TECHNICAL MEMORANDUM JonesEdmunds

Critical Infrastructure and Land Use Climate Vulnerability Analysis

TO: Shane Williams, PhD, PE (Alachua County)

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DATE: October 12, 2023

SUBJECT: Task 3.1 – Climate Data Review
Jones Edmunds Project No. 01560-157-01

1 PURPOSE AND OBJECTIVES

For Task 3 of the Climate Change Vulnerability Analysis, the Jones Edmunds Team assessed Alachua County's vulnerability to:

- Seasonal changes in precipitation and drought.
- Extreme precipitation, storm events, and flooding.
- Changes to local and regional water use.
- Changes to surface-water and groundwater hydrology.
- Extreme heat and the number of days when overnight low temperatures remain elevated.
- Chill hours and freeze events
- Wildfire risks.
- Effects of climate migration on population projections.
- Effects of weather-pattern changes on County food systems and agricultural production.

This Technical Memorandum summarizes our Team's analysis of some projected fluctuations in threats associated with changes in rainfall, temperature, evapotranspiration (ET), drought, and urban irrigation demand in Alachua County. We used this information to support the vulnerability analysis.

2 CLIMATE DATA

2.1 Assessment Periods

Jones Edmunds assessed climate data for a baseline period and for four future periods:

- Baseline (2005 to 2014)
- 2030 (2026 to 2035)
- 2040 (2036 to 2045)
- 2070 (2066 to 2075)
- 2100 (2091 to 2100)

When completing our analysis of the assessment periods, we provided both the average for each assessment period as well as the standard deviation to represent the expected variability in the impacts.

2.2 Climate Data

The Coupled Model Intercomparison Project (CMIP) is a global project that aims to *better understand past, present, and future climate changes.* The project coordinates idealized General Circulation Model (GCM) experiments to predict climate change and to make these results publicly available. CMIP results form the basis for most climate change work. CMIP5 occurred from 2010 to 2014. The results of CMIP5 were published in the Intergovernmental Panel on Climate Change (IPCC) *Fifth Assessment Report* (2014). CMIP6 occurred after CMIP5, and results from this study were published in three phases starting in 2021, with the last report published in 2023.

- *CMIP* - Coupled Model Intercomparison Project
- *GCM* - Global Circulation Model
- *IPCC* – Intergovernmental Panel on Climate Change
- *RCPs* – Representative Concentration Pathways
- *SSPs* – Shared Socio-Economic Pathways

CMIP6 results are generally accepted as improved over CMIP5 but are still very new. As a result, CMIP6 results have not been used as extensively as the results of CMIP5. The Jones Edmunds Team used the results of CMIP6 for the Alachua County Climate Change Vulnerability Analysis where feasible.

Climate change scenarios can generally be described using the following terms:

- Representative Concentration Pathways (RCPs) – These scenarios are based on a set of emissions and concentrations of greenhouse gases, aerosols, and chemically active gases and land cover assumptions leading to a particular radiative forcing. For example, RCP4.5 is one pathway that leads to a radiative forcing of 4.5 watts per square meter (Wm^{-2}) by 2100. Radiative forcing is the additional radiation or heating effect caused by greenhouse gases in the atmosphere since 1750.
- Shared Socio-Economic Pathways (SSPs) – These scenarios represent pathways based on possible socio-economic futures that account for various assumptions on how the global population will mitigate and adapt to climate change. For example, SSP1 assumes a high level of mitigation and adaptation.

RCPs and SSPs have been widely used to define climate change scenarios, although the trend is to adopt SSPs as the standard approach to defining scenarios. The IPCC *Sixth Assessment* has combined SSPs with radiative forcing. For example, IPCC used SSP2-4.5 to define a shared SSP that leads to a peak radiative forcing of 4.5 Wm^{-2} by 2100.

For sea-level rise, predictions are generally classified as Low, Intermediate-Low, Intermediate, Intermediate-High, and High. For planning purposes in Florida, the Intermediate-High assumption is usually used. Although the sea-level rise scenarios are different from the SSP-RCP-based scenarios, Figure 1 in Sweet et al. (2022) shows that the Intermediate-High scenario is between SSP2-4.5 (Intermediate) and SSP3-7.0 (High).

After discussions with the County, the Jones Edmunds Team agreed to use SSP5-8.5 since this was thought to be a good assumption for planning and will likely show trends in climate change more clearly. This scenario is equivalent to the global mean surface air temperature between 2081 and 2100, increasing by approximately 5.0 degrees Celsius (°C) or 9 degrees Fahrenheit (°F).

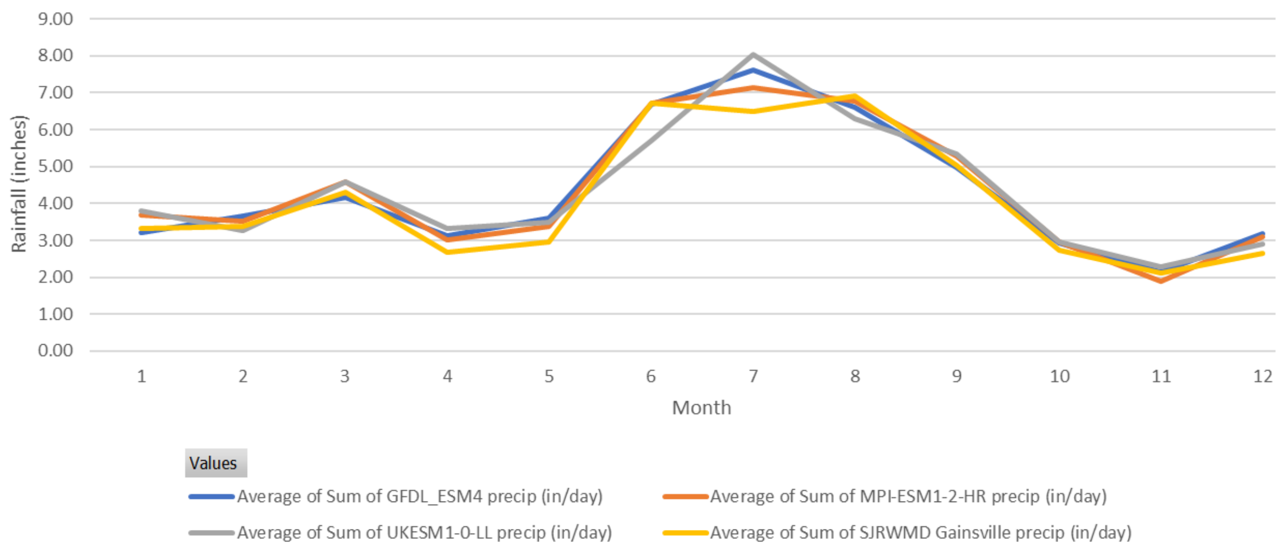
The GCMs used in CMIP6 are at a coarse resolution that allows an understanding of global changes in climate but are not at a high enough resolution needed to understand changes at the County scale. As a result, many projects have been completed to downscale and bias-correct the CMIP GCM results to assist local planning. The Jones Edmunds Team used results from the Inter-Sectoral Impact Model Intercomparison Project (ISMIP) 3b for the Alachua County Vulnerability Analysis. These downscaled and bias-corrected daily data are published by the Potsdam Institute for Climate Impact Research at a resolution of 0.5 degree.

