RECLAMATION

Managing Water in the West

Technical Memorandum No. 86-68210-17-04

Upper Red River Basin Study Estimation of Future Agricultural Irrigation and Municipal and Industrial Water Demands

U.S. Department of the Interior
Bureau of Reclamation
Oklahoma-Texas Area Office

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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public

BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado

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Prepared for:
Oklahoma-Texas Area Office
Great Plains Region

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ABBREVIATIONS AND ACRONYMS

A1B	CMIP3 Future Greenhouse Gas Middle Emissions Scenario
A2	CMIP3 Future Greenhouse Gas High Emissions Scenario
AF	Acre-feet
AFY	Acre-feet per Year
ASCE	American Society of Civil Engineers
B1	CMIP3 Future Greenhouse Gas Low Emissions Scenario
BCSD	Bias Corrected and Spatially Downscaled
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 3
CT	Central Tendency
DRI	Desert Research Institute
ET	Evapotranspiration
ET_c	Crop Evapotranspiration
ET_o	Reference Evapotranspiration
F	Fahrenheit
FAO	Food and Agricultural Organization of the United Nations
GCM	General Circulation or Global Climate Model
GDD	Growing Degree Days
gpcd	Gallons per Capita per Day
HDe	Ensemble-informed Hybrid Delta
HUC 8	Eight-digit Hydrologic Unit Code Drainage Area
IPCC	Intergovernmental Panel on Climate Change
LWW	Less warm-wetter
K_{cb}	Basal Crop Coefficient
K_e	Soil Evaporation Coefficient
K_s	Stress Coefficient
M&I	Municipal and Industrial
NIWR	Net Irrigation Water Requirement
NRCS	Natural Resources conservation Service
OCS	Oklahoma Climatological Survey
OWRB	Oklahoma Comprehensive Water Plan
OCWP	Oklahoma Water Resources Board
P	Precipitation
P_e	Effective Precipitation
PM	Penman Monteith
RCP	Representative Concentration Pathways
Reclamation	Bureau of Reclamation
USDA-SCS	Soil Conservation Service

A1B	CMIP3 Future Greenhouse Gas Middle Emissions Scenario
STATSGO	NRCS State Soil Geographic Database
T	Temperature
Tmax	Maximum Daily Temperature
Tmin	Minimum Daily Temperature
USDA	U.S. Department of Agriculture
WD	Warmer-drier
WWCRA	West-wide Climate Risk Assessments

INTRODUCTION

Changes in agricultural irrigation and municipal and industrial (M&I) water demands in the Upper Red River Basin over the next 50 years are uncertain and will depend on a number of socioeconomic and other factors. The analyses and results described in this technical memorandum are meant to assess the impacts of climate change on these water demands in the basin. This information will be evaluated relative to future supply estimates in an effort to quantify potential gaps between overall supplies and demands. Figure 1 shows the study area.

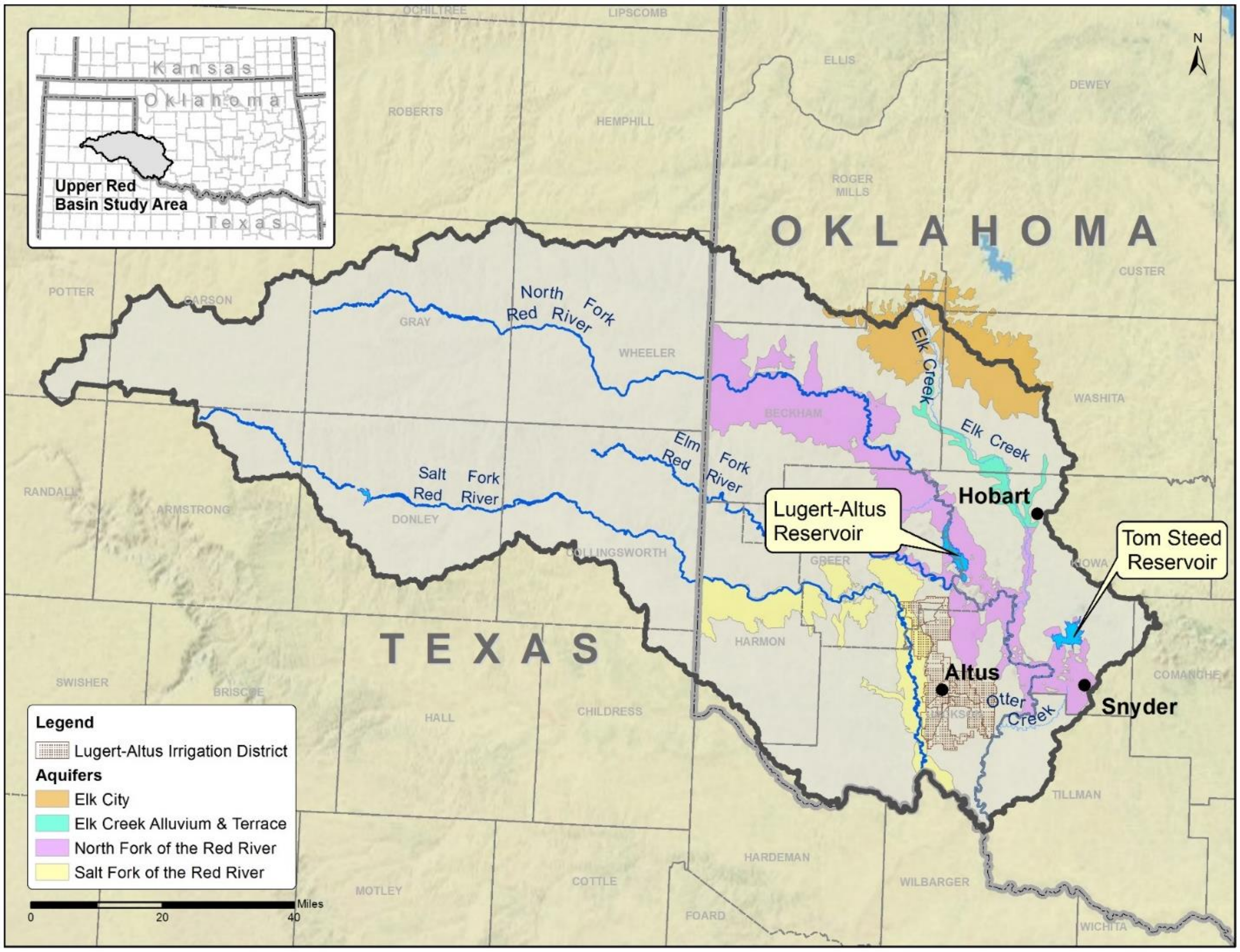

Figure 1 – Map of the Upper Red River Basin Study area.

BACKGROUND

Agricultural irrigation water use typically includes crop demands, conveyance losses, and on-farm losses. M&I demands include domestic potable consumption by residential and non-residential (commercial and industrial) users and outdoor water use by the same that is primarily for urban landscape irrigation.

The M&I demands analysis was performed for the cities of Altus and Frederick. The analysis for Altus and Frederick were based on recent water production and population data, population projections and climate change analyses similar to those used in the agricultural irrigation demand analysis discussed below.

The agricultural irrigation demand analysis focused on crop demands, or crop net irrigation water requirement (NIWR). NIWR is equal to the total crop demand minus that amount of the crop demand that is met by precipitation, i.e. effective precipitation (P_e). NIWR does not include conveyance or on-farm losses. Crop water demand is a function of evapotranspiration (ET), which is the amount of water transpired by the crop plus the amount that evaporates from the plant and surrounding soil surfaces (Jensen et al., 1990).

Conveyance and on-farm losses are a function of methods employed to convey water to the croplands (open channels, pipe, etc.) and to apply irrigation water (flood, sprinklers, etc.). Given the numerous variables associated with conveyance and on-farm losses, loss estimates were not calculated in this analysis.

Current and future NIWR estimates were developed following methods recently established under Reclamation's West-wide Climate Risk Assessments (WWCRA). Brief descriptions of these methods follow and more detailed discussions are contained in Reclamation (2014).

The 1950 through 1999 climate data used are from a published gridded data set by Maurer et al. (2002). The temperature and precipitation values used from this data set were adjusted based on historical observations from weather stations located near the irrigated crop areas to remove any biases that may exist between the gridded meteorological dataset (Maurer et al., 2002) and these point observations.

NIWR estimates were calculated for each of the basin's seven eight-digit Hydrologic Unit Code drainage areas (HUC8 sub-basin).[1] The HUC8 sub-basins are shown in Figure 2. Table 1 includes the names and corresponding HUC8 numbers for the sub-basins, as well as total areas and the estimated irrigated cropland area totals for each HUC8 sub-basin. (Note that only the northern portion of the Groesbeck-Sandy HUC8 is included.)

The estimated area of irrigated lands within the 5,406,914 acre study are is 737,702, with an estimated 296,008 irrigated acres in the Oklahoma portion of the study area and 441,694 irrigated acres in the Texas portion.

[1] The water demand sub-basins for the Upper Washita Basin Study are ten-digit Hydrologic Unit Code drainage areas since its study area is significantly smaller and consists of only two HUC8 drainage areas.

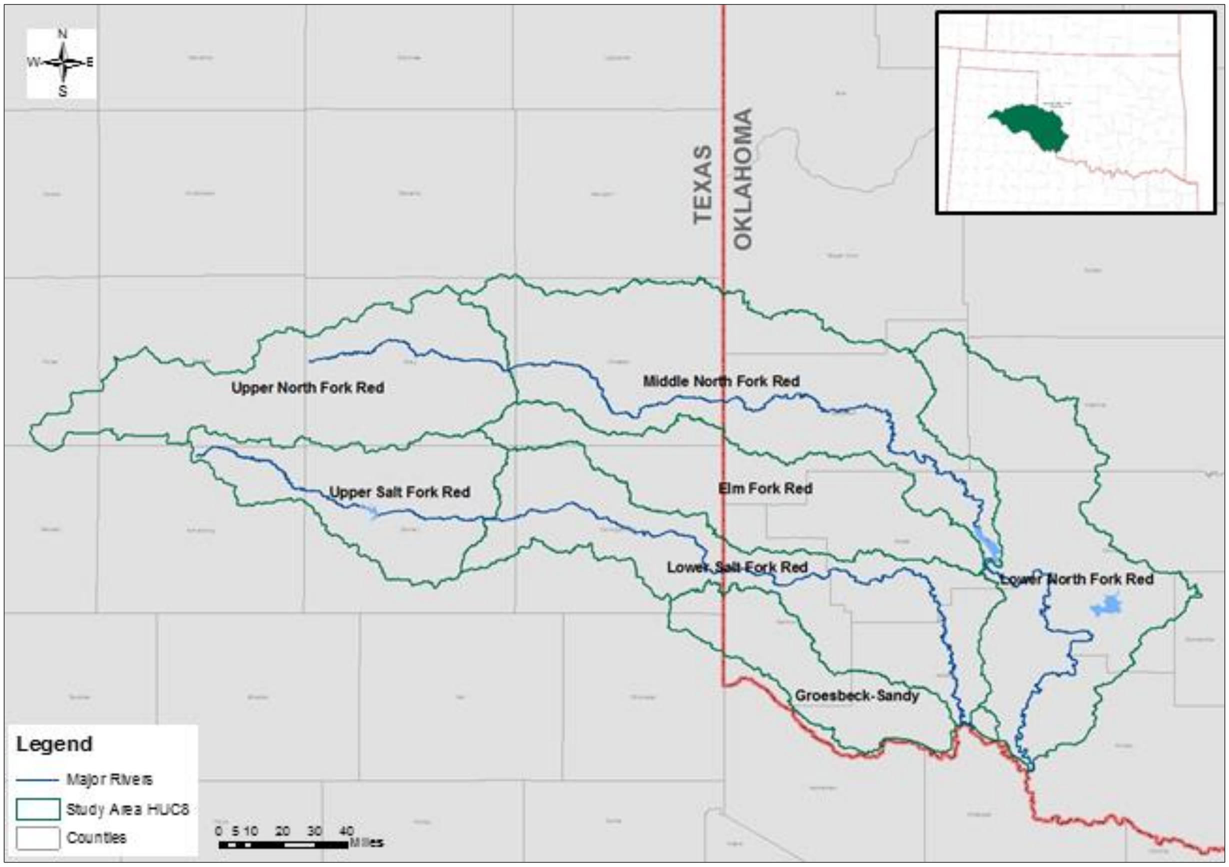

Figure 2 – Upper Red River Basin Hydrologic Unit Code Sub-basin Names

Table 1 – Eight-digit Hydrologic Unit Code (HUC8) Sub-basin Number Designations, Names, Total Areas and Estimated Irrigated Lands Areas

Number	Name	Total Surface Area (acres)	Irrigated Area (acres)
11120201	Upper Salt Fork Red	473,922	87,974
11120202	Lower Salt Fork Red	798,339	122,957
11120301	Upper North Fork Red	754,992	178,425
11120302	Middle North Fork Red	1,058,834	128,076
11120303	Lower North Fork Red	885,942	124,595
11120304	Elm Fork Red	594,190	34,764
11130101	Groesbeck-Sandy	840,695	60,912
TOTALS		5,406,914	737,702

The current or baseline irrigation water demand estimates developed are based on the most recent available crop data and on climate conditions during the historical baseline period 1950 through 1999. Irrigated crop types and quantities are from the U.S. Department of Agriculture

(USDA) National Agricultural Statistics Service as reported for 2013 (http://www.nass.usda.gov/research/Cropland/SARS1a.php). Since certain crops such as winter wheat, canola, rye, pasture and grass hay are grown without irrigation within the basin, the data for these crops were combined with spatial water rights data from the Oklahoma Water Resources Board (OWRB) and USDA county-based 2012 Census of Agriculture data (https://www.agcensus.usda.gov/) for Texas to estimate the portion of total crop lands that are irrigated. The irrigated lands used for the analysis are shown in Figure 3.

