**Research Paper**

# Changes in projected spatial and seasonal groundwater recharge in the upper Colorado River basin

**Fred D Tillman[1], Subhrendu Gangopadhyay[2], and Tom Pruitt[2]**

[1] U.S. Geological Survey, Arizona Water Science Center, Tucson, Arizona, USA

[2] Reclamation, Water Resources Planning and Operations Support Group, Denver, Colorado, USA

Corresponding author: Fred Tillman (ftillman@usgs.gov)

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**Article Impact Statement:** Projected stable or increasing UCRB groundwater recharge is not distributed uniformly throughout the basin or year

## Abstract

The Colorado River is an important source of water in the western United States, supplying the needs of more than 38 million people in the U.S. and Mexico. Groundwater discharge to streams has been shown to be a critical component of streamflow in the upper Colorado River basin (UCRB), particularly during low-flow periods. Understanding impacts on groundwater in the basin from projected climate change will assist water managers in the region in planning for potential changes in the river and groundwater system. A previous study on changes in basin-wide groundwater recharge in the UCRB under projected climate change found substantial increases in temperature, moderate increases in precipitation, and mostly periods of stable or slight increases in simulated groundwater recharge through 2099. This study quantifies projected spatial and seasonal changes in groundwater recharge within the UCRB from recent historical (1950–2015) through future (2016–2099) time periods, using a distributed-parameter groundwater recharge model with downscaled climate data from 97 Coupled Model Intercomparison Project Phase 5 (CMIP5) climate projections. Simulation results indicate that projected increases in basin-wide recharge of up to 15% are not distributed uniformly within the basin or throughout the year. Northernmost subregions within the UCRB are projected an increase in groundwater recharge, while recharge in other mainly southern subregions will decline. Seasonal changes in recharge also are projected within the UCRB, with decreases of 50% or more in summer months and increases of 50% or more in winter months for all subregions, and increases of 10% or more in spring months for many subregions.

## Introduction

The domestic and industrial water needs of more than 38 million people in the U.S. and Mexico are supplied by the Colorado River (Bureau of Reclamation 2011; Colorado River Basin Salinity Control Forum 2013). Additionally, more than 18,000 $km^2$ of agricultural land in the U.S. and Mexico is irrigated with Colorado River water, and the River and its tributaries annually generate about 12 billion kilowatt hours of hydroelectric power (Colorado River Basin Salinity Control Forum 2011). About 90% of the flow in the lower Colorado River at Lake Mead originates in the UCRB (U.S. Geological Survey, 2016). Groundwater discharge to the stream system in the upper Colorado River basin (UCRB) supplies an important component of the available flow, with an estimated 30 to 50% of total streamflow coming from groundwater (Miller et al. 2014 and Rumsey et al. 2015). A study by Castle et al. (2014) using remotely-sensed gravity observations from the NASA Gravity Recovery and Climate Experiment (GRACE) mission found that UCRB groundwater storage was depleted by more than 21 $km^3$ during the December 2004 to November 2013 time period of the investigation. An understanding of groundwater recharge is essential for the sustainable management of groundwater and surface-water supplies in the UCRB and in the Colorado River Basin as a whole.

Recently Tillman et al. (2016) investigated projected changes in temperature and precipitation in the UCRB and resulting changes in simulated groundwater recharge through 2099. The study found increasing basin-wide temperatures for all future time periods and increased basin-wide precipitation for nearly all future time periods in the UCRB. Simulated annual groundwater recharge for most future decades in the UCRB was likely to be greater than the historical average (1951–2015). Increases in recharge were observed in pooled simulation results from all climate ensembles as well as from simulation results that were grouped by emission scenarios. The magnitude and timing of changing climate parameters, as well as their relative location within the basin, were discussed as potentially important factors in explaining the projected increase in basin-wide recharge. This paper presents results from an investigation of spatial and seasonal changes in simulated recharge under projected climate change within the UCRB. Results may contribute to a better understanding of the projected basin-wide increase in recharge in the UCRB and assist water-management planning at the subregional level within the basin.

## Description of Study Area

The Colorado River (the River) basin drains parts of Utah, Wyoming, New Mexico, Colorado, Nevada, Arizona, California, and Mexico, and is divided into upper and lower basins at the compact point of Lee Ferry, Arizona, a location 1.6 km downstream of the mouth of the Paria River (Figure 1; Anderson 2004). The UCRB is defined for this study as the drainage area of the Colorado River basin above the Lee Ferry compact point and the Great Divide closed basin, as delineated by the Region 14 hydrologic unit code (HUC; see http://water.usgs.gov/GIS/huc.html). Major tributaries in the UCRB include the Green, Dolores, San Juan, Gunnison, Yampa, and White Rivers (Figure 1). Annual precipitation averages less than 150 mm in lower elevation areas of the basin, mainly from 1000-1500 m, and more than 1000 mm in higher elevations over 2500 m in the Southern Rocky Mountains (PRISM Climate Group 2012). Few high-density population centers are located within the UCRB, including Grand Junction, CO (population 60,000) and Farmington, NM (population 43,000) and land cover is predominately shrubland and evergreen forest (Fry et al. 2011). Areas with the potential for recharge of groundwater supplies through infiltration of excess precipitation are present across most of the UCRB. Permeable, moderately to well-consolidated sedimentary rocks comprise the UCRB regional aquifers that are from Cambrian to Tertiary in age (Robson and Banta 1995), although shallow alluvial deposits may contain groundwater that is locally important in some Southern Rocky Mountains locations (Apodaca and Bails 1997). In the northern and southeastern parts of the UCRB, limited extent Tertiary aquifers overlie Mesozoic aquifers that are present throughout most of the study area. Paleozoic aquifers are present throughout much of the basin and may outcrop in uplifted areas. Confining units separate the regional aquifers and interconnection between the aquifers in areas where confining units are missing results in a regional groundwater-flow system (Geldon 2003a,b; Freethey and Cordy 1991). In his investigation of the hydrologic and groundwater-flow systems in the UCRB, Geldon (2003b) estimates about 8.14 $km^3$ of recharge to all groundwater systems in the area, excluding the upper San Juan basin which was not part of the study. At least three groups of regional water-yielding geologic units have been identified in the UCRB (Robson and Banta 1995; Geldon 2003a,b; Freethey and Cordy 1991).