CMIP6 includes more than 40 independent GCMs. For this vulnerability analysis, we compared rainfall results from three models to recorded rainfall in Alachua County and selected the most representative model. The three models that we evaluated were:

- GFDL-ESM4 (Princeton, USA)
- MPI-ESM1-2-HR (Max Planck Institute, Germany)
- UKESM1-0-LL (Met Office Hadley Centre, UK)

Figure 2-1 compares the model versus recorded rainfall. The County and the Jones Edmunds Team selected the GFDL-ESM4 model results as being suitable for this analysis.

Figure 2-1 Comparison of Average Monthly Rainfall for Three GCMs to Recorded Rainfall in Alachua County



The Jones Edmunds Team downloaded the following daily data from the ISMIP 3b for SSP5-8.5 based on the GFDL-ESM4 models for each of the timeframes:

- Maximum air temperature (tasmax).
- Minimum air temperature (tasmin).
- Precipitation (pr).
- Incoming solar radiation (surface downwelling shortwave radiation [rsds]).
- Atmospheric carbon dioxide (CO_2).

2.3 Spatial Extents

The Jones Edmunds Team downloaded the daily data for a single representative cell in the County from the selected model. Only one ISMIP 3b cell was within Alachua County. The coordinates of the cell centroid were 29.75^0 N and 82.5^0 E.

3 CLIMATE DATA ANALYSIS

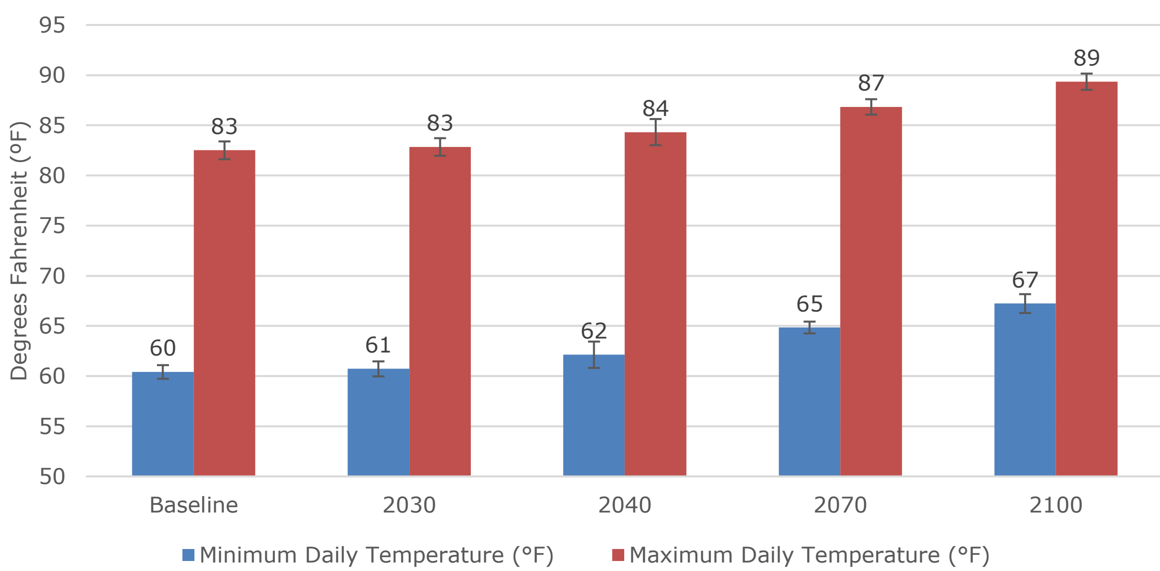
The Jones Edmunds Team analyzed the GCM climate data described in Section 2.2. We used weather data from the GCM to compare baseline conditions in Alachua County to predicted conditions for 2030, 2040, 2070, and 2100. We averaged daily values over the assessment periods in Section 2.1 to estimate future conditions. We have included the standard deviation in the predicted conditions for each assessment period where possible.

3.1 Extreme Heat, Freeze Events, and the Number of Days When Overnight Low Temperatures Remain Elevated

The Jones Edmunds Team calculated statistics based on the downloaded climate data. From baseline to 2040, average minimum and maximum daily temperatures increased by 2ºF and 1ºF, respectively. From 2040 to 2100, the average minimum and maximum daily temperatures increased by 5ºF.

The minimum daily temperature increased by 7ºF from baseline to 2100. The average maximum daily temperature increased by 6ºF over the same period. Figure 3-1 summarizes these findings. These data showed that the average annual daily maximum temperature is rising at a rate of 1ºF every 10 years from 2030 to 2070 and at a rate of 0.67ºF every 10 years from 2070 to 2100. The average annual daily minimum temperature rose at the same rates.

Figure 3-1 Average Annual Minimum and Maximum Daily Temperatures



The Jones Edmunds Team analyzed the change in extreme heat and freeze events across the assessment periods. We found the minimum and maximum daily temperatures for each year and averaged them for each assessment period (Figure 3-2). We summarized the change in the number of very warm nights (minimum temperature above 80°F) and freeze events (minimum temperature below 32°F) over each assessment period in Table 3-1.