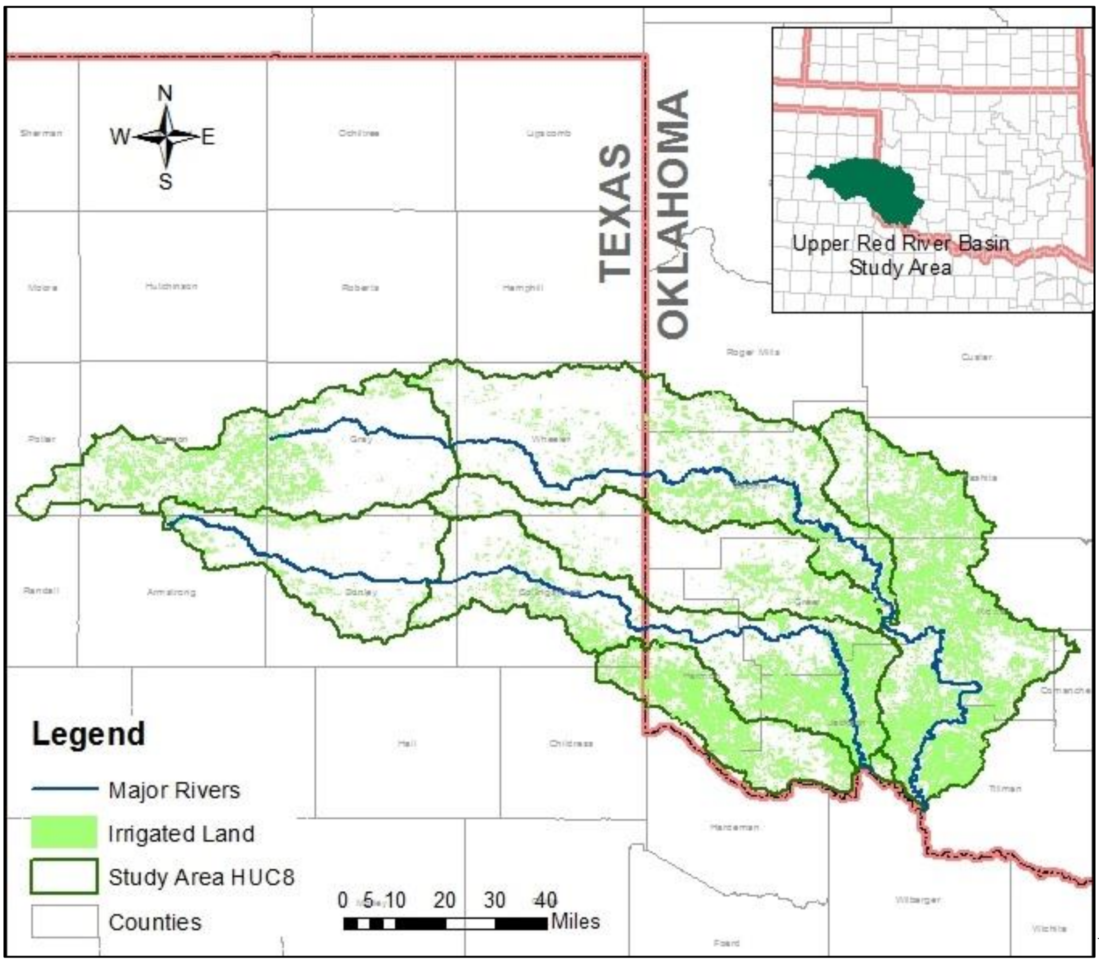

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Figure 3 – Locations of Irrigated Lands in the Upper Red River Basin

Future crop demands were evaluated under multiple scenarios assuming static cropping patterns and using a period change method which yields estimated changes in NIWR from the baseline period (1950-1999) to a future period. A brief discussion of this method and the processing of the general circulation model (or global climate model, GCM) projections are provided below and detailed descriptions on these methods are provided in Reclamation (2014).

NON-TECHNICAL OVERVIEW OF CLIMATE PROJECTIONS AND IRRIGATION DEMANDS MODELLING

The following sections of this document on climate projections and irrigation demands modelling are relatively technical and may be difficult to understand for non-technical readers. The following discussion provides simplified non-technical descriptions of the methods used.

Since climate models' output (projections or estimates of temperature and precipitation) are at a relatively coarse spatial resolution, they are often translated to finer resolution by a process known as downscaling for studies such as this one. In the case of this study, the downscaled resolution is 1/8 degree latitude and longitude, or about a 7.5-mile square.

Since there are so many models and future greenhouse gas emissions scenarios, it is difficult to select which models and scenarios to use. Ideally, one would like to analyze each of the climate projections. This is not practical given the enormous computational and data handling requirements, so a work-around is required. The approach used in this study includes 231 climate projections that are divided into five groups with similar results and then each group is combined to arrive at a representative set of projections that can be thought of as an average for the group. The end result for this study is a set of three climate-change scenarios using precipitation and temperature changes defined as follows: (1) warmer-dryer (WD); (2) central tendency (CT), and (3) less warm-wetter (LWW). For each of these climate change scenarios, assessments of changes to irrigation demands were determined for 2060. The future conditions are estimated using the baseline historical period 1950-1999.

The current or baseline irrigation demand estimates developed for this study are based on the most recent available crop data. The crop types and quantities are from data collected by the U.S. Department of Agriculture. The crop and climate data are input into a computer model that estimates irrigation demand at a daily time step. The model (ET Demands) is a sophisticated state-of-the-science tool that accounts for plant transpiration and soil moisture evaporation (evapotranspiration or ET). The historical baseline model runs have been calibrated to actual weather station data as a quality assurance measure.

Future irrigation water demand estimates were calculated using the ET Demands model by inputting the downscaled projected future temperature and precipitation estimates for the three climate change scenarios discussed above. Since future farming practices are an unknown, it is assumed that cropping patterns do not change in the future.

The future irrigation demand estimates from the ET Demands model reflect increasing ET caused by higher temperatures, changes in precipitation, and extended growing seasons due to temperature increases.

CLIMATE PROJECTIONS AND SCENARIOS

GCM projections cannot be directly used in an analysis such as this given the coarse time and spatial resolution of the models. The step of translating projections from the GCM scale (coarse spatial resolution, ~100-250 km) to the irrigation demands assessment scale (finer spatial resolution, ~10 km) is referred to as downscaling or spatial disaggregation. The projected climate variables used include precipitation (P) and air temperature (T), which are widely considered to be the primary drivers of changing demands for irrigation water. Their use in climate change irrigation demand impacts studies is routine.

Climate projections for the URRBS were obtained from an archive of climate and hydrology projections developed by Reclamation in partnership with the USGS, U.S. Army Corps of Engineers, Lawrence Livermore National Laboratory, Santa Clara University, Climate Central, and Scripps Institution of Oceanography. These projections and associated documentation are available through this downscaled climate and hydrology projections website: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html. The climate projections were statistically downscaled in space from GCM grid resolution to 1/8° latitude by 1/8° longitude. This archive of climate projections is based on GCM simulations compiled by the World Climate Research Programme's Coupled Model Intercomparison Project (CMIP).

Among the available climate and hydrology projections available on the above mentioned website, there are monthly bias-corrected and spatially-disaggregated (BCSD) projections of precipitation and temperature, which are utilized in the URRBS. Bias correction generally involves correcting systematic errors in GCM historical simulations based on finer scale observed data. Spatial disaggregation generally involves translating coarse scale GCM simulations to the 1/8° spatial resolution. Projections based on CMIP5 were used in the analysis of future water supply impacts in the Upper Red River Basin and are further described below. Both the CMIP Phase 3(CMIP3) and the CMIP Phase 5 (CMIP5) projections are briefly discussed below for completeness, but it should be noted that only CMIP5 projections are used in this study.

CMIP3 projections (Meehl et al., 2007) are summarized in the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), completed in 2007 (IPCC, 2007). Generally, climate projections are based on an assemblage of GCM simulations of coupled atmospheric and ocean conditions, with a variety of initial conditions of global ocean – atmosphere system and distinct "storylines" about how future demographics, technology and socioeconomic conditions might affect the emissions of greenhouse gases. There are four families of emissions scenarios (A1, A2, B1 and B2 - described in the IPCC Special Report on Emissions Scenarios,[SRES] Nakicenovic, 2000), in which the scenarios are potential futures based on assumptions of global economic activity and growth. Additionally, there are three subsets to the A1 family (A1F1, A1B, and A1T) based on their technology emphasis with regard to future energy sources with A1B having a balanced emphasis on all energy sources. Projected global warming associated with CMIP3 SRES scenarios available in a downscaled form is shown in the left panel of Figure .

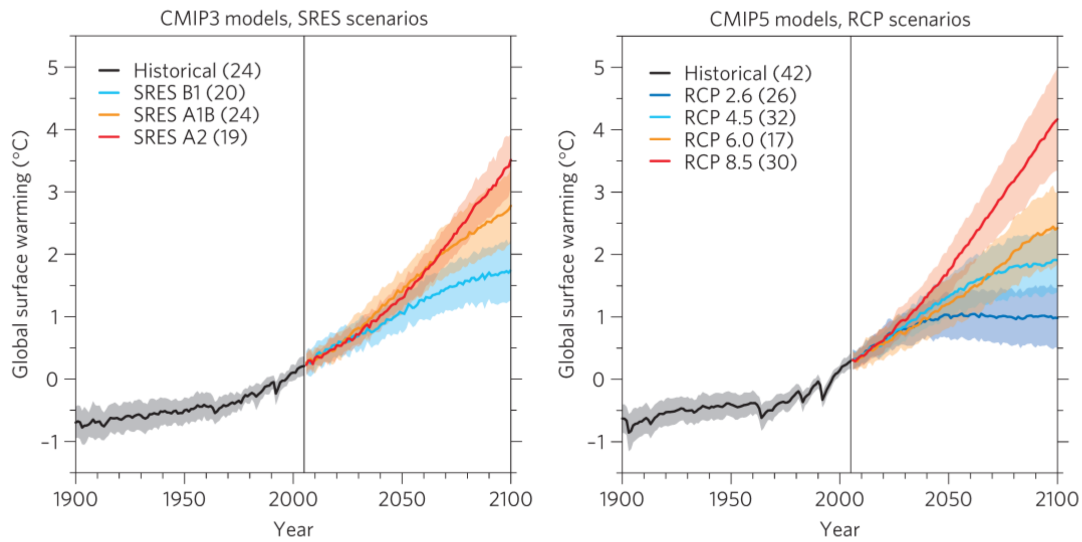

Figure 4 – Global temperature change (mean and one standard deviation as shading) relative to 1986–2005 for the SRES scenarios run by CMIP3 and the Representative Concentration Pathways (RCP) scenarios run by CMIP5. The number of model projections is given in parenthesis. Source: Figure 2 from Knutti and Sedlacek (2012).

CMIP5 projections are similar in concept but incorporate improvements in modeling and physical understanding of the Earth system since the CMIP3 effort. The raw CMIP5 model output has been available since early 2011 and has been increasingly used in climate change impacts studies, alongside those from CMIP3. The corresponding IPCC Fifth Assessment Report was completed in 2013. These GCMs rely on greenhouse gas storylines called Representative Concentration Pathways (RCP). Each RCP is representative of a particular amount of radiative forcing (2.6, 4.5, 6.0, and 8.5 Watts per square meter [W/m^2] respectively) occurring by the year 2100. The right panel of Figure illustrates projected global warming according to the CMIP5 RCP scenarios. The figure shows that the range of emissions scenarios considered by CMIP5 result in a greater range of projected global warming than by CMIP3 emissions scenarios. The website identified above contains 112 BCSD CMIP3 monthly projections and 231 BCSD CMIP5 monthly projections of precipitation and temperature, among other available hydroclimate data products. Projections based on the four CMIP5 emissions scenarios are available via the website mentioned above and are used as a basis for URRBS climate scenarios.

The CMIP5 projections were chosen in this study because they represent the most current information source and have become widely accepted in the climate science community. However, even though CMIP5 is newer and potentially benefits from climate model improvements, it has not been determined to be a better or more reliable source of climate projections compared to existing CMIP3 climate projections. And many completed and ongoing studies remain informed by CMIP3 projections that were selected as the best information available at the time of study (e.g., Upper Washita Basin Study).

