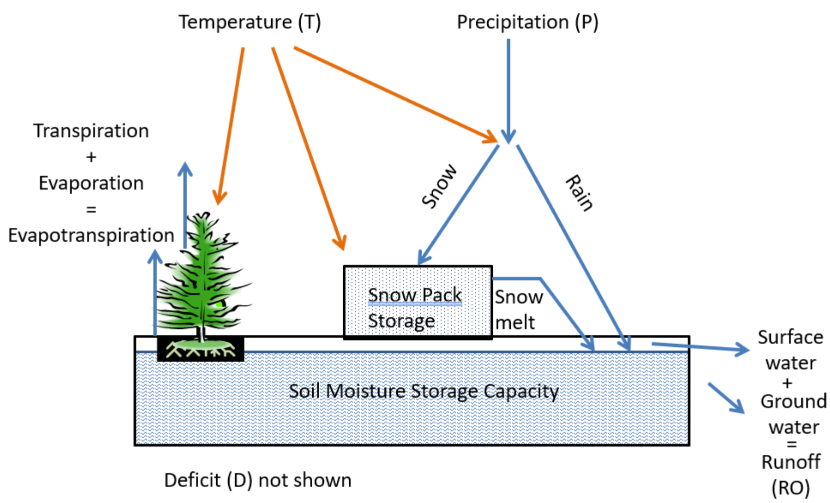
Historical and Projected Water Balance Report for DINO

Janelle Christensen, David Thoma, Mike Tercek, John Gross

07 April, 2021

Location: (40.506, -108.938)

Water balance is the mathematical accounting of water input and movement through the environment. It accounts for water storage in different phases (ice, liquid) and loss to the atmosphere (gas) via evapotranspiration. Water balance integrates the interactions of temperature and precipitation to estimate water availability, movement to streams and ground water and use by plants. Water balance accounts for heat load on different aspects and slopes in complex terrain, as well as water holding capacity of different soil types. Water balance represents the modification of regional weather and climate due to site characteristics (slope, aspect, soil properties) to represent the biophysical conditions at local scales that plants and animals "experience". For these reasons, water balance is usually more strongly correlated with natural resource response (plant growth, stream flow, fire danger) than temperature or precipitation. More information about water balance and links to studies that have used water balance to improve understanding of natural resources response to climate change can be found here (https://www.nps.gov/subjects/climatechange/waterbalance.htm).



Modified from McCabe and Markstrom 2007

This report is created from temperature and precipitation data that is input to a water balance model. The historical temperature and precipitation data are from gridMET (http://www.climatologylab.org/gridmet.html). The future climate projections, MRI-CGCM3 RCP 4.5 and NorESM1-M RCP 8.5, used in this report are from the CMIP5 experiments (https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip5) . The water balance model is maintained by the National Park Service (Mike Tercek, David Thoma and John Gross). Collectively this report summarizes historical and projected biophysical environmental conditions from 1980-2100 at the single grid cell level (gridMET = 4km; projections = 1km). A link to the NPS water balance gridded products an be found here (http://www.yellowstone.solutions/thredds/catalog.html).

Future Model Selection

The models used in this analysis were chosen based on two climate futures that best bracket the range of plausible future climate conditions. There are two methods by which models can be selected: the traditional temperature v. precipitation scatterplot, or a scatterplot using actual evapotranspiration and deficit.

Acutal Evapotranspiration v. Deficit

The preferred method is using the data from Mike Tercek's thredds server (http://www.yellowstone.solutions/thredds/catalog.html). Data can be downloaded to select models based on a range of actual evapotranspiration and deficit conditions. The models selected are typically chosen from the upper left hand corner and the upper right hand corner of the scatterplot. The graph below displays a scatterplot of these models. In order for the graph to display, the `aet_d.Rmd` code must have been run and the models should have been selected for this report *prior* to running this final report.

Temperature v. Precipitation

Alternatively, models can be chosen based on the scatter in projected temperature and precipitation in the future. The latitude and longitude of the site is used to buid a scatterplot visualization of future projections from the MACA website (https://climate.northwestknowledge.net/MACA/vis_scatterplot.php). Models from the scatterplot are selected to represent a "drier and hotter" climate future (the bottom right of the scatterplot) and a "wetter and hotter" climate future (the upper left of the scatterplot). Users are cautioned that the two models presented in this report are intended to represent a range of conditions, but other projections are available and may need to be considered for a full accounting of possible futures. The spatial resolution of climate data used in the water balance model may not be representative of site-specific conditions, especially in areas of high relief or high topographic complexity, and high variation in soil water holding capacity.

To create the temperature v. precipitation scatterplot, go to the MACA website (https://climate.northwestknowledge.net/MACA/vis_scatterplot.php), select "Mid 21st Century (2040-2069)" in the "Choose a Future Time Period:" box. The x-axis variable is "mean-temperature" and the season is "Jan-Dec." The y-axis is "Precipitation - Absolute Change" and the season is "Jan-Dec." Finally, enter the latitude 40.5059664 into BOTH latitude boxes and the longitude -108.9377028 into BOTH longitude boxes.

Change in annual values through time

The variables of runoff, rain, potential evapotranspiration (PET), actual evapotranspiration (AET), and deficit are summed to show annual values through time. Accumulated snow water equivalent (SWE) is the max value for the year regardless of the month it occurs in. Soil water shows the mean annual water content in the soil profile.

The reason for the different summary statistics is because scientists use these variables in different ways. Water variables that don't have an upper limit like rain, runoff, evapotranspiration and deficit can accumulate indefinitely within a calendar year, whereas soil moisture is limited by the soil water holding capacity, so it is averaged on an annual basis. Temperature variables are averaged by convention and growing degree days are summed to account for the seasonal accumulation of heat that controls biological metabolism and thus growth rates and phenology when water is available. Snow water equivalent is reported as a maximum value because snow accumulates during winter and the maximum water content of the snowpack is useful for predicting stream flow volume and reservoir storage needs.