Figure 3-2 Annual Minimum and Maximum Temperatures

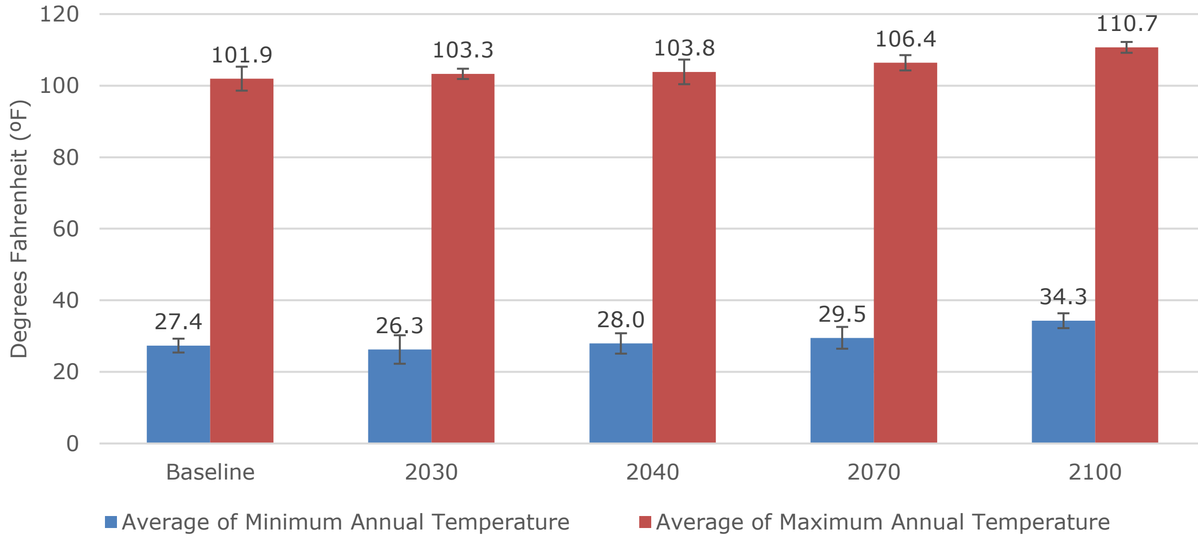


Table 3-1 Average Annual Number of Extreme Heat and Freeze Events over Assessment Periods

	Number of Very Warm Nights **(min. temp. above 80°F)** (Days)	Longest Period of Consecutive Very Warm Nights (Days)	Number of Freeze Events **(min. temp. below 32°F)** (Days)	Longest Period of Consecutive Freeze Events (Days)
Baseline	0	0	7	3
2030	1	1	6	2
2040	1	1	4	2
2070	17	7	2	2
2100	73	28	0	0

3.1.1 Heat Index

Heat Index (HI) measures how warm the air feels when accounting for humidity. Spending significant periods in high HI conditions, especially while performing physically intensive activities, can lead to dangerous heat-related illnesses such as heatstroke and heat exhaustion. HI is commonly used to gauge the safety of outdoor conditions for the public and outdoor workers. The National Weather Service (NWS) alerts the public when they expect the HI to exceed 105 to 110°F for two consecutive days and the minimum nighttime temperature is 75°F or above because being outside under these conditions is considered dangerous (National Oceanic and Atmospheric Administration [NOAA], 2022). The NWS lists possible symptoms of prolonged exposure to four categories of heat index, ranging from Very Warm, Hot, Very Hot, and Extremely Hot.

The Jones Edmunds Team calculated the projected change in HI from baseline to the future assessment periods. We calculated HI using two methods:

- The Steadman Method – This method is based on an approach proposed by Steadman (1979), which is still used by the NWS to calculate the daily maximum HI.
- The Lu and Romps Method – Lu and Romps (2022) noted that the Steadman (1979) approach produces unphysical results for higher temperature and humidity combinations, which underestimates the actual HI. Understanding HI during these higher temperatures and humidity conditions is increasingly relevant given the projected increases in temperature for Alachua County.

Both HI models depend on relative humidity (RH) and temperature. The maximum daily HI usually occurs in the afternoon when temperatures are at their highest and humidity is lower than the daily average. Jones Edmunds used hourly temperature and humidity data from the University of Florida Institute of Food and Agricultural Sciences Florida Automated Weather Network (IFAS FAWN) weather station near the City of Alachua to determine the ratio of hourly humidity to daily average humidity at the time of the maximum HI. We found that, on average, the humidity at the time of maximum HI was 78 percent of the average humidity for that day. We used 0.78 as an RH adjustment factor when calculating the daily maximum HI from the daily maximum temperature and average RH.

Jones Edmunds used the Steadman (1979) and Lu and Romps (2022) methods to calculate the average number of days per year when the daily maximum HI would be Very Warm, Hot, Very Hot, or Extremely Hot for each assessment period (Tables 3-2 and 3-3). Figures 3-3 and 3-4 display the projected change in the average annual number of days within each heat index range.

Table 3-2 Average Annual Number of Days that the Maximum HI Falls Within NOAA Categories (Steadman Method)

	Very Warm (80 to 89°F)	Hot (90 to 104°F)	Very Hot (105 to 129°F)	Extremely Hot (At or Higher Than 130°F)	Total
Baseline	55	90	71	2	218
2030	51	85	89	1	226
2040	55	71	100	6	232
2070	54	69	110	23	256
2100	42	61	105	61	268

Table 3-3 Average Annual Number of Days that the Maximum HI Falls Within NOAA Categories (Lu and Romps Method)

	Very Warm (80 to 89°F)	Hot (90 to 104°F)	Very Hot (105 to 129°F)	Extremely Hot (At or Higher Than 130°F)	Total
Baseline	58	95	58	11	222
2030	50	89	67	18	224
2040	57	72	66	37	232
2070	53	72	58	73	256
2100	40	62	53	111	266

Figure 3-3 Average Annual Number of Days that the Maximum HI Falls Within NOAA Categories (Steadman Method)