The next step in the process is to input the projections of P and T into an irrigation demands simulation model. Ideally, one would like to run each of the 231 climate projections through the model. However, this is not practical given the diversity of crops and agricultural practices across the basin and therefore enormous computational and data handling requirements. A choice was therefore made to perform the analysis where the 231 climate projections were used to inform a set of three climate change scenarios using P and T changes defined for following conditions: (1) Warmer-drier (WD); (2) Less warm-wetter (LWW); and (3) central tendency (CT). For each of the three climate change scenarios, assessments of changes to crop irrigation water requirements were determined for the future period labeled 2060s (for years covering the period 2045-2075) relative to the baseline period, 1950-1999. The future climate change scenarios were derived using an approach that allows a high number of climate projections to be distilled into a smaller number of representative scenarios. Specifically, this period change approach is known as the ensemble informed hybrid delta (HDe) method (Hamlet et al., 2013; Reclamation, 2010; Reclamation, 2011). The approach allows a high number of climate projections to be distilled into a small number of representative climate change scenarios. Again, this approach of selecting a set of future periods and analyzing change from a baseline period is referred to as period change.

IRRIGATION DEMANDS

Estimates of NIWR were developed using the ET Demands model, originally developed by the University of Idaho, Nevada Division of Water Resources, and the Desert Research Institute (DRI). Recent modifications to the model for WWCRA applications were made through a collaborative effort by Reclamation, DRI and the University of Idaho (Reclamation, 2014).

The ET Demands model is based on the Penman Monteith (PM) dual crop coefficient method, as described in the Food and Agriculture Organization (FAO) of the United Nations, FAO Irrigation and Drainage Paper 56 (Allen et. al, 1998). The American Society of Civil Engineers (ASCE) has adopted the FAO-56 PM equation as the standardized equation for calculating reference ET (ET_o) (ASCE, 2005). The short grass reference crop version of the PM equation was used to be consistent with other Reclamation work.

By using the PM dual crop coefficient method rather than a single crop coefficient approach, transpiration and evaporation are accounted for separately to better quantify evaporation from variable precipitation and simulated irrigation events. This also allows for accounting of winter soil moisture conditions, which can be a significant factor when estimating early irrigation season NIWR. The dual crop coefficient method provides a robust means for estimating NIWR based on continuous accounting of soil moisture balance.

The ET Demands model first calculates daily ET_o for each HUC8 sub-basin as a function of maximum and minimum daily air temperature (Tmax and Tmin) from the 1950-1999 climate data set mentioned above. The PM equation variables of vapor pressure, solar radiation and wind speed are empirically estimated as described in Reclamation (2014) as per the methods recommended by ASCE (2005). Figure 5 is a schematic showing the basic parameters included in the PM equation.

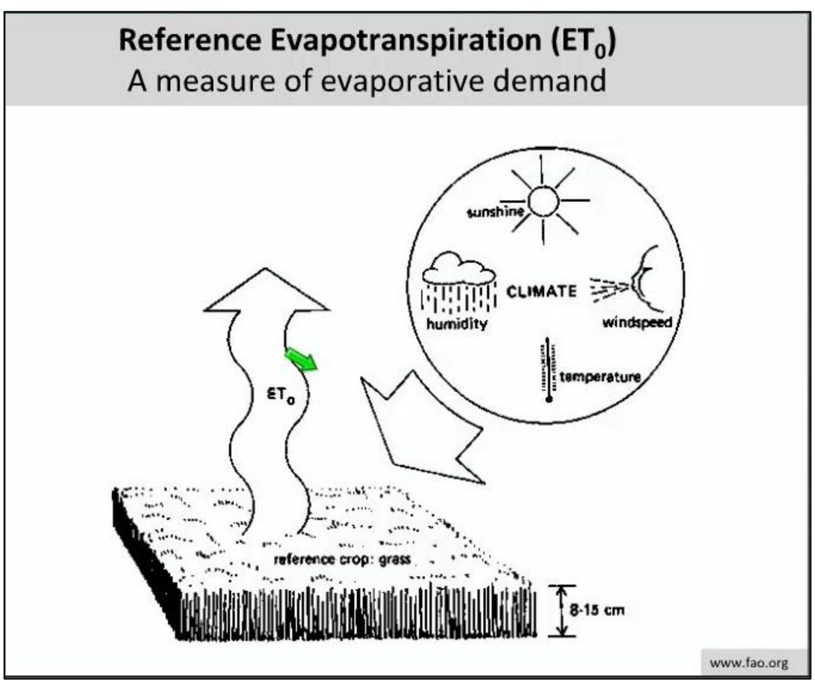

Figure 5 - Reference evapotranspiration equation parameters schematic

Weighted average soil conditions (allowable water content and percent clay, silt and sand) for the irrigated lands in each HUC8 sub-basin were input to ET Demands. The soils information is based on data from the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USDA-NRCS, 1991). The soil parameters affect the estimation of irrigation scheduling, evaporation losses from soil, moisture holding capacity, deep percolation from root zones, antecedent soil moisture conditions, and runoff from precipitation.

Once daily ET_o is calculated, the daily crop ET (ET_c) is then calculated as a function of the two primary crop coefficients and a crop stress coefficient. ET_c for all crop types within a given HUC8 was estimated as follows:

$ET_c = (K_s K_{cb} + K_e) ET_o$;

where ET_o is the ASCE-PM grass reference ET, K_{cb} is the basal crop coefficient, Ke is the soil water evaporation coefficient, and Ks is the stress coefficient. K_{cb} and K_e are dimensionless and range from 0 to 1.4. Daily K_{cb} values over a season, commonly referred to as the crop coefficient curve; represent impacts on crop ET from changes in vegetation phenology, which can vary from year to year depending on the start, duration, and termination of the growing season, all of which are dependent on temperature. K_e is a function of the soil water balance in the upper 0.1 meter of the soil column since this zone is assumed to be the only layer supplying water for direct evaporation from the soil surface. K_s ranges from 0 to 1, where 1 equates to no water stress, and is also dimensionless. A daily soil water balance for the simulated effective root zone is required and computed in ET Demands to calculate K_s. In the case of computing the ET_c and NIWR, K_s is generally 1 but can be less than 1 in the winter if precipitation is low and winter surface cover is specified to be anything other than bare soil, such as mulch or grass. The dual crop coefficient concept is illustrated in the schematic shown in Figure 6.

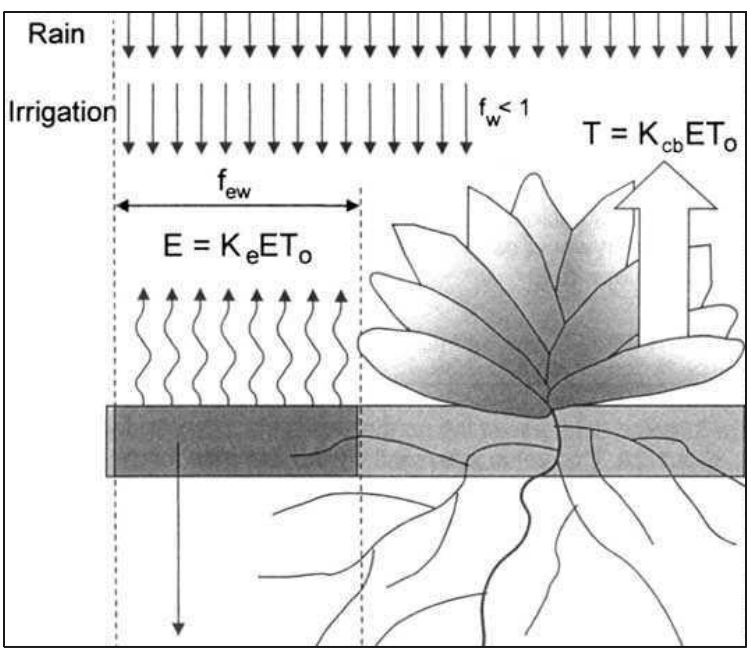

Figure 6 - Dual crop coefficient evapotranspiration concept schematic

Values of K_{cb} for a given crop vary seasonally and annually to simulate plant phenology as impacted by solar radiation, temperature, precipitation, and agricultural practice. Seasonal changes in vegetation cover and maturation are simulated in ET Demands by each crop specific K_{cb} as a function of air temperature. This is done in terms of cumulative growing degree days (GDD). After planting of annuals or the emergence of perennials, the value of K_{cb} gradually increases with increasing temperatures until the crop reaches full cover. Once this happens, and throughout the middle stage of the growing season, the K_{cb} value is generally constant, or is reduced due to simulated cuttings and harvest. From the middle stage to the end of the growing season the K_{cb} value reduces to simulate senescence. GDD is calculated in ET Demands by three different methods as described in Reclamation (2014). The GDD equations' constants were calibrated based on historical data (green-up or planting, timing of full cover, harvest, and termination dates).

Having the ability to simulate year to year variations in the timing of green-up or planting, timing of effective full cover, harvest, and termination, is necessary for integrating the effects of temperature on growing season length and crop growth and development, especially under changing climate scenarios.

The NIWR rate or depth is calculated in ET Demands by factoring in P_e (NIWR = $ET_c - P_e$). P_e is calculated as a function of daily precipitation (from the climate data set), antecedent soil moisture and precipitation runoff. Soil moisture is a function of moisture holding capacity of the weighted average soil type input to the model for each HUC8 sub-basin. Precipitation runoff is calculated based on daily precipitation using the NRCS curve number method (USDA-SCS, 1972).

Simulation of irrigation events by the ET Demands model occurs when the crop root zone moisture content drops to the crop specific maximum allowable depletion threshold. Irrigations are specified to fill the root zone by the difference between field capacity and the cumulative soil moisture depletion depth amount.

The NIWR and ET_c rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR and ET_c rates as shown in the equation below.

HUC8 sub-basin rate = $\sum_{i=1}^{i=n} crop\ ratio\ i * crop\ rate\ i$

The product of the weighted average NIWR rate and the total irrigated acreage yields the NIWR volume for each HUC8 sub-basin in acre-feet. A similar approach is used to calculate the ET_o, ET_c and NIWR estimates for the entire Upper Red River basin where the ratios of sub-basin to basin irrigated acres are applied to the sub-basin values and the average of the weighted values is calculated.

Historical Baseline Demands

The ET Demands model results for baseline conditions include ET_o, ET_c, NIWR depth, and NIWR volume for each HUC8 sub-basin. Again, for the purposes of this study, the historical baseline results presented consist of the mean annual values for 1950-1999. The results are presented graphically along with the mean annual values of the bias corrected T and P values that were input to the model. Annual average T, P, ET_o, ET_c, NIWR depth, and NIWR volume are shown respectively in Figures 4 through 9 and discussed below. The Appendix contains tabulated summaries of historical baseline and projected future estimates (discussed later) of annual average T, P, ET_o, ET_c, NIWR depth, and NIWR volume for each HUC8 sub-basin.

As shown in Figures 7 and 8, historical baseline mean annual temperature and precipitation range respectively from 58.8 degrees Fahrenheit (F) and 20.1 inches in the western portion of the basin to 62.6 degrees F and 27.2 inches in the south and eastern portions of the basin. The respective basin-wide T and P historical baseline annual averages are 62.6 degrees F and 24.1 inches.

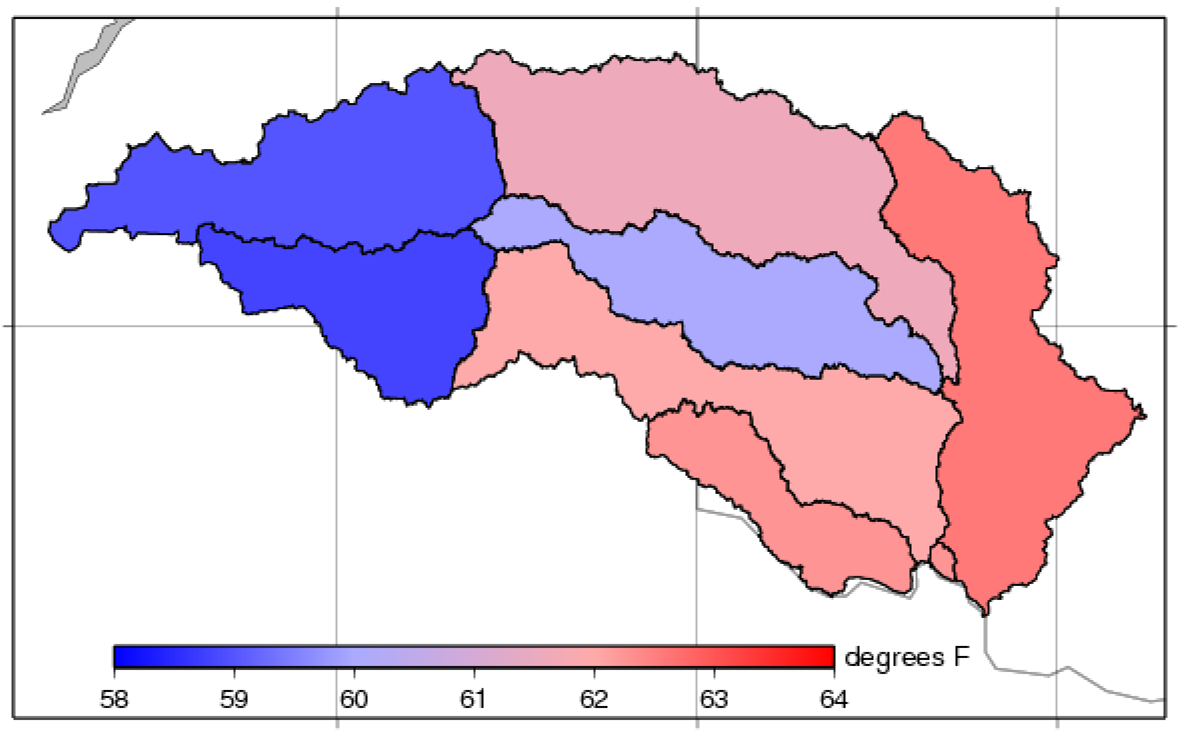

Figure 7 – Spatial distribution of historical baseline (1950-1999) mean annual temperature