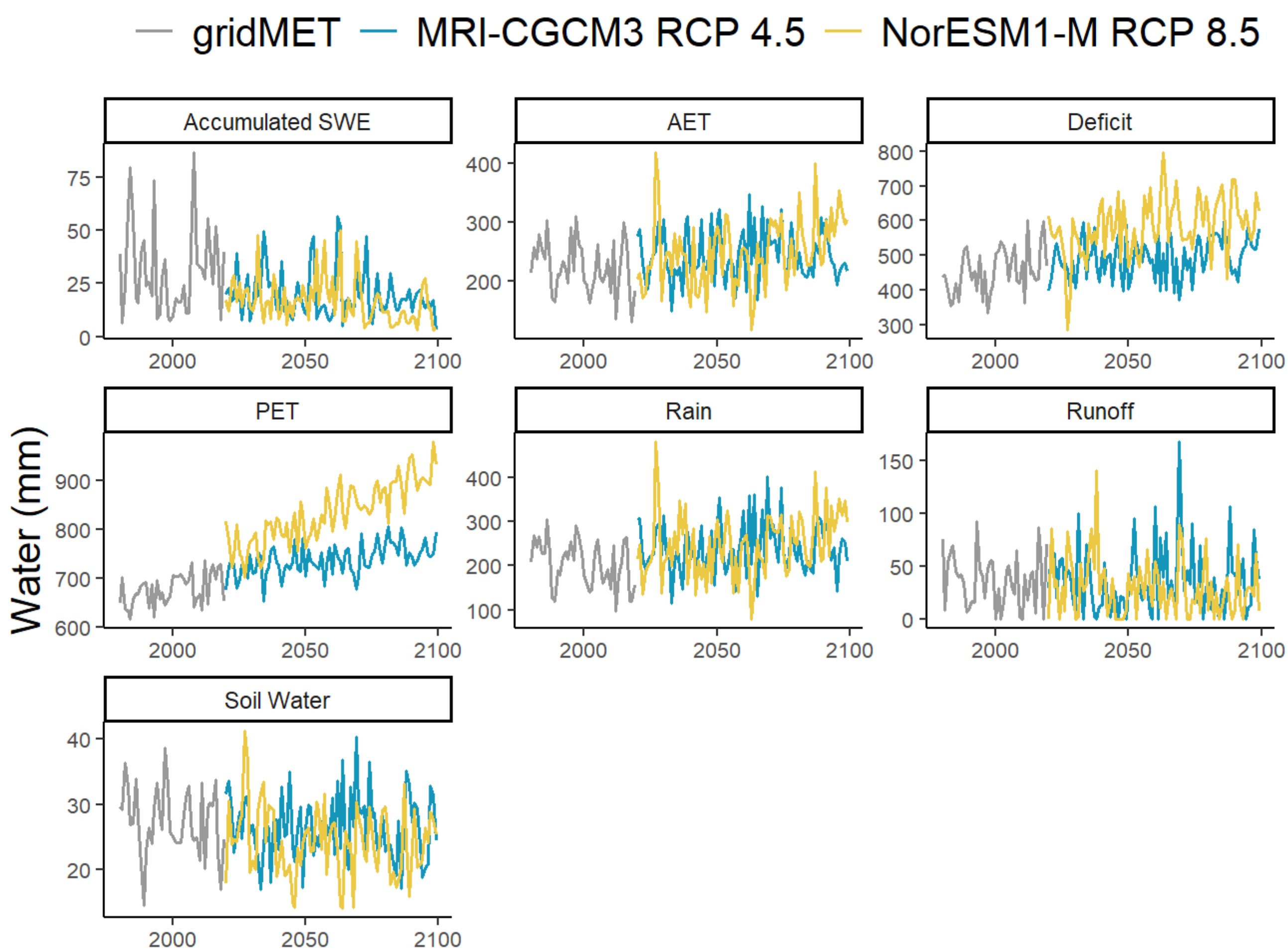


Figure 1. Annual averages over time. The gray line represents historical data modeled from gridMET climate data, the turquoise line represents MRI-CGCM3 rcp45 and the yellow line represents NorESM1-M rcp85

Deficit v. Actual Evapotranspiration

Actual evapotranspiration (AET) is an estimate of soil water used by plants and deficit (D) is an estimate of unmet water need. That is, it represents the amount of water vegetation would use if the water was available and hence is an estimate of vegetation drought stress. Collectively, AET and D have been shown to be good predictors of vegetation type and are useful variables in understanding climate stress on vegetation and how vegetation may transition in the future (Stephenson, 1998). If the clustering of AET and D change in climate space, vegetation assemblages will respond and changes in assemblages will eventually reflect the new climate space. The figure below (from Tercek et al., 2021) shows how AET v. D, calculated using the water balance model used for this report, differs across bioregions in the U.S.

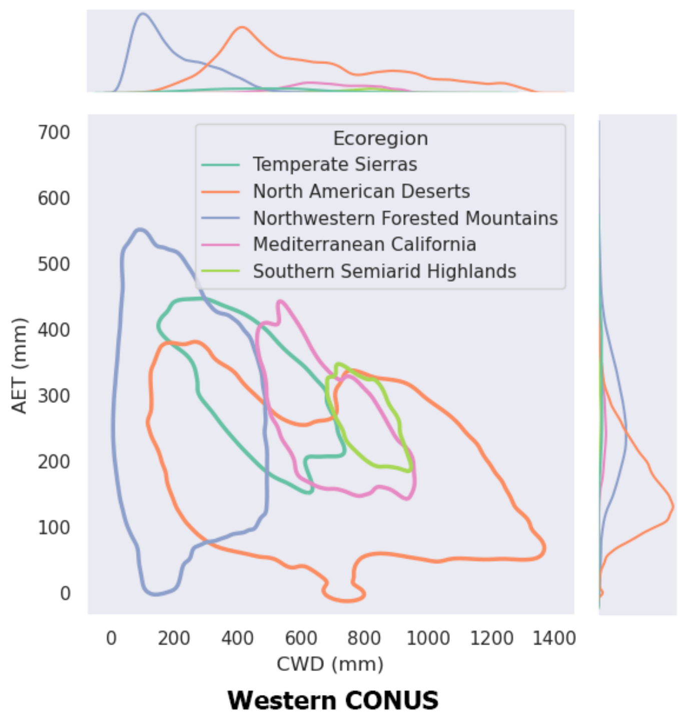


Figure 2. Ecoregions in the Western United states based on AET and Deficit (CWD). (Tercek et al., 2021)

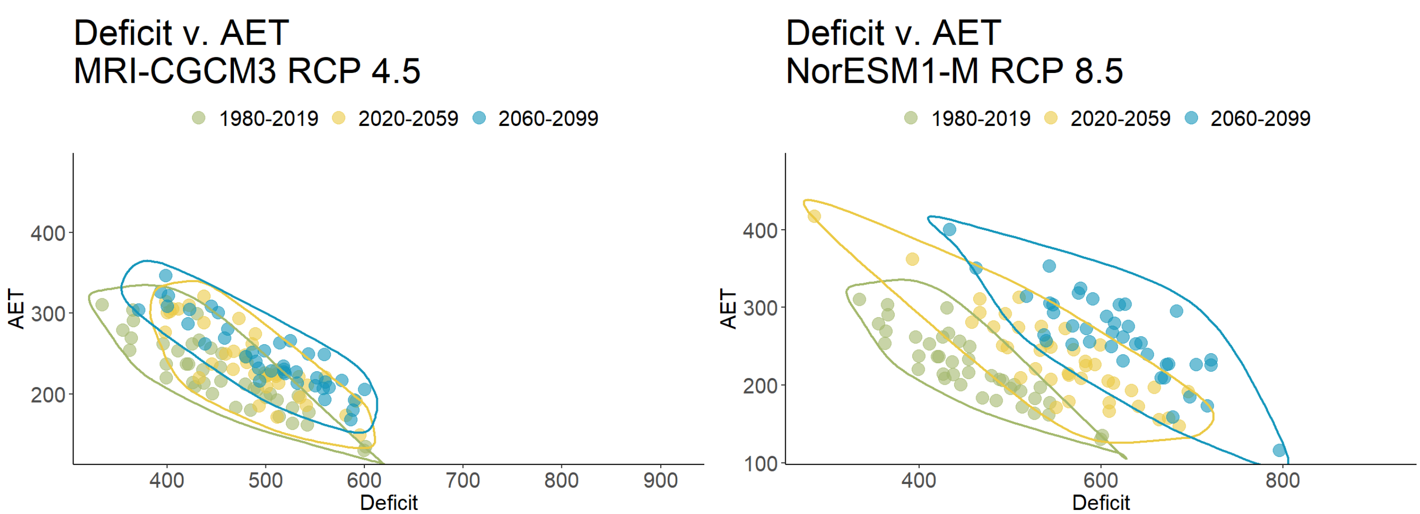
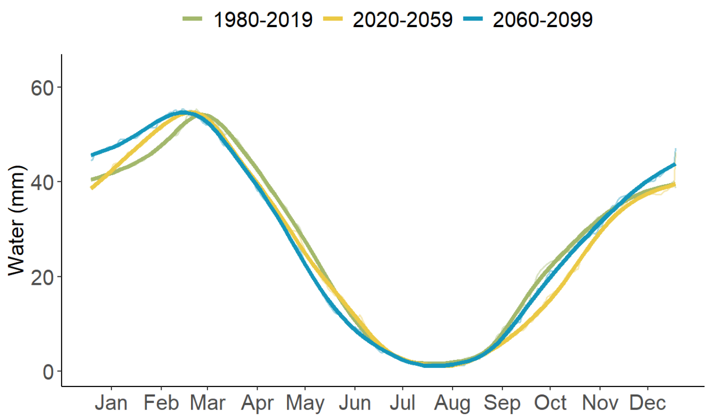


Figure 3. Modeled Deficit vs. AET. The points are annual sums of daily observations in each year. The green points represent 1980-2019; the yellow points 2020-2059; and the turquoise points 2060-2099. The contours around each set of points delineate shifts in climate space over time.