The UCRB is divided into eight hydrologic unit subregions (HUC4) that define a reach of the River and its tributaries in that reach or a closed basin (Figure 1; see http://water.usgs.gov/GIS/huc_name.html#Region14 for a description of subregion boundaries). Areal extent of the UCRB subregions range from about 20000 $km^2$ (7% of UCRB) in the Gunnison subregion to over 63000 $km^2$ (23% of UCRB) in the San Juan subregion (Table 1). Land surface elevation in the basin is highest in the southern Rocky Mountains in the eastern part of the UCRB, with the Colorado Headwaters and Gunnison subregions having almost 25% of their area above 3000 m (Figure S1 in the supporting information). The Upper Colorado – Dirty

Devil and San Juan subregions in the southern part of the UCRB contain generally lower land-surface elevation than other subregions in the basin (Figure S1).

**Figure 1.** Location of the upper Colorado River basin study area within the southwestern United States and subregions within the basin.

**Table 1**

**Upper Colorado River basin (UCRB) subregion characteristics.**

| UCRB subregion name | HUC4[a] | Area $km^2$ | Area % of UCRB | Minimum latitude | Maximum latitude |
|---|---|---|---|---|---|
| Colorado Headwaters | 1401 | 25201 | 9 | 38.943 | 40.486 |
| Great Divide – Upper Green | 1404 | 43253 | 15 | 40.527 | 43.452 |
| Gunnison | 1402 | 20539 | 7 | 37.834 | 39.258 |
| Lower Green | 1406 | 37296 | 13 | 38.102 | 40.835 |
| San Juan | 1408 | 63714 | 23 | 35.558 | 37.982 |
| Upper Colorado – Dirty Devil | 1407 | 34695 | 13 | 36.499 | 39.125 |
| Upper Colorado – Dolores | 1403 | 21367 | 8 | 37.405 | 39.459 |
| White – Yampa | 1405 | 33929 | 12 | 39.441 | 41.642 |

[a]Four-digit hydrologic unit code defining subregions of the upper Colorado River basin. See http://water.usgs.gov/GIS/huc_name.html#Region14 for descriptions.

## Methods and Data

A distributed-parameter groundwater recharge model was run with simulated climate data from 97 climate projections to simulate groundwater recharge in the UCRB. Results over future time periods (2016-2099) were compared with historical results (1950–2015) on both subregional and seasonal scales.

## The Soil-Water Balance Groundwater Recharge Model

Groundwater recharge was simulated in the UCRB with the soil-water balance (SWB) model. Groundwater recharge is estimated by the SWB model at daily time steps by calculating water-balance components for each model cell using a modified version of the Thornthwaite-Mather (Thornthwaite 1948; Thornthwaite and Mather 1957) soil-water-balance approach (see Text S1 in supporting information for model details and limitations). Water sources in SWB simulations include inflow from surrounding model cells, snowmelt, and rainfall. Water sinks in the model include outflow to other model cells, evapotranspiration (ET), and interception. Groundwater recharge is estimated on a daily basis as the difference between sources and sinks of water, and the change in soil moisture. The SWB groundwater recharge model has been used in several regional groundwater studies in the U.S. including the Northern Atlantic Coastal Plain Aquifer System (Masterson et al. 2013), the Lake Michigan Basin (Feinstein et al. 2010), basins in Wisconsin (Dripps and Bradbury 2009) and Minnesota (Smith and Westenbroek 2015), and the High Plains Aquifer (Stanton et al. 2011). Annual recharge simulated during the 1951-2015 historical time period by the SWB over the same UCRB area as the Geldon (2003b) study is 9.1 $km^3$ and 8.6 $km^3$ (mean and median annual values), representing 11% and 6% percent differences, respectively, with the Geldon (2003b) estimate. Computational details and limitations of the SWB model are discussed in the supporting information.

### Climate data

SWB recharge simulations require daily precipitation, maximum daily temperature, and minimum daily temperature climate data. Simulated climate datasets were available for 97 climate projections from the Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model archive (Table S1 in the supporting information) for the UCRB study area. CMIP5 is the fifth set of coordinated climate model experiments endorsed and promoted by the World Climate Research Programme's (WCRP's) Working Group on Coupled Modelling. Each of the 97 ensemble members were derived from a General Circulation Model (GCM) simulation using a given future-emission scenario (Representative Concentration Pathway or RCP) with a unique initial condition. Four RCPs were developed at the request of the Intergovernmental Panel on Climate Change (IPCC) and are for radiative forcing levels of 8.5, 6.0, 4.5, and 2.6 W/m$^2$ by the end of the century (Van Vuuren 2011). The four RCPs include one very high emission scenario (RCP8.5) that represents no climate policy, two medium stabilization scenarios (RCP4.5 and RCP6), and one very low forcing level (RCP2.6; Van Vuuren 2011). GCM simulations are typically run at spatial resolutions of 100-200 km on a cell side and at time scales of 100 years or longer, so there is a need to post-process GCM-derived climate output to finer spatial scales in order to conduct climate impact assessments. This post-processing step is commonly referred to as downscaling and there is a continuum of downscaling methods ranging from physically-based modeling to statistical approaches. The 97 climate projections used in this recharge study were developed using a statistical downscaling method referred to as BCSD (Bias-Correction and Spatial Disaggregation; Wood et al. 2004). BCSD was used to develop monthly precipitation and temperature fields at 1/8° × 1/8° (latitude × longitude) spatial resolution from native-scale GCM output. Monthly temperature and precipitation fields were subsequently disaggregated to daily values using a historical scaling and resampling technique (Wood et al. 2002). These daily temperature and precipitation data for the UCRB study area were obtained from the downscaled climate and hydrology projections archive (http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html; Bureau of Reclamation 2013). Owing to similarities in projected changes in UCRB recharge from separate and combined RCP simulations reported in Tillman et al. (2016), recharge simulation results from all 97 ensemble members are grouped together for this study and not separated by emission scenario.

## Projected Groundwater Recharge Results

Daily simulated groundwater recharge for the 1950–2099 time period in the UCRB was aggregated into months, seasons, and water years (October–September) for further analyses. Seasons defined for this study include winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). Seasonal and water-year recharge was averaged over 10-year periods, moving every year, to smooth out variability in recharge from individual years, whose effects are integrated over time in groundwater systems (Green et al. 2011). Moving the ten-year average through time by one year eliminates the subjectivity of picking decade start and stop years that may encompass anomalously wet or dry periods. Median values of moving ten-year averages for all RCP simulation results (97 climate projections) are discussed in this paper, with interquartile ranges ($25^{th}$ percentile to $75^{th}$ percentile) presented in figures to highlight result variability.

