CRITICAL INFRASTRUCTURE AND LAND USE CLIMATE VULNERABILITY ANALYSIS

TASK 1 – PROJECTED IMPACTS REPORT

Alachua County | August 2022

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ACRONYMS AND ABBREVIATIONS

1D	One-Dimensional
2D	Two-Dimensional
AAL	Annual Average Losses
AMO	Atlantic Multidecadal Oscillation
BEBR	Bureau of Economic and Business Research
BGD	Billion Gallons per Day
CF	Change Factors
CFWI	Central Florida Water Initiative
CMIP5	Coupled Model Intercomparison Project 5
CMIP6	Coupled Model Intercomparison Project 6
CORDEX	Coordinated Regional Downscaling Experiment
DDF	Depth-Duration-Frequency
EDR	Economic and Demographic Research
ENSO	El-Niño Southern Oscillation
EPA	Environmental Protection Agency
ERP	Environmental Resource Permit
ET	Evapotranspiration
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FIU	Florida International University
FWCA	Florida Water and Climate Alliance
GCM	General Circulation Model
GHG	Greenhouse Gas
GIS	Geographic Information System
H&H	Hydrologic and Hydraulic
HAB	Harmful Algal Blooms
IPCC	Intergovernmental Panel on Climate Change
KBDI	Keetch-Byram Drought Index
LMSL	Local Mean Sea Level
LOCA	Localized Constructed Analogs
MACA	Multivariate Adaptive Constructed Analogs
MFLs	Minimum Flows and Minimum Levels
MGD	Million Gallons per Day
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NOAA	National Oceanic and Atmospheric Administration
NFRWSP	North Florida Regional Water Supply Plan
NFSEG	North Florida-Southeast Georgia
NWFWMD	Northwest Florida Water Management District
PDO	Pacific Decadal Oscillation
POR	Period of Record
RCM	Regional Climate Model
RCP	Representative Concentration Pathways

SFWMD	South Florida Water Management District
SJRWMD	St. Johns River Water Management District
SLR	Sea-Level Rise
SRWMD	Suwanee River Water Management District
SSP	Shared Socioeconomic Pathways
SWFWMD	Southwest Florida Water Management District
SWMP	Stormwater Management Plan
USACE	US Army Corps of Engineers
USDA	US Department of Agriculture
USGS	US Geological Survey
WFDI	Wildland Fire Danger Index
WIS	Water Supply Impact Study
WUI	Wildland-Urban Interface

EXECUTIVE SUMMARY

Alachua County seeks to investigate the impacts that climate change will have on County residents and their property, particularly concerning infrastructure and natural resources. To evaluate these impacts, the County is completing a critical infrastructure and land use climate vulnerability analysis. The County's primary climatic impacts will be altered flooding conditions due to changing rainfall volume, frequency, and intensity. In addition, projected changes to seasonal rainfall patterns and evapotranspiration (ET) could change groundwater levels and may adversely affect water levels in lakes; flows in rivers, springs, and other natural systems; drinking water availability; agricultural production; and wildfire risk due to dry conditions. Extreme temperature events that may accompany seasonal climate shifts may also impact the health of residents. Finally, as an inland county, Alachua County may be a destination for citizens relocating from coastal or higher risk areas, placing additional stresses on physical and social infrastructure and land use. This project aims to determine, to the best extent possible, the future conditions that the County and its incorporated municipalities may face due to climate change.

We can generally group climate change impacts into those with which we have higher and lower degrees of confidence. High-probability trends for Florida include rising temperatures and sea levels, increased high-intensity rainfall events and decreased low-intensity rainfall events, changes in annual rain distribution, and increased ET. Those with lower degrees of certainty include the change in average annual rainfall and hurricane frequency. Direct impacts of groundwater are expected to be related primarily to sea-level rise (SLR) in coastal areas.

The Bureau of Economic and Business Research (BEBR) used their standard methodology for its state and county projections to project population growth for Alachua County. BEBR extended their forecast for 2050 to predict Alachua County populations for 2070 and 2100. BEBR also revised their forecast to include the effect of climate migration or SLR on the Alachua County population.

Florida has and continues to experience substantial population growth with the population more than doubling during the past 40 years (1980 to 2020) and a current population of 21.5 million as of 2020 (Florida County Population Census Counts: 1830 to 2020, 2021). Land use changes are expected as a part of this continued population growth impacting hydrology and water storage (Bloetscher, 2009). Bloetscher (2009) notes that these impacts will require increased reliance on conjunctive use of surface water and groundwater and potable water supply well relocation away from impacted coastal areas.

Although urban land use increased from 1987 to 2017, agricultural acreage decreased by 10 percent. However, an increase in agricultural acreage of 20 percent and 11 percent is expected in the Suwanee River Water Management District (SRWMD) and the North Florida Water Management District (NFWMD), respectively, between 2019 and 2045. Agricultural water demand may increase resulting from water stress from increased temperatures and extended dry periods.

The Office of Economic and Demographic Research (EDR) develops an annual estimate of all state water use and forecasts changes in water use for the next 20 years based on

combined water management district data and linear projections (2021). In 2021, the EDR water-use projections for Florida were presented from 2020 to 2040. Key findings, which did not account for climate change, include an approximate 15-percent increase in water use; increases across the state except for a small decrease in the Southwest Florida Water Management District (SWFWMD); a
23-percent growth in public supply, which does not account for climate migration; and a 3.7-percent increase in agricultural water use. The St. Johns River Water Management District (SJRWMD) and SRWMD evaluated regional water needs in the North Florida Regional Water Supply Plan (NFRWSP)(2015 – 2035) (2017). This study specifically evaluated water-use projections between 2010 and 2035 for the planning region that includes Alachua County. Results of this study include assumptions that:

- Water use in Alachua County will increase by approximately 14 percent.
- Domestic self-supply will decrease from 3.5 to 2.7 million gallons per day (MGD).
- Agricultural demand will increase from approximately 17.1 to 19.5 MGD.
- Water use for power generation will increase from 2.5 to 3.0 MGD.

The NFRWSP also notes that many practices used to address water resource constraints, including decreasing groundwater demand, improving water-use efficiency, and diversifying water supply, that may also be used to mitigate climate change impacts.

Current minimum flows and levels (MFL) for the Lower Santa Fe and Ichetucknee Rivers indicate that the Ichetucknee River has fallen below its MFL and is in recovery. Additionally, the Lower Santa Fe River is expected to fall below its MFL between 2035 and 2040 and is in prevention (SRWMD, 2021). Any changes in climate that further increase water demand (increased frequency of drought or increasing temperatures) or decrease water availability (decreased rainfall or increased runoff) may make meeting future water use challenging without increased conservation or reduced use. Population growth and an increase in irrigated agriculture are expected to be the primary drivers of changes in water use during the next 15 to 20 years in Alachua County. In addition, projections of the 1-in-10-year drought indicate that extended dry periods may increase water demand to satisfy landscape and agricultural irrigation demands. As water sources in the coastal areas of Florida are stressed by SLR and increased demand, the relocation of potable water supply wells further inland could cause additional stresses on the Floridan aquifer throughout North Florida, including Alachua County. This increased demand is further complicated by the current MFL status of waterbodies in and near Alachua County that are already in recovery or prevention.

Wildfire is essential for maintaining native biodiversity and ecosystem processes while having the potential for substantial environmental damage, including significant impacts to silviculture, loss of property, loss of crucial infrastructure, disruptions to traffic, and smoke pollution. Alachua County includes various ecosystems with different fire-risk characteristics. Mitchel et al. (2014) overviewed fire interactions in the southeast United States and how those are likely to be influenced by climate change. The Mitchel et al. assessment of fire risks for some forest and landscape types within Alachua County is summarized as follows:

- Forested Wetlands: Fire risk is linked to hydroperiod and drought. With a short hydroperiod, wetlands burn more frequently. With extended hydroperiods, wetlands experience more severe fires during droughts. In addition, deep histosols (peaty soils) can burn in some cases, creating significant environmental changes through the loss of peat material and accumulation of ash, e.g., the fire in the Santa Fe Swamp in 2007, which resulted in significant water-quality impacts to Lake Santa Fe.

- Pine Flatwoods: Longleaf or slash pine or a mixture of the two dominate these systems, and fires are naturally frequent (3 to 5 years). However, these systems can develop elevated fuel loads when fires are infrequent.
- Planted Pine: Management practices significantly impact these systems. Monocultures of loblolly pine, slash pine, or longleaf pine become susceptible to fire. Long periods of fire suppression combined with drought can enhance this susceptibility.

The Wildland Urban Interface (WUI) is the interface where wildland and forest vegetation meet residential structures and is where wildfire poses the highest risk to people and infrastructure. Radeloff et al. (2018) mapped the WUI change across the United States from 1990 to 2010. The study found that the WUI in Alachua County increased from 300 square miles in 1990 to 383 square miles in 2010. Expanding populations are likely to cause the WUI in the County to continue growing. Many other factors may potentially impact forest systems, such as hurricanes, tropical low systems, and changing species composition. Continued adaptation and improvement of fire management practices could offset some of the projected increases in wildfire risk. Alachua County's continued investment in the *Alachua County Forever* program has resulted in the protection of almost 40 square miles of the County. The change to public management of this land has the significant benefit of the County better managing these new areas – helping to mitigate some of the wildfire risks.

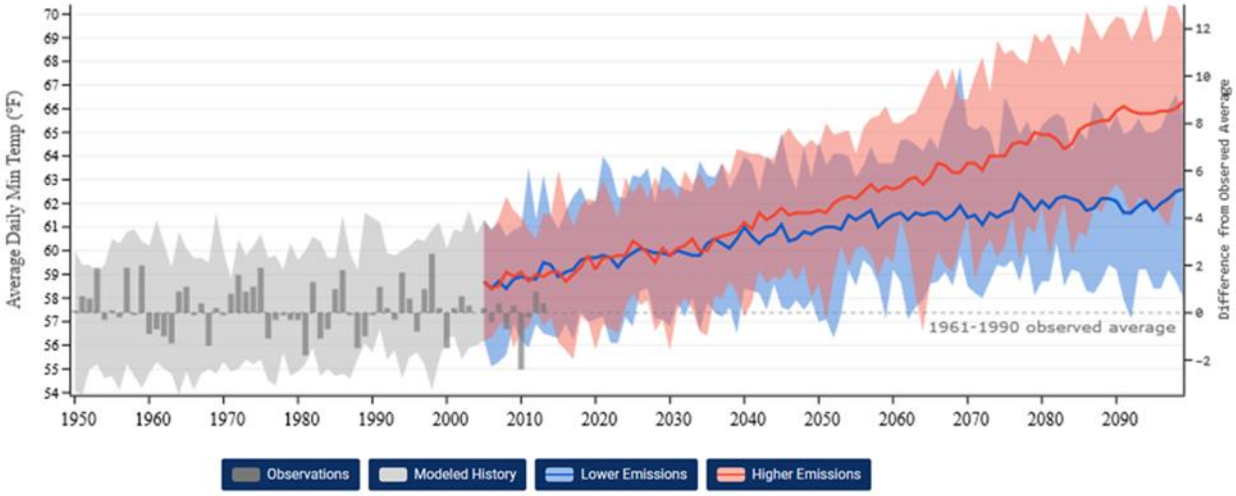
The Jones Edmunds Team reviewed available information regarding crop production in Alachua County. Our review included data from the most recent US Department of Agriculture (USDA) census of agriculture (National Agricultural Statistics Service [NASS], 2017) and the 2022 Alachua County property appraiser. The 2017 USDA census shows that Alachua County had 1,611 farms with a total farmland area of 178,182 acres.

Based on the recent reports from the Intergovernmental Panel on Climate Change (IPCC), we expect that crop production in Alachua County will experience an adverse effect from future climate change. The predicted increased frequency of drought and extreme temperatures in warmer agricultural regions (IPCC 2014, 2021, and 2022) is likely to negatively affect crop production. The relatively low percentage of irrigated cropland in Alachua County will also exacerbate these adverse effects. Therefore, we expect farmers to increase irrigation and fertilizer application to maintain ideal crop production under future climatic conditions or to switch to alternative land uses. This increased irrigation and fertilizer application could result in impacts on groundwater levels, leaching of excess nutrients to groundwater, and additional runoff of nutrients to streams and other waterbodies in the County.

Extreme heat and cold can impact human health, living expenses, and specific industries essential to the economic health of Alachua County. The National Oceanic and Atmospheric Administration’s (NOAA) Climate Explorer summarizes the Coupled Model Intercomparison Project 5 (CMIP5)-based forecasts for temperature changes across the United States. The Climate Explorer uses Representative Concentration Pathways (RCP) 4.5 and RCP8.5 for their projections. They plot trends in the mean climate results and the range in values based on results from multiple CMIP5 models. Figure ES-1 provides an overview of the NOAA Climate Explorer daily minimum temperature projections for Alachua County based on

CMIP5 for RCP4.5 (blue line) and RCP8.5 (red line). The variability in simulated results is shown on the graphs by the blue and red areas.

Figure ES-1 Average Daily Minimum Temperature for Alachua County



The following summarizes the expected trends based on results presented by NOAA:

- The number of very warm nights with a minimum temperature above 80 degrees Fahrenheit (°F) will increase. This increase will significantly impact the number of nights that require air conditioners to run continuously in the summer (ES-1).
- The average daily minimum temperature will increase.
- Warmer summer nights will impact vulnerable populations such as the very young and very old, those who cannot afford to cool their homes, who work outdoors, or who have underlying medical conditions. This increase will also increase the load on the electric grid and raise utility bills (Figure ES-1).
- The annual cooling degree days will increase. Cooling degree days are the number of degrees by which the average daily temperature is higher than 65°F multiplied by the number of days exceeding this threshold. This measure shows the trend in expected energy demand for cooling. In Alachua County, the number of cooling degree days relative to the 1961 to 1990 average will increase by approximately 10 percent under RCP4.5 and by approximately 55 percent assuming RCP8.5.
- The number of freeze days with a minimum temperature of less than 32°F will decrease. This change will result in less than 10 freeze days in 2100 compared to 14 freeze days in 2000.

Extreme precipitation events are expected to increase with climate change, leaving communities near riverine floodplains, low-lying natural areas, and closed basins at a higher risk of flooding. The Jones Edmunds Team reviewed possible changes to extreme precipitation and flood risk and the implications that this may have on design criteria to address the following questions:

- Will the frequency of the current 1-percent flooding (100-year floodplains) change?
- What will the future 100-year storm depth be?
- Will design criteria change, and by how much?

The Jones Edmunds Team reviewed relevant literature and local historical rainfall data to assess the possible change in flood risk. Although the review of historical data did not suggest any conclusive trends, the literature points to a probable future increase in extreme precipitation but uncertainty in the magnitude of changes expected. Additionally, the Team reviewed available studies on rainfall Change Factors (CFs), which are multipliers that flood management and stormwater professionals use to estimate the shift in rainfall volume associated with return periods (frequency) and storm durations. Table ES-1 outlines the results from this review. In the future, we expect regulatory agencies to consider changes to design criteria associated with rainfall distribution patterns, groundwater levels, and antecedent moisture as research into climate change continues and more data become available.

Table ES-1 Comparison of Rainfall Volumes for Existing Environmental Resource Permit (ERP) Guidance Manuals, NOAA Atlas 14 Data, and Rainfall CFs

Design Event (return period, duration	Rainfall Volume, inches			
	Associated with ERP Manual Guidance for SRWMD and SJRWMD[1,2]	NOAA Atlas 14, Version 2, Station: Gainesville 3 WSW		
		Current[3]	2030 to 2069: For the Range of CFs of the 50th to 83rd Percentiles[4]	2060 to 2099: For the Range of CFs of the 50th to 83rd Percentiles[4]
10-year/1-day	7.92	5.91	6.44 – 8.16	6.56 – 8.45
25-year/1-day	7.75	7.28	8.01 – 11.14	8.23 – 11.58
100-year/1-day	11.04	9.84	10.92 – 17.61	11.41 – 18.89
100-year/3-day	13.80	13	14.69 – 21.71	15.08 – 22.75
100-year/7-day	16.00	14.5	16.68 – 23.49	16.68 – 25.67
100-year/10-day	18.00	15.3	17.75 – 25.55	17.60 – 28.46

Notes:

1 - Rainfall volumes in the ERP manual are those listed for Alachua County in SRWMD's *Environmental Resource Permit Applicant's Handbook Volume II*. SRWMD provides consistent rainfall depths for Taylor, Lafayette, Dixie, Gilchrist, Levy, Bradford, and Alachua Counties. These depths are based on FDOT values through durations of 24 hours, and durations greater than 24 hours are based on the NWS TP No.49 (1964). By grouping Alachua Counties with coastal communities, SRWMD design rainfall depths significantly exceed other design rainfall depth requirements.

2 - Rainfall volumes for 25-year/1-day estimated based on acceptable sources listed in the SJRWMD Permit Information Manual: NWS TPs No. 40 (1961) and No.49 (1964).

3 - *Current* = NOAA Atlas 14 Volume 9 Version 2 Point Precipitation Estimates from Station Gainesville 3 WSW.

4 - CF data for Climate Division 2 from the FIU report titled *Updating the Statewide Extreme Rainfall Projections* (Obeysekera et al., 2021). CF data shown is from LOCA and MACA climate model datasets only. CORDEX data were excluded due to bias correction errors (LOCA, MACA, and CORDEX are downscaled GCMs.

1 BACKGROUND

Alachua County is concerned about the impact of climate change on its critical infrastructure and natural resources and the wellbeing of County citizens and their property. To help evaluate these impacts, the County is completing a critical infrastructure and land use climate vulnerability analysis. Primary climatic impacts in the County will most likely be altered flooding conditions due to changing rainfall volume, frequency, and intensity. In addition, projected changes to seasonal rainfall patterns and evapotranspiration (ET) could change groundwater levels and may adversely affect water levels in lakes; flows in rivers, springs, and other natural systems; drinking water availability; agricultural production; and wildfire risk due to dry conditions. Extreme temperature events that may accompany seasonal climate shifts may also impact the health of residents. Finally, as an inland county, Alachua County may be a destination for citizens relocating from coastal or higher risk areas, placing additional stresses on physical and social infrastructure and land use. This project aims to determine, to the best extent possible, the future conditions that the County and its incorporated municipalities may face due to climate change.

The County selected the Jones Edmunds Team to conduct this vulnerability analysis. This *Projected Impacts Report* is the first phase of the vulnerability analysis and summarizes the likely climate change impacts to Alachua County based on the most recent literature and regional studies. This review provides the County with a qualitative overview of the current literature. The County did not expect the report to be an exhaustive literature review. The Jones Edmunds Team will conduct a more detailed analysis of the threats identified in this report during later project phases.

The Jones Edmunds Team reviewed multiple reports evaluating impacts due to climate change. The sources we reviewed based their evaluations on many climate change scenarios. These climate change scenarios can generally be described using the following terms:

- Representative Concentration Pathways (RCPs) – These are scenarios based on a defined set of emissions and concentrations of greenhouse gases, aerosols, and chemically active gases and land cover assumptions that lead to a heating effect called radiative forcing. For example, RCP4.5 is one pathway that leads to a radiative forcing of 4.5 Wm^{-2} by 2100.
- Shared socio-economic pathways (SSPs) – These scenarios represent pathways based on possible socioeconomic 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 Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment has combined SSPs with radiative forcing. For example, IPCC used SSP2-4.5 to define a shared socio-economic pathway that leads to a peak radiative forcing of 4.5 Wm^{-2} by 2100. As part of Task 3 of this study, the County will need to select an SSP/RCP to use for planning.

2 SEASONAL CHANGES IN PRECIPITATION AND DROUGHT

2.1 PRECIPITATION

Understanding the future impact of climate change on precipitation is an essential but complex aspect of planning at the local governmental scale. The relatively coarse spatial resolution of general circulation models (GCMs), a climate model of atmospheric circulation, coupled with the natural variability in precipitation in Florida, creates uncertainty in future predictions. The following is a brief review of relevant literature regarding future precipitation and drought, emphasizing the challenges and uncertainties associated with predicting future rainfall patterns.