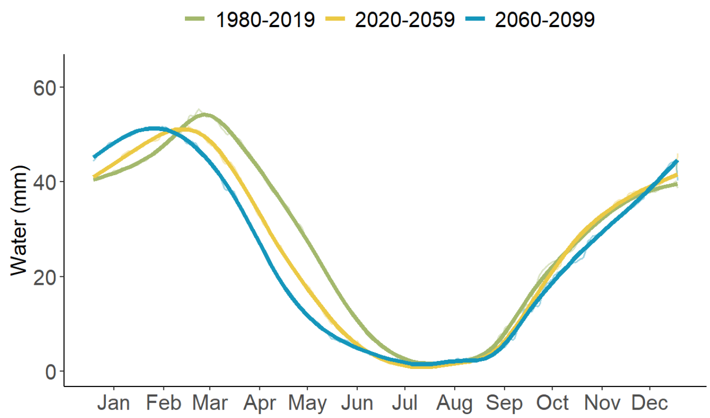
Water Balance Projections

Soil Water

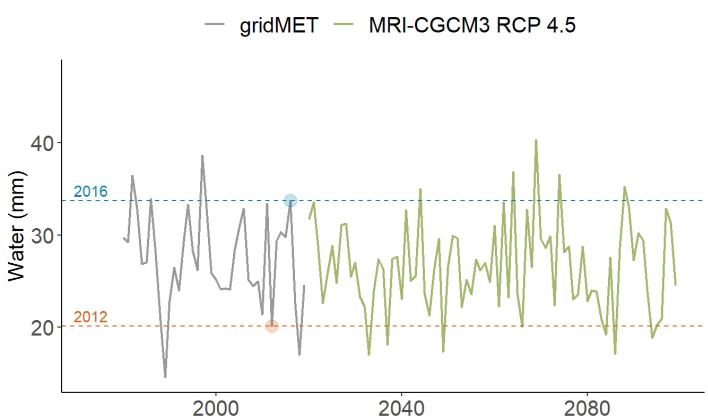
Soil Water Seasonality
MRI-CGCM3 RCP 4.5



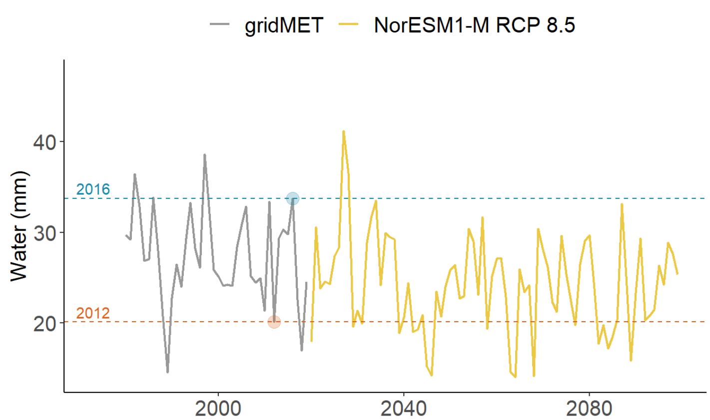
Soil Water Seasonality
NorESM1-M RCP 8.5