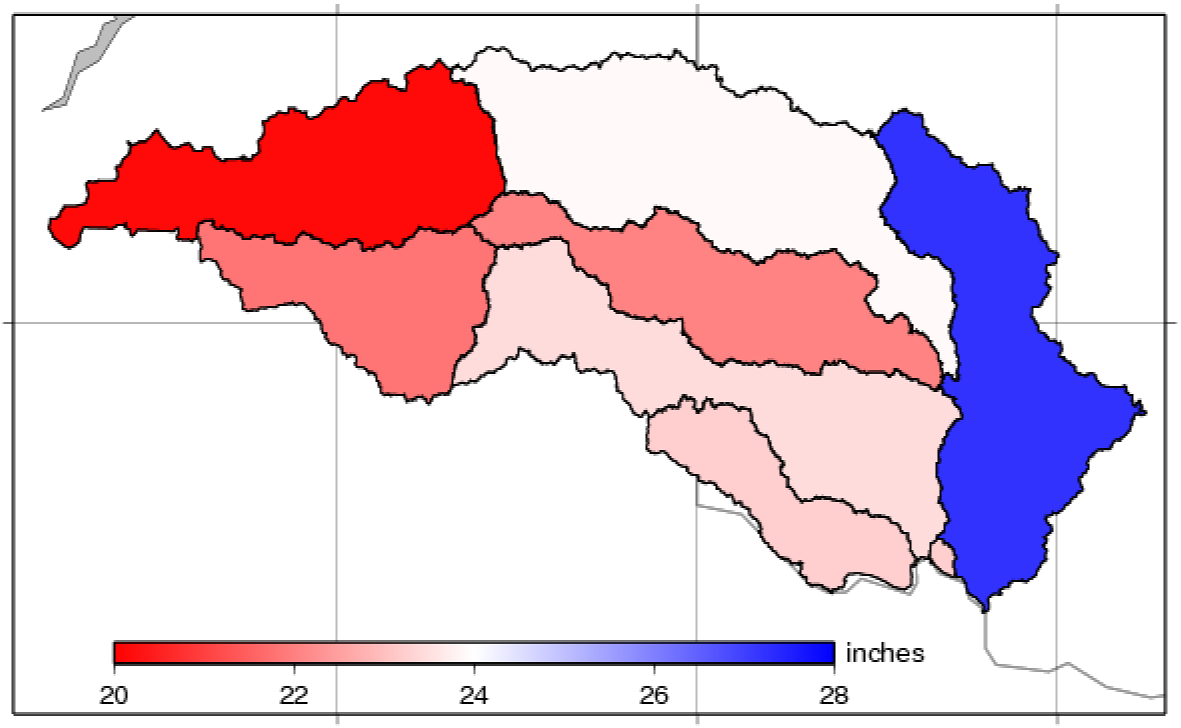

Figure 8 – Spatial distribution of historical baseline (1950-1999) mean annual precipitation

Spatial distributions of historical baseline mean annual ET_o and ET_c are shown in Figures 9 and 10, respectively. ETo, which is primarily a function of temperature, solar radiation, wind speed and humidity, ranges from 61.6 inches in the northwestern portion of the basin to 68.0 inches in the southern portion of the basin. The basin-wide ET_o historical baseline annual average is 65.6inches.

ET_c, which is a function of ET_o and the crop pattern (types and acres), ranges from 42.6 inches in the northwestern portion of the basin to 58.7 inches in the southern portion of the basin. The basin-wide ET_c historical baseline annual average is 52.2 inches.

NIWR depth, which is a function of ET_c and effective precipitation, ranges from 26.3 inches in the eastern portion of the basin to 34.6 inches in the southern portion, as shown in Figure 8. The basin-wide NIWR depth historical baseline annual average is 30.2 inches.

Spatial distribution of NIWR volumes is shown in Figure 12. NIWR volumes, which are a function of NIWR depth and irrigated acreage, range from 83,350.9 acre-feet per year (AFY) in the Elm Fork Red HUC8 sub-basin where it is estimated there are less than 35,000 acres of irrigated crops to 390,982.2 AFY in the Upper North Fork Red HUC8 sub-basin where there are an estimated 178,425 acres of irrigated crops. The basin-wide total estimated historical baseline average annual NIWR volume is 1,778,200.6 AFY.

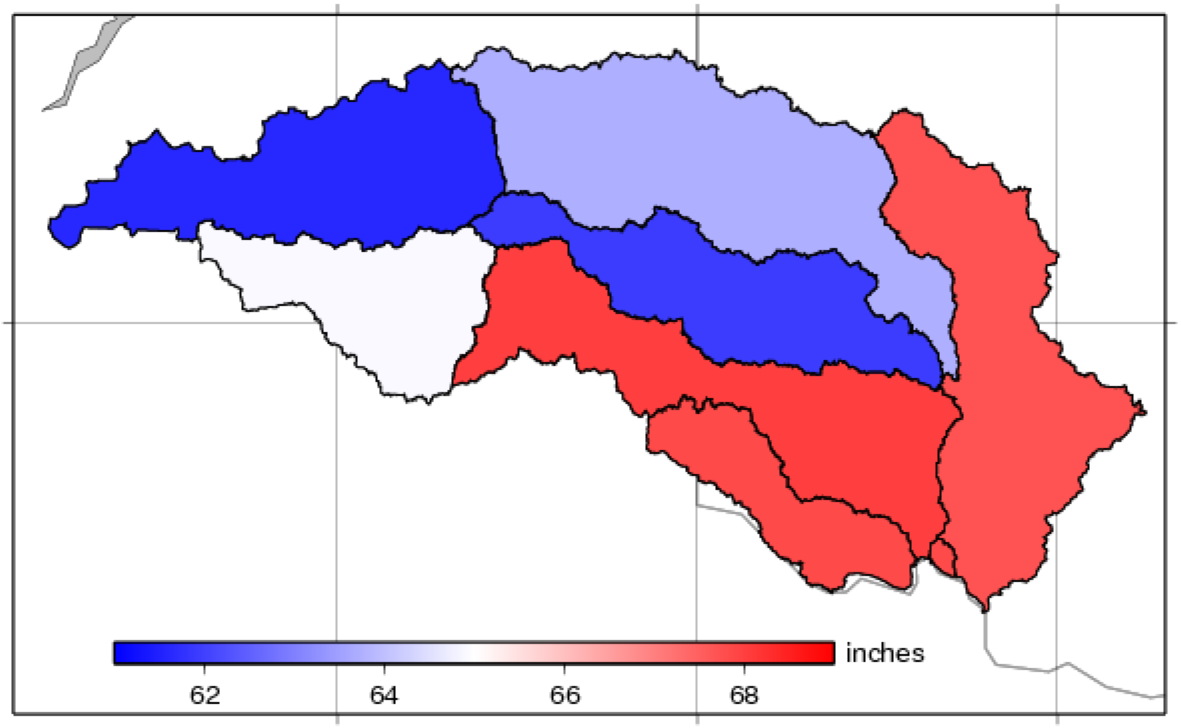

Figure 9 – Spatial distribution of historical baseline (1950-1999) reference evapotranspiration

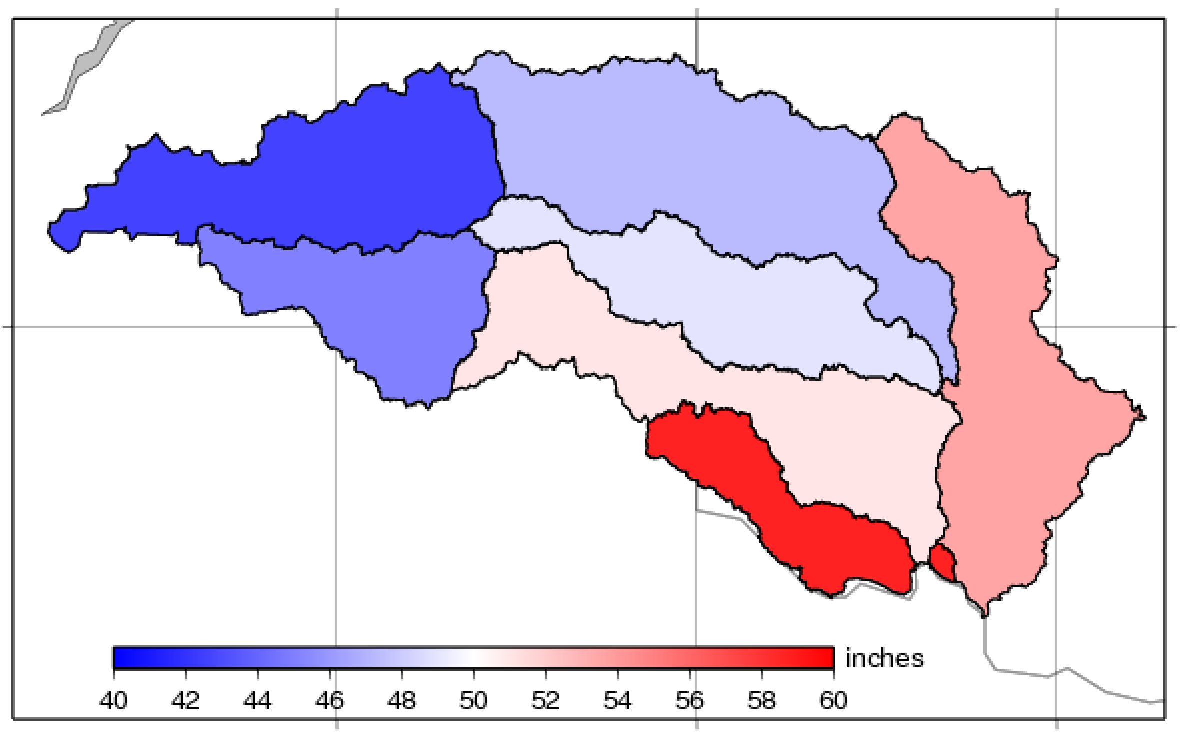

Figure 10 – Spatial distribution of historical baseline (1950-1999) crop evapotranspiration

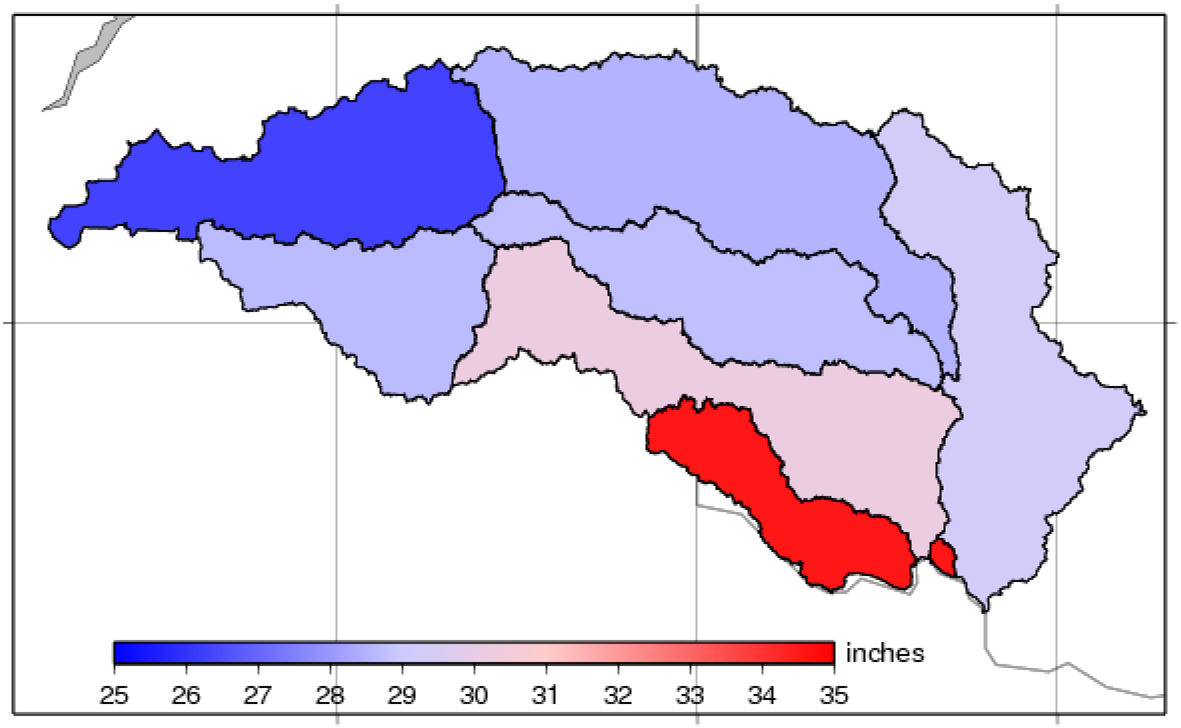

Figure 11 – Spatial distribution of historical baseline (1950-1999) net irrigation water requirement depth