GCMs are typically built at resolutions that are too coarse to capture the narrow Florida peninsula and do not effectively represent the convective rainfall processes. Therefore, these models are generally unskilled at predicting future precipitation (Obeysekera, et al., 2011; Chassignet, Jones, Misra, & Obeysekera, 2017; Misra, et al., 2011; Obeysekera, Sukop, Troxler, & John, 2021). Regional Climate Models (RCMs), which use GCMs for boundary conditions, represent regional areas at a finer scale but are typically more computationally intensive (Obeysekera, Sukop, Troxler, & John, 2021). Efforts to downscale GCMs with statistical and dynamical downscaling methods have resulted in improved precipitation predictions but still include significant uncertainties (Obeysekera, et al., 2011; Chassignet, Jones, Misra, & Obeysekera, 2017; Obeysekera, Sukop, Troxler, & John, 2021).

Florida has a humid subtropical to tropical climate characterized by generally wet conditions in summer and drier conditions in winter. Rainfall is highly variable in Florida, which is due in part to interannual and decadal variability (South Florida Water Management District, 2021; Chassignet, Jones, Misra, & Obeysekera, 2017; Misra, et al., 2011). Climate phenomena, such as the El-Niño Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multidecadal Oscillation (AMO), affect Florida and can impact large areas in complex manners (Obeysekera, et al., 2011). Due to the large spatial and temporal scales they affect, these climate phenomena can be complicated to understand and model. Therefore, changes in rainfall due to anthropogenic climate change can be challenging to discern from these natural interannual, decadal, and multi-decadal variations (Misra et al., 2011; Seager, Tzanova, & Nakamura, 2009; South Florida Water Management District (SFWMD), 2021). The ENSO interannual variability and PDO decadal variability play a large part in the inconsistency of winter precipitation patterns in Florida (Chassignet, Jones, Misra, & Obeysekera, 2017; Misra, et al., 2011). The AMO multi-decadal variability is more difficult to predict and impacts summer precipitation (Chassignet, Jones, Misra, & Obeysekera, 2017). No conclusive findings are in the literature on expected change to characteristics of ENSO or PDO due to anthropogenic climate change (Misra, et al., 2011).

The consensus in the literature we reviewed is that climate change will have various impacts across Florida. We can generally group these changes into those with a higher degree and those with a lower degree of confidence in the expected trend. Within each category, the magnitude of change is less certain and generally depends on the GCM simulation considered. In the category of a high degree of certainty in the expected trend, general agreement is that:

- Temperatures in Florida will continue to increase and sea levels will continue to rise (South Florida Water Management District 2009; Misra et al. 2011; Jayantha Obeysekera, Barnes, and Nungesser 2015; Her et al. 2017; L. M. Carter et al. 2014).
- Trends in observed data and models of future scenarios shows that rainfall depths associated with tropical systems will increase (Gori et al., 2022, Trenberth 2018). In addition, trend analysis of rainfall stations and model simulations shows an increase in the number of larger precipitation events (McNulty et al., 2015; Lynne M. Carter et al., 2018; Wang et al., 2010; Bloetscher 2009; Chen et al., 2014; South Florida Water Management District, 2009). Trend analysis for rainfall stations also showed an increase in higher intensity rainfall events and a decrease in the number of lower intensity rainfall events (Wang et al., 2010; LM Carter et al., 2018; Her et al., 2017). Figure 2-1 shows an example of this trend.
- The distribution of rain within the year will become less consistent for Florida with potentially drier springs and summers and wetter winters (Misra et al., 2011; Her et al., 2017; J. Obeysekera et al., 2011; McNulty et al., 2015). Several studies have also discussed the potential for increases in the severity of wet and dry periods (South Florida Water Management District, 2009; Bloetscher, 2009; Emrich et al., 2014; Berry et al., 2011). The literature also agrees that total monthly rainfall will increase marginally during the dry season and decrease during the wet season for Florida (National Oceanic and Atmospheric Administration [NOAA], Environmental Protection Agency [EPA], National Aeronautics and Space Administration [NASA], US Geological Survey [USGS], FernLeaf Interactive, 2021; Chassignet, Jones, Misra, & Obeysekera, 2017; Irizarry et al., 2011; Misra et al., 2011; Obeysekera et al., 2011; Carter et al., 2018).
- With prevailing warmer temperatures, ET will increase (Georgakakos, Zhang, and Yao, 2010; Misra et al., 2011; South Florida Water Management District, 2009; J. Obeysekera et al., 2011; Berry et al., 2011). These ET increases will potentially contribute to drier conditions and additional competition for water supply, especially during prolonged dry periods (Berry et al., 2011; Misra et al., 2011). Trend analysis also showed that the daily temperature range had decreased rapidly, with daily minimum temperatures rising three times faster than daily maximum temperatures (J. Obeysekera et al., 2011; LM Carter et al., 2018).

In the category of a low degree of certainty in direction is:

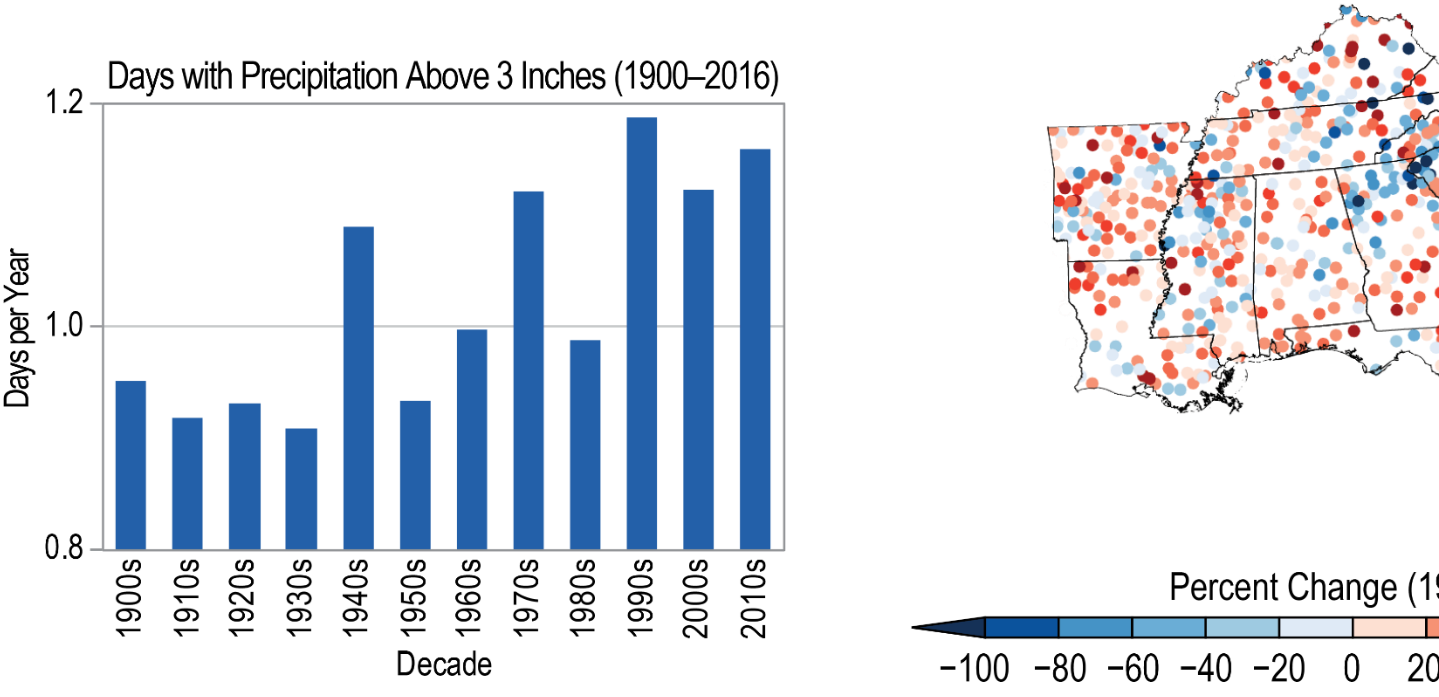
- Average annual rainfall with projected increases or decreases depending on the model simulation and area of the state (J. Obeysekera et al., 2011; Hovenga et al., 2016; Her et al., 2017; Georgakakos, Zhang, and Yao, 2010; Jayantha Obeysekera, Barnes, and Nungesser, 2015). However, the literature shows that GCMs do not accurately represent Hurricanes (Emanual, 2013) or represent extreme rainfall (Kendon et al., 2014) responsible for a significant portion of the annual rainfall in Florida.
- The change in frequency of hurricanes is uncertain. Some research shows that the number of hurricanes each year will decrease because of increased wind shear (sudden change in wind velocity) over the Atlantic that reduces the likelihood of storms being able to form, while other research shows that the number of major storms (Categories 4

and 5) will increase by 2100 (Emrich et al., 2014; Misra et al., 2011; Bender et al., 2010; Bhatia et al., 2018).

The literature reveals a lack of confidence regarding changes to total annual precipitation due to climate change. Some models and historical trend analyses report an increase in annual rainfall for the east and southeast United States and North Florida (Intergovernmental Panel on Climate Change (IPCC), 2021; Seager, Tzanova, & Nakamura, 2009; Obeysekera, et al., 2011). Other models predict possible decreases or increases in annual precipitation in Florida or the southeast United States depending on the climate change scenario and the period of projection (near- or long-term) (Chassignet, Jones, Misra, & Obeysekera, 2017; NOAA, EPA, NASA, USGS, FernLeaf Interactive, 2021; Maliva, Manahan, & Missimer, 2021).

The US Climate Resilience Toolkit Climate Explorer (Version 3.1) provides spatial and graphical tools to examine historical and potential future precipitation for Alachua County (https://crt-climate-explorer.nemac.org/). The website reports very little change in total annual rainfall for low- and high-emission scenarios when comparing the modeled history from 1961 to 1990 to the low- and high- emissions scenario from 2035 to 2090.

For Alachua County, Figure 2-1 Figure from Cater et al. (2018) showing change in number of extreme recorded rainfall events across the Southeast



The figure shows variability and change in (left) the annual number of days with precipitation greater than 3 inches (1900–2016) averaged over the Southeast by decade and (right) individual station trends (1950–2016). The number of days with heavy precipitation has increased at most stations, particularly since the 1980s. Sources: NOAA NCEI and CICS-NC.

Figure 2-2 shows that the US Climate Resilience Toolkit Climate Explorer predicts this same trend of increased dry-season rainfall and decreased wet-season rainfall with high uncertainty (NOAA, EPA, NASA, USGS, FernLeaf Interactive, 2021). Figure 2-1 Figure from Cater et al. (2018) showing change in number of extreme recorded rainfall events across the Southeast

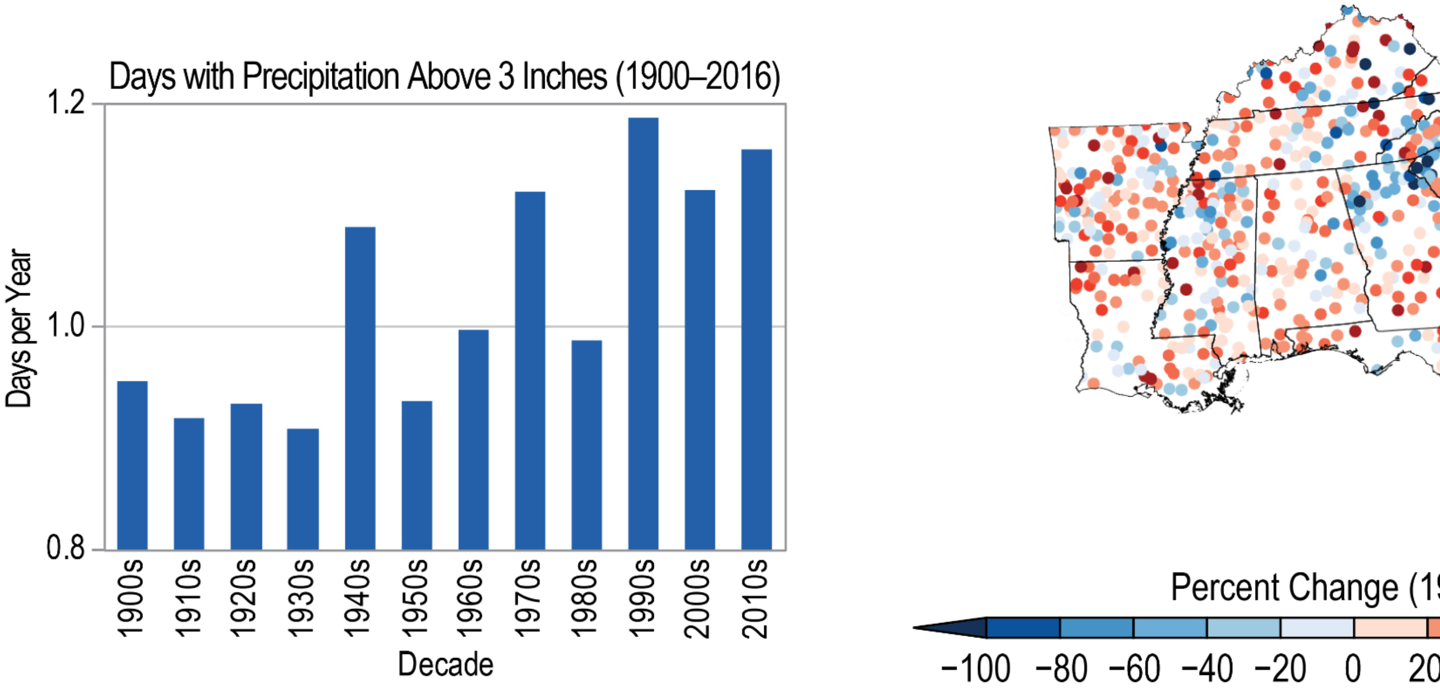


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Figure 2-2 shows Total Monthly Precipitation averaged for 2060 to 2090 for lower emissions (blue line) and higher emissions (red line) scenarios compared to the 1961 to 1990 observed average (black line). The modeled history, which is shown in the legend, is not displayed in or available for this figure. The shaded red and blue areas show the range of results from various models used for the predictions – indicative of the high level of uncertainty associated with future precipitation predictions (February 2021: https://crt-climate-explorer.nemac.org/). The Climate Explorer shows similar high levels of uncertainty and low changes in projected monthly rainfall for the period from 2010 to 2040 and the period from 2035 to 2065.

Figure 2-1 **Figure from Cater et al. (2018) showing change in number of extreme recorded rainfall events across the Southeast**

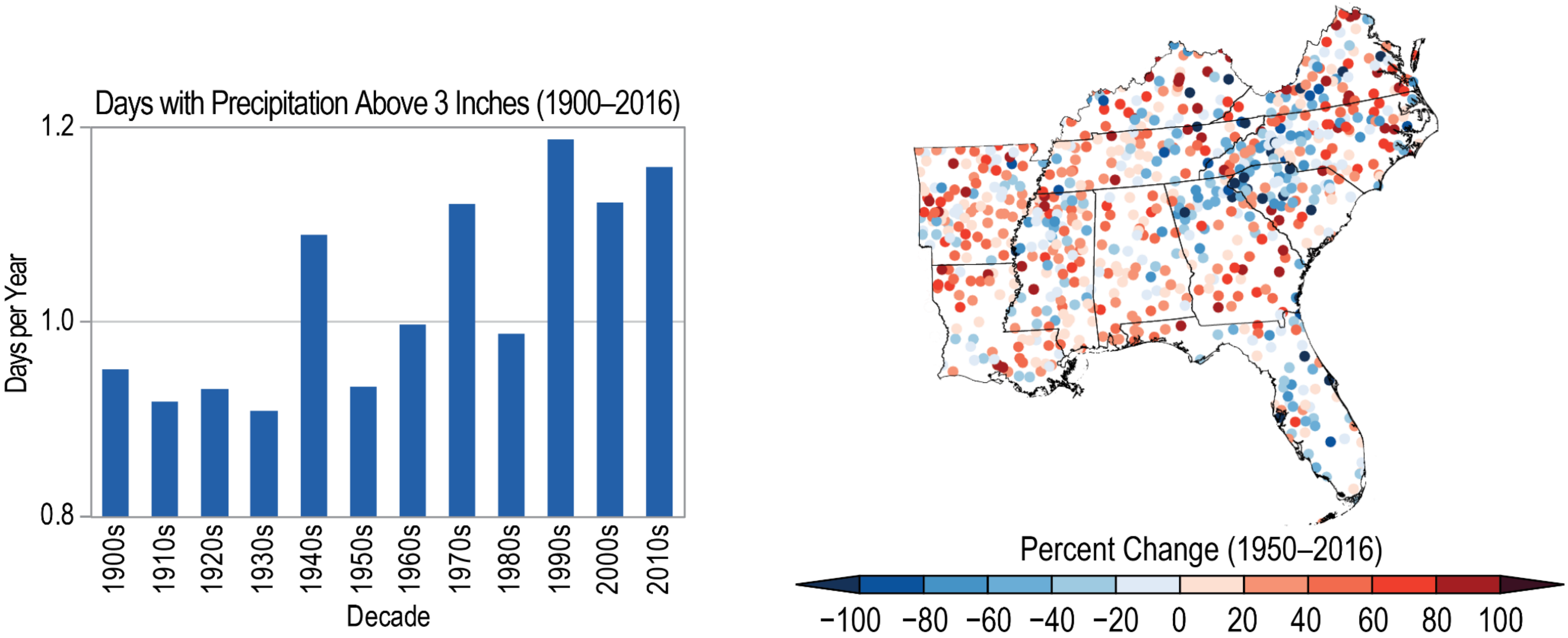

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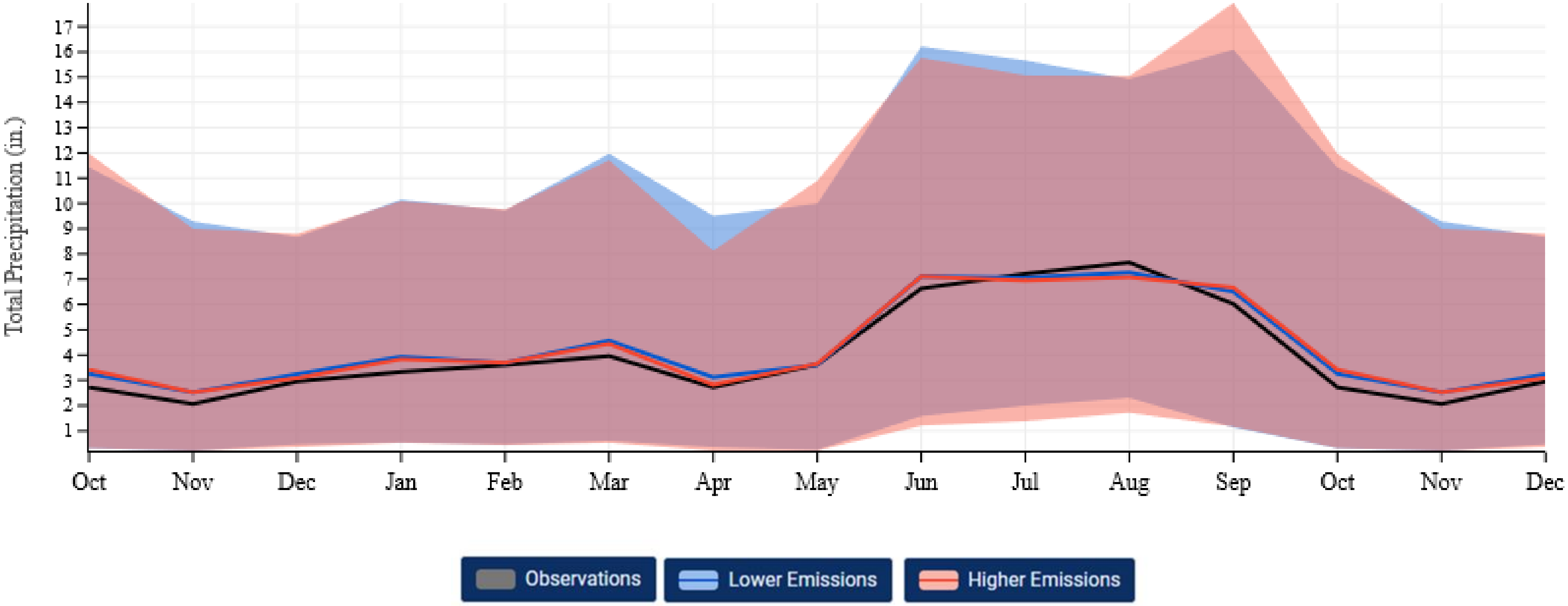
Figure 2-2 Total Monthly Precipitation for Alachua County Averaged for 2060 to 2090 from the US Climate Resilience Toolkit Climate Explorer (February 2021: https://crt-climate-explorer.nemac.org/).