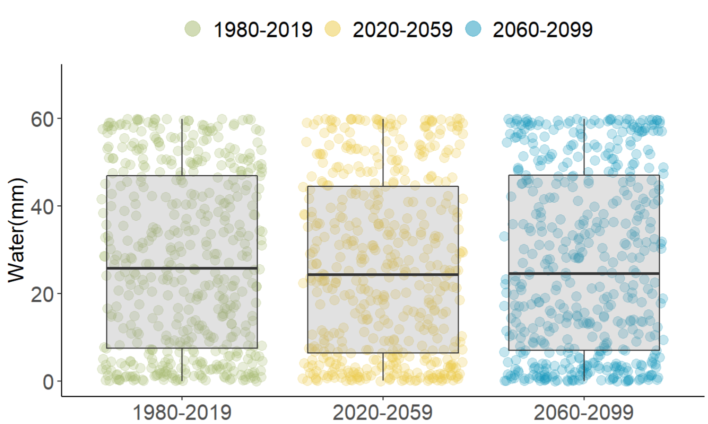
AnnualSoil Water
MRI-CGCM3 RCP 4.5



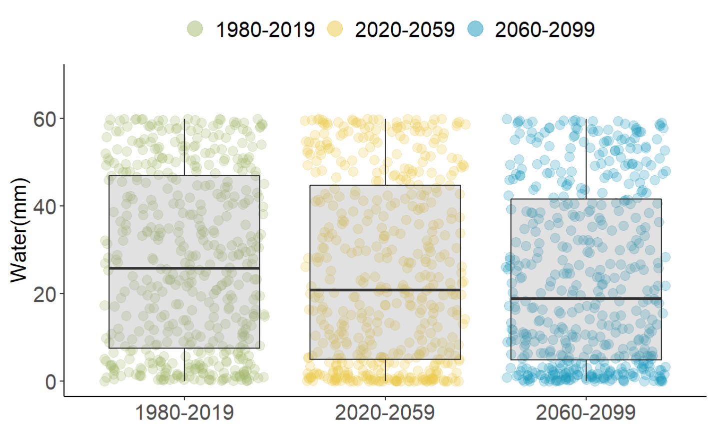
Annual Soil Water
NorESM1-M RCP 8.5



Annual Soil Water
MRI-CGCM3 RCP 4.5

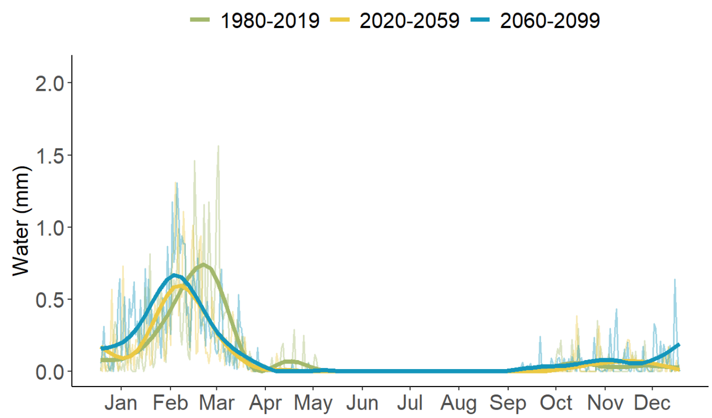


Annual Soil Water
NorESM1-M RCP 8.5

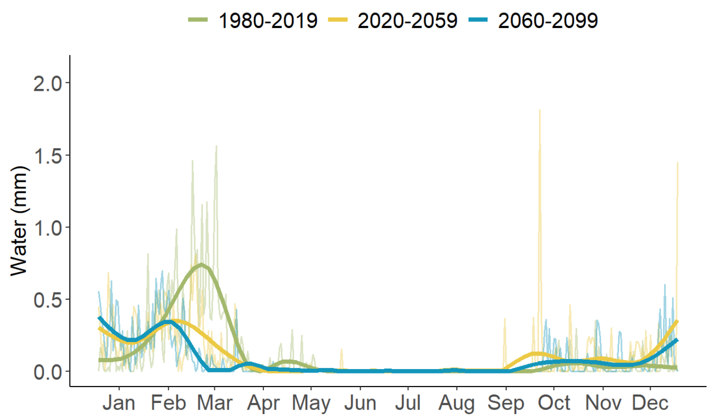


Runoff

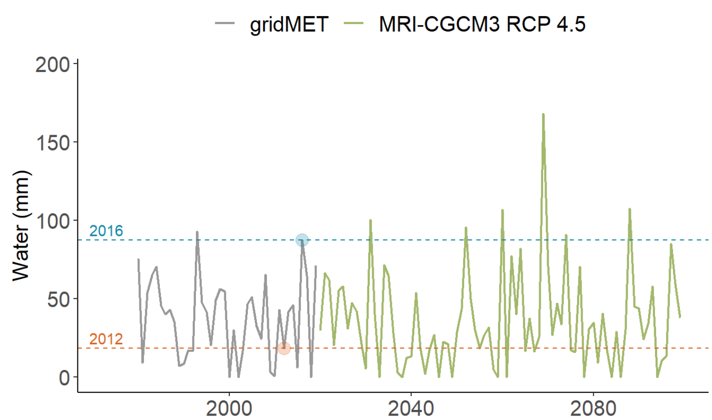
Runoff Seasonality
MRI-CGCM3 RCP 4.5



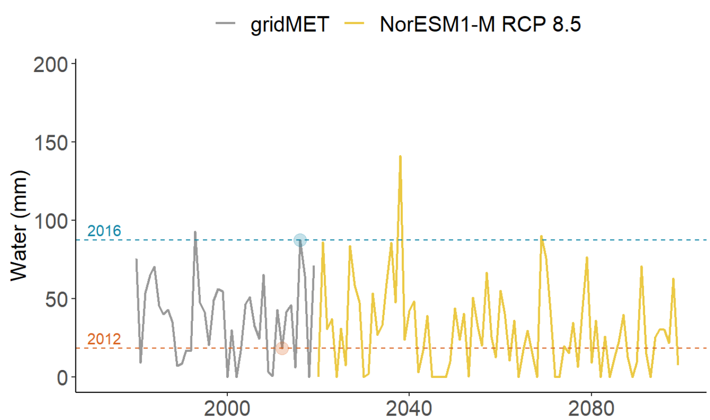
Runoff Seasonality
NorESM1-M RCP 8.5



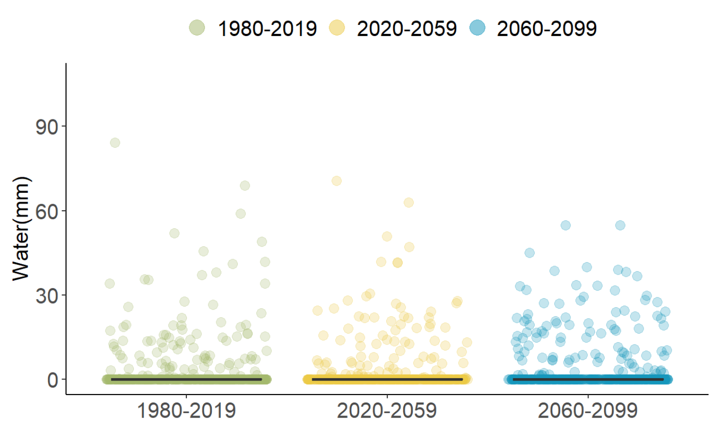
AnnualRunoff
MRI-CGCM3 RCP 4.5



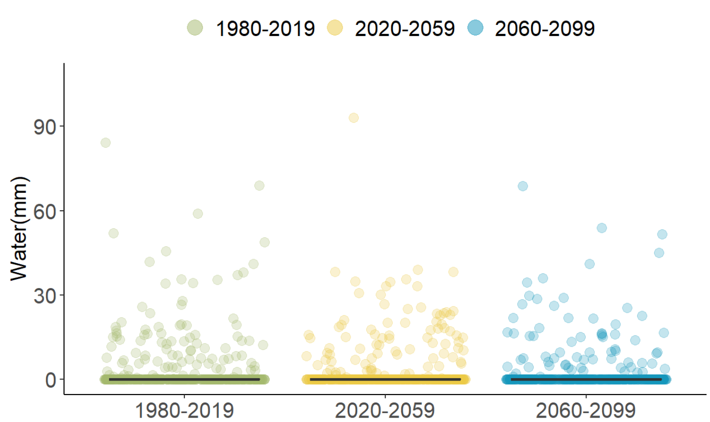
Annual Runoff
NorESM1-M RCP 8.5



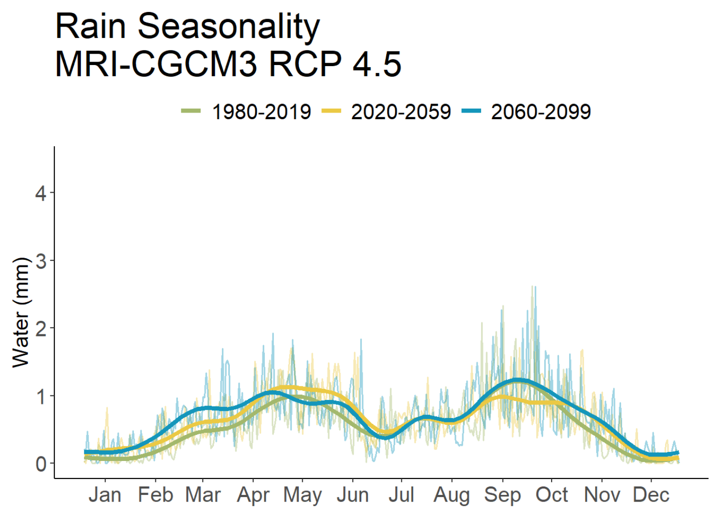
Annual Runoff
MRI-CGCM3 RCP 4.5



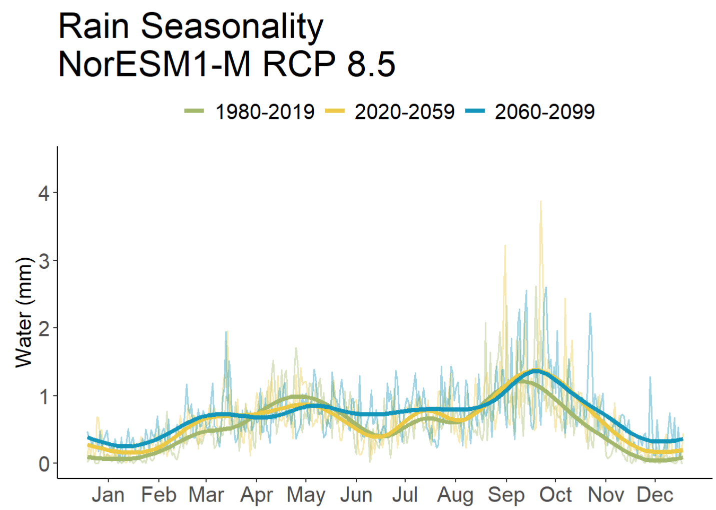
Annual Runoff
NorESM1-M RCP 8.5



Rain



Rain Seasonality
MRI-CGCM3 RCP 4.5
1980-2019
2020-2059
2060-2099
Water (mm)
0
1
2
3
4
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec



Rain Seasonality
NorESM1-M RCP 8.5
1980-2019
2020-2059
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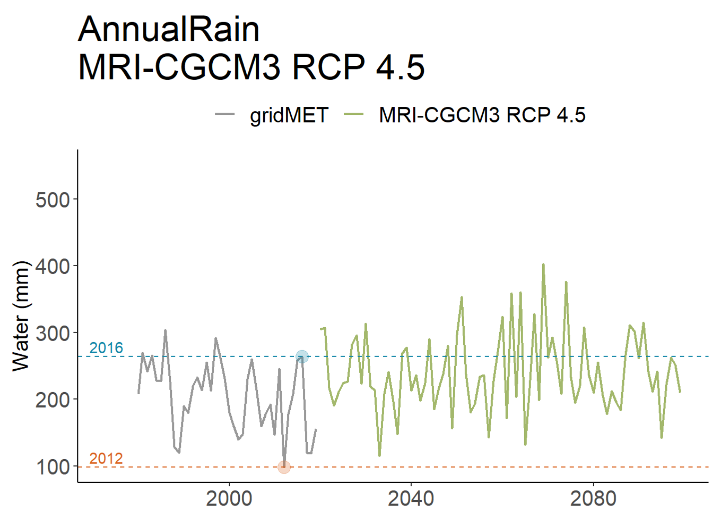
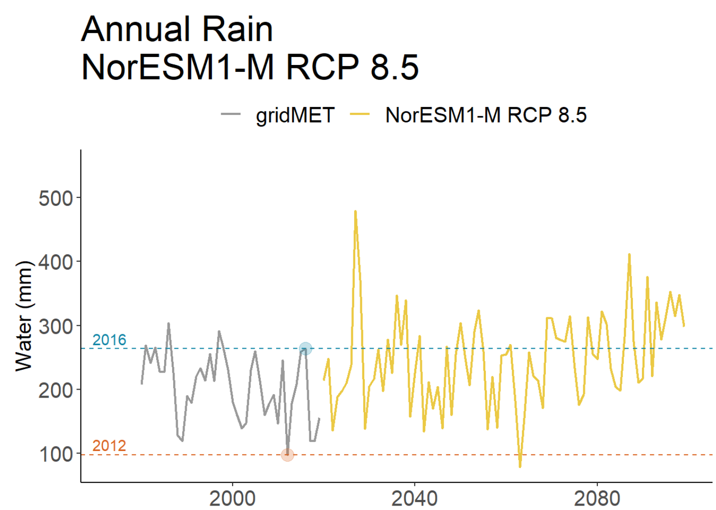


