true value, quantitative 95% confidence intervals can be assigned to the calibration gages in the model during the 1975-2010 historical period based on the annual ratings assigned to that gage. Annual stream gage ratings for gages used in the NMDSWB were compiled to provide one, time independent, overall quality rating per stream gage, which is presented in Appendix A.24. This conceptual stream gage calculation error factor distribution is represented in the NMDSWB as normal about 1 (no error) with a standard deviation of 0.05, 0.08, and 0.25 for good, fair, and poor gage ratings, respectively. None of the stream gages used in the NMDSWB had an average annual assigned rating of "excellent."

A.24.3 National Land Cover Dataset Wetlands Uncertainty

In the NMDSWB, riparian area by MBAU is used in the estimation of Groundwater ET, which is determined from the 2011 USGS NLCD (see Section 5.1.5) (Jin et al., 2013). The overall accuracy of the 2001 NLCD for level II and level I accuracies is given as 78.7% and 85.3%, respectively (Wickham et al., 2010). However, these accuracies do not implicitly represent riparian areas nor do they give a distribution of the uncertainty. Although the model only uses 2011 NLCD data, at the time this analysis took place level II and level I accuracies for the NLCD data were only available for the 2001 dataset. Thus 2001 NLCD accuracies were the best representation of accuracy we could use for the 2011 NLCD dataset.

The 2001 NLCD maps 8 level I and 16 level II land-cover classes across the conterminous United States at a 30 X 30 m pixel resolution (Wickham et al., 2010). The accuracy assessment for the 2001 NLCD was a two-stage cluster sample with three levels of stratification, with the first level involving the partitioning of the conterminous United States into 10 geographic regions. For more detailed information on the methodology refer to (Wickham et al., 2010). Each geographic region has its own unique accuracies for each land-cover classification. New Mexico is roughly equally distributed between three geographic regions (2, 3, and 4).

In the NMDSWB, riparian area is represented by NLCD level II classification of woody wetlands (class 90) and emergent herbaceous wetlands (class 95). For the remainder of this discussion "wetlands" will refer to the NLCD level I classification wetlands (90), which is a combined classification of woody wetlands and emergent herbaceous wetlands. In New Mexico, wetlands were classified to be approximately 1% of the total land-cover, on average between the three geographic regions.

For the accuracy assessment of wetland (riparian) area in the NMDSWB, four possible outcomes of the NLCD accuracy assessment were considered:

Accurate wetland classification - A true wetland pixel is classified accurately as wetland pixel
False negative - A true wetland pixel is inaccurately classified as not a wetland pixel (i.e., misrepresented as some other land-cover class)
Accurate non-wetland classification - A non-wetland pixel is classified accurately as a non-wetland pixel
False positive - A non-wetland pixel is classified inaccurately as a wetland pixel

The probabilities for each outcome where determined by the error matrices provided by Wickham et al., 2010) (Table 52).

Table 52. NLCD error matrices by geographic region.

Outcome	Region 2	Region 3	Region 4	Average
1 Accurate wetland classification	92.1%	68.9%	80.3%	80.4%
2 False negative	7.9%	31.1%	19.7%	19.6%
3 Accurate non-wetland classification	99.934%	99.63%	99.66%	99.75%
4 False positive	0.066%	0.37%	0.33%	0.25%

In order to determine how these probabilities affect the outcome of total wetland area, an analysis was performed where 10,000 cells were randomly assigned as wetland or non-wetland so that the wetland area represented 1% of the total area. A classification analysis was then performed where the probability outcomes in Table 52 were assigned to each pixel. The results of 200 independent random classifications had a mean wetland area of 1.05% and a standard deviation of 6.7% (Figure 24). Based on this analysis, the 2001 NLCD over estimates wetland land-cover area for combined geographic regions 2, 3, and 4 by 5%. However, this estimate is heavily influenced by the “true” total area of wetland, i.e., if wetland area were to represent 5% of the total land-cover as opposed to 1%, then the same probability outcomes would lead to an underestimation of wetland land-cover. For this uncertainty analysis the NMDSWB assumes that the total wetland area reported in the NLCD database is correct, and instead uses the distribution of possible errors involved with using the NLCD dataset, to determine modeled uncertainty. This conceptual wetland land-cover calculation error factor distribution is represented in the Dynamic Statewide Water Budget as normal about 1.0 (no error) with a standard deviation of 0.067.