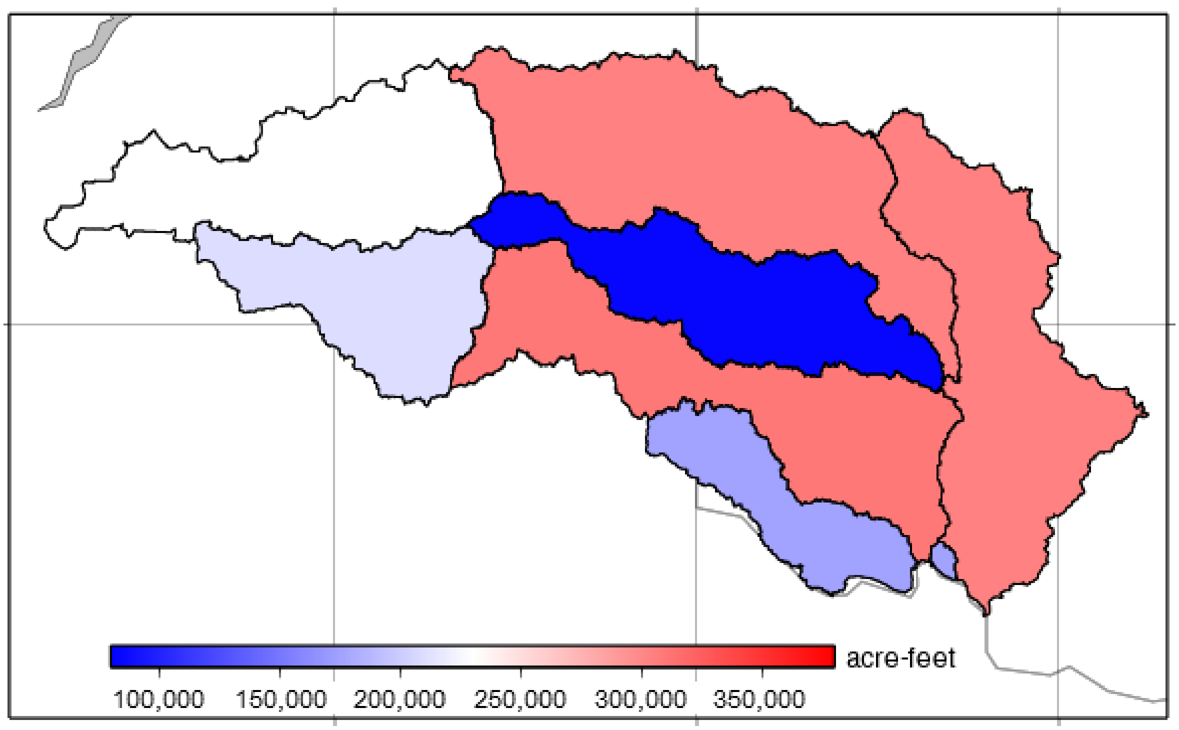

Figure 12 – Spatial distribution of historical baseline (1950-1999) mean annual net irrigation water requirement volumes

Comparison of Historical Baseline Demands to Other Estimates

The historical baseline NIWR and ET_c estimates calculated with the ET Demands model were compared to similar estimates by others and actual alfalfa NIWR measurements made with a weighing lysimeter. A brief discussion of these comparisons follows.

The Oklahoma Climatological Survey (OCS) estimates ET_c for numerous crops using data from the Oklahoma Mesonet network of 120 automated weather stations. Growing season ET_c estimates beginning with 2005 are available at the Mesonet website[2] for most of the primary annual crops grown in the basin (corn, cotton, peanuts, sorghum and soybeans). The historical baseline average growing season ET_c estimates from the ET Demands model were compared to the OCS values for 2015. The comparison was made for the south-central portion of the basin near where the Lugert-Altus irrigation District is located (Lower Salt Fork Red HUC8 sub-basin). The 2015 OCS values were used since the annual OCS ET_o values for this year were the closest fit to the ET Demands historical baseline average ET_o. As shown in Table 2, most of the values compare very well with the largest variability being for cotton and soybeans with respective discrepancies of 12 and 11 percent.

Table 2 – Summary of ET Demands Model and OCS ET_c Estimates Compared

Crops:	Corn	Cotton	Peanuts	Sorghum	Soybeans
ET Demands Historical Baseline Average Growing Season ET_c (inches)	31.9	35.8	36.0	24.5	29.9
2014 Mesonet Growing Season ET_c (inches)	33.1	32.0	33.9	23.5	26.9

The OWRB's 2012 Update to the Oklahoma Comprehensive Water Plan (OCWP) includes crop water demand estimates (CDM, 2011) for 11 regions; 2 of which overlap with the Upper Red River Basin. The NIWR values used were taken from the NRCS Irrigation Guide Report, Oklahoma Supplement (USDA NRCS, 2010). The ET_c values used to estimate NIWR were calculated using the Modified Blaney-Criddle formula (USDA-SCS, 1970) and the method used to calculate P_e is not specified. The Blaney-Criddle formula is a temperature-based method and does not account for solar radiation, humidity, and wind. Based on comparisons to lysimeter data, the formula has been found to under estimate actual ET by up to 25 percent in dry and windy locations (Jensen et al., 1990). The only location within the basin for which the NRCS estimates are available is Altus, Oklahoma and crop types include alfalfa, corn, cotton, sorghum, peanuts, soybeans, pasture grass, watermelons and wheat. With the exception of sorghum, the historical baseline annual average NIWR estimates calculated using the ET Demands model for these crops are approximately 10 to 30 percent greater than the NRCS estimates. As mentioned above, given the methods used by NRCS, it was anticipated that the estimates calculated using the ET Demands model would be on significantly greater than the NRCS estimates.

The significant discrepancy between the NRCS and most of the ET Demands model estimates is concerning. Regardless, given the good agreement with the other sources discussed, it is assumed errors may have been made in the calculation of the NRCS estimates and researching the matter further is beyond the scope of this effort.

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[2] Mesonet website: https://www.mesonet.org/index.php/agriculture/monitor

Future Demands

To evaluate the impacts of climate change on agricultural irrigation demands, the ET Demands model described above was used following the approach of Reclamation (2014) with some adjustments. For example, the URRBS utilizes one future time period for analysis of climate change impacts (2060s), compared with three future time periods (2020s, 2050s, 2080s) used in the WWCRA.

As discussed previously, a single growth scenario or cropping pattern (2015 conditions) was used in conjunction with three scenarios of future climate to encompass a range of potential future irrigation water demands. In the discussion of Historical Baseline Demands, the ET Demands model is described as using basal crop coefficient (K_{cb}) curves which are developed as a function of GDD. For this study, the K_{cb} curves for annual crops are developed using baseline (historical) temperatures, while perennial K_{cb} curves are developed using future projected temperatures.

It is acknowledged that actual K_{cb} curves for annual crops under future conditions will likely vary. Changes in future farming practice of annual crops, such as potential earlier planting, development, and harvest are uncertain under warming climatic conditions. These potential changes will depend on future crop cultivars, water availability, and economics. For these reasons, 'static phenology' annual crop K_{cb} curves were simulated for future periods, where historical baseline temperatures were used for simulating planting, crop development and harvest dates using the GDD approach previously described. In effect, all scenarios and time periods have identical seasonal K_{cb} curve shapes for each annual crop, and only exhibit differences in daily ET_c magnitudes due to daily ET_o and precipitation differences. A detailed discussion on this 'static phenology' approach is included in Reclamation (2014).

The future irrigation demands results cover mean annual precipitation, temperature, ET_o, ET_c, and NIWR (both depth and volume). The future ET_o, ET_c and NIWR sub-basin and basin total estimates were calculated using the same methods as for the historical baseline values. Specifically, the NIWR depth and ET_c rates for each crop within a given HUC8 sub-basin are multiplied by the ratio of the acres of the crop to total irrigated acres within the HUC8 sub-basin and all crop values are summed to calculate weighted average HUC8 sub-basin NIWR depth and ET_c rates. And ET_o, ET_c and NIWR depth estimates for the entire basin were calculated using the ratios of sub-basin to basin irrigated acres.

The results are summarized below in a series of figures showing predicted changes from historical baseline values, with accompanying discussions. Predicted changes are presented as the difference from historical baseline mean values for temperature, and percent change from baseline mean values for all other results. As mentioned above, the Appendix contains tabulated summaries of the projected future estimates of annual average T, P, ET_o, ET_c, NIWR depth, and NIWR volume for each HUC8 sub-basin. And again, the three future scenarios are: Less warm-wetter (LWW), Central Tendency (CT) and Warmer-drier (WD).

Figure 13 shows the spatial distribution of projected precipitation percent change for the different scenarios. Depending on the scenario, precipitation percent changes range from -7.6%

to 611.7%, with basin-wide average percent changes of -0.6-5.4 to 11.1%. The central tendency future scenario basin-wide annual average estimate of 25.5 inches is 1.4 inches more than the baseline value 24.1inches.

Figure 14 shows the spatial distribution of projected average temperature change for the different climate scenarios. Increased temperatures are shown for all scenarios with slightly larger projected average temperature changes in the northwest portion of the basin for all scenarios. Depending on the scenario, basin-wide annual average temperature changes range from 3.7 to 7.9 degrees Fahrenheit with the central tendency future scenario basin-wide annual average estimate of 66.6 degrees increasing 5.3 degrees F from the baseline value of 61.3 degrees F.

Figure 15 shows the spatial distribution of projected ET_o percent change for the different climate scenarios.   Depending on the scenario, basin-wide average ET_o percent changes range from -0.2 % to 10.4% with the central tendency future scenario basin-wide annual average estimate increasing 3.5 inches from the baseline value of 65.6 inches.

Figure 16 shows the spatial distribution of projected ET_c percent change for the different climate scenarios. Spatial differences in the distribution of projected percent change in ET_c are due to differences in ET_o, crop types and historical baseline ET_c. The southwest portion of the basin is projected to experience the largest percent change increase. Depending on the scenario, basin-wide average ET_c percent changes range from 1.3% to 7.2% with the central tendency future scenario basin-wide annual average estimate of 54.7 inches increasing 2.5 inches from the baseline value of 52.2 inches.

Figure 17 shows the spatial distribution of projected NIWR depth percent change for the different climate scenarios. Spatial differences in the distribution of projected percent change in NIWR depth are a function of ET_c and precipitation. The southwest portion of the basin is projected to experience the largest percent change increase, due the difference between the projected and historical baseline ET_c and relatively high reductions in precipitation (Figure 13). Depending on the scenario, basin-wide average NIWR depth percent changes range from -2.0% to 19.7% with the central tendency future scenario basin-wide annual average estimate of 32.6 inches increasing 2.4 inches from the baseline value of 30.2 inches.

Figure 18 shows the spatial distribution of projected NIWR volume percent change for the different climate scenarios. Spatial differences in the distribution of projected percent change in NIWR volume are a function of NIWR depth change and the quantity of irrigated lands within each sub-basin. The southwest portion of the basin is projected to experience the largest percent change increase, due the difference between the projected and historical baseline ET_c, relatively high reductions in precipitation (Figure 13) and the relatively large amount of irrigated lands. Basin-wide average NIWR volume percent changes range from -2.0% to 19.7% with the central tendency future scenario basin-wide annual estimated total of 1,922,894 AFY increasing 93,156 AFY from the baseline value of 1,788,201 AFY.

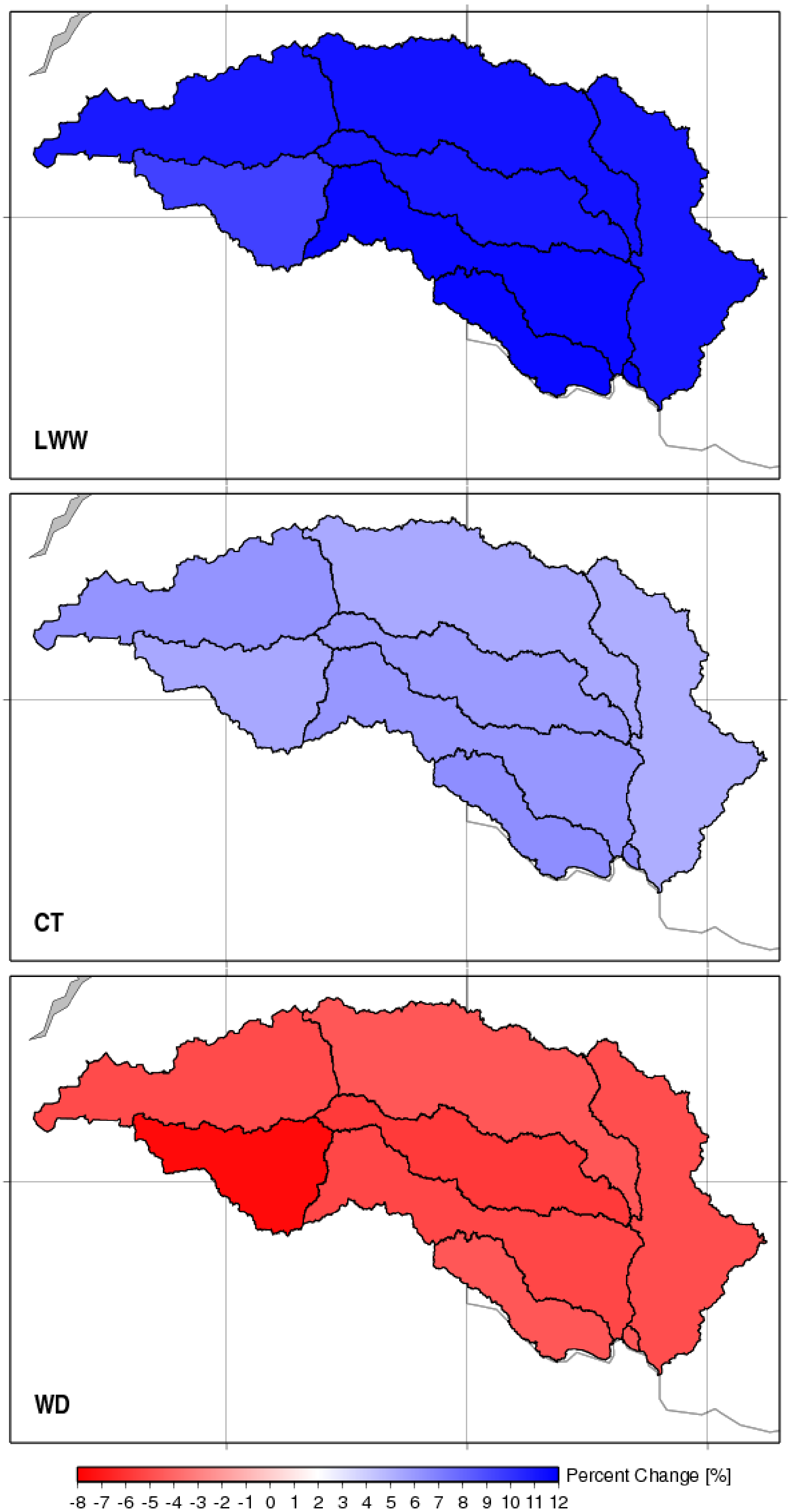

Figure 13 – Spatial distribution of projected 2060s precipitation percent change from historical baseline