2.2 DROUGHT

The literature suggests that climate change will result in higher temperatures and increases in the duration and intensity of drought for the southeast United States (Carter, et al., 2018; Misra, et al., 2011). The models also predicts subtropical drying with climate change driven mainly by an increase in evaporation (due to increases in mean temperature) rather than a reduction in precipitation (Seager, Tzanova, & Nakamura, 2009). Our literature review identified many indexes that have been used to quantity 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. Figure 2-3 and Figure 2-4 show the projected change in the maximum number of consecutive dry days each year for Shared Socioeconomic Pathway 2-4.5 (SSP2-4.5) and SSP5-8.5 (IPCC, 2021). These figures show no clear trend in consecutive dry days under SSP2-4.5 but an increase in consecutive dry days under SSP5-8.5.

2.3 SUMMARY

Based on the literature reviewed by the Jones Edmunds Team, we expect climate change to have the following effects on the climate in Florida by 2100, with relative confidence noted in parenthesis:

- Increased temperatures across the state (high).
- Increased freeze-free season (high).
- Increased sea levels along Florida's coastlines (high).
- Changes to average annual precipitation (low).
- Increased frequency of higher intensity rainfall events (high).
- Less frequent small rainfall events (low).
- More extended inter-event dry periods (low).
- More severe wet periods and droughts (more significant variability) (low).
- Compressed average daily temperature range due to increased daily minimum temperature (high).
- Increased ET due to higher temperatures (high).
- Decreased tropical system activity but increased severe tropical system (Categories 4 and 5) activity (medium).

Figure 2-3 Change in Consecutive Dry Days for the Southeast United States for SSP2 (IPCC, 2021)

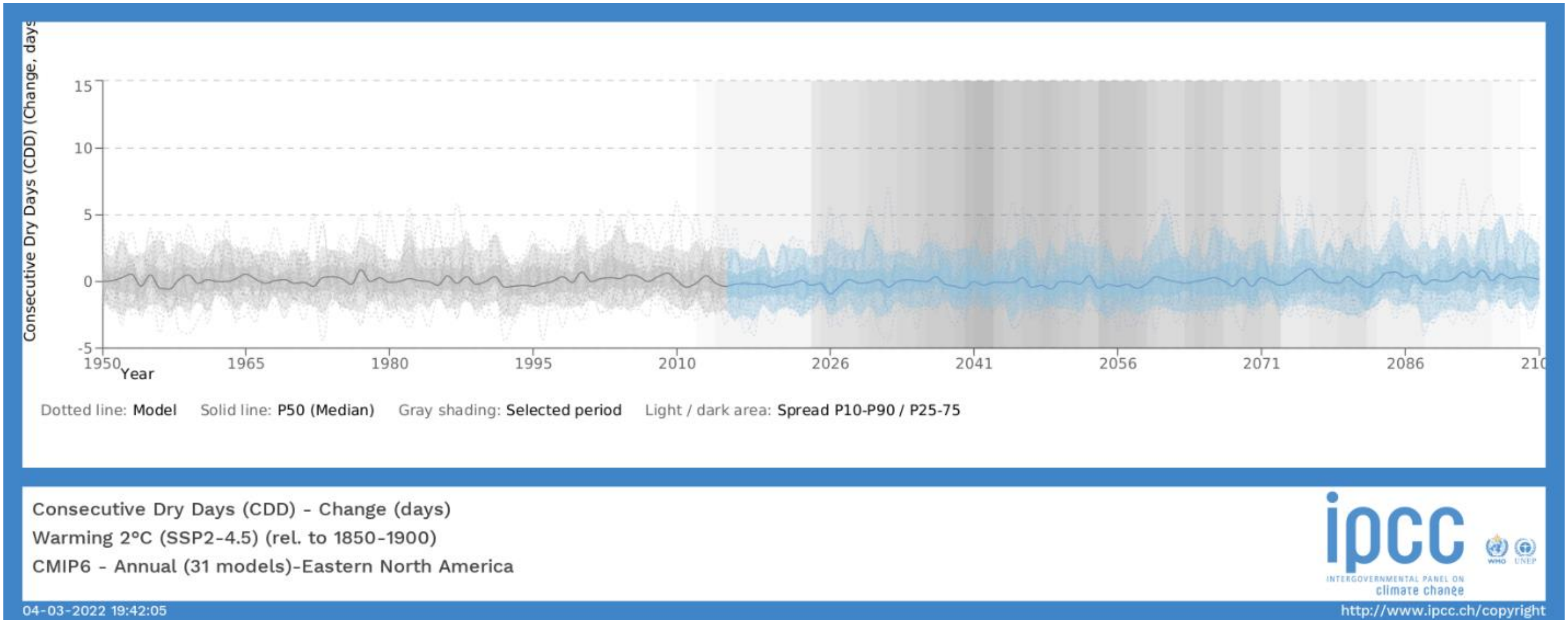
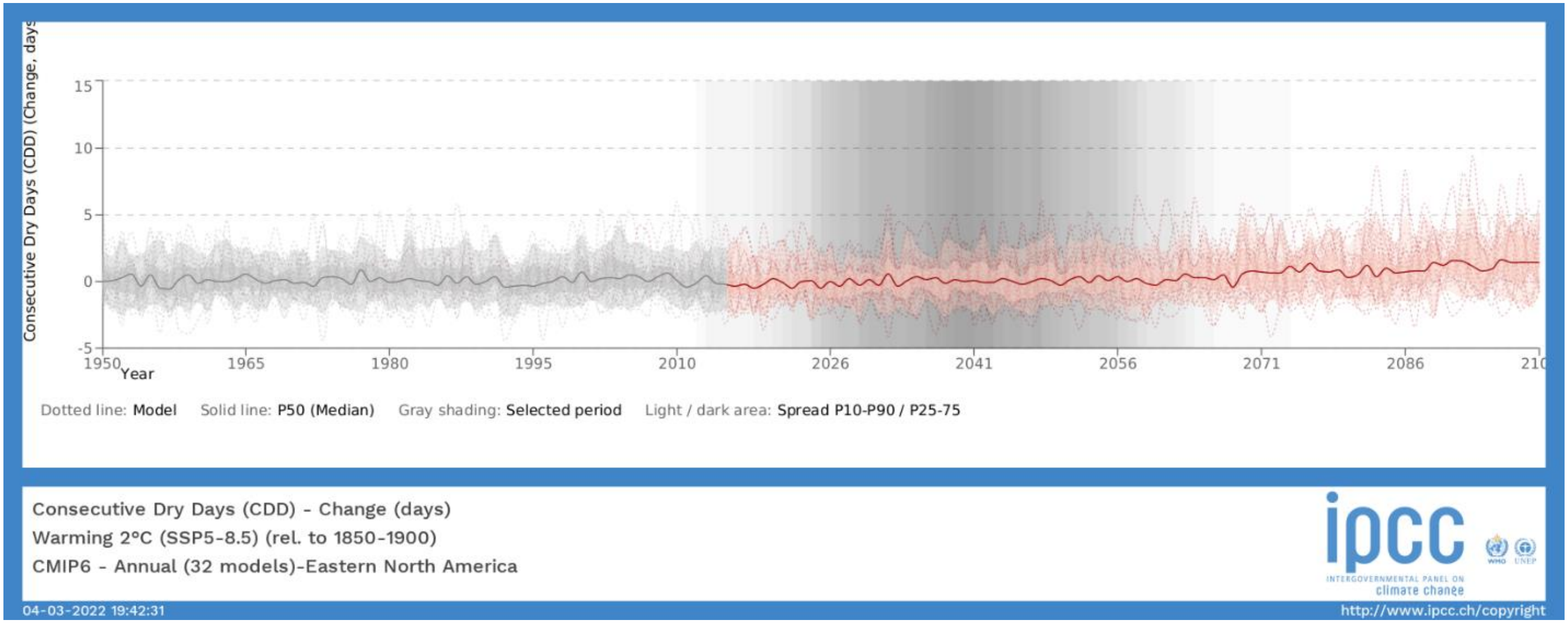


Figure 2-4 Change in Consecutive Dry Days for the Southeast United States for SSP5 (IPCC, 2021)



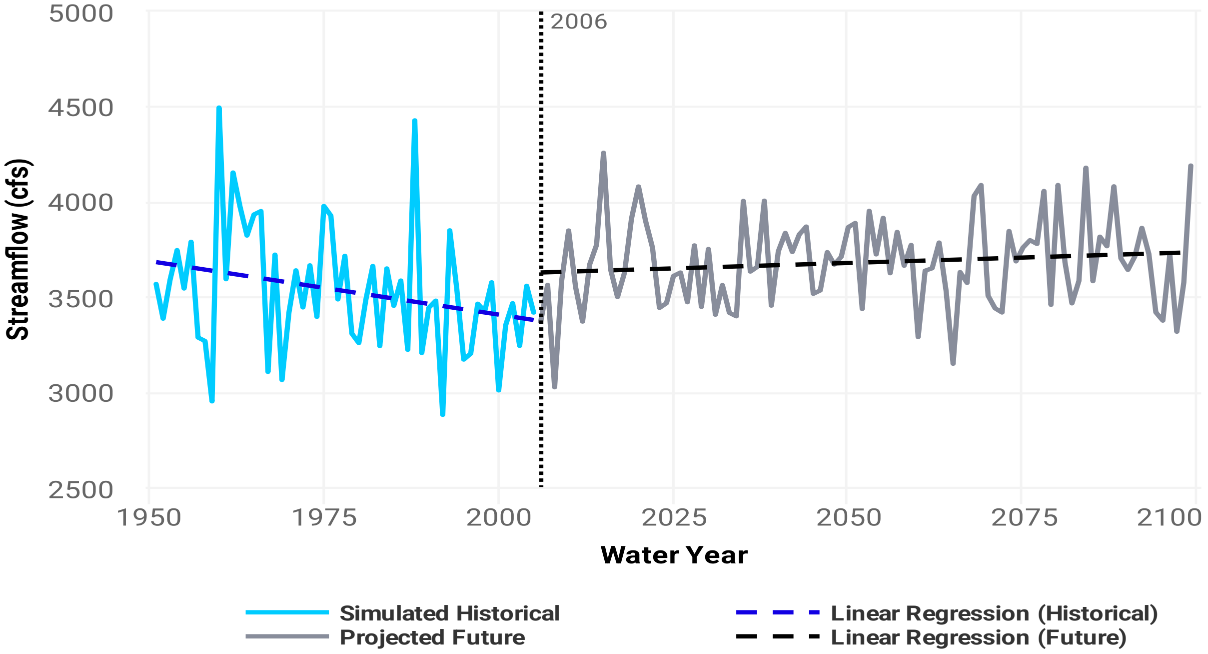
Consecutive Dry Days (CDD) - Change (days)
Warming 2°C (SSP5-8.5) (rel. to 1850-1900)
CMIP6 - Annual (32 models)-Eastern North America

3 CHANGES TO SURFACE WATER AND GROUNDWATER HYDROLOGY

One or more aquifers generally underlie Florida, with the Floridan Aquifer being the primary water-producing aquifer in Alachua County and across most of the state. The west portion of the Panhandle, where the Sand and Gravel Aquifer is the primary water-producing aquifer, and in South Florida, where the Biscayne Aquifer is the primary water-producing aquifer, are exceptions. Rainfall is the primary source of water for these aquifers. Rainfall infiltrates in areas of higher aquifer recharge and lower aquifer confinement or directly recharges in sinkholes or swallets. Florida's surface hydrology is driven mainly by combined rainfall-derived runoff, shallow sub-surface drainage/baseflow, ET, and spring flow depending on the part of the state. This water generally feeds into progressively larger riverine systems, such as the Santa Fe River in Alachua County, until reaching the Gulf of Mexico or the Atlantic Ocean.

The United States Army Corps of Engineers (USACE) Climate Hydrology Tool (CHAT) provides simulated historical and projected changes to streamflow based on climate data generated by Coupled Model Intercomparison Project 5 (CMIP5). The CHAT provides a time series of simulated annual maximum of monthly streamflow as well as an analysis of histrocila and projected trends. These time series were based on 64 Climate-Change hydrology models developed by USACE. Figure 3-1 shows the trend analysis for the Santa Fe Basin, which covers a large portion of Alachua County. The CHAT shows a statistically significant decreasing trend in the annual maximum of average monthly flows for simulated historical period, but not a statistically significant trend in the projected flows until 2100.

Figure 3-1 Trends in Mean Annual Maximum of Average Monthly Streamflow for the Santa Fe Basin based on the USACE CHAT



Obeysekera et al. (2017) summarizes climate change studies for major water resource systems in Florida, including the Everglades, the Tampa Bay region, the St. Johns River watershed, and the Suwannee River and Apalachicola River basins. Some of the key points highlighted were:

- Water resources are an integral contributor to Florida's economy, but population growth in the state is causing increasing competition for water supply among the urban, agricultural, and environmental sectors.
- Climate change along with rising sea levels will exacerbate the competition for water.
- Although climate models predict a consistent increase in future temperatures (increasing ET), precipitation is not yet consistently predicted and could be higher or lower. Differences in rainfall propagate significant differences in future streamflow, and groundwater levels.
- Assessments completed on large-scale, regional basins in the state demonstrate that future climate change can significantly impact water quantity and quality.
- Potential increases in temperature and variations in precipitation patterns may degrade water quality, exacerbate algae problems, and cause eutrophication of important water bodies.

The St. Johns River Water Management District (SJRWMD) completed the St. Johns River Water Supply Impact Study (WIS) in 2012 that evaluated the potential environmental effects of proposed withdrawals from the St. Johns and Ocklawaha Rivers. As part of the WIS, SJRWMD evaluated climate change impacts on the St. Johns River, including those parts of Alachua County that drain to the St. Johns River. The WIS found minimal changes to runoff hydrology in 2030. However, the WIS found that in 2100, combined reduced rainfall amounts and increased ET led to decreased surface-water flows in some watersheds. In others, projected increased rainfall resulted in increased flows. They also noted that some watersheds showed increased floods but small changes in middle and lower flows.

Limited studies of groundwater impacts to the Alachua County region associated with climate change are available. However, Zhang (2015) reviewed the impacts of climate change on groundwater more broadly and noted that groundwater systems can be robust due to storage capacity and the conjunctive management of surface and groundwater, which allows for reducing the risk associated with climate change (Zhang, 2015). Direct impacts of climate change on groundwater are expected to be primarily related to sea-level rise (SLR) in coastal areas (Berry et al., 2011; Jayantha Obeysekera, Barnes, and Nungesser, 2015; Misra et al., 2011; LM Carter et al., 2014; Her et al. 2017; South Florida Water Management District, 2009). Prolonged droughts may also increase reliance on groundwater causing impacts to aquifer levels from withdrawals (Misra et al. 2011; Emrich et al. 2014; Berry et al., 2011).

The North Florida Regional Water Supply Plan (NFRWSP) (SJRWMD, SRWMD; 2017) covers water supply planning for the Suwannee River Water Management District (SRWMD) and SJRWMD, encompassing Alachua County. The NFRWSP notes that an increase in the intensity of rainfall events and the duration of drought from climate change are projected impacts to water-supply planning. The NFRWSP states that it addresses climate change through the same practices used to address water resource constraints, which include:

- Decreasing groundwater demand (e.g., increase the use of reclaimed water and maximize water conservation).
- Improving efficiency (e.g., agricultural irrigation upgrades; distribution system repairs).
- Improving infrastructure capacity and flexibility (e.g., interconnecting water supply systems).
- Diversifying water supply sources.

The NFRWSP references the Florida Water and Climate Alliance (FWCA) as a venue for collaboration to address water supply challenges associated with climate change. Water resource impacts from future demand scenarios were evaluated using the draft North Florida-Southeast Georgia (NFSEG) regional groundwater model. The NFSEG model included a 1-in-10 drought event for 2035 but did not consider climate change.

Also of interest are the water-quality impacts expected under a changing climate because of surface-water and groundwater hydrology changes. We expect these to include:

- Increasing harmful algal blooms (HABs) associated with higher temperatures (L.M. Carter et al., 2014; Coastal Resilience Partnership of Southeast Palm Beach County, 2021; Lettenmaier, 2008).
- Possible additional runoff of suspended solids and nutrients entering waterbodies associated with more significant rainfall events and increased runoff (Chen et al., 2014; Jayantha Obeysekera, Barnes, and Nungesser, 2015; Lettenmaier, 2008).
- Lower dissolved oxygen levels and warmer water temperatures due to increased temperatures (EPA's *Watershed Academy*).
- Shrinkage of water bodies due to increased ET. We would expect decreased volumes of waterbodies to be associated with increases in concentrations of conservative water quality parameters including: specific conductance, chlorides, metals, potentially some nutrient forms.

The following summarizes the expected impacts on surface and groundwater hydrology in Alachua County based on the Jones Edmunds Team's review of existing studies:

- Surface waters are likely to experience higher peak flows due to more intense rainfall.
- More intense, less frequent rainfall will lead to a higher percentage of runoff with less infiltration and potentially lower aquifer levels.
- Flooding is likely to occur more frequently due to more intense rainfall events and larger tropical systems. Changes in long-term rainfall and ET could change wet-season water levels in closed basins, average soil moisture conditions, and water tables resulting in different antecedent conditions, which could affect flooding.
- Median flows are likely to decrease due to more extended inter-event rainfall periods.
- Increased ET will contribute to drought severity.
- More extended or frequent droughts will cause ecological shifts in marginal wetland areas.
- Sinkhole incidence could increase if extreme droughts significantly decrease aquifer levels or groundwater levels change more rapidly than under current conditions. Changes in groundwater levels combined with high-intensity rainfall events that

generate increased runoff depths and accumulation in stormwater basins and depressional areas could further increase the incidence of sinkhole formation.

- Degraded water quality is likely because of increased temperatures and changes to rainfall patterns.
- There is the potential for changes in the prevalence of some invasive exotic species including both plants and animals. This is particularly true for species that are highly impacted by freezing which could experience range expansion with reduced frequency of freeze events.

4 ALACHUA COUNTY FLOODING

This Section summarizes historical and current flood conditions assembled from previous hydrologic studies and local knowledge. Section 10 covers the predicted changes to extreme precipitation due to climate change. The figures in this Section show areas that have reported flooding issues. The Jones Edmunds Team will use these identified areas during future project tasks to assess the results of the threat analyses and current and future inundation mapping.

Alachua County consists of a variety of hydrologic systems with different flood characteristics, including:

- High-gradient streams and creeks that are most sensitive to local high-intensity rainfall.
- Large prairie systems such as Paynes Prairie that are most sensitive to long-term seasonal changes in rainfall and surficial aquifer levels.
- Closed basins that are sensitive to multi-day rainfall volumes.
- Large riverine systems such as Santa Fe River that are sensitive to regional rainfall.