## Spatial Changes in Groundwater Recharge within the UCRB

Results from Tillman et al. (2016) indicated mostly nominal increases in UCRB-wide simulated groundwater recharge in future decades compared with historical recharge, but an analysis of subregional results indicates that this projected increase in recharge is not distributed uniformly across the eight UCRB subregions (Figure 2). The Great Divide – Upper Green and White – Yampa subregions are projected to experience increased recharge through all future decades. These two subregions account for a total of 35% of historical UCRB recharge. Simulated recharge in the Great Divide – Upper Green and White – Yampa subregions both increase about 6% by the 3rd quarter of this century (2050–2074) and both increase about 10% by century's end (2075–2099). Simulated recharge increases follow similar increases in projected precipitation in the two subregions (Figure 3), but do not appear to be controlled by steadily increasing projected temperatures as demonstrated in potential evapotranspiration (PET; Figure 4; see supporting information for relation between PET and temperature). One explanation for this decoupling of recharge from temperature, described in the Seasonal Changes section below, is a temporal separation of increased precipitation and PET in the subregions. Great Divide – Upper Green and White – Yampa are not among the most elevated UCRB subregions (Figure S1), but do encompass the highest minimum and maximum latitudes (Table 1).

On the other end of the projected recharge spectrum within the UCRB, the San Juan and Upper Colorado – Dolores subregions are projected to experience mostly decreased recharge in future decades relative to historical recharge (Figure 2). San Juan and Upper Colorado – Dolores are among the lower elevation (Figure S1 in the supporting information) and lower latitude (Table 1) subregions within the UCRB. Simulated recharge in the San Juan and Upper Colorado – Dolores subregions decreases 6% and 10%, respectively, by the 3rd quarter of this century and

5% and 9%, respectively, by century's end. Precipitation in both San Juan and Upper Colorado – Dolores subregions is projected to mostly increase in future decades (Figure 3), but in substantially smaller amounts than projected precipitation increases for Great Divide – Upper Green and White – Yampa subregions. Although the San Juan and Upper Colorado – Dolores subregions have the largest projected decrease in recharge among the UCRB subregions, together they only contribute about 12% to UCRB recharge over the historical period. Other UCRB subregions fall somewhere in between the mostly-increasing and mostly-decreasing projected recharge extremes, with sustained periods of both increasing and decreasing recharge relative to historical values. Among these subregions, there are more periods of increased recharge for subregions at higher latitudes (Colorado Headwaters, Lower Green) and more periods of decreased recharge for subregions at lower latitudes (Gunnison, Upper Colorado – Dirty Devil; Figure 2).

General increases in precipitation (Figure 3) and fairly consistent increases in temperature, as demonstrated by PET results (Figure 4), are projected for all subregions, yet some subregions are expected to experience increased recharge and others are not. This can partially be explained by the magnitude of projected precipitation increases in recharge-increasing versus recharge-decreasing subregions, but not entirely. For example, both Colorado Headwaters and White – Yampa subregions are projected to experience similar precipitation increases of 6.5% and 8.2%, respectively, during the 2050–2074 time period (Figure 3), but increased recharge is projected in the White – Yampa subregion while the Colorado Headwaters subregion is projected to experience mainly decreased recharge during this same period (Figure 2), based on a 10-year moving average estimate. The timing of projected changes in precipitation relative to changes in temperature within the subregions also appears to be important in projected trends in recharge.

**Figure 2**. Median of ten-year moving averages of simulated annual groundwater recharge in upper Colorado River basin (UCRB) subregions, and pie-chart showing subregion percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure 3**. Median of ten-year moving averages of projected precipitation in upper Colorado River basin (UCRB) subregions, and pie-chart showing subregion percentage of historical UCRB precipitation. Symbols are placed at the end of the ten-year averaging period.

**Figure 4**. Median of ten-year moving averages of simulated potential evapotranspiration (PET) in upper Colorado River basin (UCRB) subregions, and pie-chart showing subregion percentage of historical UCRB PET. Symbols are placed at the end of the ten-year averaging period.

## Seasonal Changes in Groundwater Recharge within the UCRB

In all eight UCRB subregions, most of the simulated historical annual groundwater recharge occurs during the spring months of March, April, and May (MAM), accounting for as little as 57% and 64% of annual recharge in the southern Upper Colorado – Dirty Devil and San Juan subregions, respectively, to as much as 84% and 87% of annual recharge in the Lower Green and White – Yampa subregions, respectively, of annual recharge (Figures 5–8, Figures S2–S5). Projected change in recharge in MAM could, therefore, be expected to play an important role in determining whether a subregion experiences an increase or decrease in recharge in future climates. The two UCRB subregions projected to experience increased recharge through all future decades, Great Divide – Upper Green and White – Yampa (Figure 2), also are expected to experience increased recharge in MAM for all future decades (Figures 5, 6).

Increased recharge in MAM is a result of greater increases in precipitation relative to increases in temperature, resulting in additional available water for groundwater recharge. The two subregions with the greatest declines in century's end MAM recharge, Upper Colorado – Dirty Devil and Upper Colorado – Dolores (Figures S3 and S4 in the supporting information), also are expected to experience mainly decreased annual recharge in future decades (Figure 2). However, these two subregions combined account for only 11% of historical UCRB recharge, and thus do not contribute substantially to projected changes in overall UCRB recharge. There are exceptions to the apparent relation between trends in MAM recharge and subregion annual recharge in Figure 2. For example, both the Gunnison and Colorado Headwaters subregions are projected to have greater than 10% increases in MAM recharge in the 3$^{rd}$ quarter of the century (Figures 7, 8), but these two basins are projected to have overall declining recharge during these years (Figure 2). A possible explanation for this apparent inconsistency may be in the trends in projected recharge for the summer months of June, July, and August (JJA).