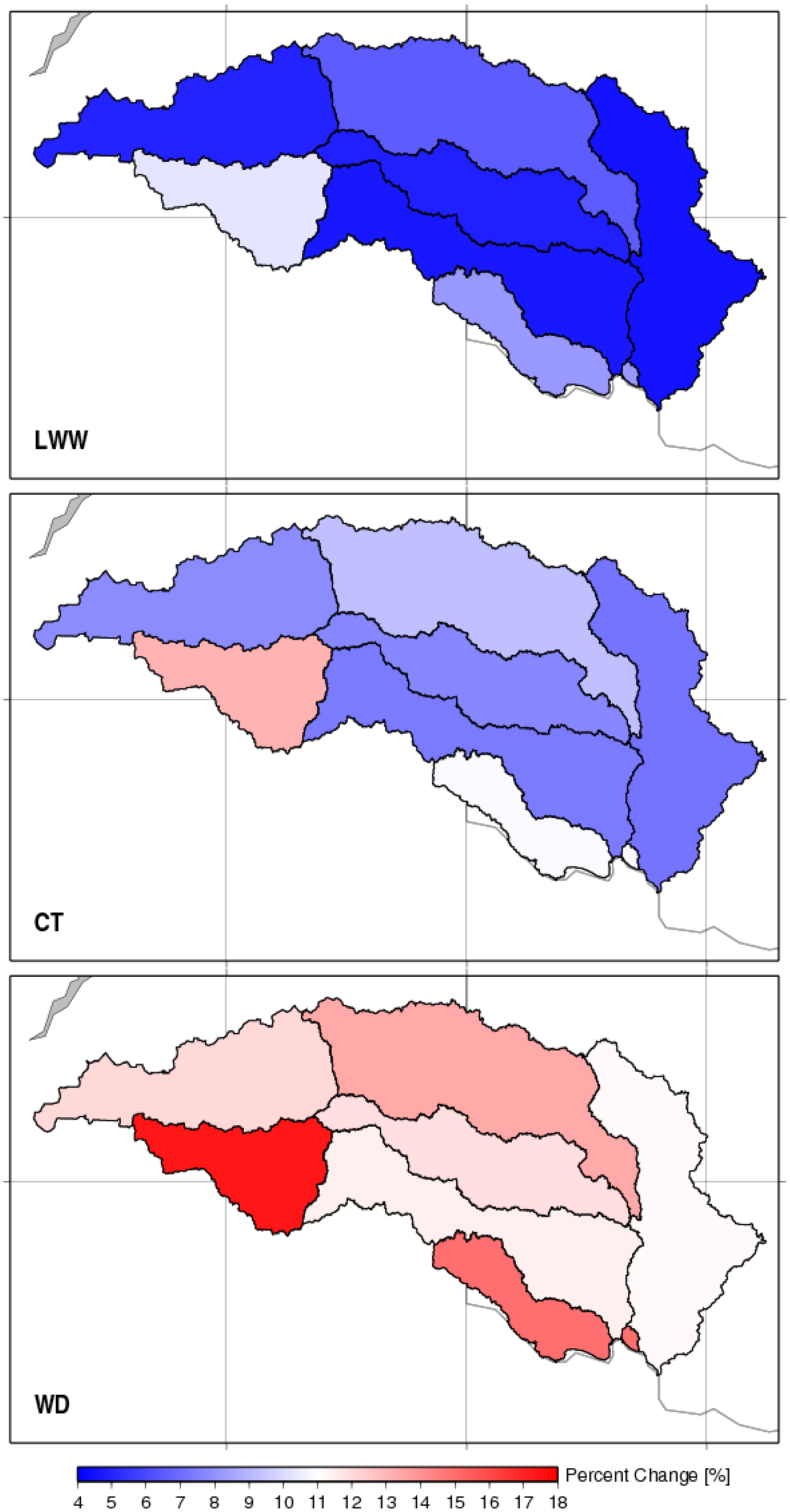

Figure 144 – Spatial distribution of projected 2060s temperature change from historical baseline

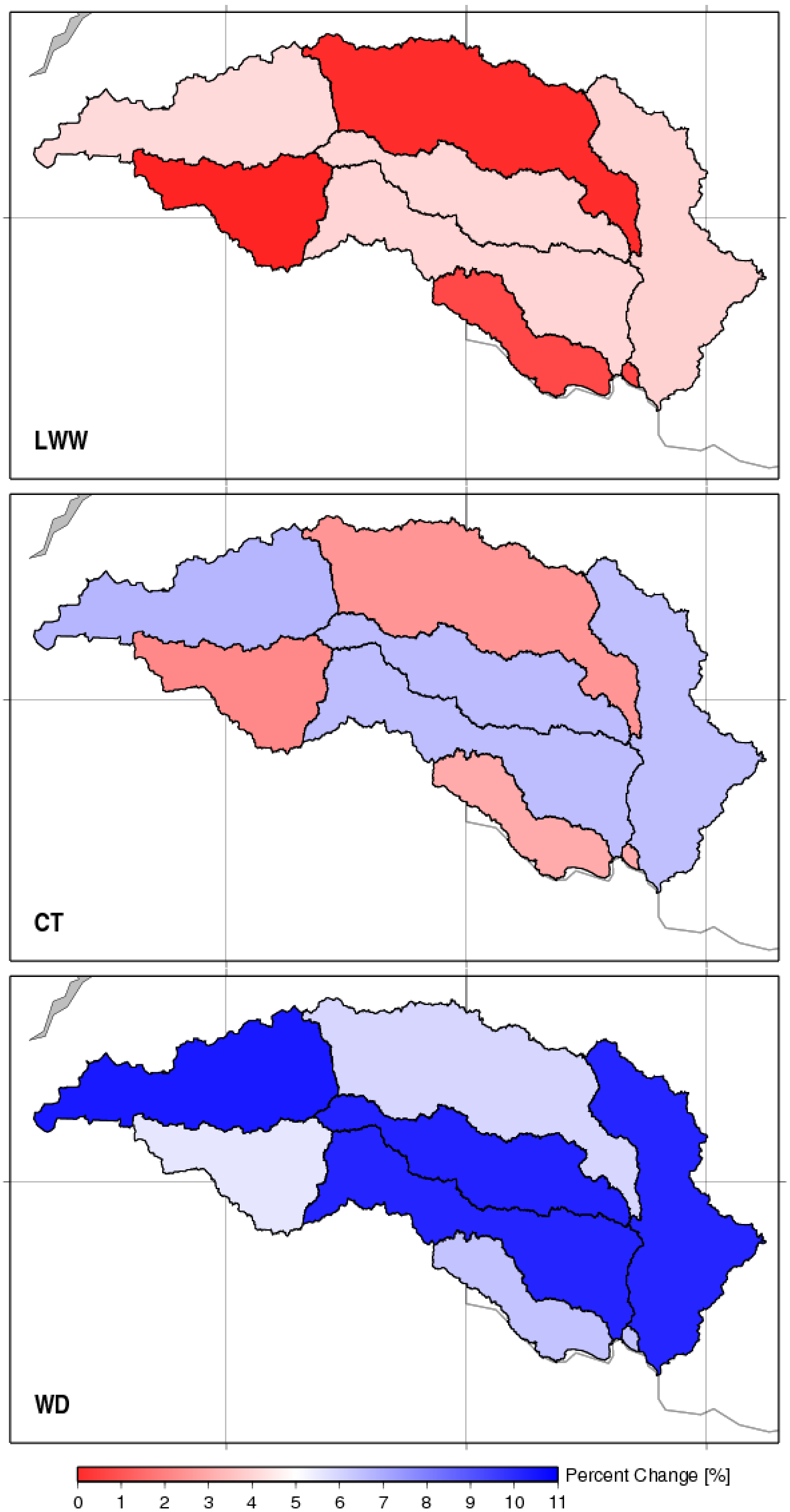

Figure 15 – Spatial distribution of projected 2060s reference ET percent change from historical baseline

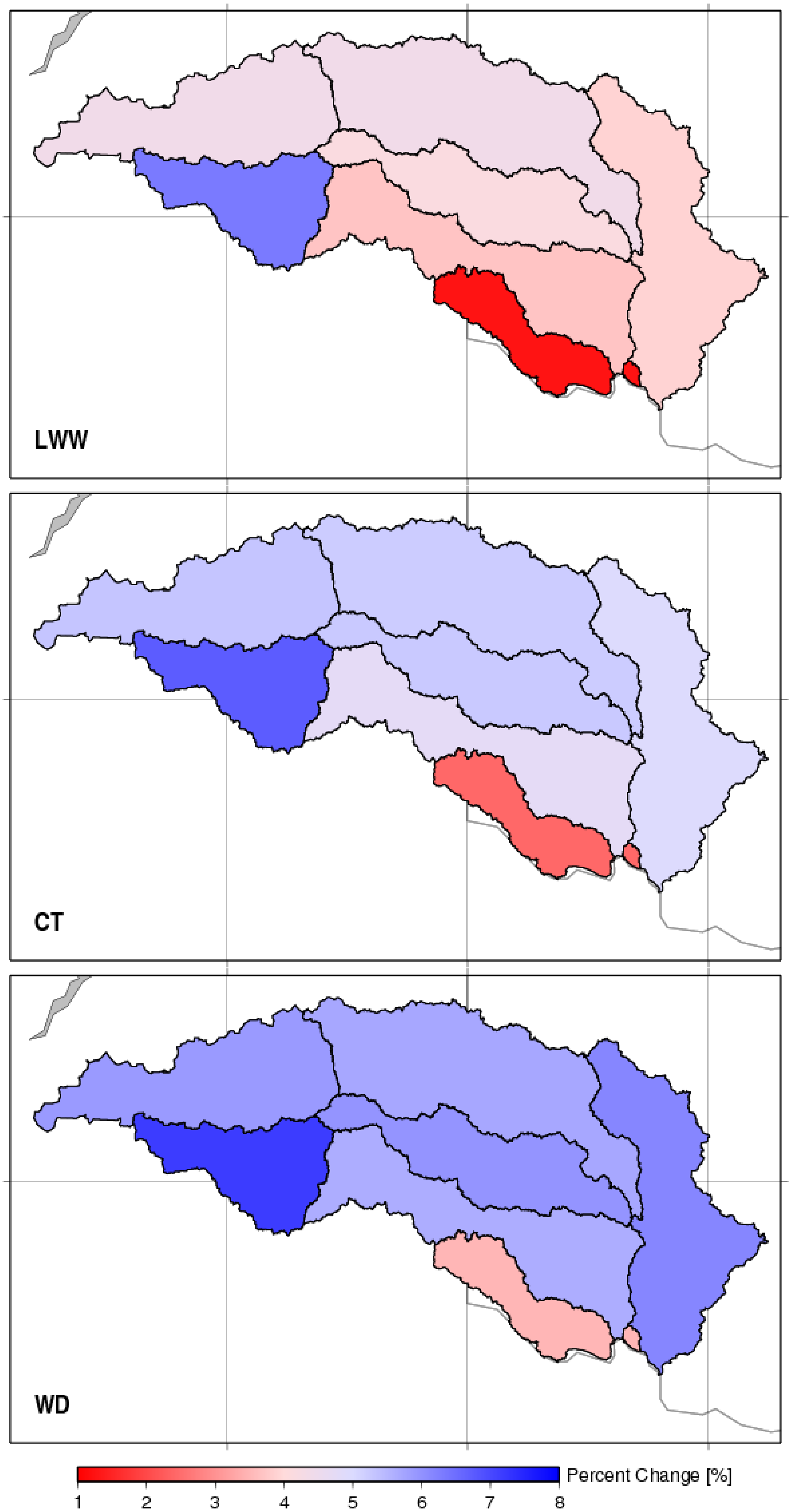

Figure 165 – Spatial distribution of projected 2060s crop ET percent change from historical baseline