Four main hydrologic basins are in Alachua County:

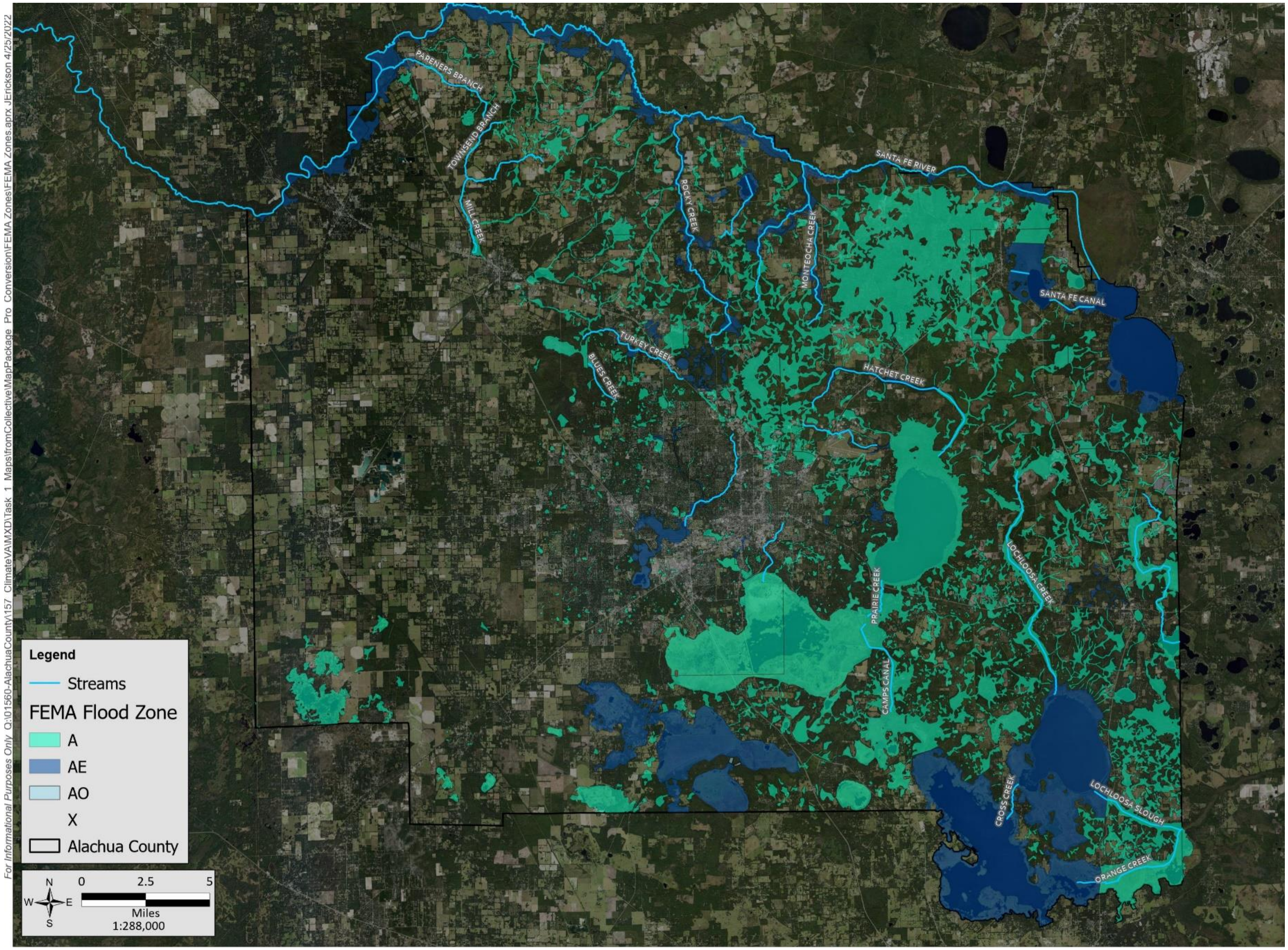
- Orange Creek Basin – Drains south and east toward the St. Johns River Basin.
- Santa Fe River Basin – A significant tributary of the Suwanee River along the north County line.
- Florida Ridge and Waccasassa River Basins – Drain into smaller water bodies south of the County that are also part of the Suwanee River Basin. Watersheds that drain into these systems flow via surface-water streams and canals or into sinkholes, depressions, or ponds that connect to the river systems via the groundwater system.

A significant portion of flooding in Alachua County is due to closed basins experiencing long-duration or high-volume storms. Since these closed basins discharge mainly through percolation, they typically experience flooding when the upper Floridan aquifer is elevated and percolation capacity is limited.

The Federal Emergency Management Agency (FEMA) noted that severe flooding in Alachua County usually occurs due to hurricanes as streams overflow into the adjacent low-lying areas (FEMA, 2021). **Error! Reference source not found.** shows the FEMA Special Flood Hazard Areas in Alachua County:

- Zone A are areas subject to 1-percent-annual-chance flooding, without Base Flood Elevations (BFEs) being determined.
- Zone AE are areas subject to 1-percent-annual-chance flooding, with BFEs determined.
- Zone AO are areas subject to 1-percent-annual-chance flooding with shallow flooding depths of 1 to 3 feet.

Figure 4-1 Key High Risk FEMA Flood Zones in Alachua County Flood Insurance Study (FIS) (September 24, 2021)



The FEMA FIS notes that significant waterbodies that have flooded are:

- Santa Fe Lake, Lake Alto, and the Waldo Canal (impacting Waldo).
- State Fe River, affecting Worthington Springs (just north of the Alachua-Union County line) and High Springs.
- Kanapaha Prairie, Paynes Prairie, and Levy Lake (impacting US Highway 441 resulting in road closures).

One of the project initiatives listed in the *Suwannee River Basin Surface Water Improvement and Management Plan* (ESA, 2017) is a Prairie Creek Diversion Structure Replacement. This structure, operated by the Florida Park Service, is intended to help reduce the frequency of flooding on US 441.

The *Alachua County Stormwater Master Plan* (SWMP) (Inwood, 2009) divided the County into 69 watersheds, excluding watersheds predominantly in the City of Gainesville. The SWMP provides details on areas in each watershed where the County identified localized flooding problems. Many of these are reoccurring problem areas that flooded during the 2004 hurricanes including structural flooding and significant roadway overtopping (Inwood, 2010). Figure 4-1 shows the watersheds color-coded by the number of flood locations identified with the highest numbers concentrated just west of the City of Gainesville. The SWMP also identified 18 high-priority areas and developed projects to improve the stormwater systems. Figure 4-2 shows that most of these projects are between NW 39th Avenue and SW 24th Avenue, east and west of Interstate 75. Gainesville was not part of the County SWMP.

Most of Gainesville's watersheds are part of the Orange Creek Basin. Previous hydrologic studies in this area have focused on flooding and the hydrologic impacts on water quality, particularly low water levels (Alachua County, 2007; Lippincott Consulting, 2011). Watershed Management Plans for Tumblin Creek (Jones Edmunds, 2004) and Sweetwater Branch (Jones Edmunds, 2004) include analysis of flooding, water quality, and erosion issues caused by significant rainfall events. The City of Gainesville maintains a geographic information system (GIS) database with flood locations and high-water marks for specific events. Figure 4-3 shows areas of reported flooding.

Hurricane threats to the County – noted by news sources during recent years – are evidence that ongoing flood issues are persistent countywide. For example, after Hurricane Irma in September 2017, press releases described Alachua County's extended mandatory evacuations for communities in the floodplain adjacent to the Santa Fe River and for properties adjacent to creeks, rivers, and streams north of northwest US 441. Impacted communities included High Springs, the City of Alachua, and the Town of Lacrosse (Hurricane Irma – River Flooding (alachuacounty.us)). This riverine flooding generally occurred 3 to 4 days after Hurricane Irma and was caused by heavy rain in the Santa Fe River Basin.

Figure 4-1 Number of County-Identified Problem Areas (Inwood, 2009)

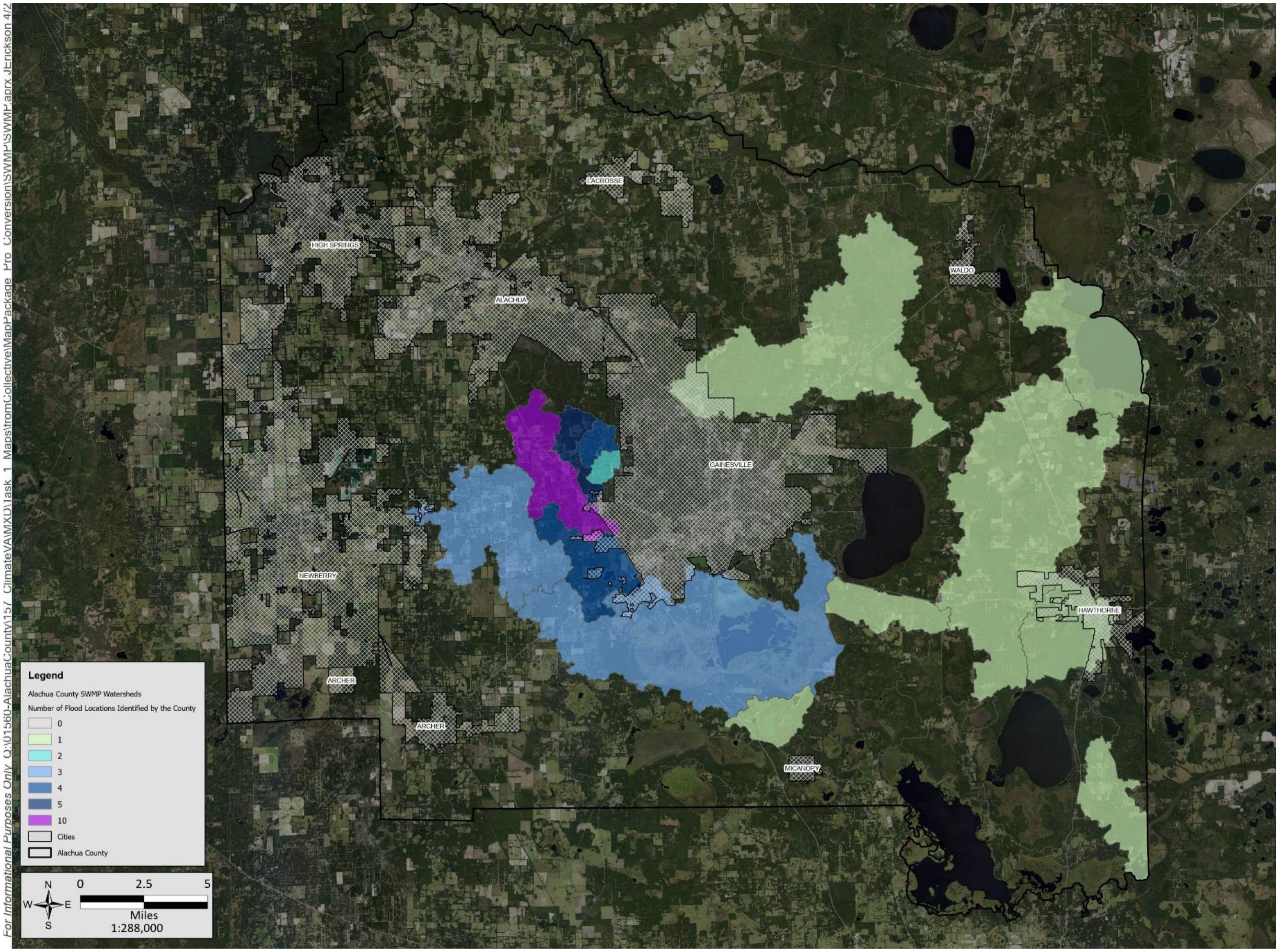


Figure 4-2 County High-Priority Flood Problem Areas (Inwood, 2010)

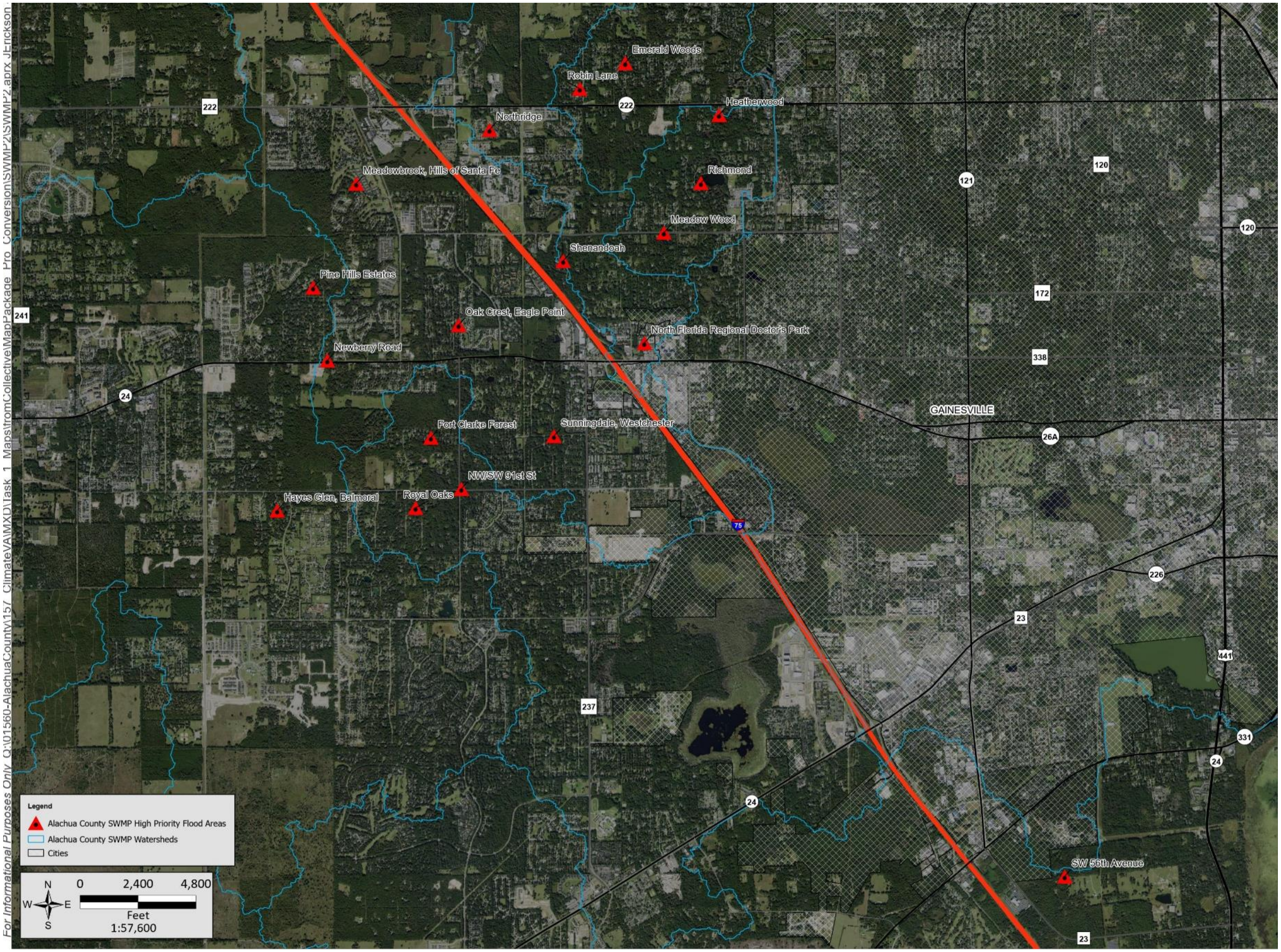
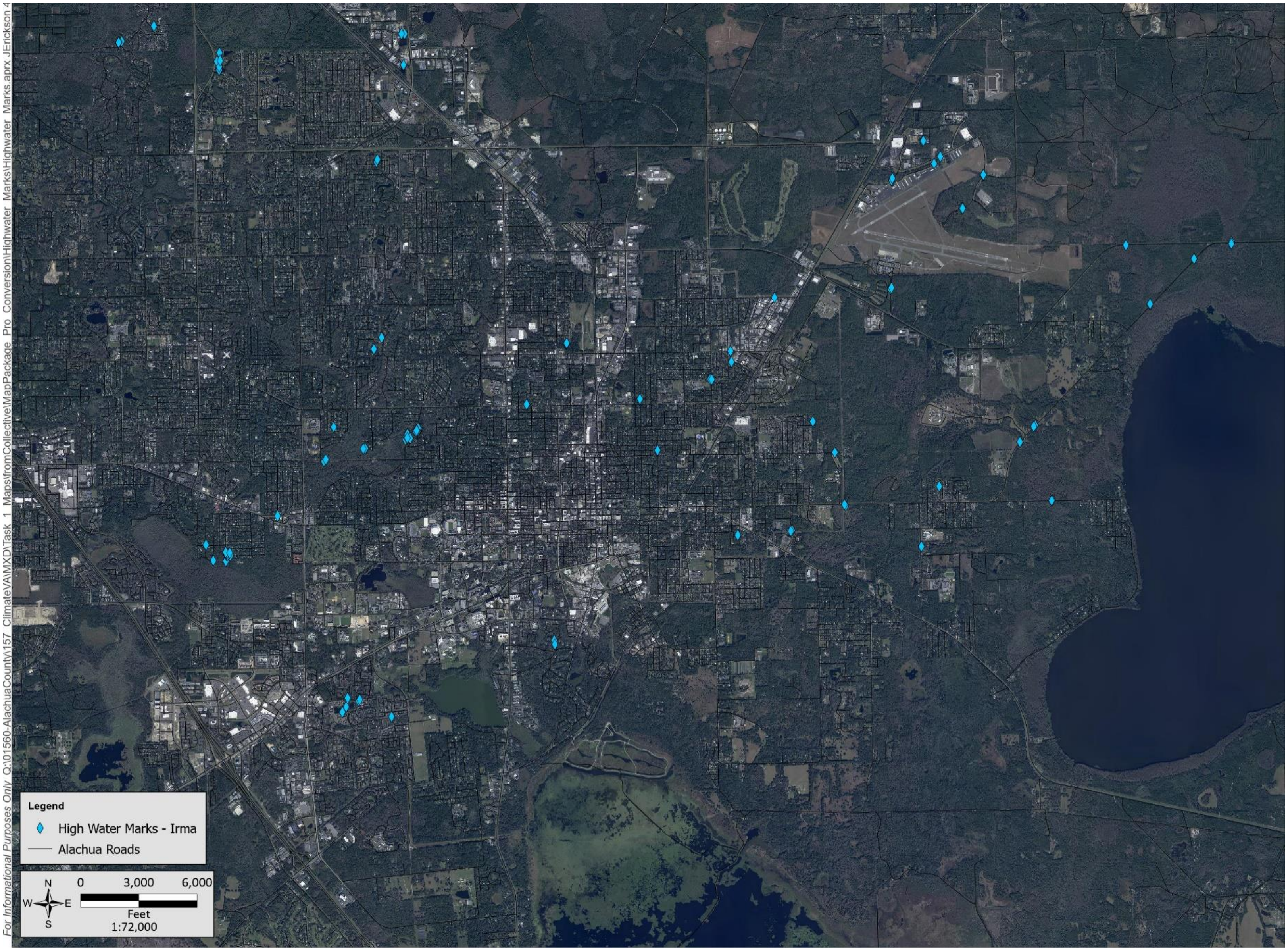


Figure 4-3 City of Gainesville High-Water Marks and Reported Flooding During Hurricanes Irma and Elsa



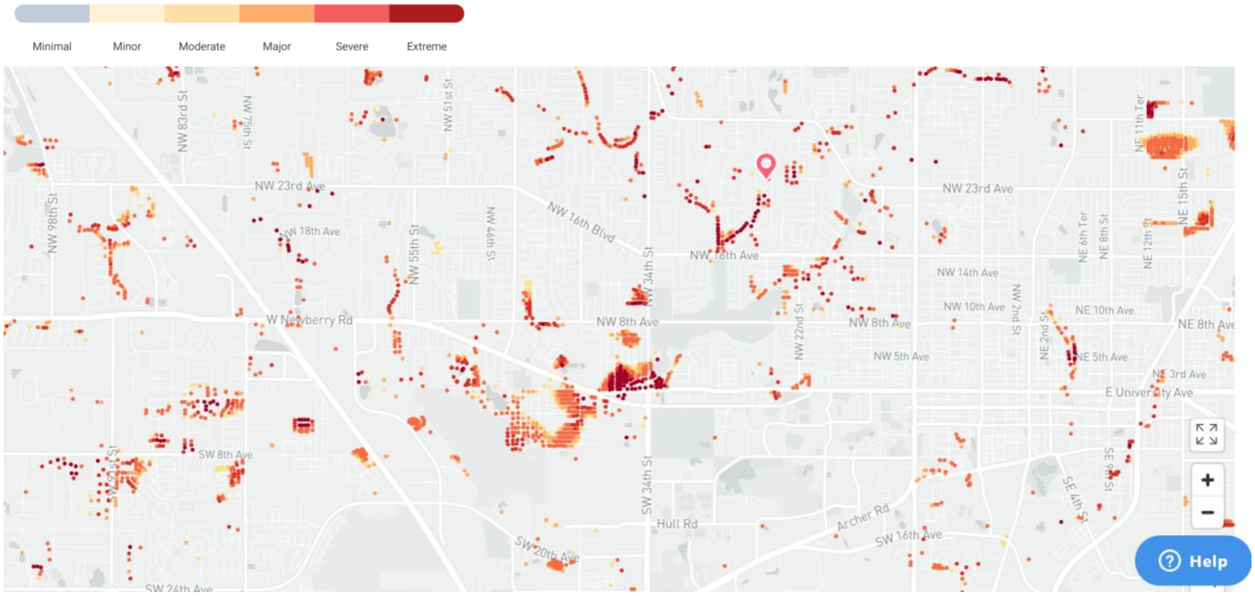
During Hurricane Elsa in June 2021, the Gainesville Sun reported flooding in Meadowbrook Golf Course, NW 39th Avenue and NW 98th Street, and approximately 2 feet of water inside homes on NW 40th Avenue (*Home, Roads Flooded in Some Low-Lying Parts of Alachua County, Thanks to Elsa* (gainesville.com)). Alachua County also issued a press release at the request of the Florida Department of Health warning of sewage overflows due to flooding from Hurricane Elsa (*Flood Waters Pose Health Risks* (alachuacounty.us)).