AnnualRain
MRI-CGCM3 RCP 4.5
gridMET
MRI-CGCM3 RCP 4.5
Water (mm)
100
200
300
400
500
2016
2012
2000
2040
2080



Annual Rain
NorESM1-M RCP 8.5
gridMET
NorESM1-M RCP 8.5
Water (mm)
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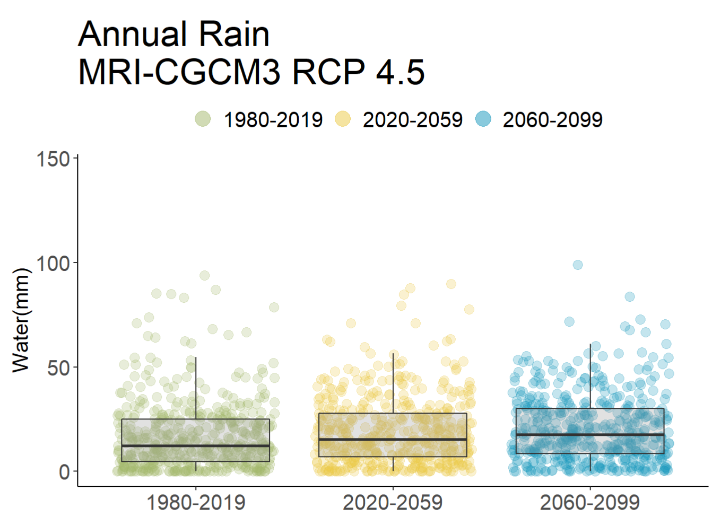
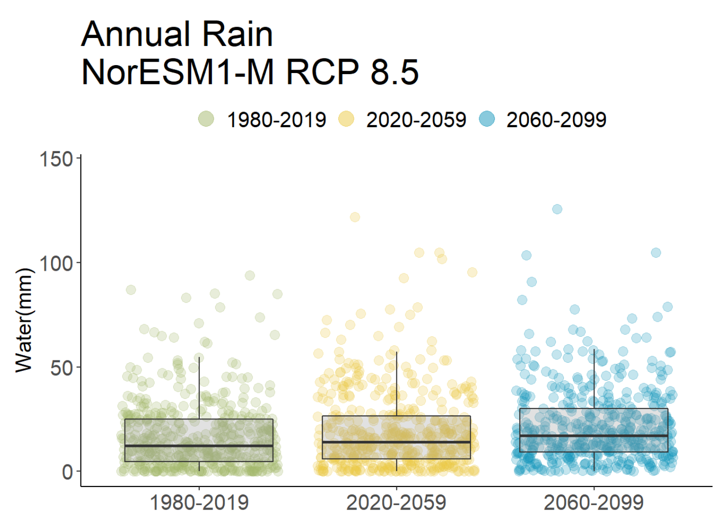


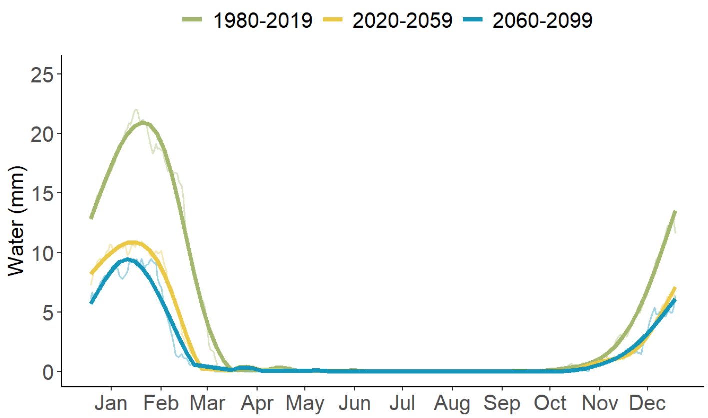
Annual Rain
MRI-CGCM3 RCP 4.5
1980-2019
2020-2059
2060-2099
Water(mm)
0
50
100
150
1980-2019
2020-2059
2060-2099



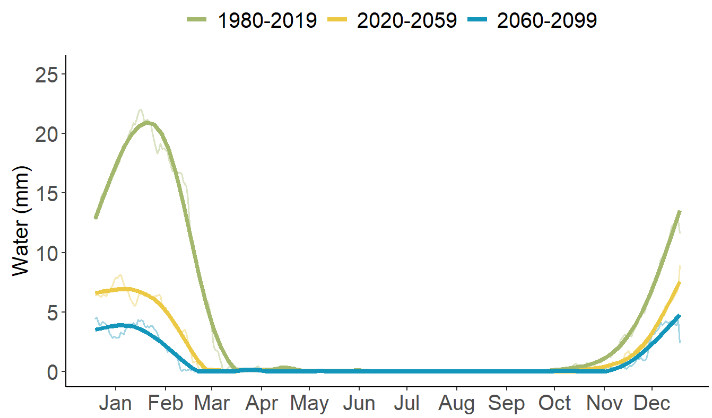
Annual Rain
NorESM1-M RCP 8.5
1980-2019
2020-2059
2060-2099
Water(mm)
0
50
100
150
1980-2019
2020-2059
2060-2099

Accumulated Snow Water Equivalent (SWE)