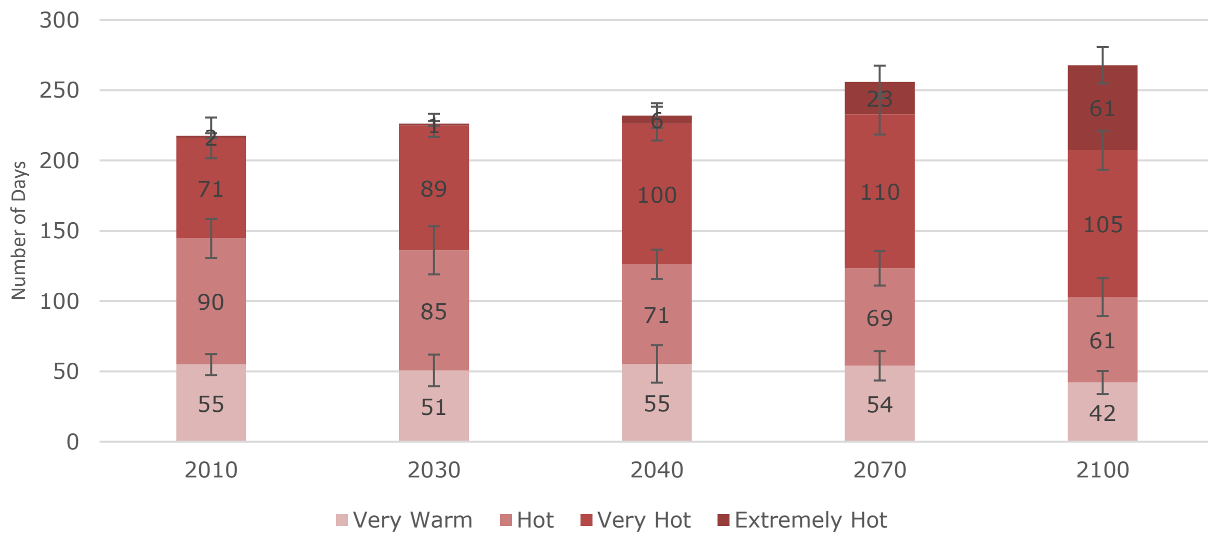
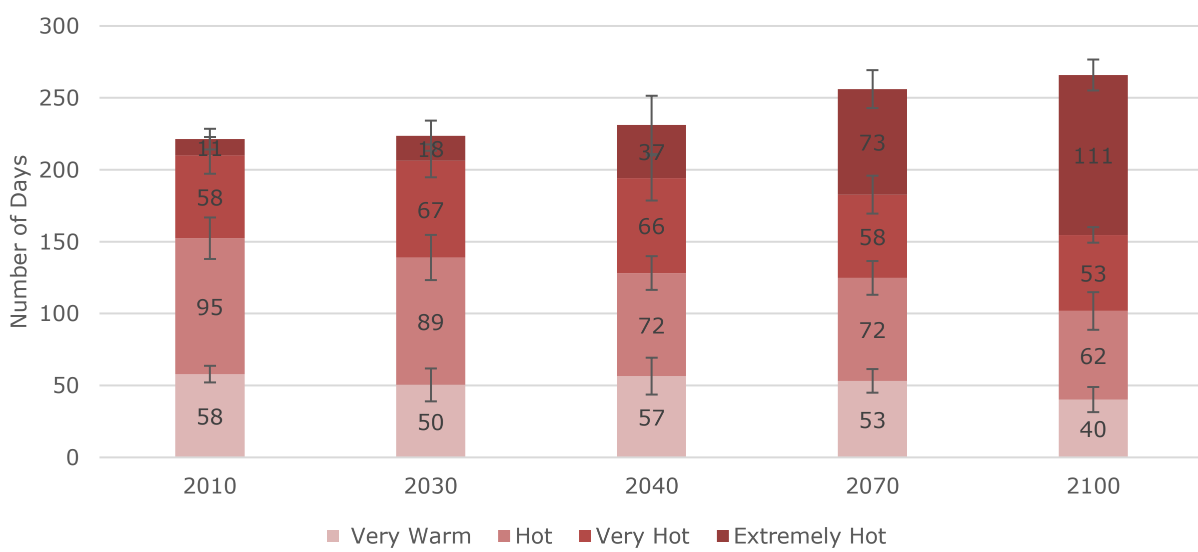


Figure 3-4 Average Annual Number of Days that the Maximum HI Falls Within NOAA Categories (Lu and Romps Method)



3.1.2 TEMPERATURE HUMIDITY INDEX

Temperature-Humidity Index (THI) measures the combined effects of air temperature and humidity. THI is widely used for weather safety and was developed to monitor and reduce heat-stress-related losses of livestock. Animal species have different sensitivities to temperature and moisture levels in the air.

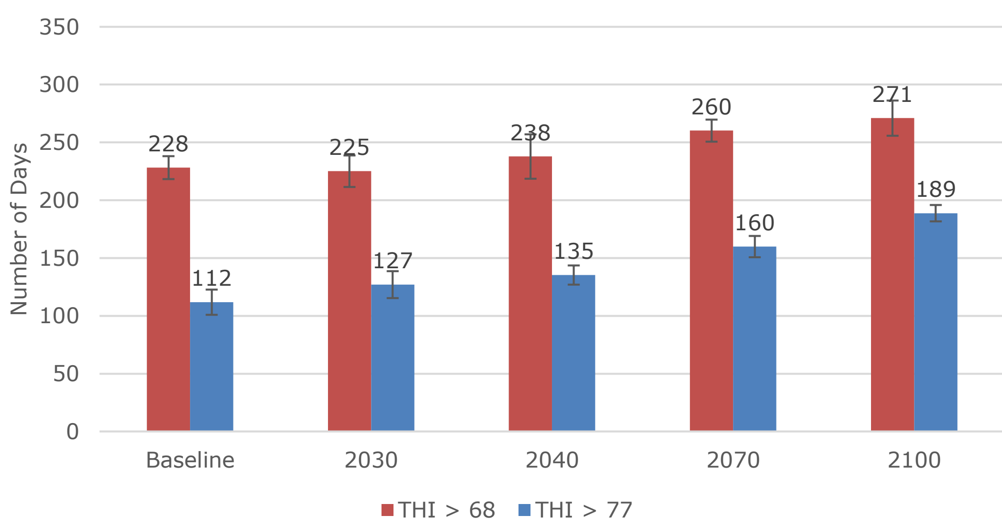
For example, cattle can typically handle high temperatures. However, as humidity increases, the ability of cattle to dissipate heat load decreases, and they exhibit signs of thermal stress. Lactating cows are even less thermotolerant than dry cows. The effects of this stress can result in significant economic losses to the dairy industry due to the cows' decreased milk production, fertility, feed intake, growth, and longevity. This index is described by Ouellet et al. (2021) who also recorded the effects of THI on cows in Florida.

The THI thresholds at which cows become thermally stressed are 68 for non-milk-producing cows (dry) and 77 for lactating cows. When THI values surpass this threshold, dairy farms employ heat-abatement technologies to reduce stress on cows. The Jones Edmunds Team calculated the projected change in THI from baseline to future assessment periods. We calculated the days when daily average THI values are expected to exceed 68 and 77 (Table 3-4 and Figure 3-5).

Table 3-4 Average Annual THI Counts Based on Daily Minimum and Maximum Temperatures

	THI > 68	THI > 77
Baseline	228	112
2030	225	127
2040	238	135
2070	260	160
2100	271	189