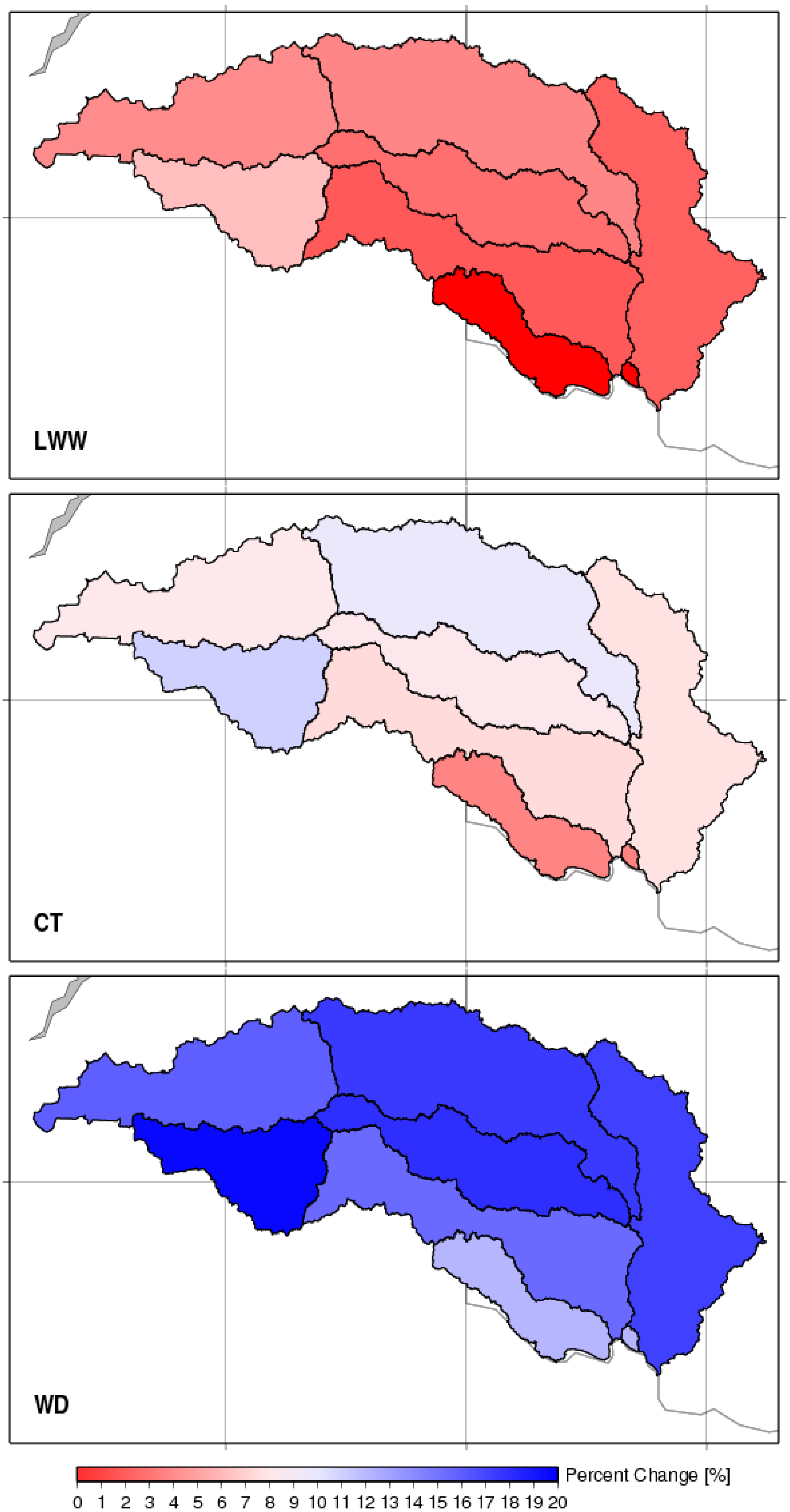

Figure 17 – Spatial distribution of projected 2060s NIWR depth percent change from historical baseline

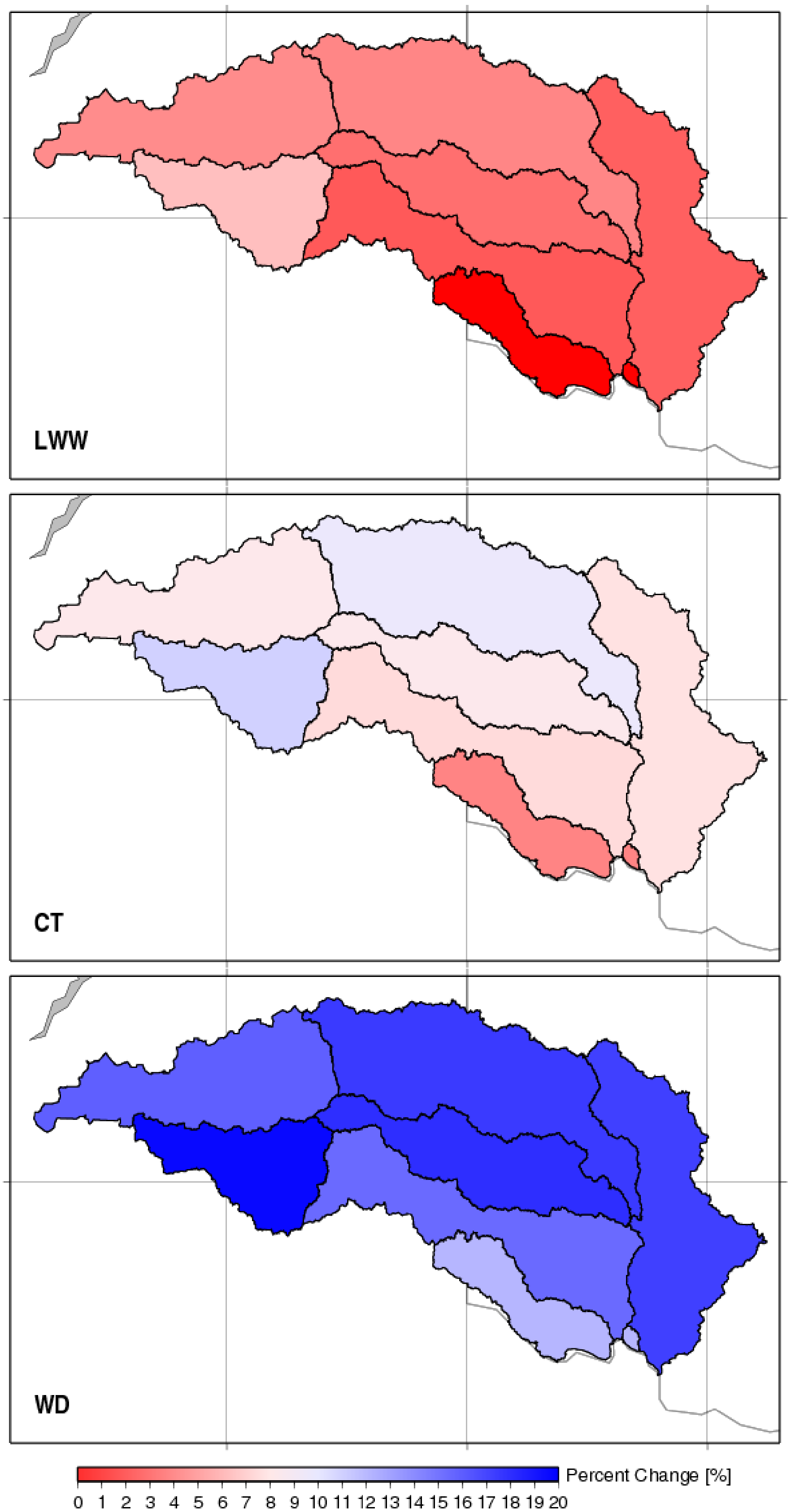

Figure 18 – Spatial distribution of projected 2060s NIWR volume percent change from historical baseline

M&I demands

M&I water demands include demands that are met by public water supply systems that range in size from 15 connections to many thousands of connections[3]. Current M&I demands estimates are based on the suppliers' recent production quantities that include water delivered to customers plus leakage and other unaccounted for water. M&I water users include domestic households, industrial facilities, and commercial businesses. M&I demands include domestic potable consumption and outdoor water use that is primarily for urban landscape irrigation.

The URRBS Plan of Study specified that future M&I demands were to be estimated for the cities of Altus, Frederick and Snyder, however, water production data needed for the analysis was not available for Snyder. Public works entities for Altus and Frederick provided monthly water production data for the past six years (2010-2015) that was used to estimate current demands that provide the basis for the future demand estimation as discussed below. Specifically, the average monthly and annual production quantities for 2010-2015 are considered to represent current demand.

Water demands during 2010-2015 varied significantly, but appear to be consistent with dry versus wet weather conditions and water restrictions that were in place during drought periods. And it is also relevant to note that the average annual precipitation amount for this period, as reported for the Altus Mesonet Station, is very similar to the average for the 1997-2015 period of record (21.3 versus 22.5 inches, respectively).

Although production data from water supply entities are typically in units of millions of gallons (per day, month or year), demand units in this study are in AF per year (AFY) or gallons per capita per day (gpcd). The latter is calculated by dividing daily average total demands (calculated from monthly production data) by population estimates[4].

In order to incorporate estimated changes in future M&I demands due to changes in landscape irrigation under climate change, the outdoor use portion of the total estimated demands were estimated. This estimation was done based on the assumption that all water use during the months of December through February is exclusively indoor. The outdoor demand for all other months was estimated by subtracting the average of the December, January and February demand from total demand. The results of this process are summarized in Table 3.

Table - 3. Total and per capita current M&I water demands (2010 – 2015 averages)

City	Annual Demand (AFY)	Per Capita Demand (gpcd)	Indoor Per Capita Demand (gpcd)	Outdoor Per Capita Demand (gpcd)
Altus	5,142	199	157	42
Frederick	1,289	249	210	39

[3] The Safe Drinking Water Act, Section 1401(4) defines a public water system as that delivering water for human consumption to not less than 15 service connections or 25 regularly served persons.
[4] Population estimates are from the Oklahoma State Data Center - Oklahoma Department of Commerce accessed at http://www.digitalprairie.ok.gov/cdm/ref/collection/stgovpub/id/8379

Future M&I demand estimates are based on population growth projections and climate change scenarios. It is assumed the outdoor portion of current per capita demands will change as a function of changes in landscape irrigation demands due to climate change. Although it is likely that socio-economic factors such as water conservation, reduced landscape areas, etc. may cause changes in per capita demand, these impacts are not accounted for. Hence, the indoor portion of per capita demand is held constant at the current average rates and the outdoor portion is adjusted only for climate change.

The first step in estimating future M&I demands is to calculate the future indoor and outdoor base demands using current demands and future population growth estimates (i.e. including growth scenario but no climate change scenarios). The base future outdoor demands are then adjusted for climate change effects on landscape irrigation. The adjustments were made using the same methods as discussed previously for the future agricultural irrigation demand estimates. Specifically, the ET Demands model was used to calculate percent change in turf grass NIWR under the three climate change scenarios (LWW, CT and WD).

The future M&I demand estimates for Altus and Frederick were calculated based on the current demand estimates shown in Table 3 and population growth rates published by the Oklahoma Department of Commerce (see footnote 3 on previous page). Projected compounded annual growth rates range from 0.42 to 0.61 percent for Altus and 0.21 to 0.22 percent for Frederick. The published growth rates for these cities are at 5-year increments up to 2030. These data were extrapolated using regression methods to estimate 2060 populations. The current and future population estimates are summarized in Table 4.

Table - 4. Summary of Current and Future Population Estimates

City	**Current (2015) Estimated Population**	**Future (2060) Estimated Population**
Altus	23,380	29,094
Frederick	4,790	5,090

As discussed above, each of the M&I base consumptive use estimates were adjusted for climate change. Specifically, the current indoor and outdoor per capita demand and rates were multiplied by the future population estimates to estimate the future indoor and outdoor base demands. The future base outdoor demand estimates were then multiplied by the climate change factors for each of the three scenarios (LWW, CT and WD). Again, these are the same climate change factors used in the agricultural demands analysis that represent the estimated changes from the 1950-1999 baseline period to 2060. The climate change adjusted outdoor demand estimates were then added to the indoor demands estimate to calculate the total future demand estimates for each scenario. The components of the future demand estimates (indoor, outdoor base, adjusted outdoor and totals) and climate change factors are summarized in Table 5.