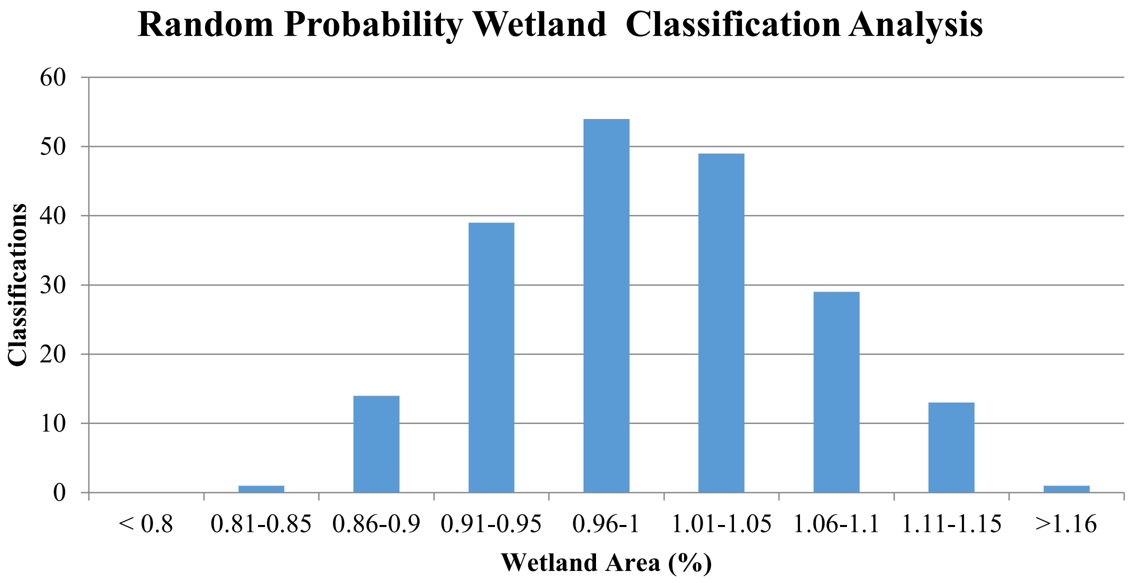

Figure 24. Random probability wetland classification analysis.

A.25 Incorporation of SWA Data into NMDSWB

The Statewide Water Assessment is an effort that will complement existing state agency water resource assessments. It will provide new, dynamic (updated frequently), spatially representative assessments of water budget components for the entire state of New Mexico. Projects included in the Statewide Water Assessment bring new technologies that expand existing studies and are applicable statewide. Of particular interest are water budget components for which state agencies require improved information, such as evapotranspiration (ET), crop consumptive use, groundwater recharge, runoff, streamflow, and groundwater storage change. The NM WRRI is coordinating different components of the Statewide Water Assessment effort with work being done by researchers from New Mexico State University, New Mexico Tech, University of New Mexico, U.S. Geological Survey, New Mexico Bureau of Geology and Mineral Resources, Petroleum Recovery Research Center, Office of the State Engineer, Sandia National Laboratories, and Tetra Tech Inc.

A.25.1 NMDSWB comparisons to ETRM

The Evapotranspiration and Recharge Model (ETRM) (Ketchum et al., 2015) is a model that estimates diffuse groundwater recharge for the entire state of New Mexico. Diffuse recharge is the proportion of precipitation that infiltrates vertically through the soil and past the root zone to potentially contribute water to the groundwater system. In addition to groundwater recharge outputs, ETRM conjunctively calculates runoff and landsurface ET daily at 250 meter by 250 meter grid cells.