With future climate change and an increase in frequency and intensity of tropical storms, areas historically prone to flooding in the County will likely experience more significant impacts. Section 10 of this report discusses this possible future increase in storm frequency and flood risk in greater detail.

Wing et al. (2022) used a national-scale hydrologic and hydraulic flood risk model to evaluate parcel-level expected annual flood damages under current climate conditions and in 2050 under projected climate change assuming Representative Concentration Pathway 4.5 (RCP4.5) (SSP2-4.5). The study found that expected long-term average annual flood damages for Alachua County – estimated to be more than $25 million a year under current conditions – would increase by 20 percent by 2050. This increase was due to increasing rainfall associated with hurricane and non-hurricane storms.

The City of Gainesville's preliminary flood vulnerability analysis is based on inundation mapping provided by First Street Foundation, which publishes current and projected future flood risk information for the United States on its Flood Factor website. First Street derived its flood risk information from an earlier version of the national-scale model used by Wing et al. (2022). First Street's maps show that 9,348 properties in Alachua County have more than a 26-percent chance of being severely affected by flooding over the next 30 years. These affected properties represent 9 percent of all properties in the County (Alachua County, Florida | Flood Factor). Figure 4-4 shows a heat map of the properties at risk of flooding from the Flood Factor tool, zoomed into the Gainesville area.

Figure 4-4 Properties at Risk of Flooding In and Near Gainesville According to the Flood Factor Online Tool



5 EFFECTS OF CLIMATE MIGRATION ON POPULATION PROJECTIONS

Understanding potential demographic changes in Alachua County due to sea level rise (SLR) will be necessary for long-term planning. Although a fair amount of research has been done into climate migration due to climate change/SLR, very few studies have attempted to quantify climate migrants at the county level. Two studies that recently tried to quantify impacts at the county level were the primary focus of our review, along with the latest projections for population and SLR.

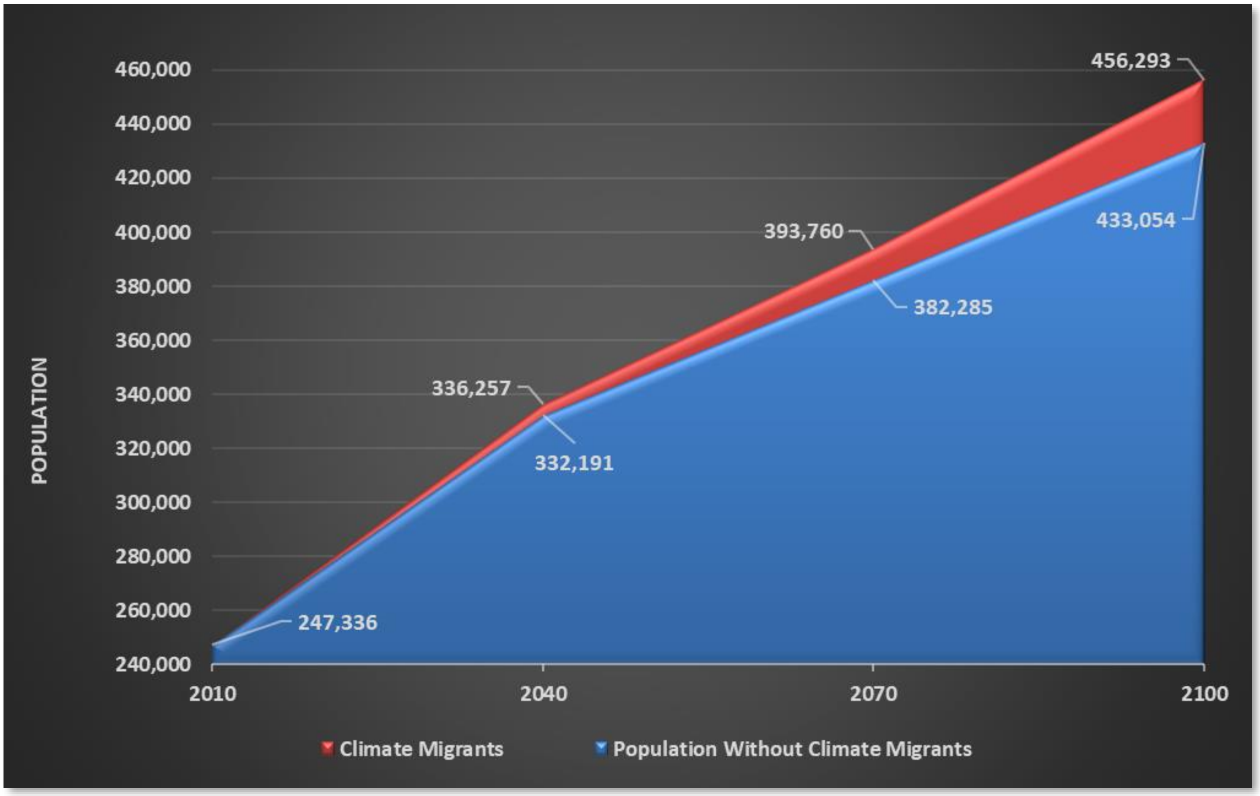
5.1 ALACHUA COUNTY POPULATION PROJECTIONS

Population growth for Alachua County was forecast using the Bureau of Economic and Business Research’s (BEBR) standard methodology for its state and county projections. The 2030 projection was already available from BEBR's latest (2022) forecast (Rayer, Stefan, and Ying Wang, 2022) for the state and Alachua County, which extends to 2050. This forecast was published on February 11, 2022, and incorporates data from the 2020 Census (Bureau of Economic and Business Research, 2021*)* and BEBR's 2021 Estimates (Bureau of Economic and Business Research, 2022). This 2050 forecast was then extended to 2070 and 2100 using standard BEBR methodology (Rayer, Stefan, and Ying Wang, 2022). BEBR reduced the County projections to control them to the state total because BEBR controls its official 2050 forecast for all 67 counties to its forecast for the state. Due to the long forecast horizon and the likelihood that climate will reduce growth in coastal counties disproportionally to inland counties (like Alachua), we used an average of the uncontrolled and controlled forecasts for this project. Table 5-1 and Figure 5-1 provide these forecasts.

Table 5-1 BEBR Population Projections for Alachua County

Population Forecast	2040	2070	2100
Forecast Not Controlled to State Forecast	335,614	397,942	461,573
Forecast Controlled to State Forecast	328,767	366,628	404,535
Average of the Controlled and Uncontrolled Forecasts	332,191	382,285	433,054

Figure 5-1 **BEBR Population Projections for Alachua County Including Climate Migrants**



5.2 SLR PROJECTIONS

Various models are available for projecting SLR, with multiple scenarios estimating its severity, and different impacts modeled for specific locations (or stations). Based on guidance from SLR experts at the University of Florida (Goodison, 2022), the latest consensus choice for Florida is the NOAA 2022 model of intermediate-high SLR for the local mean sea level (LMSL) (Table 5-2). We selected four stations in Florida that are near likely sources of climate migrants to Alachua County, and used the averages for 2040, 2070, and 2100 to calculate SLR projections for this project.

Table 5-2 **NOAA 2022 Intermediate-High SLR Projections in Meters for Locations in Florida (Sweet et al., 2022)**

Location	2040	2070	2100
Key West	0.28	0.80	1.63
St. Petersburg	0.29	0.80	1.63
Cedar Key	0.27	0.76	1.56
Mayport	0.29	0.79	1.58
Average	0.28	0.79	1.60

Notes:

Values were derived using the NOAA Interagency Sea-Level Rise Scenario Tool, which provides data from Sweet et al. (2022). These are the latest published projections for SLR for Florida.

Florida has adopted the NOAA Intermediate-High Projection scenario.

5.3 CLIMATE MIGRANT PROJECTIONS

Although significant research is available into the localized impacts of SLR, little research is available to quantify altered human migration patterns due to SLR. We identified and evaluated two such studies. Hauer et al. (2017) was the first study that projected climate migration using SLR models and historical migration flows for the United States from IRS data. The Hauer et al. (2017) study produced scenarios for human adaptation to reduce these flows (e.g., constructing flood defenses, raising homes, etc.) and for no adaptation. Hauer points out that some adaptation to mitigate SLR may occur, particularly in affluent areas, but he features the *no adaptation* scenario in his charts and graphs. We selected the *no adaptation* scenario for this project.

We adjusted our baseline forecasts to include net climate migrants to Alachua County. By 2100, the SLR model used in Hauer's 2017 work showed a rise of 1.8 meters, whereas the 2022 NOAA Intermediate-High (Sweet et al., 2022) forecast shows an average increase of 1.6 meters for the four representative stations selected in the Florida peninsular (**Error! Reference source not found.**). Also, the population Hauer projected for Alachua County was different from the latest BEBR forecast. To convert the 2017 results to our current data, we applied the proportion of the latest 2040, 2070, and 2100 SLR forecasts to the 1.8 meters used by Hauer to project climate migrants. This approach has limitations since the change in climate migrants may not be proportional to the change in SLR. However, since we lack climate migrant projections corresponding to the SLR projections for 2040 and 2070, this approach is appropriate and produced migrant projections deemed reasonable by BEBR. Table 5-3 shows the projections that we derived and reflect a projected increase in net migration to Alachua County due to SLR of more than 23,000 (5 percent) by 2100. Our estimates may be low or high depending on the accuracy of the SLR models, BEBR's projections, and assumptions about climate migration. However, we deem the forecast is reasonable for this planning exercise.

Table 5-3 BEBR Population Projections for Alachua County Including Climate Migrants

Population Forecast	2040	2070	2100
Average of the Controlled and Uncontrolled Forecasts	332,191	382,285	433,054
Projected Additional Net In-Migration Due to SLR	4,067	11,475	23,239
Projected Population Including Additional SLR Migration	336,257	393,760	456,293

Hauer's other research efforts (Hauer, Evans, and Mishra, 2016; Hauer et al., 2021) contributed to our understanding of the implications of SLR to migration patterns but did not provide any additional data for use in this project. Therefore, we included these papers as references to give more context.

We evaluated the research performed by Robinson et al. (2020), which also modeled population migration due to SLR at the county level. They did not base their county-to-county migration model on historical flows but instead used population and distance features. Robinson et al. argued that this approach *has the benefit of predicting flows between pairs of counties for which there are no historical flows*. However, we believe that the results were not always reasonable, such as their prediction of a large influx of climate migrants in Miami-Dade County. Our conclusion was the same as the team working on the Florida 2070 Project, which consulted BEBR on this issue.

In 2016, the Florida Department of Agriculture and Consumer Services, 1000 Friends of Florida, and the University of Florida's Geoplan Center conducted the *Florida 2070 Project* (Carr and Zwick, 2016), exploring alternative future development scenarios to accommodate Florida's projected 2070 population. Updates are now being made to the Florida 2070 Project to assess the impacts of climate change and SLR, although no documentation is available yet. That effort is also leveraging the Hauer et al. (2017) study, but that team is adjusting the data to facilitate a comparison with the 2016 report rather than a forecast based on the latest available data. Despite the different goals, that work helped inform Alachua County's projections.

6 CHANGES TO LOCAL AND REGIONAL WATER USE

Florida has and continues to experience substantial population growth with the population more than doubling during the past 40 years (1980 to 2020), and a current population of 21.5 million as of 2020 (*Florida County Population Census Counts: 1830 to 2020*, 2021). This growth has resulted in various changes in the state, including an increase in housing and demand for water to meet indoor and outdoor residential uses. Furthermore, this population growth is expected to continue with a projected 26-percent growth by 2045 (Rayer and Wang, 2021). Land use changes are expected as a part of this continued population growth impacting hydrology and water storage (Bloetscher, 2009). Furthermore, current growth patterns in Florida result in significant increases in population along Florida's coastlines, which are highly vulnerable to climate change (Misra et al,. 2011). Currently, the primary water source for Florida's urban population is groundwater, which is expected to become more vulnerable to impacts associated with SLR and extended drought (Coastal Resilience Partnership of Southeast Palm Beach County, 2021; South Florida Water Management District [SFWMD] ,2009; Bloetscher, 2009). Bloetscher (2009) notes that these impacts will require increased reliance on conjunctive use of surface water and groundwater and potable water supply well re-location away from impacted coastal areas.

Conversely to real increases in urban land uses, acreage in agriculture decreased statewide by approximately 10 percent between 1987 and 2017. However, the acreage in irrigated agriculture did not decrease at the same rate, leading to an increase in the percentage of irrigated agricultural land (The Balmoral Group, 2021). Additionally, changes in agricultural acreages are not evenly spread across the state, with some areas experiencing increases in agricultural and irrigated acreages. This expected increase in irrigated agricultural area is particularly true in North Florida within the Suwannee River Water Management District (SRWMD) and the Northwest Florida Water Management District (NWFWMD), which are expected to experience a 20-percent and 11-percent increase, respectively, between 2019 and 2045 (The Balmoral Group, 2021). Agricultural water demand may also increase due to decreased crop production at higher temperatures or water stress during extended dry periods (Allen and Boote, 2000; Oppenheimer et al., 2014). Similar production decreases have been described for dairy and poultry, leading to increased water demand for cooling to mitigate elevated temperatures (LM Carter et al., 2014; McNulty et al., 2015).

The Office of Economic and Demographic Research (EDR) develops an estimate of all state water use annually and forecasts changes in water use for the next 20 years based on combined water management district data and linear projections (EDR, 2021). In 2021, the EDR water-use projections were presented from 2020 to 2040. The EDR estimates did not account for climate change, but do acknowledge that climate change may impact water supply. The following are some key findings from the 2021 EDR expected water-use projections:

- Changes in water use will increase from approximately 6.4 to 7.4 billion gallons per day (BGD), an approximate 15-percent increase.
- Increases will occur across the state except for a small decrease in the Southwest Florida Water Management District (SWFWMD) Heartland Planning Region (outside the Central Florida Water Initiative [CFWI] Area).

- Increases will occur across all categories with the most significant increase in public supply, which will grow by 23 percent and reach 3.2 BGD.

- The rate of public supply expansion will closely follow the population growth rate for the same period. This finding does not account for climate migration.

- Agricultural water use will increase by 3.7 percent to approximately 2.5 BGD.

- Other water use categories included the following projected uses in 2040:

  - Domestic self-supply (0.3 BGD).
  - Commercial/industrial/institutional (0.5 BGD).
  - Power generation (0.2 BGD).
  - Landscape/recreational (0.7 BGD).

- EDR also considered potential water conservation savings of 0.4 BGD by 2040, based on Florida Department of Environmental Protection (FDEP) estimates. This conservation led to the expected total water use of 7.0 BGD in 2040 for the conservation scenario.

- The final scenario considered by EDR was a 1-in-10-year drought with expected water use of approximately 8.5 BGD in 2040.

- EDR examined expected needs and inferred water supply reported by FDEP for each region. This comparison showed a shortage of approximately 320 million gallons per day (MGD) across the state with approximately 112 MGD in the North Florida Regional Water Supply Plan (NFRWSP) area, including Alachua County.

St. Johns River Water Management District (SJRWMD) and SRWMD have evaluated regional water needs in the NFRWSP (2017). This study specifically evaluated water-use projections between 2010 and 2035 for the planning region that includes Alachua County. Based on this report we can expect that:

- Water use in Alachua County will increase from approximately 50.7 to 57.9 MGD, a 14-percent increase.
- The 1-in-10-year drought demand projection will increase water use further to 64.3 MGD, an additional 6.4 MGD.
- Most water-use change was due to an estimated increase in the public supply of almost 5 MGD during the study period from 25.5 to 30.3 MGD.
- In Alachua County, domestic self-supply will decrease from 3.5 to 2.7 MGD.
- Agricultural demand will increase from approximately 17.1 to 19.5 MGD. Increases in agricultural demand were driven by an expected acreage increase of more than 7,000 acres or a 63-percent growth in the agricultural area in Alachua County.
- Primary increases in agricultural acreage will occur in non-citrus fruit, field crops, hay, and sod.
- The primary increases in water demand will occur in fresh-market vegetables, field crops, and hay, and greenhouses/nurseries will experience a significant decrease in water use (>50 percent).
- Landscape/recreational/aesthetic self-supply and commercial/industrial/institutional/mining self-supply of water will have minor increases in use from 1.4 to 1.6 MGD and from 0.7 to 0.8 MGD, respectively.

- Water use for power generation will increase from 2.5 to 3.0 MGD.

The NFRWSP addressed climate change by describing the associated uncertainty and identifying that many of the practices used to address water resource constraints are the same that can be used to mitigate climate change impacts, including:

- Decreasing groundwater demand.
- Improving water-use efficiency.
- Improving infrastructure capacity and flexibility.
- Diversifying water supplies.

Current minimum flows and minimum levels (MFL) for the Lower Santa Fe and Ichetucknee Rivers indicate that the Ichetucknee River has fallen below its MFL and is in recovery. At the same time, the Lower Santa Fe River is expected to fall below its MFL between 2035 to 2040 and is in prevention (SRWMD, 2021). This basin covers a large portion of Alachua County, and flows in the Santa Fe and Ichetucknee Rivers rely on groundwater from the Floridan Aquifer, the primary water source for the County. This current and expected future condition indicates the challenge of meeting growing water demand in Alachua County while providing adequate flow to support environmental systems. Any changes in climate that further increase water demand (increased frequency of drought or increasing temperatures) or decrease water availability (decreased rainfall or increased runoff) may make meeting future water use challenging without increased conservation or reduced use.