Figure 3-5 Average Number of Days per Year Exceeding THI Thresholds



3.2 Evaluation of Modeled Evapotranspiration

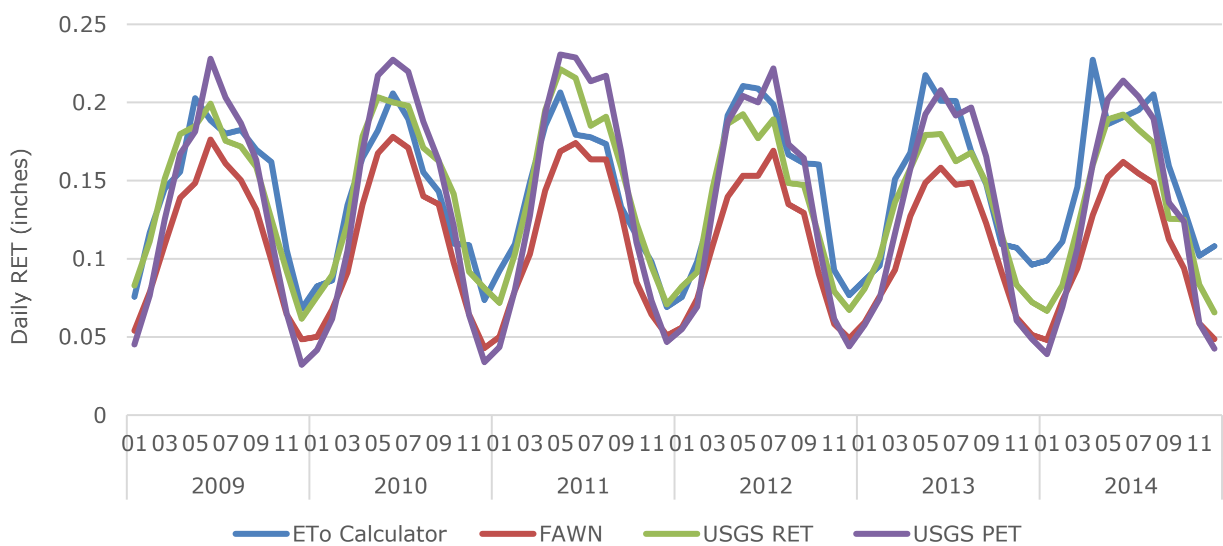
The Jones Edmunds Team calculated reference ET (RET) values over each period using ETo Calculator Version 3.1, which was developed by the Food and Agriculture Organization of the United Nations (FAO, 2009). The program computes daily RET values using the Penman-Monteith equation and requires the following inputs:

- Daily minimum and maximum temperatures (°C).
- Relative humidity (%).
- Wind speed (m/s).
- Solar radiation (Wm^{-2}).
- Latitude and longitude.

We compared the RET values that we calculated using the CMIP6 model results for the baseline period to daily RET values downloaded from the FAWN station in Alachua County (Station Identification [ID] 260). These FAWN daily RET values are also calculated by FAWN using the FAO Penman-Monteith equation based on climate data collected at the FAWN weather station. On average, calculated daily RET values over the baseline period were 0.03 inch/day higher than the FAWN values and differed by a maximum of 0.1 inch/day. Figure 3-6 compares our calculated daily RET values to historical data from FAWN.

We also compared our calculated RET values to the US Geological Survey (USGS) Geostationary Operational Environmental Satellite (GOES)-derived RET and potential ET (PET) for Alachua County. On average, our calculated daily RET values were 0.007 inch/day lower than USGS RET values and differed by a maximum of 0.07 inch/day. Figure 3-6 also compares our calculated RET values to historical data from USGS. Overall, the daily RET values calculated based on the CMIP6 model results during the baseline period compared favorably to the calculated RET at the Alachua FAWN station and USGS calculated RET for the same period.

Figure 3-6 Baseline Daily RET Value Comparison



3.3 Seasonal Changes in Projected Precipitation and Drought

The Jones Edmunds Team analyzed seasonal changes in RET and rainfall across the assessment periods to better understand possible trends under the climate change scenario. Figure 3-7 illustrates average seasonal rainfall and RET across the assessment periods listed in Section 2.1. For this analysis, June to October represents the wet season, and November to May represents the dry season.

Total rainfall and ET from the baseline to the 2100 period increased more over the dry season than wet season. Tables 3-5 and 3-6 outline the seasonal rainfall and ET values for each assessment period and their percent increase from baseline to 2100.

Figure 3-7 Average Annual Rainfall and RET By Season

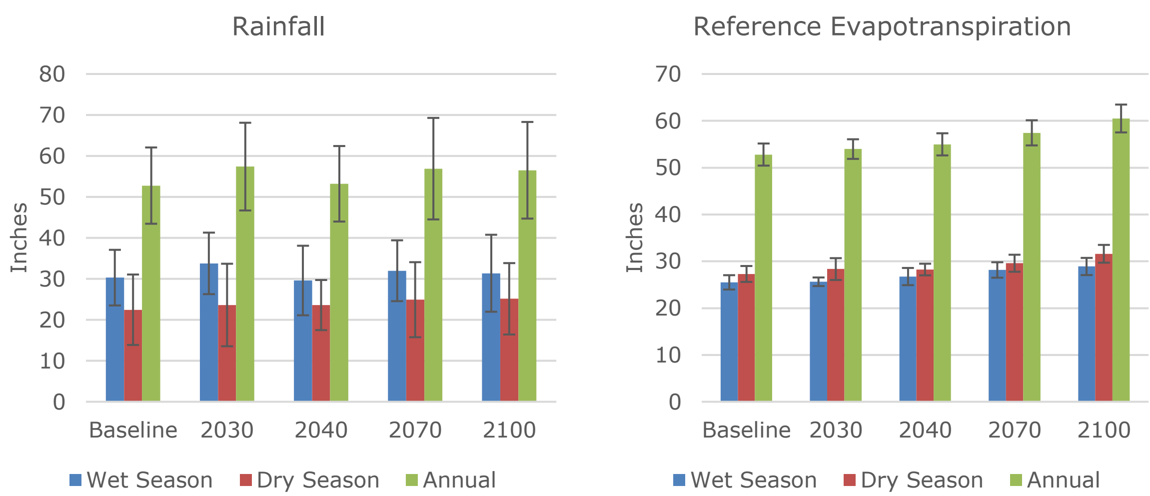


Table 3-5 Average Annual and Average Seasonal Changes in Rainfall

	Wet Season (inches)	Dry Season (inches)	Annual (inches)	Annual Increase from Baseline (%)
Baseline	30.3	22.5	52.8	–
2030	33.8	23.6	57.4	8.8
2040	29.6	23.6	53.2	0.8
2070	32.0	24.9	56.9	7.8
2100	31.4	25.1	56.5	7.1

Annually, the modeled future rainfall based on the scenario evaluated by the Jones Edmunds Team increases from an average of 52.8 inches/year during the baseline period to an average of more than 56.5 inches/year in the 2100 period, representing a 7.1-percent increase. Maximum annual rainfall over the assessment period rose from a baseline value of 66.4 inches/year to 71.6 inches/year in the 2100 period, representing an increase of 7.8 percent.

Table 3-6 Average Annual and Average Seasonal Changes in RET

	Wet Season (inches)	Dry Season (inches)	Annual (inches)	Annual Increase from Baseline (%)
Baseline	25.5	27.3	52.8	–
2030	25.6	28.3	54.0	2.3
2040	26.7	28.2	55.0	4.2
2070	54.2	29.6	57.4	8.9
2100	28.9	31.6	60.5	14.7

Annually, the calculated future RET based on the scenario evaluated by the Jones Edmunds Team increases from an average of 52.8 inches/year during the baseline period to an average of more than 60.5 inches/year in the 2100 period, representing a 14.6-percent increase. Maximum annual RET rose from a baseline value of 56.7 inches/year to 66.8 inches/year in 2100, representing an increase of 17.8 percent.