The NMDSWB modeled outputs for recharge, runoff and land surface ET were compared to preliminary values from ETRM (Ketchum et al., 2015) for the years 2000 through 2010. While the NMDSWB model estimates runoff and recharge at the county level, these calculations are fundamentally based on differences in flow between available stream gages. The NMDSWB model is “blind” to recharge that occurs in ungaged basins, and applies all contributing area upstream of a given gage to a specific county. A map depicting the gaged watershed areas assigned to each county for purposes of NMDSWB model recharge and runoff calculations and county based accounting is shown in Figure 25.

The ETRM values, on the other hand, are spatially gridded, and the estimates for recharge and runoff seen in Table 53 have been summed up for both the political county boundaries as well as the gaged watershed areas assigned to each county. Land surface ET for ETRM is only aggregated for political county boundaries as this is a more direct comparison with the NMDSWB model’s land surface ET methodology. Average values for recharge, runoff, and land surface ET by county from the NMDSWB model and ETRM is shown in Table 53. Statewide recharge values from the NMDSWB model are 61% and 63% higher than values from ETRM for political and gaged watershed areas respectively. These ETRM values are preliminary and ETRM currently calculates only diffuse recharge while the NMDSWB model estimates total recharge which includes, in addition to diffuse recharge, focused recharge, which occurs in arroyos and river channels along mountain fronts where water that fell as precipitation in one location recharges groundwater in another location. Thus, it is expected that estimates of total recharge in the NMDSWB model would be higher than estimates of diffuse recharge from ETRM.

Statewide runoff values from the NMDSWB model (1.2 million AF/yr) are an order of magnitude smaller than runoff values estimated by ETRM (16 and 10 million AF/yr) for political and gaged watershed areas respectively, see Table 53. This may be in part because the NMDSWB model relies only on gaged stream networks to calculate runoff. Thus, any runoff that does not pass an active stream gage is not accounted for in the NMDSWB model. Thus, if runoff is physically generated in a watershed, but is subsequently lost to infiltration or evapotranspiration, the NMDSWB model will only count the amount reaching the gage less estimated baseflow (which is assumed to come from groundwater) as runoff, while ETRM would count all water running off (an individual grid-cell) regardless of ultimate fate as runoff. Additionally, runoff is only measured when there is an increase in flow of the downstream gage compared to the upstream gage of a given MBAU. While factors such as surface water evapotranspiration, surface water diversions for human use, and groundwater surface water interactions are incorporated into comparisons between upstream and downstream flows, any error in estimates of these terms will directly impact resulting estimates of surface water runoff. Currently ETRM estimates of runoff are being compared to gaged data where available, and further comparisons between the NMDSWB and ETRM are likely premature until the ETRM model has been fully calibrated.

The statewide land surface ET values calculated by the NMDSWB model are roughly 16% greater from 2000 through 2010 than ET calculated by ETRM. Both models conserve mass and thus statewide NMDSWB model estimates of runoff that are approximately 15 million AF/yr less than the ETRM estimates are balanced by NMDSWB model land surface ET and recharge estimates that are together a similar amount larger than corresponding ETRM estimates.