Population growth and an increase in irrigated agriculture are expected to be the primary drivers of changes in water use during the next 15 to 20 years in Alachua County. In addition, projections of the 1-in-10-year drought indicate that extended dry periods may increase water demand to satisfy landscape and agricultural irrigation demands. As water sources in the coastal areas of Florida are stressed by SLR and increased demand, the re-location of potable water supply wells further inland could cause additional stresses on the Floridan Aquifer throughout North Florida, including Alachua County. This increased demand is further complicated by the current MFL status of waterbodies in and near Alachua County that are already in recovery or prevention.

7 WILDFIRE RISKS

Wildfire is essential for maintaining native biodiversity and ecosystem processes while having the potential for substantial environmental damage, including significant impacts to silviculture, loss of property, loss of crucial infrastructure, disruptions to traffic, and smoke pollution. The United Nations (UN) (2022) identified that worldwide changes in fuel load driven by changes in land use, fire suppression, and climate change are changing wildfire characteristics. Smith et al. (2020) reviewed 116 articles published between 2013 and 2019 and found a strong consensus that climate change increases the likelihood of fire occurrence. In addition, Kelley et al. (2021) estimated that by 2100 the global increase in wildfire events would be between 31 and 52 percent assuming Representative Concentration Pathways (RCP) 2.6, and between 36 and 57 percent assuming RCP 6.0.

Alachua County includes various ecosystems with different fire risk characteristics. Mitchel et al. (2014) overviewed fire interactions in the southeast United States and how those are likely to be influenced by climate change. The following is a summary of the Mitchel et al. assessment of fire risks for some forest and landscape types within Alachua County:

- Forested Wetlands: Fire risk is linked to hydroperiod and drought. With a short hydroperiod, wetlands burn more frequently. With a more extended hydroperiod, wetlands experience more severe fires during droughts. In addition, deep histosols (peaty soils) can burn in some cases, creating significant environmental changes through the loss of peat material and the accumulation of ash, e.g., the fire in the Santa Fe Swamp in 2007 resulted in significant water-quality impacts to Lake Santa Fe.
- Pine Flatwoods: Longleaf or slash pine or a mixture of the two dominate these systems, and fires are naturally frequent (3 to 5 years). However, these systems can develop elevated fuel loads when fires are infrequent.
- Planted Pine: Management practices significantly impact these systems. Monocultures of loblolly pine, slash pine, or longleaf pine become susceptible to fire. Long periods of fire suppression combined with drought can enhance this susceptibility.

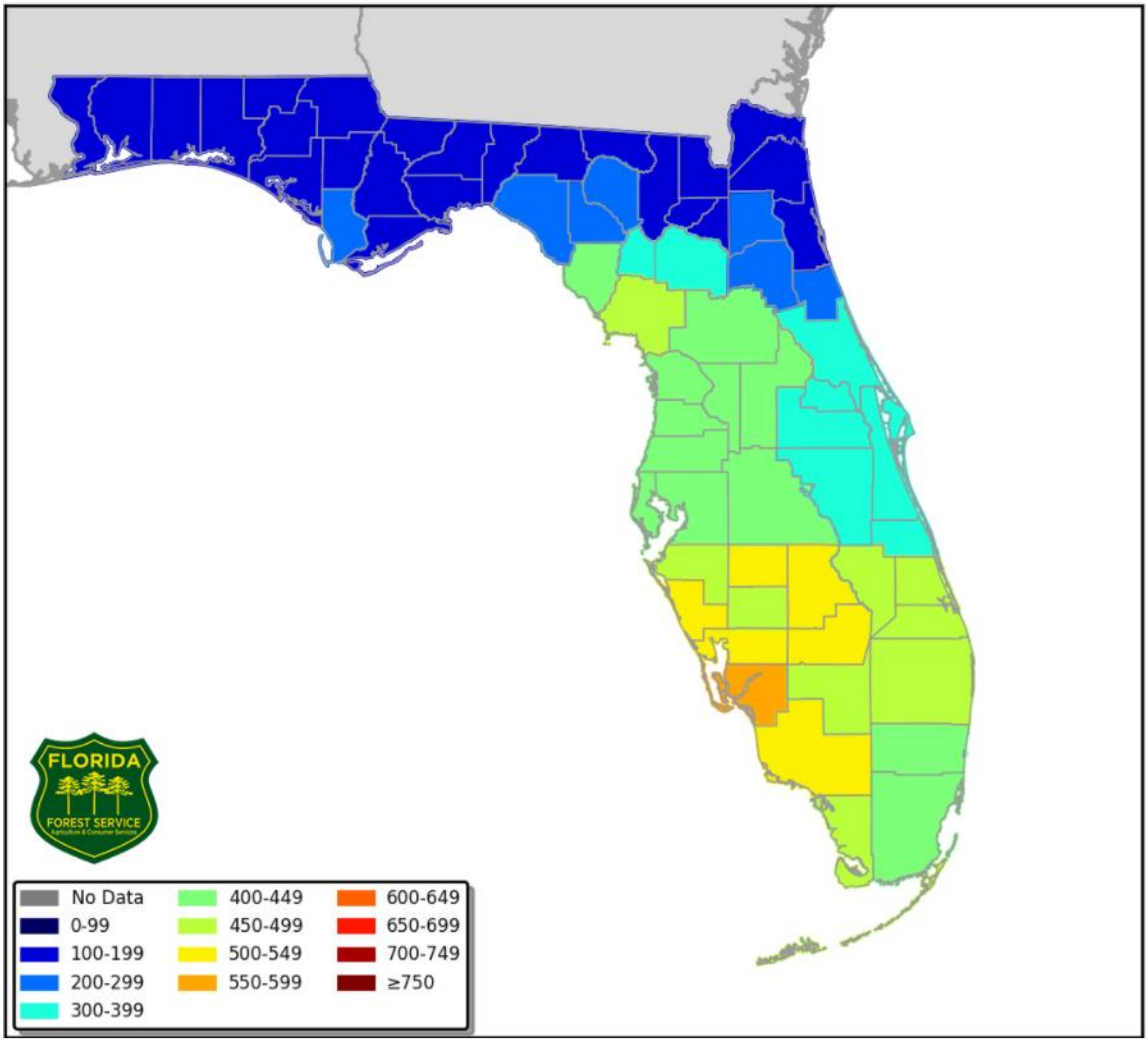
Our Team has observed an increase in the planting of loblolly pine within Alachua County and has noted that – when not managed appropriately – this planted pine can be particularly susceptible to wildfire.

Climate indices help predict the change in fire risk due to weather. For example, in Florida, private and state foresters generally use the Wildland Fire Danger Index (WFDI) or the Keetch-Byram Drought Index (KBDI) to predict the relative fire risk each day.

The WFDI is a continuous-reference scale used by the Florida Fire Service that estimates the potential for a fire to start each day. The WFDI is based on the energy release component and daily minimum relative humidity and considers the past 7 days when calculating each day’s WFDI (Figure 7-1).

The KBDI ranges from 0 (no moisture deficit) to 800 (maximum moisture deficit). The Florida Fire Service calculates the KBDI using daily rainfall totals, maximum daily temperature, and soil type. High KBDI values indicate favorable conditions for the occurrence and spread of wildfire. The Florida Forest Service publishes daily WFDI and KBDI values for Florida.

Figure 7-1 Example Map of KBDI Values for Florida Published by the Florida Forest Service

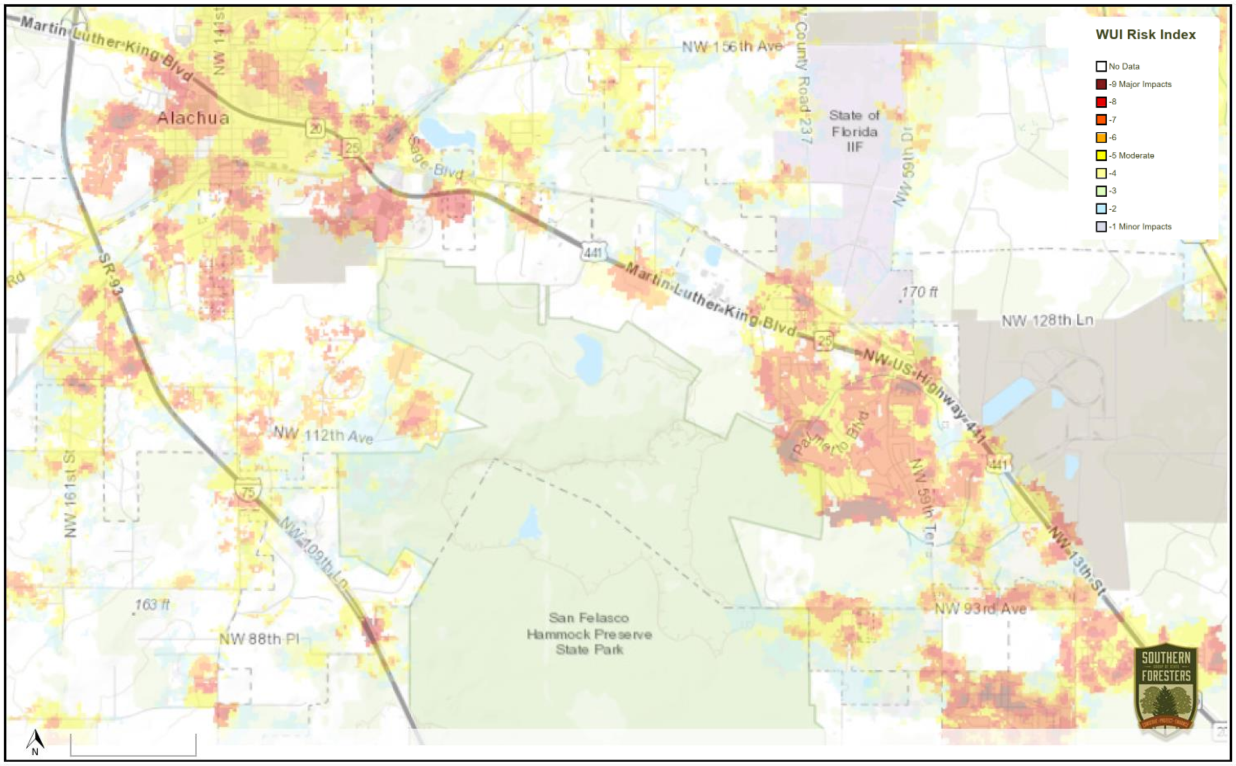


The KBDI has been used to assess changes in fire potential (Gannon and Steinberg, 2021; Liu et al., 2013) under climate change scenarios. In a worldwide analysis, Gannon and Steinberg found that most regions would experience an increasing trend in the number of days with high KBDI, which is likely to increase the number of wildfires. Liu et al. also used KBDI to evaluate wildfire potential in the United States under climate change scenarios and found that the fire season in the southeast United States would increase by 1 to 5 months when comparing 1941 through 2000 to 2041 through 2071. However, all these papers note that the uncertainty in precipitation forecasts makes these projections uncertain.

The wildland-urban interface (WUI) is a significant factor driving wildfire risk. The WUI is the interface where wildland and forest vegetation meet residential structures. This interface is where wildfire poses the highest risk to people and infrastructure – because this interface is where a fire is more likely to start because of human activity and the presence of residential structures makes controlling wildfires more challenging. Understanding the possible change in the WUI will be necessary for planning and mitigating fire risk in the future.

Radeloff et al. (2018) mapped the WUI change across the United States from 1990 to 2010. The study found that the WUI in Alachua County increased from 300 square miles in 1990 to 383 square miles in 2010. Expanding populations are likely to cause the WUI in the County to continue growing. The Southern Group of State Foresters Wildfire Risk Assessment Portal provides a WUI Risk Index (Figure 7-2) that rates the potential impacts of wildfire on people and their homes. Calkin et al. (2019) described a WUI risk assessment approach to help rate fire risk at the WUI. Indices such as these that consider the likelihood and intensity of wildfires burning into communities can be helpful in understanding where wildfire is more likely to impact communities.

Figure 7-2 WUI Risk Index Published by Southern Group of State Foresters



Hurricanes can significantly impact forest systems. For example, Kenney et al. (2021) found that Hurricane Michael severely impacted a longleaf pine woodland approximately 100 miles from the Florida coast in 2018. The study looked at mesic (moist) and xeric (dry) sites and estimated that the forests would take 10 to 35 years to recover from the loss of trees and vegetation (carbon losses) caused by the hurricane. They also found that the xeric forest was less impacted than the mesic forest because it was shorter on average and had larger root systems. Fallen trees and debris can serve as fuel for wildfires. The Florida Forest Service noted that the 2022 Bertha Swamp Road Fire, a 33,000-acre fire in the Florida Panhandle, was fueled by "vegetation left behind from Hurricane Michael".

Tropical low systems can also promote fire. For example, the Georgia-Florida Bay Fire complex, the largest fire in this region in 50 years, was driven by a stationary tropical low pressure that led to consistently strong winds (Mitchel et al., 2014). Forecasts of increasing hurricane activity associated with global warming could exacerbate this fire risk potential.

Changing species composition may also impact wildfire risk. For example, Mitchel et al. (2014) noted that many areas of the southeast are likely to experience an increase in the flammability of vegetation. However, Mitchel et al. (2014) also notes that a reduction in the total fuel load forecast for the middle of this century could offset this increase.

Continued adaptation and improvement of fire management practices could offset some of the projected increases in wildfire risk. Development of plans for managing wildfire fuels is critical for reducing wildfire risk. Alachua County's continued investment in the *Alachua County Forever* program has resulted in the protection of almost 40 square miles of the County. The change to public management of this land has the significant benefit of the County better managing these new areas – helping to mitigate some of the wildfire risks.

8 CHANGES TO COUNTY FOOD SYSTEMS AND AGRICULTURAL PRODUCTION

The Jones Edmunds Team reviewed available information on crop production in Alachua County. Our review included data from the most recent (2017) US Department of Agriculture (USDA) census of agriculture (National Agricultural Statistics Service [NASS], 2017) and the 2022 Alachua County property appraiser.

The 2017 USDA census shows Alachua County had 1,611 farms with a total farmland area of 178,182 acres. The following summarizes the 2017 census of agriculture results for Alachua County:

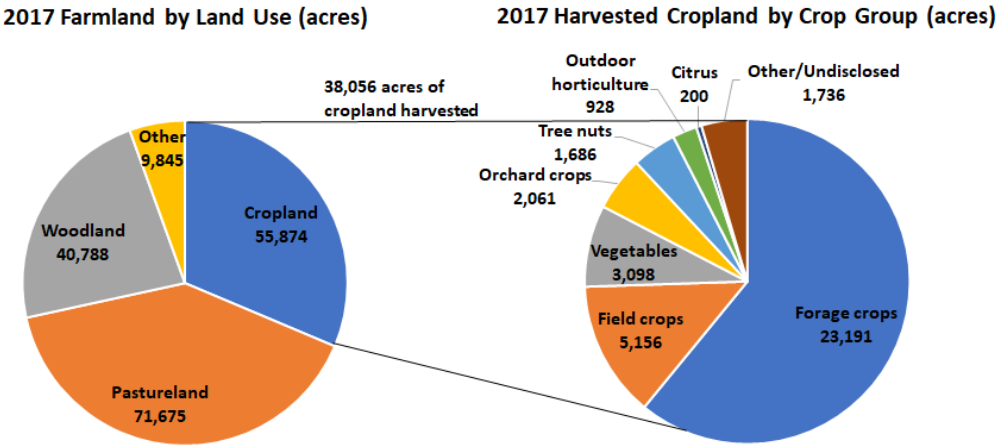
- Cropland accounted for 55,874 acres. The following is the reported breakdown in cropland:
    - Harvested area was 38,056 acres.
    - Irrigated area was 10,352 acres.
    - Fertilized area was 26,962 acres.
- Pastureland accounted for 71,675 acres.
- Woodland accounted for 40,788 acres.
- Other agricultural uses accounted for 9,845 acres.

The results from the 2017 census show the following breakdown of harvested cropland within the County:

- Forage/hay and haylage (23,191 acres, 61 percent) consist primarily of Bahiagrass and Bermudagrass in Alachua County.
- Field crops (5,156 acres consisting of corn/maize, grasses, peanuts, and tobacco).
- Vegetables (3,098 acres consisting mainly of watermelons, snap beans, and green peas).
- Orchard crops (2,061 acres consisting mainly of blueberries).
- Tree nuts (1,686 acres consisting mainly of pecans).
- Outdoor horticulture/nursery (928 acres, crops under protection not considered).
- Citrus (200 acres).
- Other/undisclosed crops (1,736 acres).

Figure 8-1 shows the breakdown of farmland and harvested cropland within Alachua County.

Figure 8-1 **Breakdown of 2017 Alachua County Farmland (Left) and Harvested Cropland (Right)**



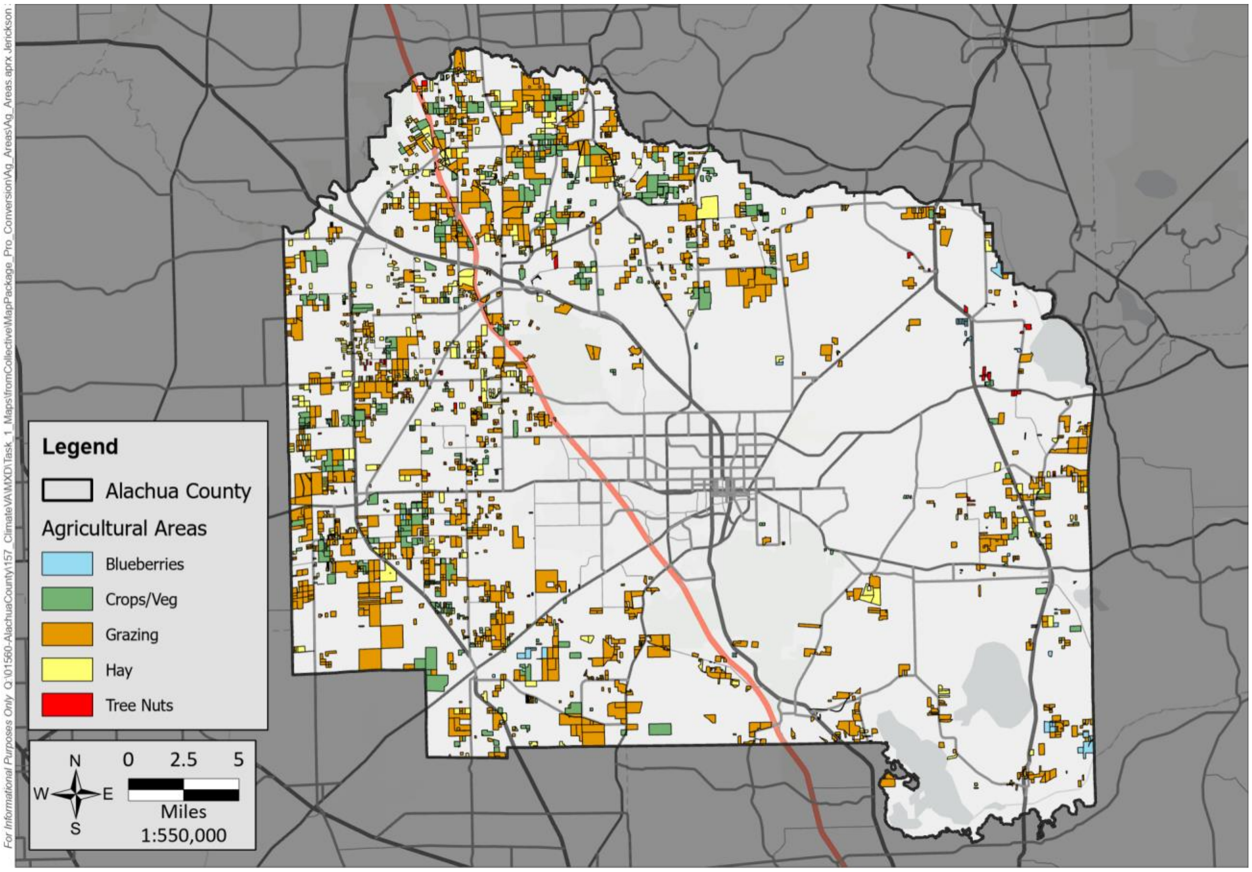
Data from USDA National Agricultural Statistics Service (NASS 2017).