3.3.1 Keetch-Byram Drought Index

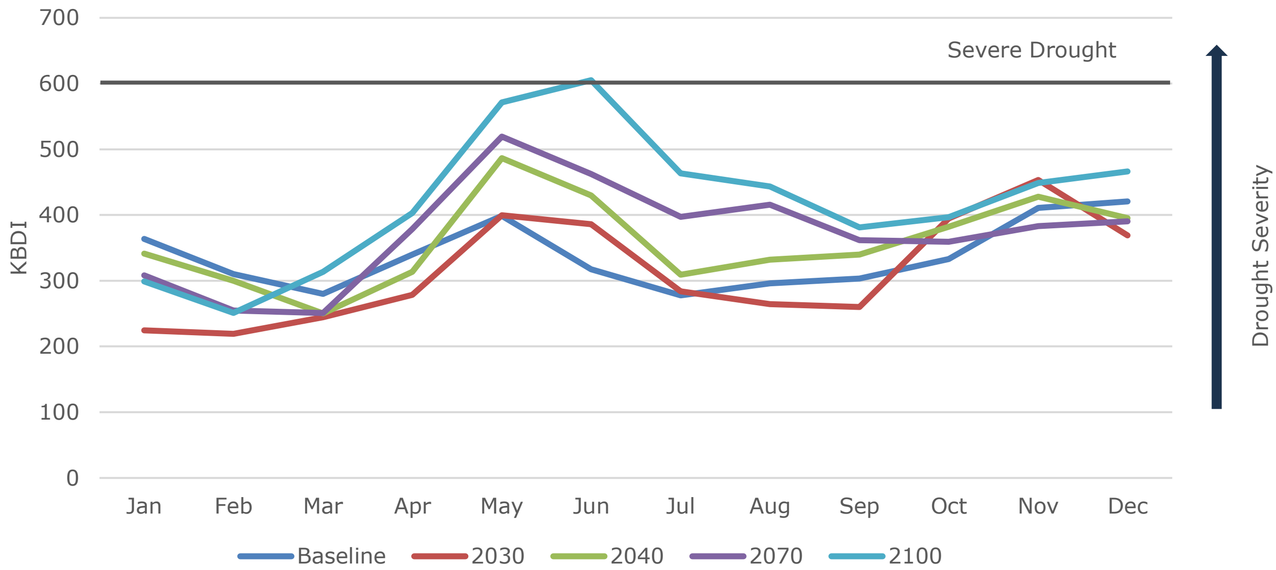
Several indexes have been used in Florida to quantify drought. For example, climate change literature commonly uses the maximum number of consecutive dry days each year to evaluate changes in drought due to climate change. Another commonly used index for classifying drought in the Southeast United States is the Keetch-Byram Drought Index (KBDI).

The Jones Edmunds Team used the KBDI to investigate the intensity and frequency of drought over the assessment periods. This index was originally designed by members of the Southeastern Forest Experiment Station to classify soil moisture deficit in the Southeast United States (Keetch and Byram, 1968). The index is commonly used for measuring drought severity and is frequently used in Florida to indicate the current level of wildfire risk. The KBDI estimates the dryness of the soil and duff layers to determine an area's stage of drought. The KBDI is posted daily on the Florida Department of Agriculture website (http://fireweather.fdacs.gov/wx/kbdi_index.html).

The KBDI is a continuous reference scale that relies on daily precipitation and maximum temperature measurements to generate a drought index. This index increases after days with no rainfall and decreases after rain events. The extent of the increase or decrease depends on the amount of rainfall and the maximum daily temperature. The KBDI ranges from 0 (no moisture deficit) to 800 (maximum moisture deficit). High KBDI values indicate favorable conditions for the occurrence and spread of wildfires.

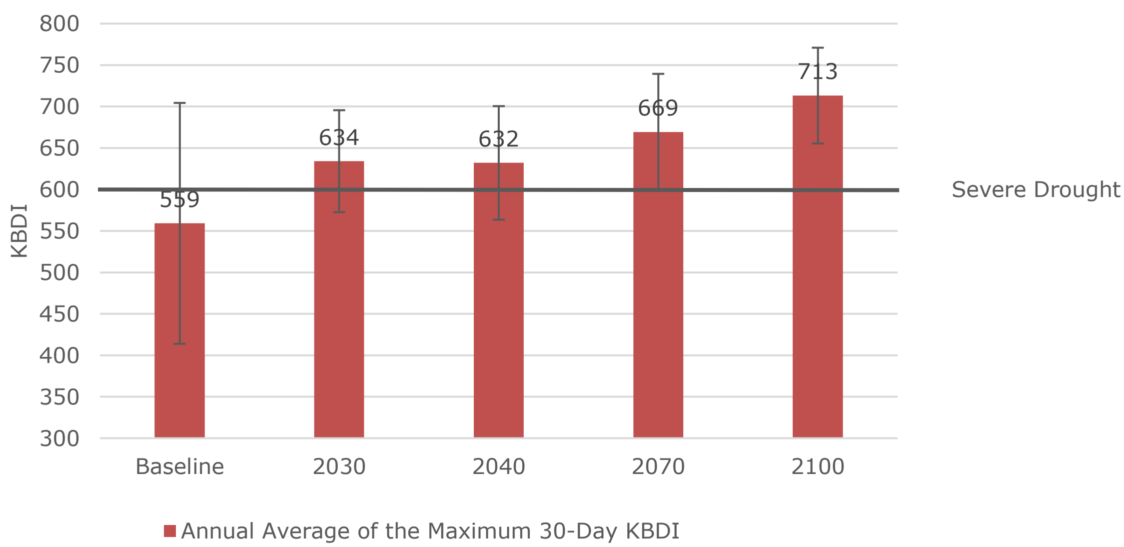
The Jones Edmunds Team calculated the daily drought indices for the County over each assessment period. We used daily precipitation and maximum temperature values from the GCM to compare the length and severity of droughts from the baseline period to future periods. Figure 3-8 illustrates the change in average monthly KBDI over the assessment periods. This figure shows a projected increase in the average monthly KBDI in the summer months.

Figure 3-8 Comparison of Average Monthly KBDI Values Under Future Climate Conditions for Alachua County



The Team also compared the annual maximum 30-day KBDI average for the assessment periods. We calculated the 30-day KBDI as a 30-day sliding average. Figure 3-9 displays this information, representing how the severity of the driest 30-day period each year may change over time. The figure also shows the standard deviation of the annual maximum KBDI during each evaluation period. The figure shows that droughts would become more severe under the climate change scenario we evaluated. Under this scenario, Alachua County would likely experience a severe drought yearly by 2100.