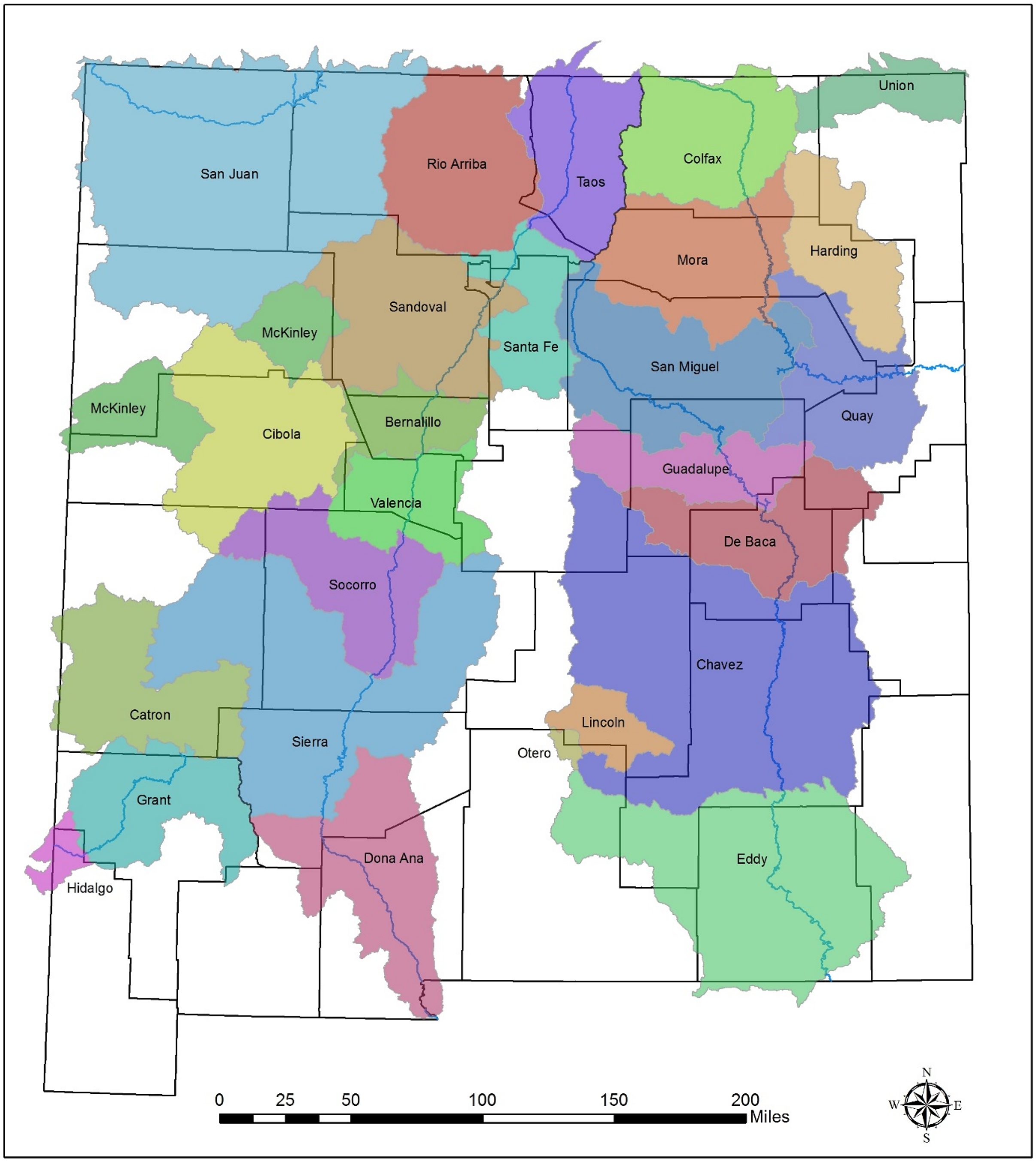

Figure 25. Watershed area of NMDSWB model runoff and recharge estimates as applied to county level accounting.

Table 53. Comparison between NMDSWB model and ETRM runoff, recharge, and land surface ET values from 2000 through 2010 in KAF/yr.