The Jones Edmunds Team also reviewed the Alachua County property appraiser land zoning and land use codes. The Alachua County property appraiser database identified the following approximate areas:

- 300,000 acres of the County is zoned for agriculture.
- 127,000 acres of the area zoned for agriculture was classified by the property appraiser as being a non-agricultural land use, such as single-family residential.
- 101,000 acres that are zoned agricultural is in timber production.
- 72,000 acres were classified as being in agricultural production. The primary land uses were:
  - 47,600 acres of pasture and livestock grazing.
  - 13,500 acres of cropland and vegetables.
  - 8,600 acres of hay.
  - 1,000 acres of blueberries.
  - 500 acres of tree nuts.

The Jones Edmunds Team used the property appraiser data to map the distribution of these primary agricultural land uses in Alachua County. Figure 8-2 shows that this agricultural land is primarily in the County's west portion, with some agricultural land in the east near US Highway 301.

Figure 8-2 Map of Agricultural Properties in Alachua County



Based on the recent reports from IPCC, we expect that crop production in Alachua County will experience an adverse effect from future climate change. The predicted increased frequency of drought and extreme temperatures in warmer agricultural regions (IPCC 2014, 2021, and 2022) is likely to affect crop production negatively. The relatively low percentage of irrigated cropland in Alachua County will also exacerbate these adverse effects. Therefore, we expect farmers to increase irrigation and fertilizer application to maintain ideal crop production under future climatic conditions or to switch to alternative land uses. This increased irrigation and fertilizer application could result in impacts on groundwater levels, leaching of excess nutrients to groundwater, and additional runoff of nutrients to streams and other waterbodies in the County.

9 EXTREME HEAT AND FREEZE EVENTS

Extreme heat and cold can impact human health, living expenses, and specific industries essential to the economic health of Alachua County. The National Oceanic and Atmospheric Administration (NOAA) Climate Explorer summarizes Coupled Model Intercomparison Project 5 (CMIP5)-based forecasts for temperature changes for locations across the United States. The Climate Explorer used Representative Concentration Pathways (RCP) 4.5 and RCP8.5 for their projections. They plotted trends in the mean climate results and the range in values based on results from multiple CMIP5 models. Figure 9-1 through Figure 9-4 provide an overview of the NOAA Climate Explorer projections for Alachua County based on CMIP5 for RCP4.5 (blue line) and RCP8.5 (red line). The variability in simulated results is shown on the graphs by the blue and red areas. The following summarizes the expected trends based on these plots:

- The number of very warm nights with a minimum temperature above 80 degrees Fahrenheit (°F) will increase. This increase will significantly impact the number of nights that require air conditioners to run continuously in the summer (Figure 9-1).

- The average daily minimum temperature will increase. Warmer summer nights will impact vulnerable populations such as the very young and very old, those who cannot afford to cool their homes, who work outdoors or who have underlying medical conditions. This increase will also increase the load on the electric grid and raise utility bills (Figure 9-2).

- The annual cooling degree days will increase. Cooling degree days are the number of degrees by which the average daily temperature is higher than 65°F multiplied by the number of days exceeding this threshold. This measure shows the trend in expected energy demand for cooling. In Alachua County, the number of cooling degree days relative to the 1961 to 1990 average will increase by approximately 10 percent under RCP4.5 and by approximately 55 percent assuming RCP8.5 (Figure 9-3).

- The number of freeze days with a minimum temperature of less than 32°F will decrease. This change will result in less than 10 freeze days in 2100 compared to 14 freeze days in 2000 (Figure 9-4). This change could have a number of impacts including:

    - Increased spread of exotic plant species that are negatively affected by freezes.
    - Increased spread of existic animals that are negatively affected by freezes.
    - Increased mosquito populations.

The IPCC (2021) forecast based on Coupled Model Intercomparison Project 6 (CMIP6) shows a similar warming trend for the southeast United States. Figure 9-5 shows general expected changes in temperature for the East United States.

Figure 9-1 Number of Days per Year with a Minimum Temperature Above 80°F for Alachua County

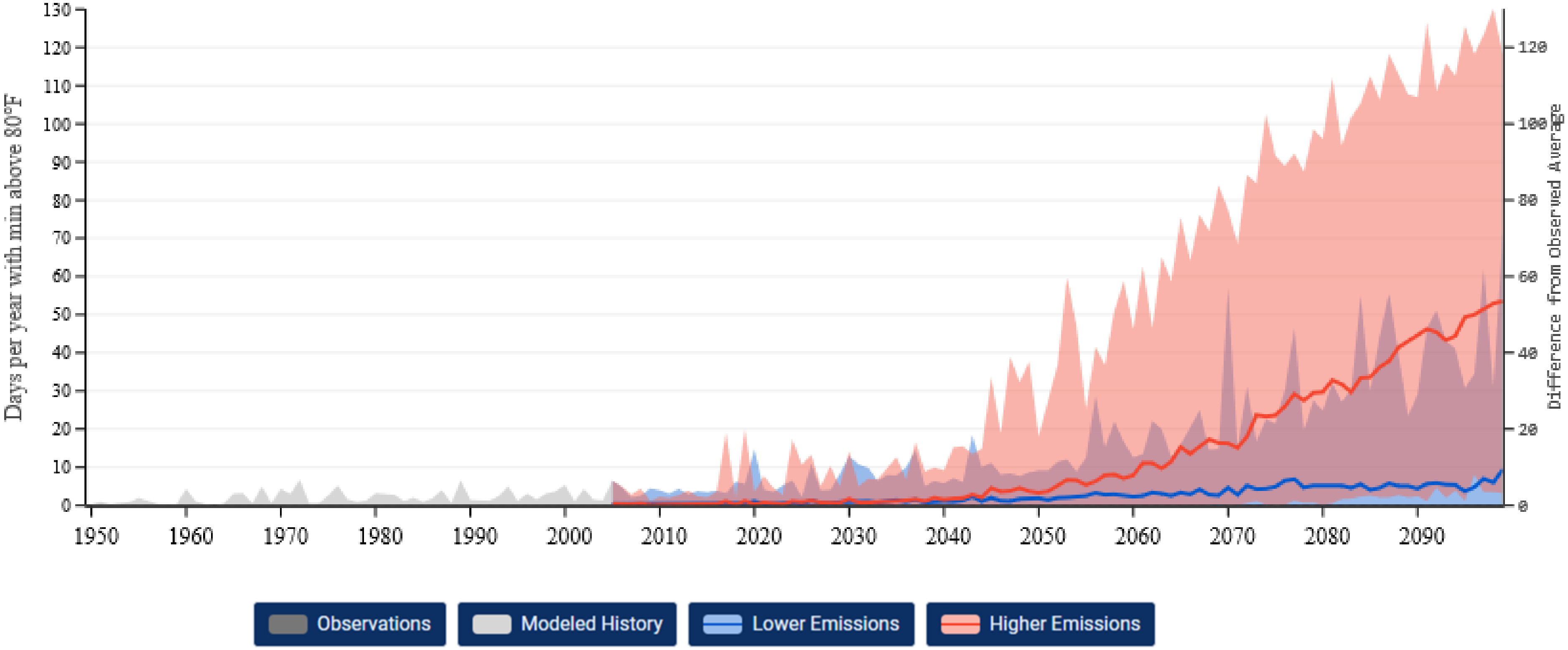


Figure 9-2 Average Daily Minimum Temperature for Alachua County

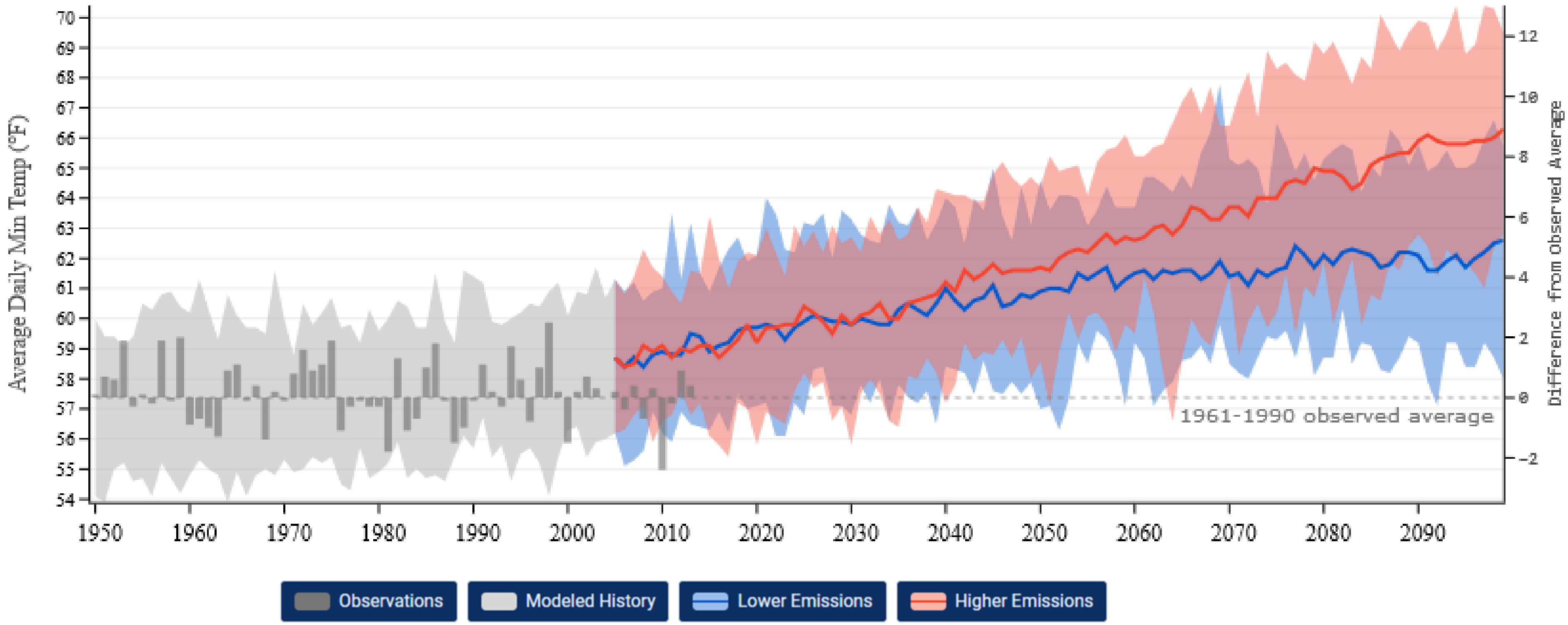


Figure 9-3 Average Cooling Degree Days for Alachua County

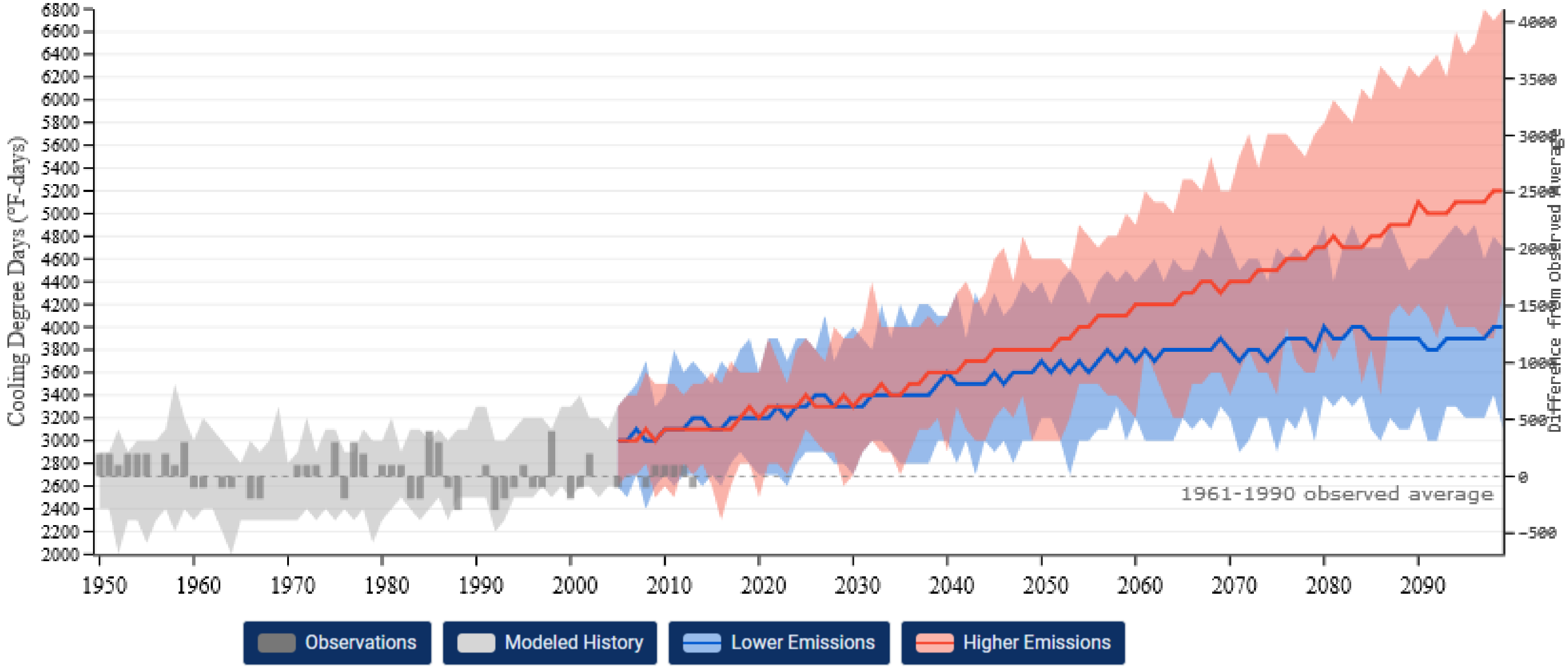


Figure 9-4 Days per Year with a Minimum Temperature Below 32°F

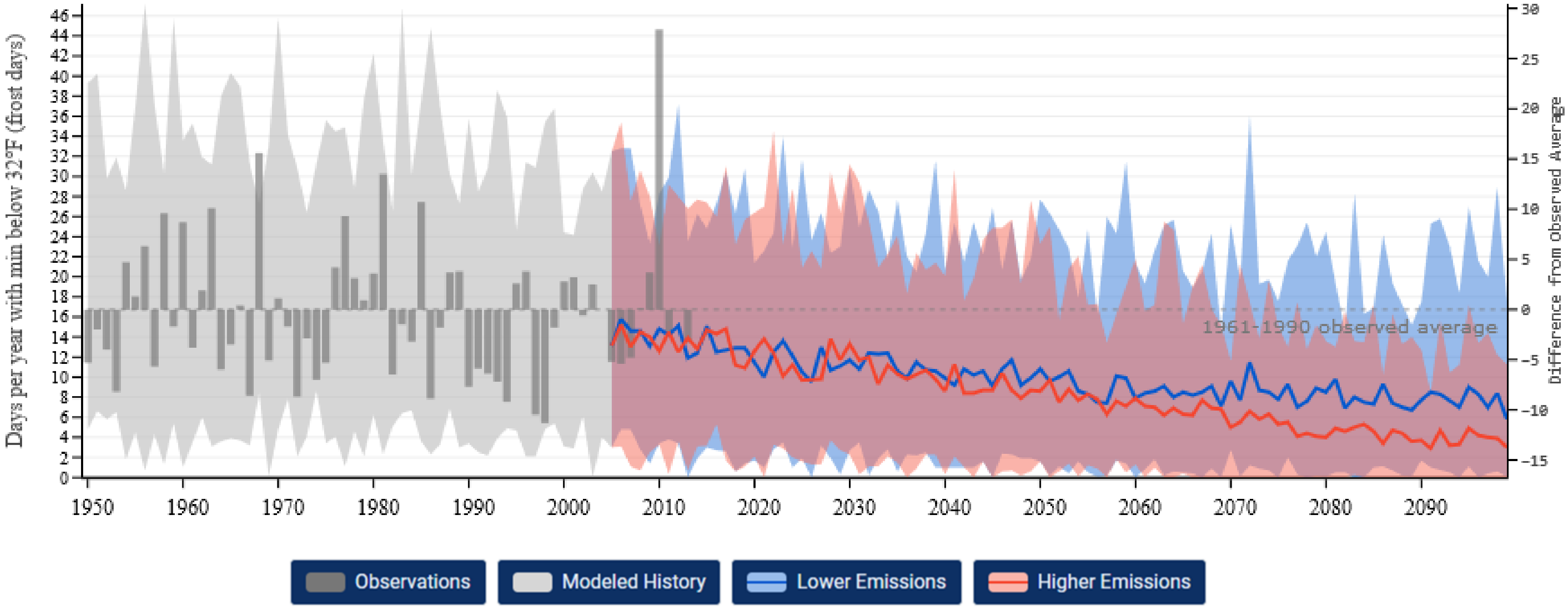
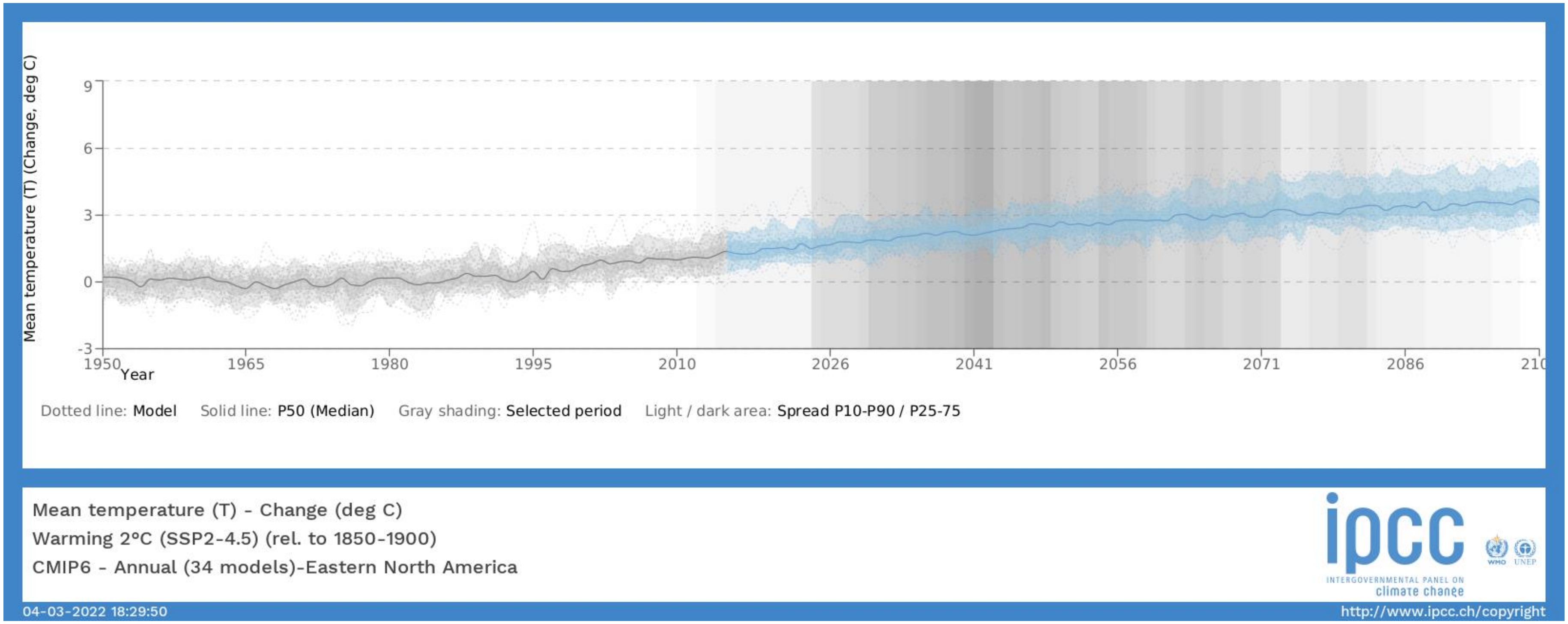


Figure 9-5 Mean Temperature Change (Degrees Celsius [°C]) for the East United States



Dotted line: Model Solid line: P50 (Median) Gray shading: Selected period Light / dark area: Spread P10-P90 / P25-75

Mean temperature (T) - Change (deg C)
Warming 2°C (SSP2-4.5) (rel. to 1850-1900)
CMIP6 - Annual (34 models)-Eastern North America

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10 CHANGES TO EXTREME PRECIPITATION AND FLOOD RISK

Future climate change will likely increase extreme precipitation (Obeysekera, Sukop, Troxler, and John, 2021; Intergovernmental Panel on Climate Change [IPCC], 2021; Obeysekera et al., 2011; Carter et al., 2018; Bender et al., 2010) and therefore increase the potential for future flood risk in Alachua County. In this inland non-coastal County, higher flood risk occurs in communities near riverine floodplains, low-lying natural areas, and closed basins. Changes to future extreme precipitation and other compounding factors such as land cover, groundwater levels, water management practices, and stormwater infrastructure will change the County's flood risk. For example, if stormwater infrastructure continues to be designed based on historical rainfall, it will likely be undersized for future storms. The Jones Edmunds Team looked at possible changes to extreme precipitation and flood risk and the implications that this may have on design criteria to address the following questions:

- Will the frequency of the current 1-percent flooding (100-year floodplains) change?
- What will the future 100-year storm depth be?
- Will design criteria change, and by how much?