Across all UCRB subregions, projected summer recharge declines substantially (Figures 5-8 and Figures S2-S5), indicating temperature increases during these months are large relative to changes in precipitation, reducing the amount of available water for summer recharge. For six of the eight UCRB subregions including Gunnison and Colorado Headwaters (Figures 7, 8), recharge in summer is second only to spring recharge, with summer months accounting for 19% and 17% of the annual historical recharge for Gunnison and Colorado Headwaters subregions, respectively. Projected declines of almost 70% in summer recharge in the Gunnison and Colorado Headwaters subregions by the 3$^{rd}$ quarter of this century appear to negate the projected 10% increases in spring recharge (Figures 7, 8). The Great Divide – Upper Green subregion has the highest percentage of historical summer recharge at 24% and also about a 70% decrease in summer recharge by 3rd quarter (Figure 5), but increases of 20% in spring recharge and over 200% in the winter months of December, January, and February (DJF) during this time result in an overall slight gain in recharge for the subregion (Figure 2). Although winter recharge makes up less than 4% of the annual total for the five subregions contributing more than 10% to UCRB historical recharge (Figure 2), substantial projected increases in recharge during these months (over 200% for these subregions by century's end) contribute as much to UCRB basin-wide recharge gain as increases during spring months.

**Figure 5**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Great Divide – Upper Green subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure 6**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the White – Yampa subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure 7**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Gunnison subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure 8**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Colorado Headwaters subregion of the upper Colorado River basin (UCRB), and

pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

## Conclusions

Stable to slight increases in UCRB-wide groundwater recharge are projected through 2099 (Tillman et al. 2016), but climate impacts on simulated recharge vary within the basin. Subregions at northernmost latitudes within the UCRB are projected to experience mainly increased recharge while southernmost basins are expected to see mainly decreased recharge. The Great Divide – Upper Green and White – Yampa subregions contribute almost 80% of the total projected increase in UCRB recharge by century's end (2074–2099). Seasonal changes in recharge also are projected within the UCRB, with substantial increases in winter months and substantial decreases in summer months for all subregions by century's end, and increases in spring months for most subregions. Over 96% of the projected increase in UCRB recharge by century's end is expected from increases in winter and spring months. Depending upon other changes to subregional groundwater budgets, changes in future recharge could result in challenges for local groundwater supply and diminished streamflow in areas with declining recharge, and potential concerns for seasonal flooding in areas where increased recharge results in higher water tables.

As with any investigation of simulated impacts on hydrologic systems from projected climate data, the substantial amount of variability and uncertainty inherent within each step of the process should be considered when evaluating and interpreting these results. Uncertainty in recharge simulation results comprises variability within the original CMIP5 GCM results, BCSD techniques used to downscale CMIP5 results to a useable spatial scale for hydrologic investigations, uncertainty within SWB recharge model input data other than climate data, simplifications and processes related to how the SWB model estimates groundwater recharge, and potential spatial and temporal scale issues.  Future improvements in any of these steps will help reduce uncertainties in projected impacts of climate change on groundwater recharge.

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## Supporting Information

Additional Supporting Information may be found in the online version of this article:

**Text S1.** Computational details and limitations of the Soil-Water Balance (SWB) groundwater recharge model.

**Figure S1.** Distribution of the altitude of 1 arc-second (~30m) digital elevation model (DEM) cells within UCRB subregions.

**Figure S2.** Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the San Juan subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure S3.** Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Upper Colorado – Dirty Devil subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure S4.** Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Upper Colorado – Dolores subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Figure S5.** Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Lower Green subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

**Table S1.** CMIP5 multi-model ensembles and institutions providing model output used in the upper Colorado River basin groundwater recharge investigation.

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**Figure 1.** Location of the upper Colorado River basin study area within the southwestern United States and subregions within the basin.