	Runoff			**Recharge**			**ET Land Surface**	
KAF/yr	**NMDSWB**	**ETRM (Gaged Watershed)**	**ETRM (Political)**	**NMDSWB**	**ETRM (Gaged Watershed)**	**ETRM (Political)**	**NMDSWB**	**ETRM (Political)**
STATE TOTAL	**1,244**	**10,033**	**15,776**	**1,492**	**547**	**575**	**86,837**	**76,426**
Bernalillo County	33	85	94	22	4	7	651	673
Catron County	46	352	580	51	25	29	5,447	4,996
Chaves County	40	1,611	1,131	38	2	0	4,258	3,517
Cibola County	3	200	249	4	10	11	2,998	2,704
Colfax County	24	337	517	50	14	14	3,388	2,927
Curry County	0	n/a	439	0	n/a	0	1,259	941
De Baca County	17	485	397	15	0	0	1,660	1,293
Dona Ana County	17	354	406	9	0	0	1,986	1,753
Eddy County	48	1,038	810	103	9	4	2,874	2,328
Grant County	86	341	496	78	9	8	2,989	2,858
Guadalupe County	58	287	541	36	0	0	2,045	1,919
Harding County	9	399	419	4	0	0	1,650	1,427
Hidalgo County	5	20	299	5	0	1	2,092	1,830
Lea County	0	n/a	1,101	0	n/a	9	3,456	2,753
Lincoln County	7	149	689	6	3	5	3,728	3,302
Los Alamos County	0	n/a	9	0	n/a	3	87	91
Luna County	13	n/a	263	6	n/a	0	1,579	1,458
McKinley County	5	100	220	4	2	9	3,238	2,956
Mora County	11	526	348	32	15	31	1,960	1,612
Otero County	14	36	1,011	13	3	15	5,093	4,221
Quay County	34	631	749	16	0	0	2,386	1,936
Rio Arriba County	170	355	552	225	126	166	5,034	4,541
Roosevelt County	0	n/a	674	0	n/a	0	2,050	1,599
Sandoval County	20	261	246	38	55	42	2,934	2,338
San Juan County	208	370	189	199	25	24	3,754	2,560
San Miguel County	88	711	807	85	28	12	2,405	3,447
Santa Fe County	17	125	145	15	34	22	1,465	1,289
Sierra County	62	517	382	77	4	2	2,560	2,381
Socorro County	17	175	496	112	0	2	3,840	3,799
Taos County	91	236	202	196	169	150	1,825	1,777
Torrance County	0	n/a	423	9	n/a	7	2,506	2,152
Union County	5	196	822	20	3	0	3,190	2,507
Valencia County	96	139	71	22	6	0	452	542

A.25.2 NMDSWB Groundwater Storage Change Comparisons

Groundwater storage change values are compared for the two calibration time periods of 1975–1999 and 2000–2015 between the NMDSWB model and Rinehart et al. (2016) estimates (Table 54 and Table 55). Within the NMDSWB model, groundwater storage change is calculated as the difference between inputs to the groundwater system (recharge, groundwater returns from the human use sector, and $SW \Leftrightarrow GW$) and losses from the groundwater system (groundwater diversions, baseflow (negative $SW \Leftrightarrow GW$ term), and riparian ET). In the NMDSWB model, groundwater storage change is estimated through mass balance calculations over the entire extent of a given MBAU. Groundwater storage change estimates from Rinehart et al. (2016) only occur within select zones within a MBAU where well data is available to be interpolated over a given spatial extent (Rinehart et al., 2016). Figure 26 demonstrates the areas where groundwater storage change estimates are provided by Rinehart et al. (2016) within the NMDSWB model MBAUs of the Rio Grande and Central Closed river basins.

The inverse-distance-weighting interpolation (IDW) decadal groundwater storage change estimates from Rinehart et al. (2016) were used within the NMDSWB to calibrate the two time periods of 1975–1999 and 2000–2015. Although, Rinehart et al. (2016) also report ordinary kriging (OK) interpolation estimates of groundwater storage change, the IDW decadal estimates are used within the NMDSWB because they are more spatially and temporally robust than the OK estimates. The IDW decadal groundwater storage change estimates from Rinehart et al. (2016) were provided as 100x100m rasters of change in depth (m) at the HUC 8 spatial scale. Decadal IDW statewide mosaics were created from the HUC 8 rasters, from which zonal stats for counties and WPRs were calculated to provide groundwater storage change estimates for the spatial scales included within the NMDSWB.

Cumulative groundwater storage change for the two calibration time periods was aggregated from the decadal estimates (Rinehart et al., 2016). Since the historical period of the NMDSWB begins in 1975, the 1970s-minus-1960s estimate was divided in half to set storage change equal to zero at 1975. This assumes that the decadal estimates are uniformly distributed throughout a given decade. Therefore, the 1975–1999 cumulative groundwater storage change estimate used to calibrate that time period is the aggradation of one-half of the 1970s-minus-1960s decadal estimate plus the 1980s-minus-1970s and the 1990s-minus-1980s decadal estimates. The 2000–2015 cumulative groundwater storage change estimate used to calibrate that time period is the aggradation of the 2000s-minus-1990s and the 2010s-minus-2000s decadal estimates.

Table 54. Groundwater storage change (kAF) comparisons between NMDSWB and Rinehart et al. (2016) county MBAUs. Published groundwater storage change estimates from counties with * are from Daniel B. Stephens & Associate INC. (2007).