Table - 5. Summary of Future Demand Estimates and Climate Change Factors

Future Water Demand Estimates, Change Factors and Percent Change	Altus	Fredrick
Indoor Demand (AFY)	5,141	1,202
Outdoor Base Demand (AFY)	1,360	221
LWW Change Factor	15.6%	15.6%
CT Change Factor	30.1%	30.1%
WD Change Factor	47.9%	47.9%
LWW Outdoor Demand (AFY)	1,573	255
CT Outdoor Demand (AFY)	1,770	287
WD Outdoor Demand (AFY)	2,012	326
LWW Total Demand (AFY)	6,714	1,457
CT Total Demand (AFY)	6,911	1,489
WD Total Demand (AFY)	7,154	1,529
LWW Total Demand (gpcd)	206	256
CT Total Demand (gpcd)	212	261
WD Total Demand (gpcd)	219	268
LWW Total Demand Percent Change	3.3%	2.4%
CT Total Demand Percent Change	6.3%	4.7%
WD Total Demand Percent Change	10.0%	7.4%

The net changes in total M&I water demand from current to future for the three climate change scenarios range from 3.3 to 10.0 percent for Altus and 2.4 to 7.4 percent for Frederick.

UNCERTAINTIES

There are numerous uncertainties and limitations in modeling ET_o, ET_c, and NIWR. One source of uncertainty is associated with underlying assumptions in modeling; for example, static cropping patterns and farming practices. This study uses data from the USDA crop land data layer and OWRB water rights data as the sources for quantifying the types of irrigated crops grown in the basin. It is assumed these crop types and quantities do not change in the modeling. Obviously, increases or decreases in the overall amounts irrigated areas would result in respective changes in demands. Changes in crop choice may significantly affect future agricultural demands given the variability in water demand for different crop types.

Another source of uncertainty is the weighted average soil conditions used in the estimation of NIWR. Precipitation runoff and soil water holding capacity are a function of soil type and soil types can vary significantly even within a single irrigated parcel of land. The degree of uncertainty in the method used depends on the variability of soil types within each HUC8 sub-basin for which a weighted average soil type was calculated as described in Reclamation (2014).

Climatic data used in this basin study analysis were limited to daily maximum and minimum temperatures and daily precipitation; therefore, solar radiation, humidity, and windspeed were approximated for baseline and future time periods using empirical approaches. Solar radiation was simulated for baseline and future periods based on empirical relationships of differences between daily maximum and minimum air temperatures, where maximum air temperature generally decreases during cloud cover, and minimum temperature is increased due to increased downward emission of long wave radiation by clouds at night. Integration of potential changes in solar radiation, and evaluating the potential impact of such changes on irrigation water demands was not addressed in this analysis.

Historical agricultural weather station data were used to estimate the spatial distribution of baseline and projected mean monthly dewpoint depression and windspeed. Given the uncertainties and limited availability in future projections of humidity and windspeed, mean monthly dewpoint depression and windspeed were considered static for future periods. While there is considerable uncertainty in projecting future reference ET, estimation of reference ET for historical periods using assumptions outlined above was shown to be robust when compared to agricultural weather station estimated reference ET.

An important limitation in the application of the ET Demands model for this assessment is the lack of consideration as to how CO_2 potentially impacts crop development and water use. The impact of increased CO_2 on crop transpiration, water use efficiency, and yield is of particular interest and is probably one of the largest uncertainties. Recent studies have described how elevated CO_2 concentrations may reduce stomatal aperture, transpiration, and crop production processes (Kruijt et al. 2008 and Islam et al. 2012). However, estimating CO_2-induced changes on irrigation demands remains an extremely difficult task because of plant dependency, adaptation, unknown non-linear near-surface boundary-layer feedbacks from reduced transpiration and resulting increased leaf temperatures and vapor pressure deficits, uncertainties of increased leaf area index, stomatal and aerodynamic resistances, and plant-dependent stomatal sensitivities (i.e., C3 versus C4 plants). For these reasons, this study focused on major change factors and considerations such as physically based reference ET estimation, temperature-dependent growing seasons and crop development, bare soil evaporation, and non-growing-season soil moisture accounting for better representation of monthly and annual net irrigation water requirements. Addressing the impacts of CO_2 on irrigation water demands is currently, and will be, the focus of further Reclamation studies.

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APPENDIX

Table A-1 – Summary of HUC8 Sub-basin Average Annual Historical Baseline and Projected Future Temperatures and Projected Future Average Annual Change in Temperature

HUC8	Average Annual Temperature (°F)				Change in Temperature (°F)		
Sub-basin	Baseline	LWW	CT	WD	LWW	CT	WD
11120201	58.8	64.8	66.5	69.0	6.0	7.7	10.2
11120202	62.0	64.9	66.6	69.1	2.9	4.6	7.1
11120301	59.0	61.9	63.6	66.1	2.9	4.6	7.1
11120302	61.6	65.6	67.3	69.8	4.0	5.7	8.2
11120303	62.6	65.4	67.1	69.6	2.8	4.5	7.0
11120304	60.0	63.0	64.6	67.2	2.9	4.6	7.1
11130101	62.3	67.4	69.0	71.6	5.1	6.8	9.3
Total Basin	61.3	65.0	66.6	69.2	3.7	5.3	7.9
Maximum	62.6	67.4	69.0	71.6	6.0	7.7	10.2
Minimum	58.8	61.9	63.6	66.1	2.8	4.5	7.0

Table A-2 – Summary of HUC8 Sub-basin Average Annual Historical Baseline and Projected Future Precipitation, Projected Future Average Annual Change in Precipitation and Percent Change in Precipitation

HUC8	Average Annual Precipitation (inches)				Change in Precipitation (inches)			Percent Change in Precipitation (%)		
Sub-basin	Baseline	LWW	CT	WD	LWW	CT	WD	LWW	CT	WD
11120201	21.8	23.9	23.0	20.2	2.1	1.2	-1.7	9.5%	5.4%	-7.6%
11120202	23.5	26.2	24.9	22.2	2.7	1.4	-1.2	11.6%	6.1%	-5.2%
11120301	20.1	22.4	21.4	19.1	2.2	1.3	-1.0	11.0%	6.2%	-5.1%
11120302	23.9	26.6	25.2	22.8	2.7	1.3	-1.1	11.3%	5.4%	-4.6%
11120303	27.2	30.2	28.6	25.9	3.0	1.4	-1.3	11.1%	5.2%	-4.9%
11120304	22.1	24.5	23.4	20.8	2.4	1.3	-1.3	11.0%	5.9%	-5.7%
11130101	23.2	26.0	24.7	22.2	2.7	1.5	-1.1	11.7%	6.4%	-4.6%
Total Basin	24.1	26.8	25.5	22.8	2.7	1.4	-1.3	11.1%	5.7%	-5.4%
Maximum	27.2	30.2	28.6	25.9	3.0	1.5	-1.0	11.7%	6.4%	-4.6%
Minimum	20.1	22.4	21.4	19.1	2.1	1.2	-1.7	9.5%	5.2%	-7.6%

Table A-3 – Summary of HUC8 Sub-basin Average Annual Historical Baseline and Projected Future Reference Evapotranspiration (ET), Projected Future Average Annual Change in Reference ET and Percent Change in Reference ET

HUC8 Sub-basin	Average Annual Reference ET (inches)				Change in Reference ET (inches)			Percent Change in Reference ET (%)		
	Baseline	LWW	CT	WD	LWW	CT	WD	LWW	CT	WD
11120201	64.9	64.8	66.3	68.5	-0.1	1.4	3.6	-0.2%	2.2%	5.6%
11120202	68.0	70.7	72.5	74.9	2.7	4.4	6.9	4.0%	6.5%	10.2%
11120301	61.6	64.2	65.8	68.0	2.6	4.1	6.4	4.1%	6.7%	10.4%
11120302	63.7	63.8	65.3	67.5	0.0	1.6	3.8	0.0%	2.5%	6.0%
11120303	67.7	70.4	72.1	74.5	2.7	4.4	6.9	4.0%	6.5%	10.1%
11120304	61.9	64.5	66.0	68.3	2.5	4.1	6.3	4.1%	6.6%	10.2%
11130101	67.8	68.3	69.9	72.2	0.5	2.1	4.3	0.7%	3.0%	6.4%
Total Basin	65.6	67.5	69.1	71.4	1.8	3.5	5.8	2.8%	5.3%	8.8%
Maximum	68.0	70.7	72.5	74.9	2.7	4.4	6.9	4.1%	6.7%	10.4%
Minimum	61.6	63.8	65.3	67.5	-0.1	1.4	3.6	-0.2%	2.2%	5.6%

Table A-4 – Summary of HUC8 Sub-basin Average Annual Historical Baseline and Projected Future Crop Evapotranspiration (ET), Projected Future Average Annual Change in Crop ET and Percent Change in Crop ET

HUC8 Sub-basin	Average Annual Crop ET (inches)				Change in Crop ET (inches)			Percent Change in Crop ET (%)		
	Baseline	LWW	CT	WD	LWW	CT	WD	LWW	CT	WD
11120201	45.1	47.9	48.1	48.3	2.9	3.0	3.2	6.3%	6.7%	7.2%
11120202	51.0	52.9	53.4	53.9	1.9	2.4	2.9	3.7%	4.7%	5.6%
11120301	42.6	44.4	44.8	45.1	1.9	2.3	2.5	4.4%	5.3%	5.9%
11120302	47.3	49.4	49.8	50.0	2.1	2.5	2.7	4.4%	5.2%	5.7%
11120303	53.5	55.6	56.2	56.8	2.1	2.7	3.3	3.9%	5.0%	6.2%
11120304	49.0	51.0	51.5	51.9	2.0	2.6	2.9	4.1%	5.2%	6.0%
11130101	58.7	59.4	60.1	60.7	0.7	1.4	2.0	1.3%	2.4%	3.5%
Total Basin	52.2	54.2	54.7	55.2	2.0	2.5	3.0	3.8%	4.8%	5.7%
Maximum	58.7	59.4	60.1	60.7	2.9	3.0	3.3	6.3%	6.7%	7.2%
Minimum	42.6	44.4	44.8	45.1	0.7	1.4	2.0	1.3%	2.4%	3.5%

Table A-5 – Summary of HUC8 Sub-basin Average Annual Historical Baseline and Projected Future Net Irrigation Water Requirement (NIWR) Depth, Projected Future Average Annual Change in NIWR Depth and Percent Change in NIWR Depth

HUC8	Average Annual NIWR Depth (inches)				Change in NIWR Depth (inches)			Percent Change in NIWR Depth (%)		
Sub-basin	Baseline	LWW	CT	WD	LWW	CT	WD	LWW	CT	WD
11120201	28.7	30.5	31.8	34.3	1.8	3.1	5.6	6.3%	11.0%	19.7%
11120202	30.2	30.8	32.5	34.9	0.6	2.2	4.7	1.9%	7.4%	15.4%
11120301	26.3	27.4	28.4	30.5	1.1	2.2	4.2	4.0%	8.2%	15.9%
11120302	28.5	29.6	31.3	33.5	1.1	2.8	5.0	3.8%	9.7%	17.5%
11120303	29.3	29.9	31.6	34.4	0.6	2.3	5.1	2.1%	7.8%	17.2%
11120304	28.8	29.6	31.1	33.9	0.8	2.4	5.2	2.8%	8.2%	18.0%
11130101	34.6	33.9	35.8	38.8	-0.7	1.3	4.2	-2.0%	3.7%	12.1%
Total Basin	30.2	30.8	32.6	35.3	0.6	2.4	5.0	2.1%	7.8%	16.7%
Maximum	34.6	33.9	35.8	38.8	1.8	3.1	5.6	6.3%	11.0%	19.7%
Minimum	26.3	27.4	28.4	30.5	-0.7	1.3	4.2	-2.0%	3.7%	12.1%

Table A-6 – Summary of HUC8 Sub-basin Average Annual Historical Baseline and Projected Future Net Irrigation Water Requirement (NIWR) Volume, Projected Future Average Annual Change in NIWR Volume and Percent Change in NIWR Volume

HUC8	Average Annual NIWR Volume (acre-feet)				Change in NIWR Volume (acre-feet)			Percent Change in NIWR Volume (%)		
Sub-basin	Baseline	LWW	CT	WD	LWW	CT	WD	LWW	CT	WD
11120201	210,110.8	223,273.4	233,182.3	251,437.5	13,162.5	9,908.9	18,255.2	6.3%	11.0%	19.7%
11120202	309,600.0	315,330.0	332,619.8	357,404.6	5,729.9	17,289.8	24,784.8	1.9%	7.4%	15.4%
11120301	390,982.2	406,751.2	422,956.3	453,214.4	15,769.0	16,205.2	30,258.1	4.0%	8.2%	15.9%
11120302	304,323.2	315,844.5	333,971.7	357,512.5	11,521.4	18,127.1	23,540.9	3.8%	9.7%	17.5%
11120303	304,387.0	310,830.8	327,988.7	356,866.5	6,443.7	17,158.0	28,877.8	2.1%	7.8%	17.2%
11120304	83,350.9	85,684.2	90,221.1	98,347.2	2,333.3	4,536.9	8,126.1	2.8%	8.2%	18.0%
11130101	175,446.5	172,024.4	181,954.4	196,715.8	-3,422.1	9,930.1	14,761.4	-2.0%	3.7%	12.1%
Total Basin	1,778,200.6	1,829,738.4	1,922,894.4	2,071,498.6	51,537.7	93,156.1	148,604.2	2.9%	8.1%	16.5%
Maximum	390,982.2	406,751.2	422,956.3	453,214.4	15,769.0	18,127.1	30,258.1	6.3%	11.0%	19.7%
Minimum	83,350.9	85,684.2	90,221.1	98,347.2	-3,422.1	4,536.9	8,126.1	-2.0%	3.7%	12.1%