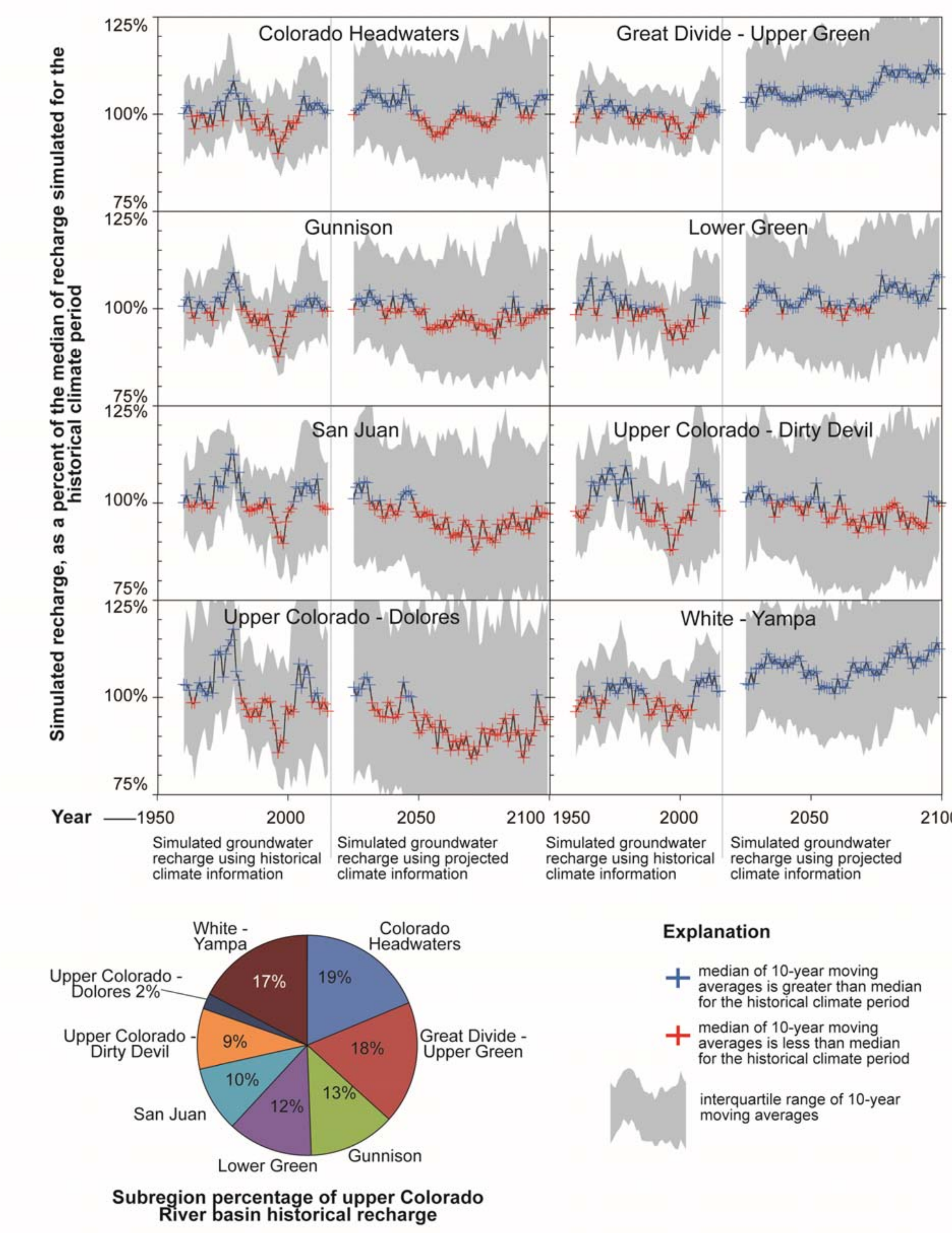


**Figure 2**. Median of ten-year moving averages of simulated annual groundwater recharge in upper Colorado River basin (UCRB) subregions, and pie-chart showing subregion percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

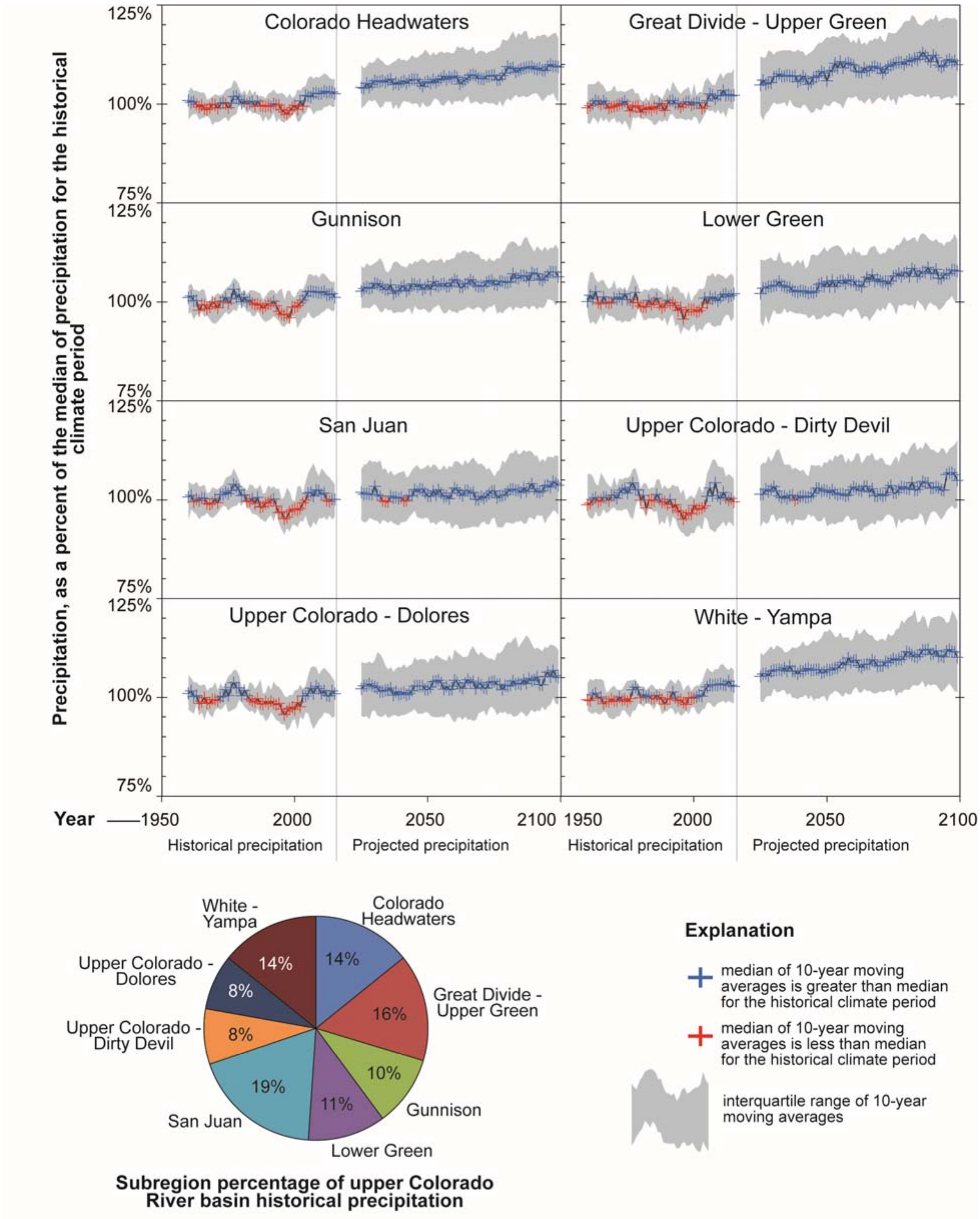


**Figure 3**. Median of ten-year moving averages of projected precipitation in upper Colorado River basin (UCRB) subregions, and pie-chart showing subregion percentage of historical UCRB precipitation. Symbols are placed at the end of the ten-year averaging period.