	1975–1999				**2000–2015**			
County	**Published Groundwater Storage Change (kAF)**	**NMDSWB (kAF)**			**Published Groundwater Storage Change (kAF)**	**NMDSWB (kAF)**		
Bernalillo County	-2,228	-2,220	+/-	*1,540*	105	-400	+/-	*960*
Cibola County	-160	-120	+/-	*30*	-126	-170	+/-	*20*
Curry County*	-3,413	-5,490	+/-	*2,360*	n/a	-	-	-
Dona Ana County	-938	-930	+/-	*770*	186	220	+/-	*480*
Grant County	222	-90	+/-	*140*	173	-170	+/-	*90*
Harding County*	515	-60	+/-	*50*	n/a	-	-	-
Hidalgo County	68	-450	+/-	*510*	-79	-470	+/-	*320*
Lincoln County	8	-40	+/-	*40*	-281	-120	+/-	*30*
Luna County	-962	-2,130	+/-	*500*	-281	-810	+/-	*310*
McKinley County	-113	-280	+/-	*30*	-35	-210	+/-	*20*
Otero County	-865	-350	+/-	*80*	-141	-240	+/-	*50*
Quay County*	1,370	50	+/-	*350*	n/a			
Rio Arriba County	544	560	+/-	*420*	-52	-20	+/-	*260*
Roosevelt County*	-2,880	-3,730	+/-	*1,890*	n/a	-	-	-
Sandoval County	99	110	+/-	*370*	-171	-180	+/-	*230*
Santa Fe County	-391	-390	+/-	*40*	-102	-350	+/-	*30*
Sierra County	121	120	+/-	*50*	-268	-300	+/-	*30*
Socorro County	225	210	+/-	*240*	-388	-280	+/-	*150*
Taos County	94	170	+/-	*320*	-666	-510	+/-	*200*
Union County*	-13	-1,380	+/-	*650*	n/a			
Valencia County	-1,108	-380	+/-	*560*	-138	-150	+/-	*350*

Table 55. Groundwater storage change (kAF) comparisons between NMDSWB and Rinehart et al. (2015; 2016) for WPRs.

	1975–1999				**2000–2015**			
WPR	**Published Groundwater Storage Change (kAF)**	**NMDSWB (kAF)**			**Published Groundwater Storage Change (kAF)**	**NMDSWB (kAF)**		
Jemez y Sangre WPR	197	84	+/-		-60	-184	+/-	
Tularosa-Salt-Sacramento WPR	-856	-460	+/-		-425	-285	+/-	
Northwest WPR	-272	-359	+/-		-161	-350	+/-	
Estancia WPR	-563	-1036	+/-		-752	-878	+/-	
Rio Chama WPR	35	1321	+/-		-	-	-	-

The calibration parameters developed are physically constrained by model calculations of surface water surplus (Section 4.1, and Equation 2), and the model in the current configuration is not capable of matching all targeted groundwater storage change estimates. In several instances such as Taos County for the 2000–2015 calibration period, the NMDSWB calculated groundwater storage change is underestimated compared to Rinehart et al. (2016). In this case, the $SW \Leftrightarrow GW$ calibration parameter has been set to zero, meaning that the entire calculated surface water surplus at a given timestep is partitioned to additional ET_{sw}, and no surface water surplus (if any is calculated) enters the groundwater system as a $SW \Leftrightarrow GW$ flow. Taos County is characterized as primarily having a gaining river system, so it is to be expected that net flow of $SW \Leftrightarrow GW$ is negative (i.e., baseflow dominated). The underestimates of groundwater storage change calculated in the model suggest that recharge is likely overestimated, as more water is entering the groundwater stock than expected. Other terms such as ET_{gw}, $\mathrm{GW_d}$, and $\mathrm{GW_r}$, also impact the estimates of groundwater storage change, yet these terms are better constrained and have less associated model uncertainty than recharge.

Incorporation of groundwater storage change estimates from Rinehart et al. (pending) for the entire state into the NMDSWB model calibration should constrain and improve the calibrated mass balance terms such as recharge, runoff, and surface water-groundwater interactions.