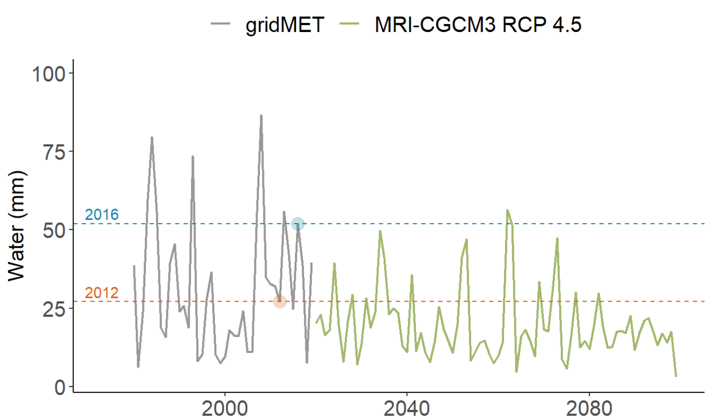
SWE Seasonality
MRI-CGCM3 RCP 4.5



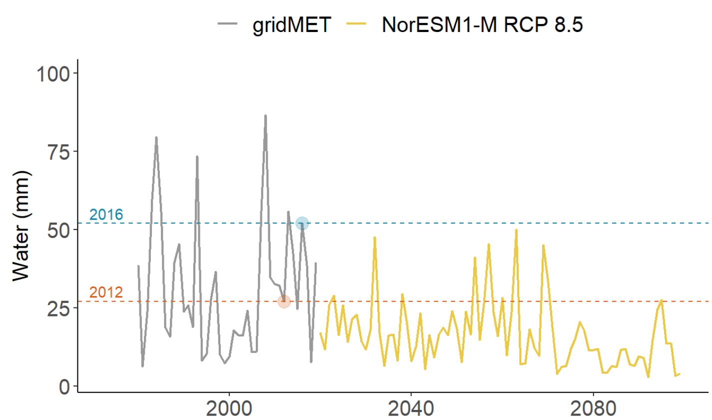
SWE Seasonality
NorESM1-M RCP 8.5



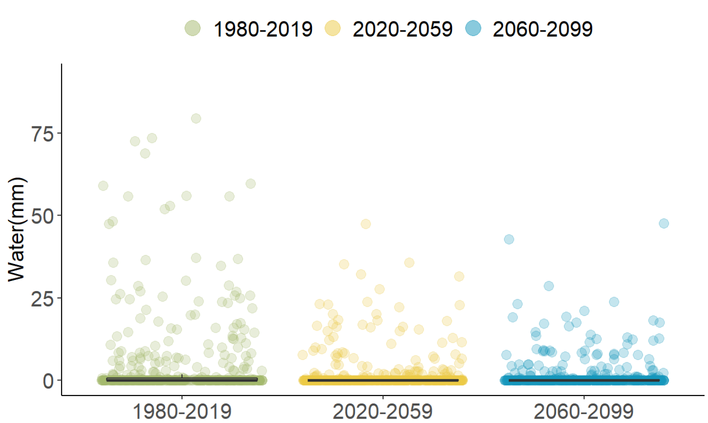
AnnualAccumulated SWE
MRI-CGCM3 RCP 4.5



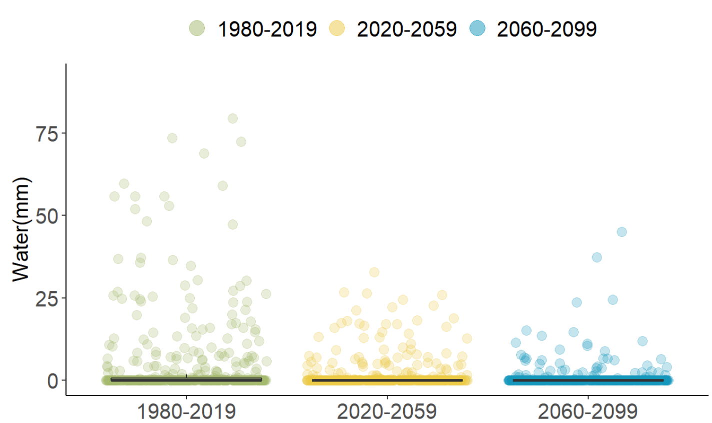
Annual Accumulated SWE
NorESM1-M RCP 8.5



Annual Accumulated SWE
MRI-CGCM3 RCP 4.5

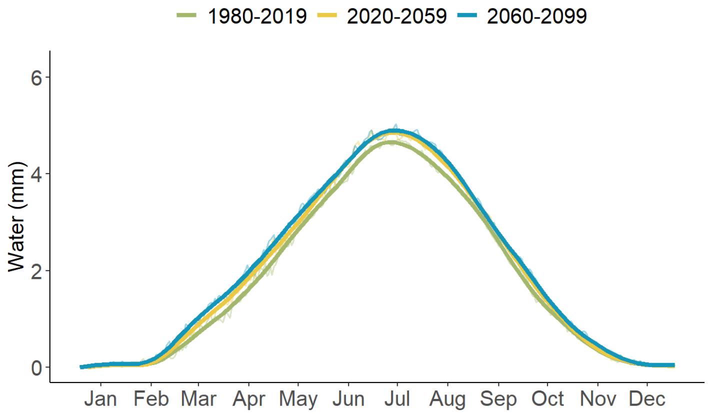


Annual Accumulated SWE
NorESM1-M RCP 8.5

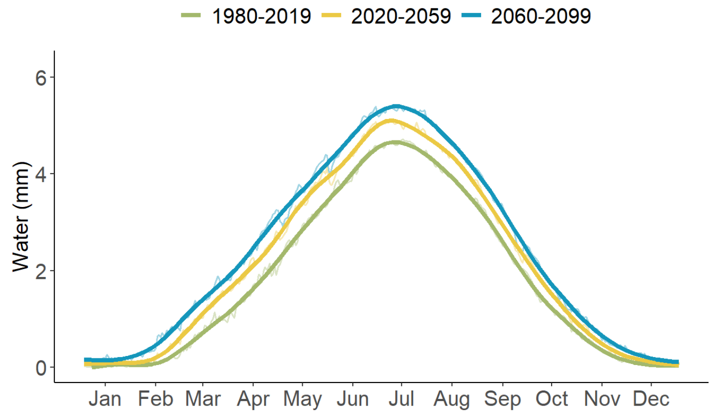


Potential Evapotranspiration (PET)

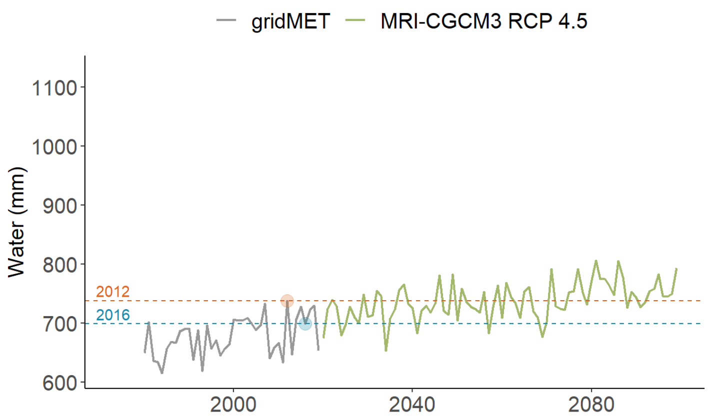
PET Seasonality
MRI-CGCM3 RCP 4.5



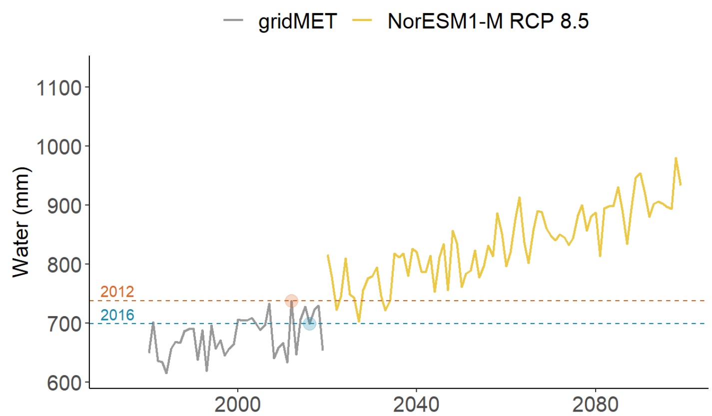
Potential Evapotranspiration Seasonality
NorESM1-M RCP 8.5