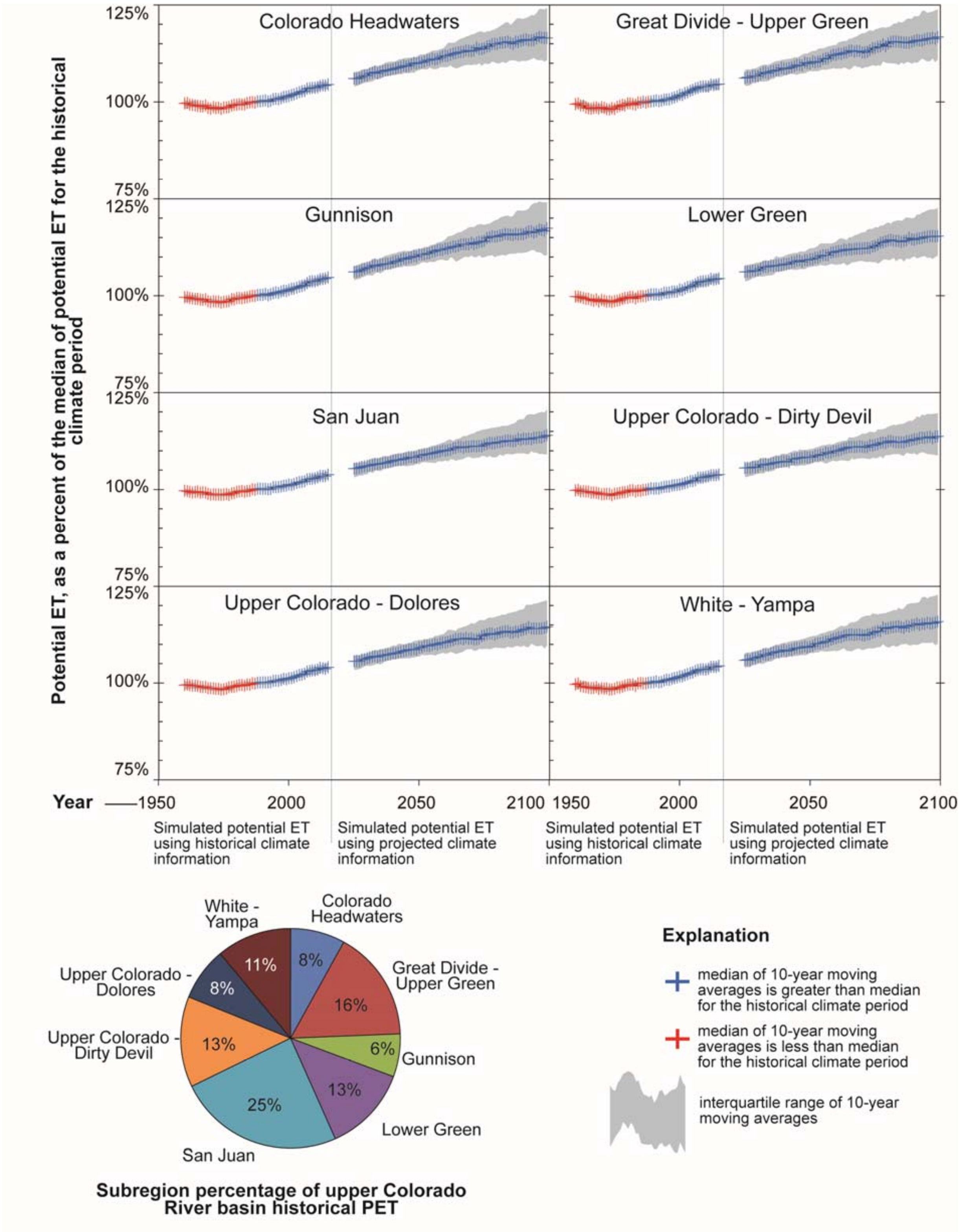


**Figure 4**. Median of ten-year moving averages of simulated potential evapotranspiration (PET) in upper Colorado River basin (UCRB) subregions, and pie-chart showing subregion percentage of historical UCRB PET. Symbols are placed at the end of the ten-year averaging period.

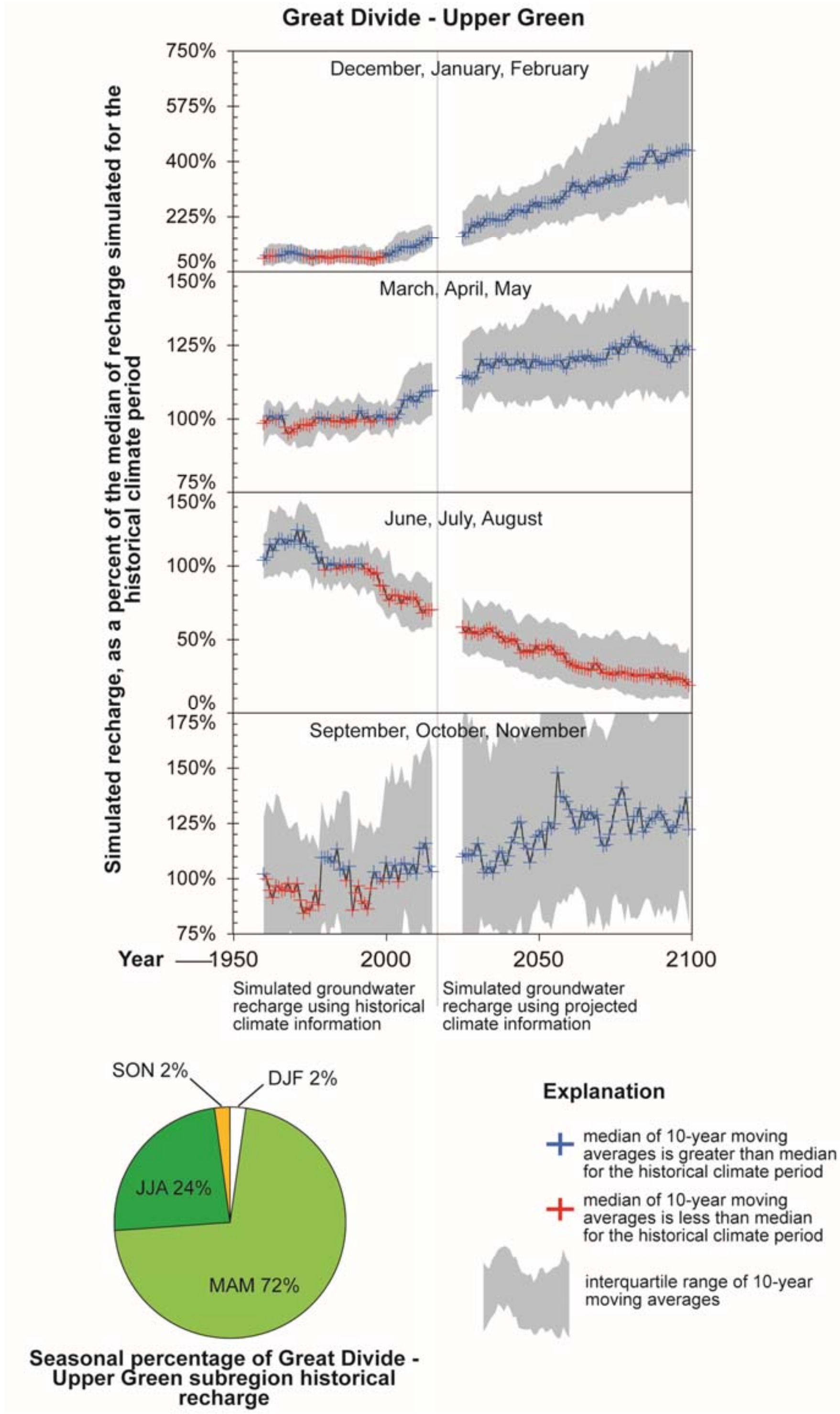


**Figure 5**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Great Divide – Upper Green subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