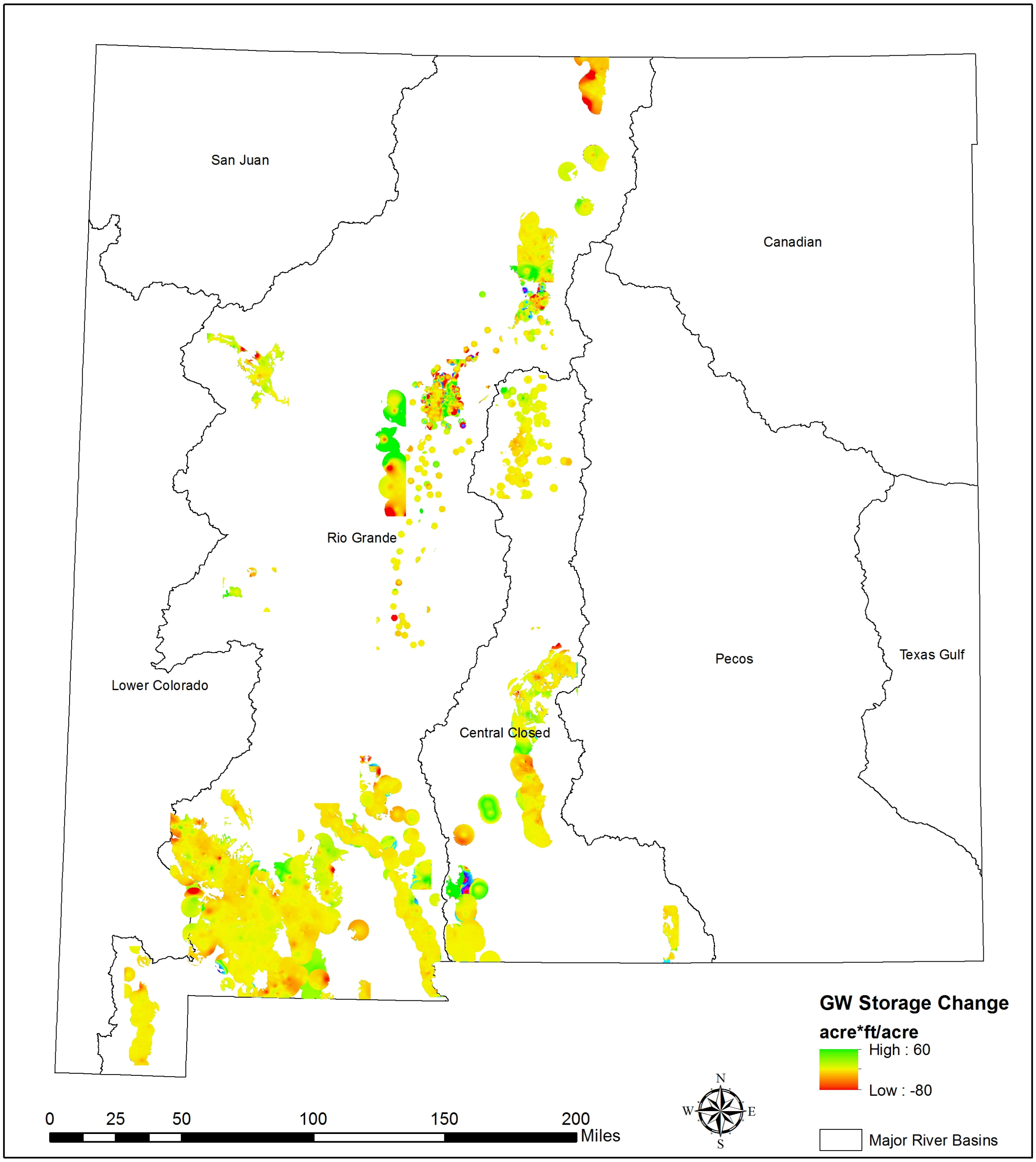

Figure 26. Statewide estimates of groundwater storage change in acre feet per acre from Rinehart et al. (2015; 2016).