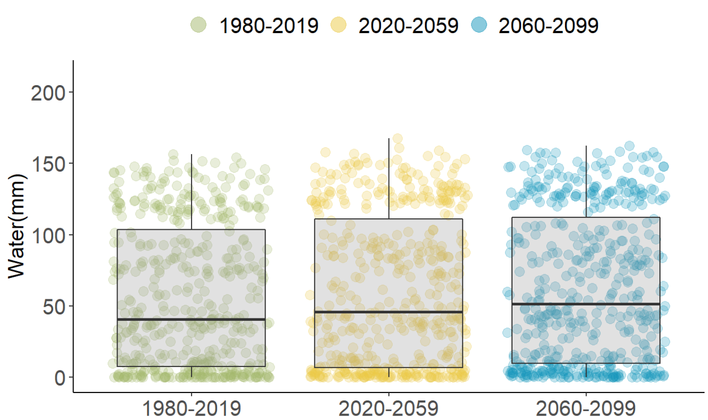
AnnualPET
MRI-CGCM3 RCP 4.5



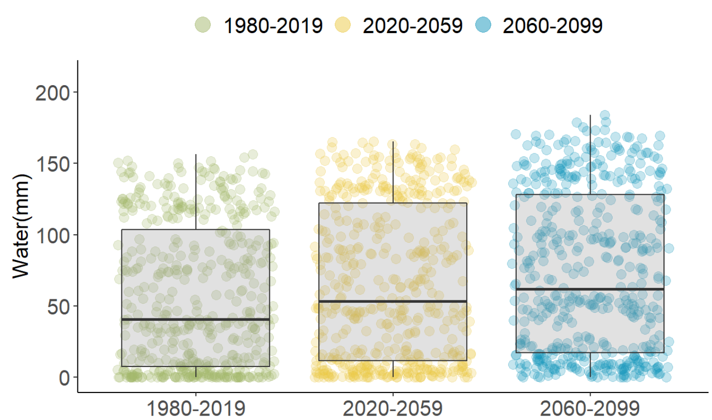
Annual PET
NorESM1-M RCP 8.5



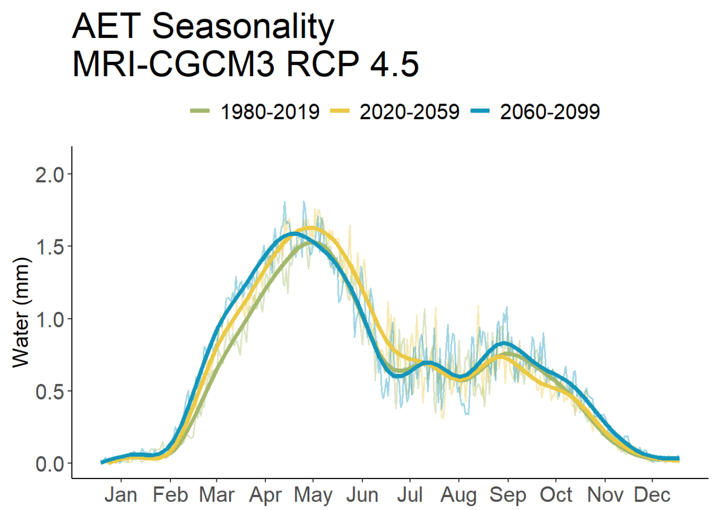
Annual PET
MRI-CGCM3 RCP 4.5

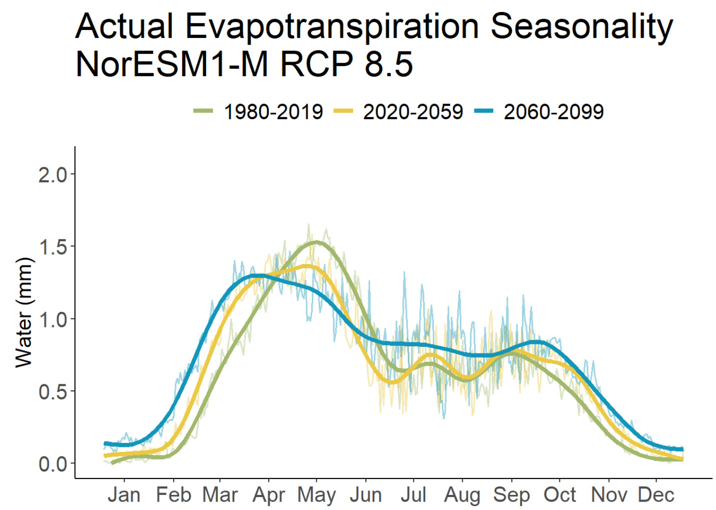


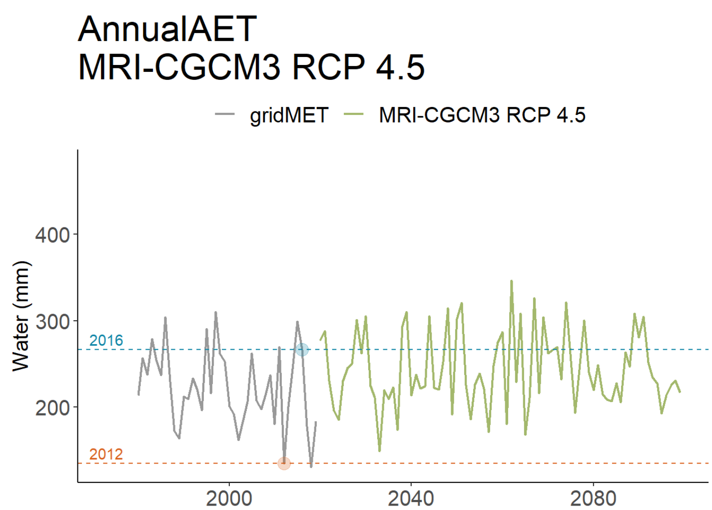
Annual PET
NorESM1-M RCP 8.5

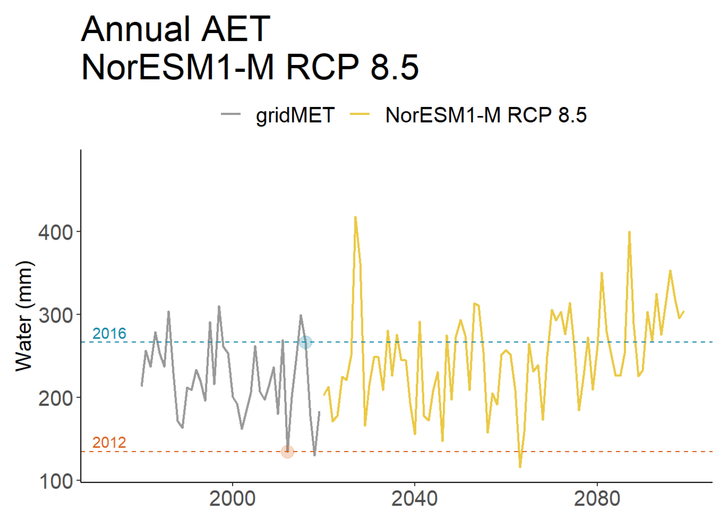


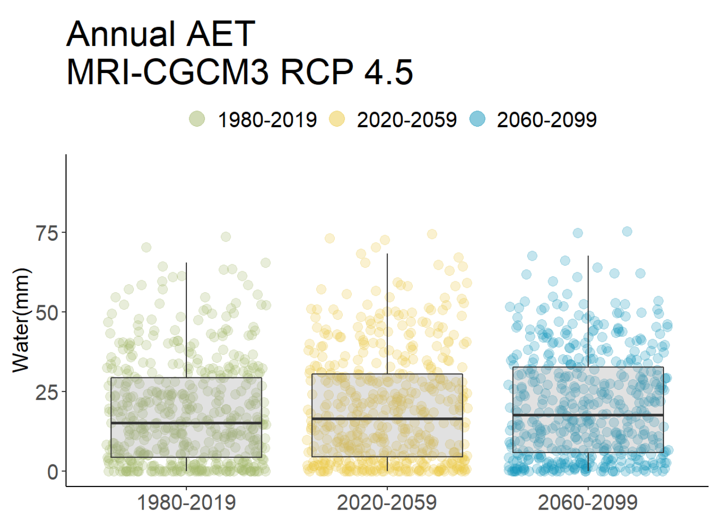
Actual Evapotranspiration (AET)