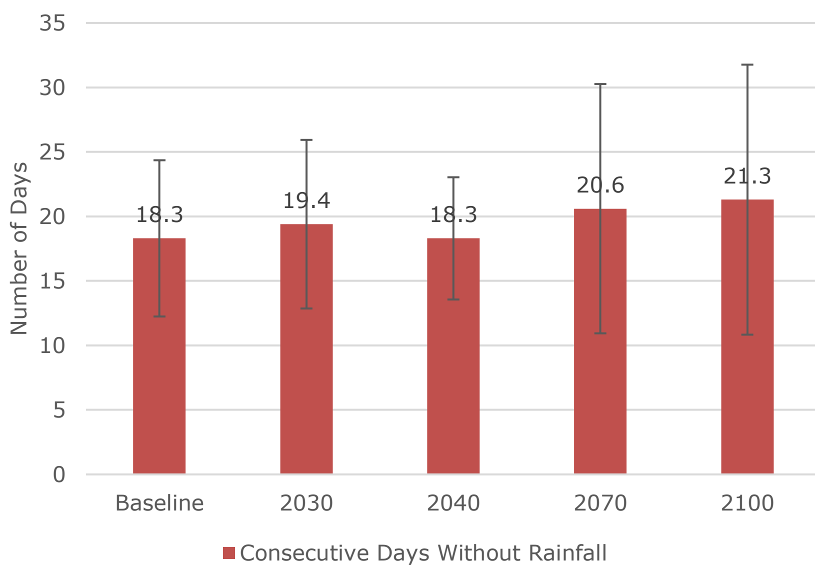
Figure 3-9 Annual Average of the Maximum 30-Day KBDI



3.3.2 Maximum Number of Consecutive Days without Rainfall

The maximum number of consecutive days without rainfall can be used as an approximation of drought. The Jones Edmunds Team evaluated the effects of the projected climate scenario on this indicator. We calculated the maximum number of consecutive days without rainfall (dry days) each year. We then averaged the annual maximum dry days over the assessment periods (Figure 3-10). This calculation estimates how the length and annual variation of the dry period may change over time. The duration of the longest dry period increased from an average of 18.3 days during the baseline period to 21.3 days by 2100. During the basline period, the longest number of dry days (32 days) occurred during the wet season. However, for all assessment periods after the baseline, the longest number of dry days occurred during the dry season.

Figure 3-10 Duration of Longest Annual Dry Period

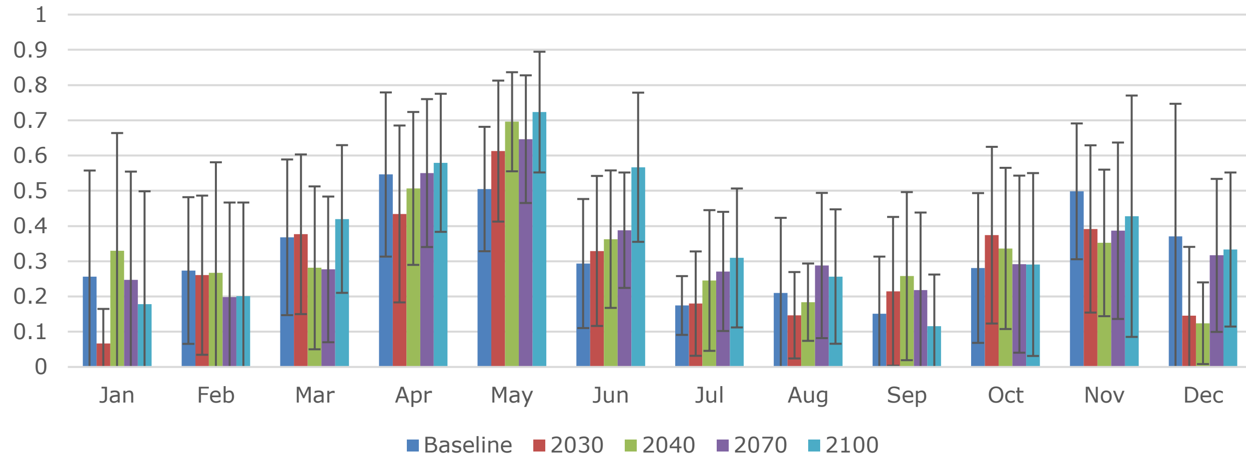


3.3.3 Agricultural Reference Index for Drought

Researchers at the University of Florida developed the Agricultural Reference Index for Drought (ARID) to represent and quantify agricultural droughts (Woli et al., 2012). The index indicates crop water deficiency and is defined as the actual to potential ET ratio. ARID values range from 0 to 1, with 1 indicating a full-water deficit. This index has been used in the Southeast United States and is publicly available to farmers in Florida and Georgia.

Figure 3-11 summarizes the average monthly ARID for the assessment periods. The figure shows that agricultural droughts in Alachua County will continue to be highly variable. However, drought severity is projected to increase in May, June, and July.

Figure 3-11 Average Monthly ARID For Assessment Periods



3.4 Turfgrass Irrigation Demand

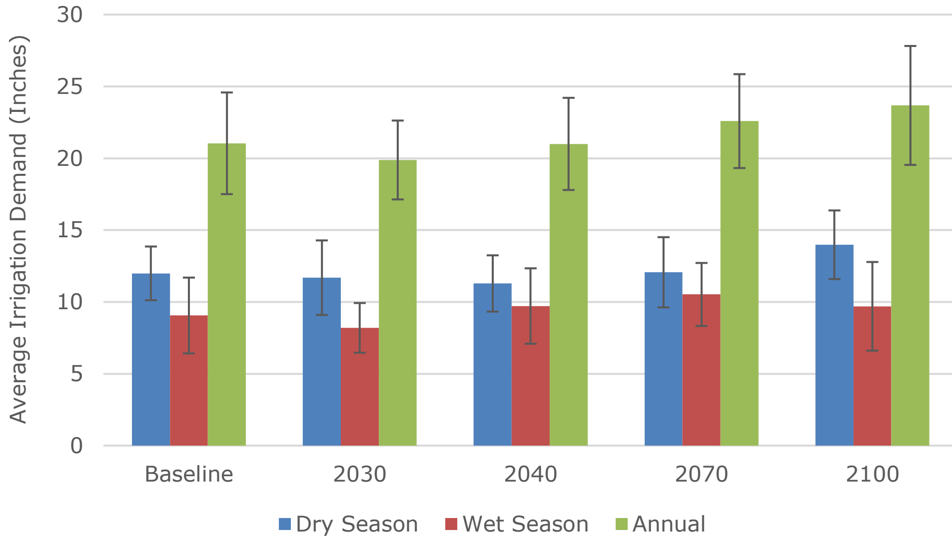
Romero and Dukes (2013) developed a soil-water-balance model that predicts the required irrigation for a turf landscape. The Jones Edmunds Team used calculated RET values to estimate turf irrigation requirements following the method outlined by Romero and Dukes. This model forecasts irrigation requirements based on the following inputs:

- Precipitation.
- Crop ET.
- The available water-holding capacity of the soil.
- Maximum allowable water depletion (wilting point).
- Average root zone.