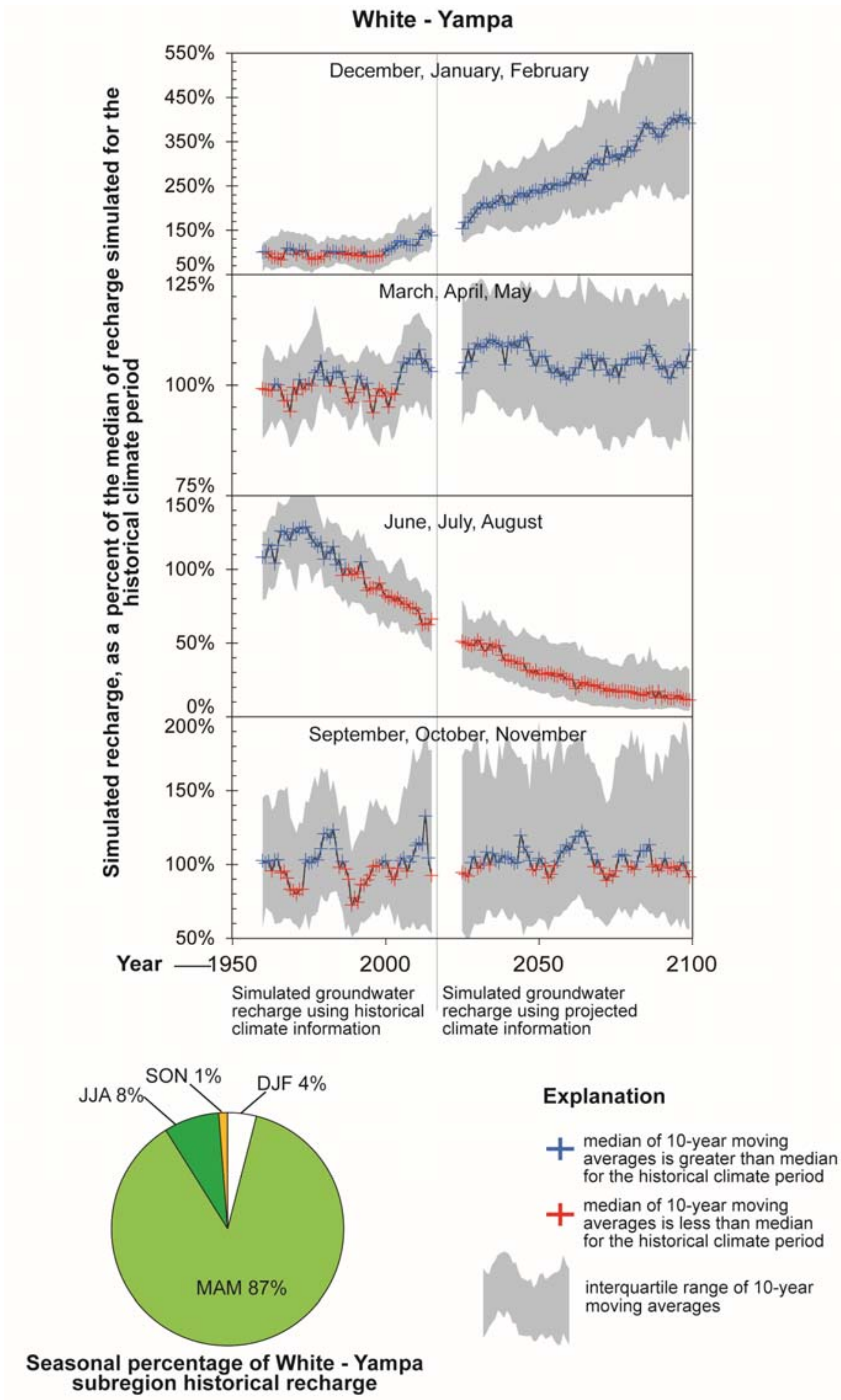


**Figure 6**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the White – Yampa subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