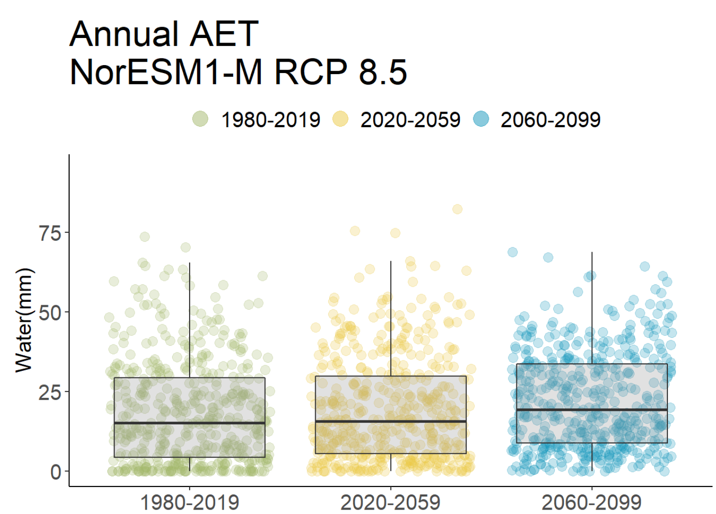




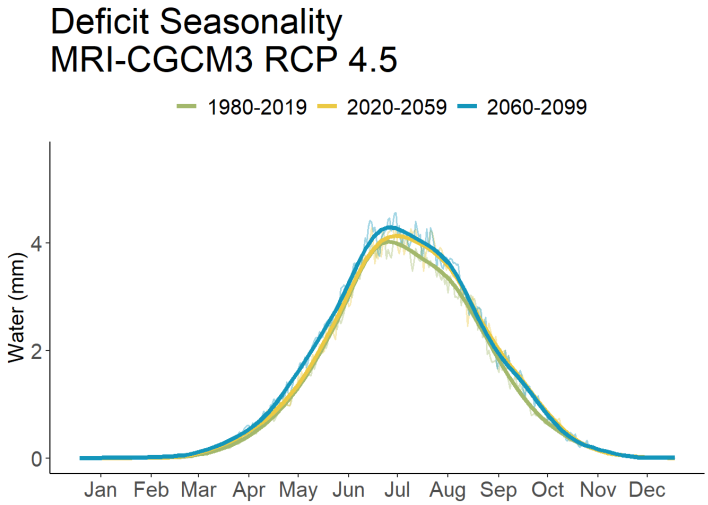


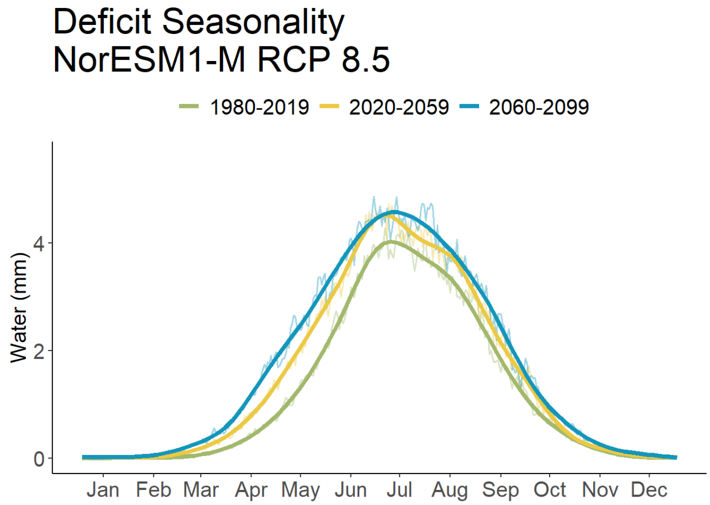


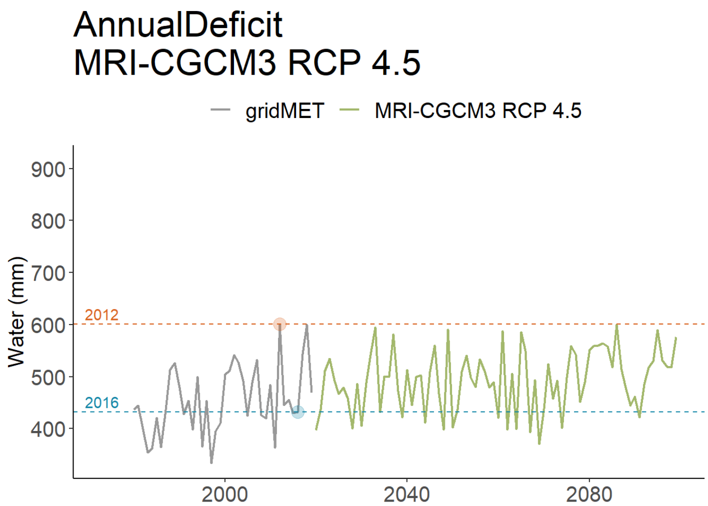


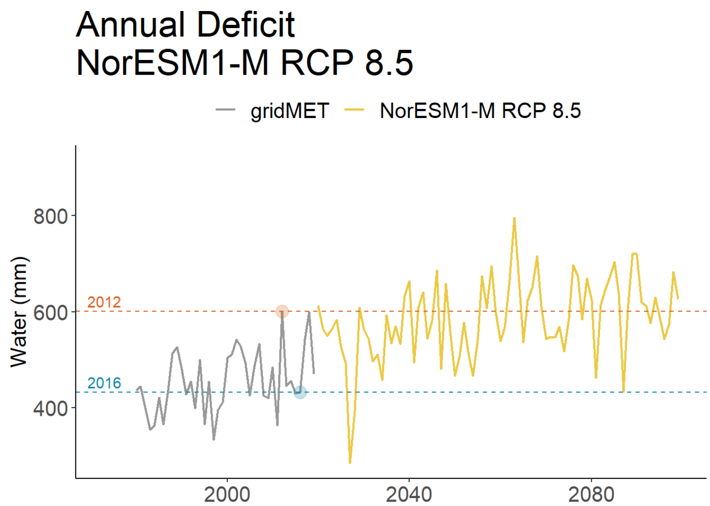


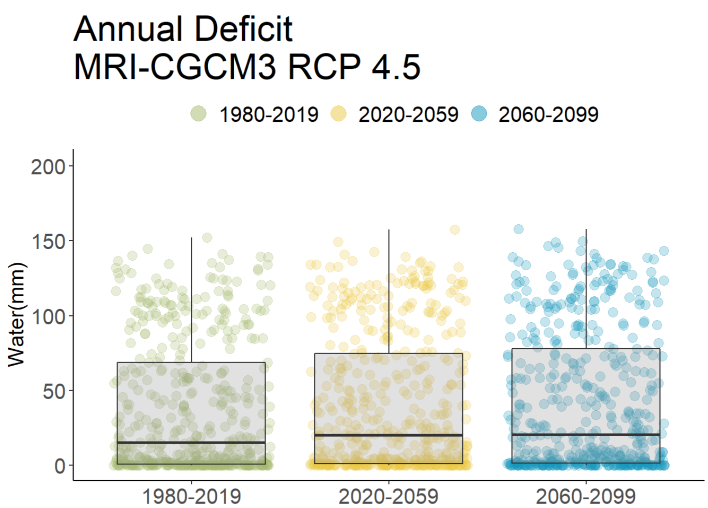
Deficit

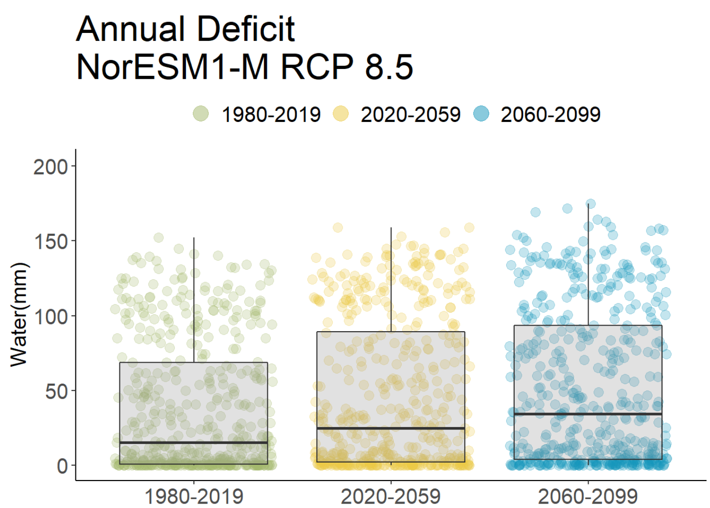












Works Cited

Stephenson, N. (1998). Actual evapotranspiration and deficit: biologically meaningful correlates of vegetation distribution across spatial scales. Journal of biogeography, 25(5), 855-870.

Tercek, M., Thoma, D., Sherrill, K., Kagone, S., Senay, G., Gross, J. 2021 Historical changes in plant water use and need in the continental United States. In review.