We modeled maximum allowable water depletion and average root zones for St. Augustine grass and based available water-holding capacity on Arredondo fine sand. We selected Arredondo fine sand because it is one of the predominant soil types in Alachua County (9 percent) and is representative of the sandy soils that make up more than 70 percent of the County (NRCS, 2022). We used the monthly crop coefficients developed for Gainesville listed in Romero and Dukes to calculate the actual ET.

Figure 3-12 illustrates the increase in average irrigation demand over the assessment periods by season. In the dry season, average annual irrigation demand increases by 16.6 percent from 12.0 inches/year in the baseline period to 14.0 inches/year in 2100. Year-round average annual irrigation demand increases 12.5 percent from 21 inches/year to 23.7 inches/year.

Figure 3-12 Average Annual Turf Irrigation Demand by Season

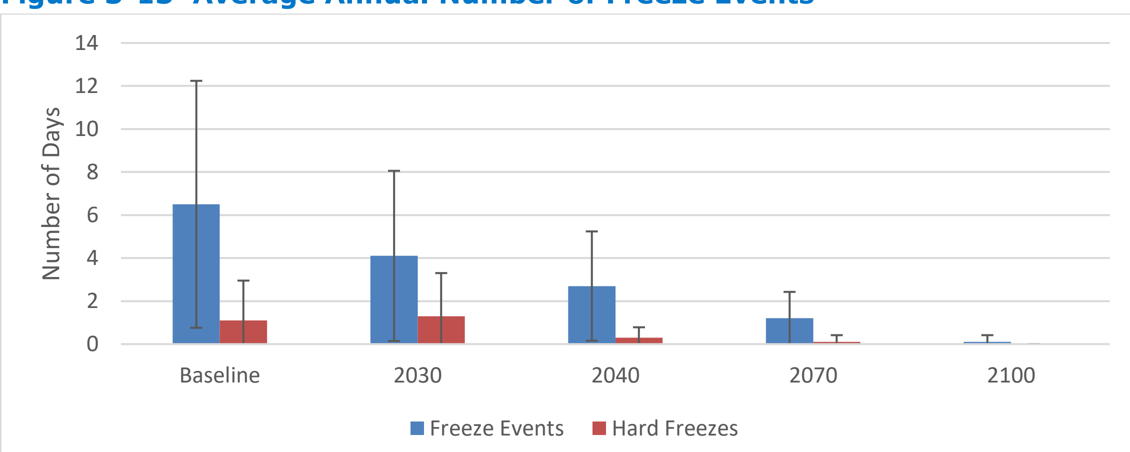


3.5 Freeze Events

The NWS defines a freeze event as when the temperature drops below 32ºF for 2 or more hours and a hard freeze when the temperature drops below 28ºF for 2 or more hours. Jones Edmunds disaggregated the GCM minimum and maximum daily temperature data based on 10 years of hourly temperature data recorded at the IFAS FAWN weather station. We developed a temperature pattern for each day of the year based on how the hourly temperatures varied relative to the minimum and maximum temperatures recorded each day. We applied that pattern to the projected temperature data. Freezes and hard freezes play an essential role in agricultural production and the growth and propagation of vegetation in the County.

Figure 3-13 shows the change in the number of freeze and hard-freeze events under the climate scenario we evaluated.

Figure 3-13 Average Annual Number of Freeze Events



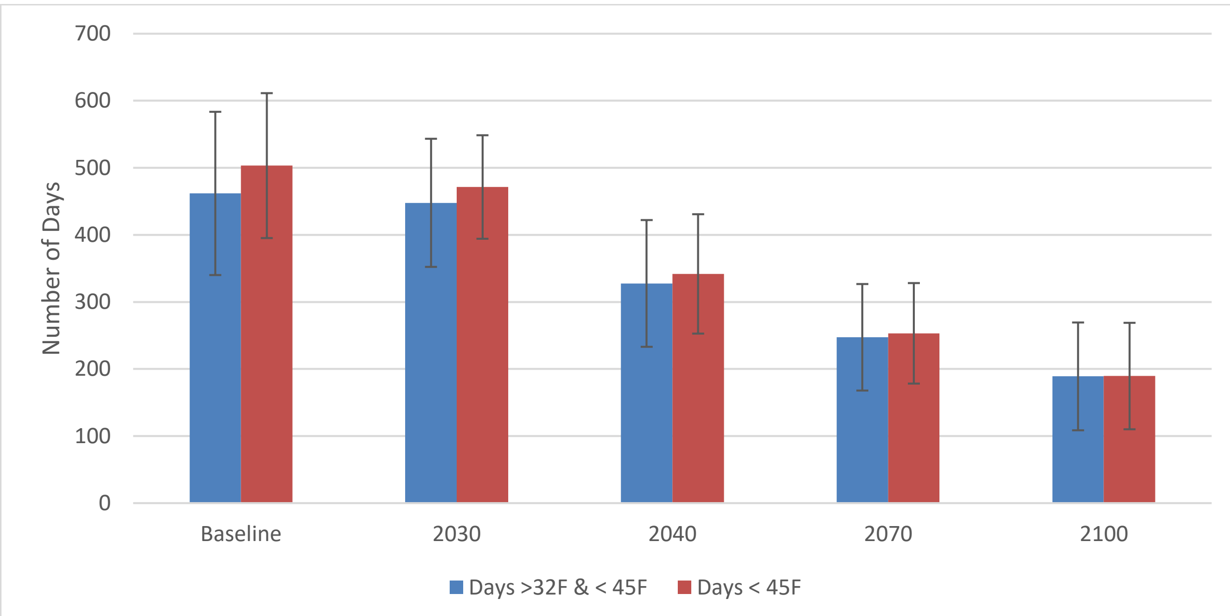
3.6 Chill Hours

Deciduous trees generally require cold weather before they will blossom. This requirement for cold weather can be measured in chill hours. Two commonly used methods to calculate the chill hour for fruit trees are:

- Summing the total number of hours that the temperature is less than 45°F.
- Summing the number of hours that the temperature is between 32°F and 45°F.

The chill hours requirement for fruit trees varies by cultivar. For example, traditional blueberry cultivars in Alachua County need 300 to 500 chill hours to blossom. However, newer varieties need fewer chill hours. Figure 14 shows the projected chill hours under the climate scenarions that were evaluated.

Figure 3-14 Average Annual Chill Hours



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