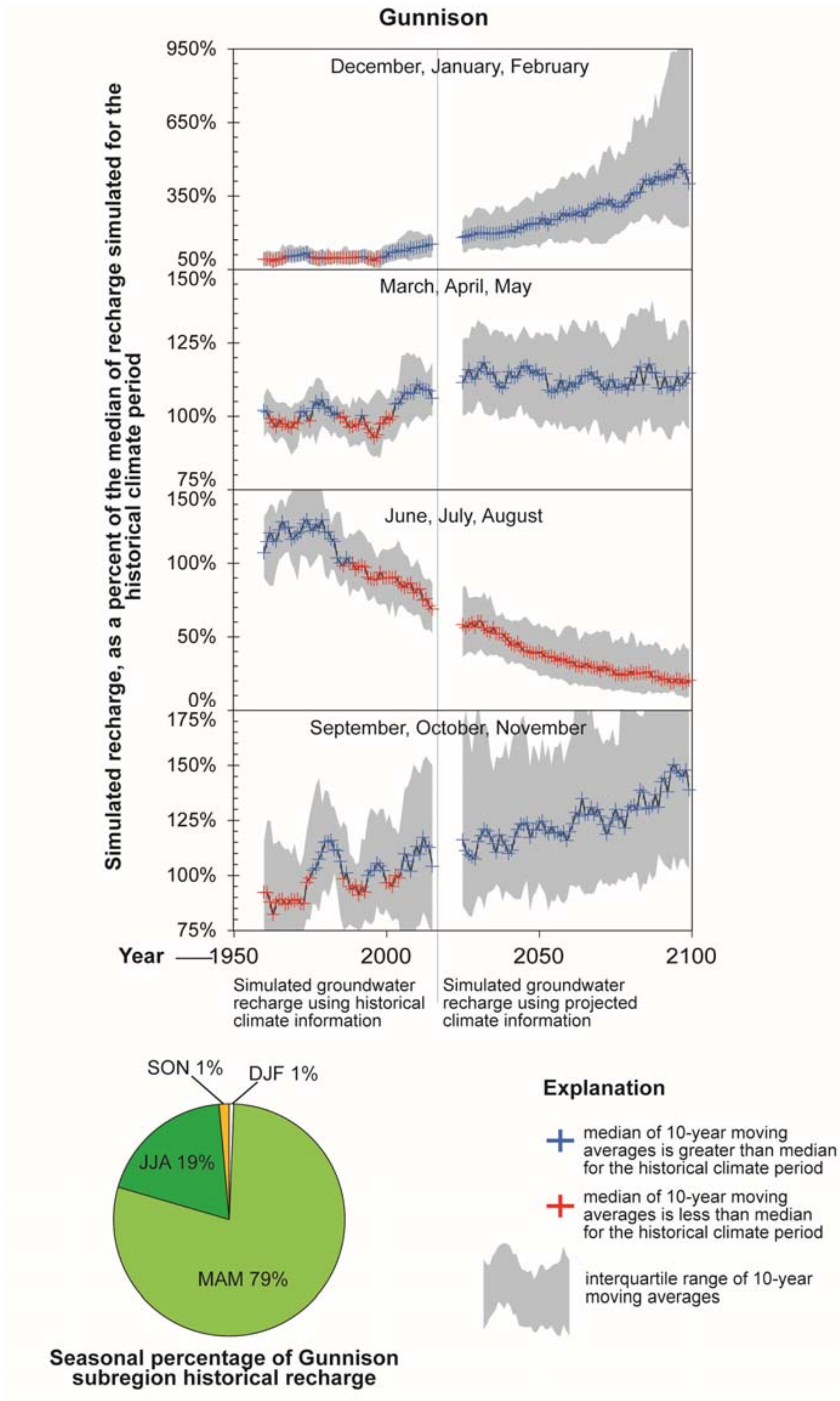


**Figure 7**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Gunnison subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.

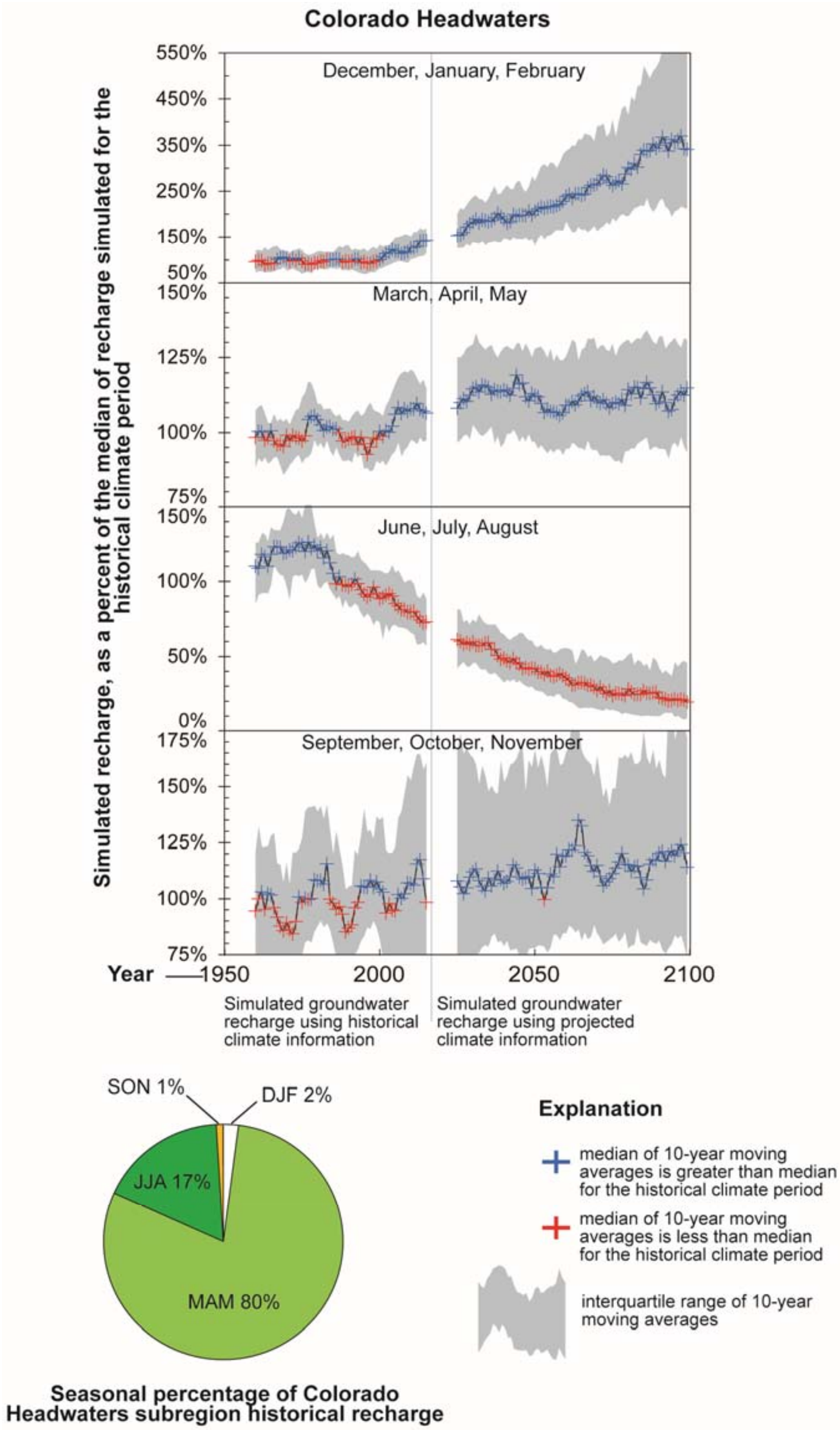


**Figure 8**. Median of ten-year moving averages of simulated annual groundwater recharge by seasons in the Colorado Headwaters subregion of the upper Colorado River basin (UCRB), and pie-chart showing seasonal percentage of historical UCRB recharge. Symbols are placed at the end of the ten-year averaging period.