10.1 WILL THE FREQUENCY OF THE CURRENT 1-PERCENT FLOODING (100-YEAR FLOODPLAINS) CHANGE?

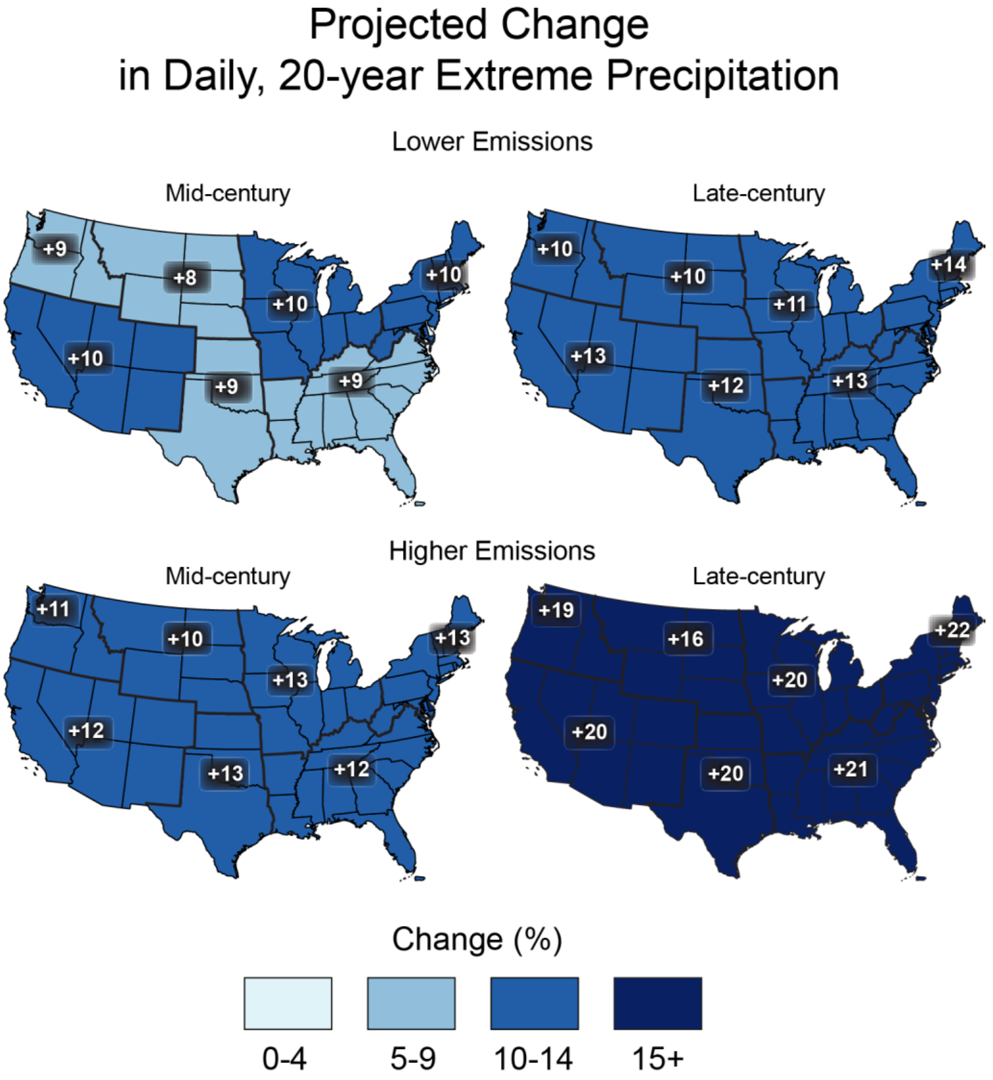
The Jones Edmunds Team reviewed relevant literature and local historical rainfall data to assess the possible change in flood risk. The Team assumed that a future increase in precipitation would increase the frequency of the current 1-percent flooding. However, other compounding factors such as future land cover, groundwater levels, water management practices, and future changes to stormwater infrastructure could alleviate or exacerbate future flood risk. Section 4 of this report discusses current flooding in Alachua County in more detail. Although the review of historical data did not suggest any conclusive trends, the literature points to a probable future increase in extreme precipitation but uncertainty in the magnitude of changes expected.

10.1.1 LITERATURE REVIEW: FUTURE CHANGES TO EXTREME PRECIPITATION

As discussed in Section 2, coarse-scale general circulation models (GCMs) lead to uncertainty in estimating future changes to precipitation. Much of the literature reviewed notes that coarse-scale GCMs underestimate extreme precipitation (Carter et al., 2018; Kendon et al., 2014; Obeysekera, Sukop, Troxler, and John, 2021). According to the literature, using bias correction to compensate for this underestimation is common (Obeysekera, Sukop, Troxler, and John; 2021). Studies also suggested that higher-resolution weather models more accurately represent extreme rainfall events and predict a more significant increase in storm event frequency and intensity under future climate scenarios (Kendon et al., 2014; Emanuel, 2013). However, other literature notes that Regional Climate Models (RCMs) do not reasonably predict extreme rainfall, particularly convective rainfall extremes (Gregersen et al., 2013). Many sources of uncertainty are listed in the literature.

For expected changes to extreme precipitation, most of what The Jones Edmunds Team reviewed predicts an increase in the intensity of future extreme precipitation (Obeysekera et al., 2021; IPCC, 2021; Obeysekera et al., 2011; Carter et al., 2018; Bender et al., 2010). Figure 10-1 from the Fourth National Climate Assessment shows an increase in the 20-year extreme precipitation event. The same source predicts an even greater increase in higher return levels (Easterling et al., 2017). For tropical storms, many reports indicate an overall decrease in the number of tropical cyclones but an increased intensity in those occurring (Misra et al., 2011; Obeysekera, Sukop, Troxler, and John, 2021; Bender et al., 2010; Carter et al., 2018). One study on Atlantic hurricanes predicts that the frequency of Category 4 and 5 storms could nearly double by the end of the 21st Century, even with a decrease in the frequency of all types of tropical cyclones (Bender et al., 2010).

Figure 10-1 Percent Change to the Depth of the 20-Year Precipitation Event with Climate Change

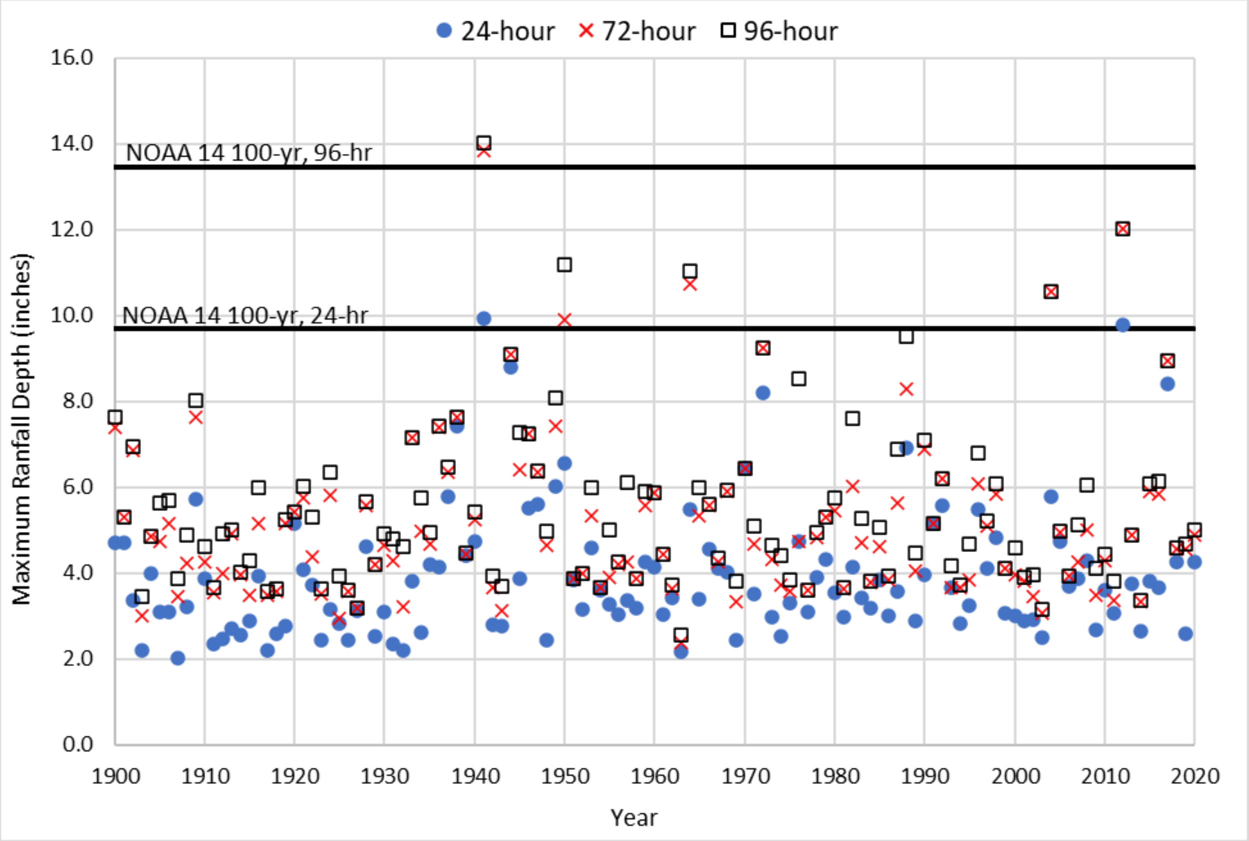


From *Fourth National Climate Assessment Volume 1, Climate Science Special Report: Precipitation Changes in the United States*, 2017 (https://science2017.globalchange.gov/chapter/7/).

10.1.2 HISTORICAL RAINFALL DATA ANALYSIS

The Jones Edmunds Team reviewed local historical rainfall data to look for changes in frequency and duration. For this, the Team reviewed an hourly composite dataset for Gainesville developed by SJRWMD, which combines data from various stations back to 1897 (SJRWMD, 2012). Figure 10-2 shows that the Team calculated annual maximum moving (or rolling) sums for 24-hour, 72-hour, and 96-hour durations for the period of record (POR). These storm durations are used for design purposes throughout the County, as discussed in Section 10-3 regarding design criteria. For reference, the plot also includes the 100-year/24-hour and 100-year/94-hour depths estimated in NOAA Atlas 14. The data show no clear trends of increasing or decreasing magnitudes in recent decades (1990 to present) compared to previous decades. However, the data show that two extreme events (exceeding the 100-year/24-hour depth) have occurred during the 2000s that had not happened since the 1960s.

Figure 10-2 Maximum Rainfall Depths During Three Duration Periods (24-Hour, 72-Hour, and 96-Hour)



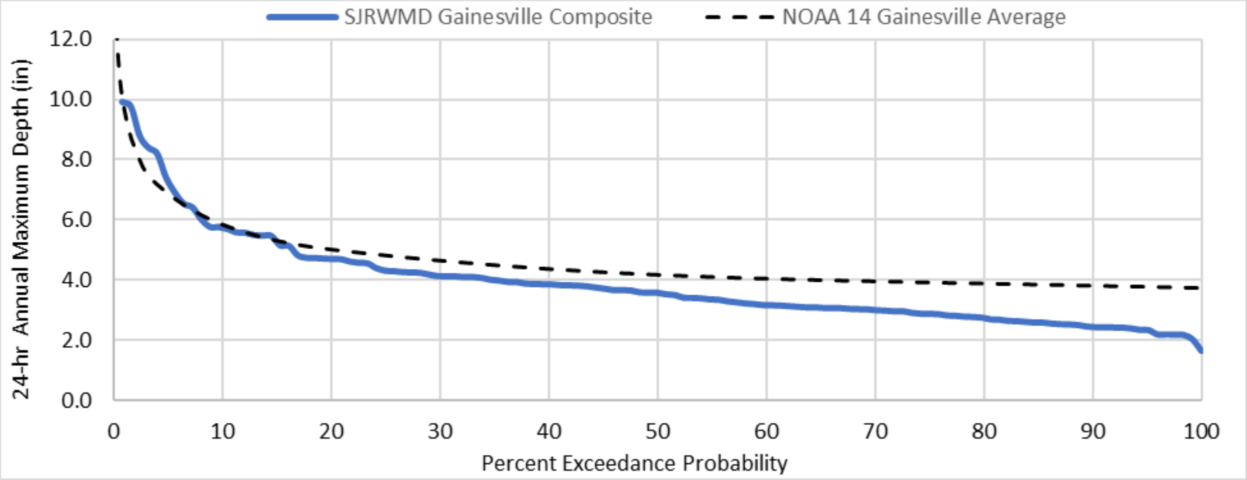
Calculated from composite hourly Gainesville station data from St. Johns River Water Management District (SJRWMD) for the Period of Record (POR): 1987 through 2020.

We also reviewed the 10 highest rainfall storms recorded at the Gainesville station. We found that these storms occurred between June and October and were associated with hurricanes or recorded tropical storms. The strong relationship between these tropical storms and extreme precipitation points to the importance of understanding how climate change will affect these storms and the rainfall they produce. Regionally, flooding has also occurred in the winter, and winter storms pose a flood risk to Alachua County. For example the City of Archer received more than 8 inches of rain between March 10 and 13, 2022.

The Jones Edmunds Team also compared the rainfall frequency depths estimated by NOAA Atlas 14 with available gauge data. The more recently published depth-duration frequency curves in NOAA Atlas 14 for the southeast region of the United States (Perica et al., 2013) is missing at least the last decade of rainfall records. Moreover, a recent paper in Delaware found that NOAA Atlas 14 underestimated long-duration depths compared to their analysis based on more detailed localized data (Leathers et al., 2019).

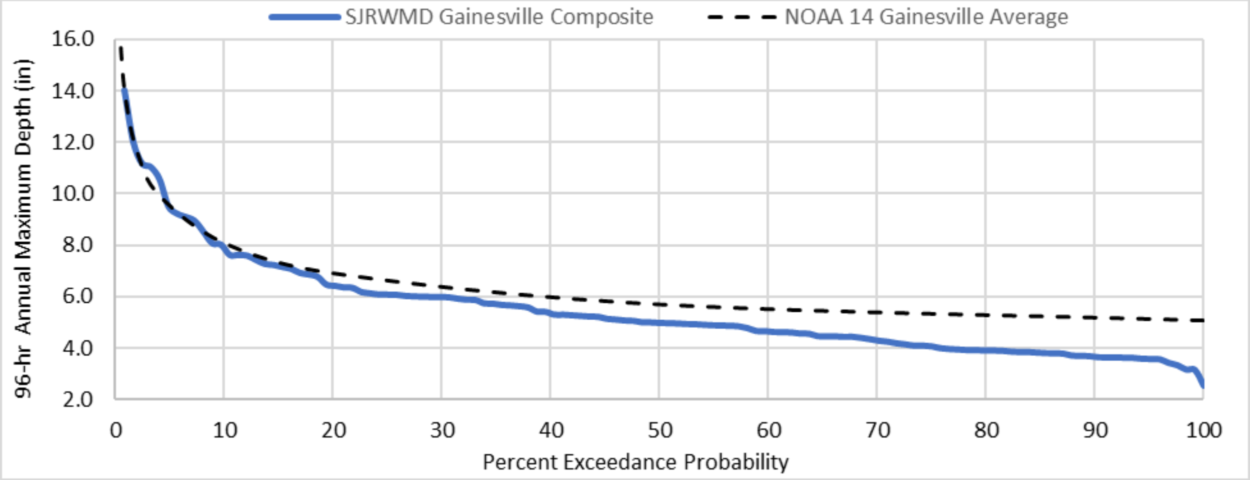
Figure 10-3 and Figure 10-4 shows that for the 24-hour and 96-hour annual maximum values, the Team plotted the percent of annual maximum values that exceeded a given rainfall depth. For comparison, we plotted these data against NOAA Atlas 14 24-hour and 96-hour depths versus the annual percent probability (the inverse of the recurrence interval). The NOAA data shown in the figures are the average of two Gainesville stations (Gainesville 3 WSW and Gainesville Regional Airport stations) and the High Springs station. Both plots show that the data closely match the NOAA Atlas 14 estimates at the lower probabilities; however, at the higher annual probabilities (> 50 percent), i.e., shorter recurrence intervals (< 2 years), the NOAA Atlas 14 predictions are higher than the measured depths.

Figure 10-3 Probability of Exceeding a Given Maximum Depth During a 24-Hour Duration Period



Calculated from composite hourly Gainesville station data from SJRWMD for the POR: 1987 through 2020. Compared with the average of three NOAA Atlas 14 Gainesville stations (Gainesville 3 WSW, Gainesville Regional Airport, High Springs stations).

Figure 10-4 Probability of Exceeding a Given Maximum Depth During a 96-Hour Duration Period



Calculated from composite hourly Gainesville station data from SJRWMD for the POR: 1987 through 2020. Compared with the average of three NOAA Atlas 14 Gainesville stations (Gainesville 3 WSW, Gainesville Regional Airport, High Springs stations).

The NOAA Atlas 14 depths for the 100-year/24-hour are 9.8, 9.5, and 10.2 inches for the Gainesville 3 WSW, Gainesville Regional Airport, and High Springs stations, respectively. For the 100-year/96-hour depths at the Gainesville 3 WSW, Gainesville Regional Airport, and High Springs stations, the NOAA Atlas 14 depths are 13.6, 13.3, and 14.0 inches, respectively.

For each decade in the Period of Record (POR), the Team plotted the number of events above 4.2 inches (the 50-percent probability of annual exceedance) and the number of events above 7.2 inches (the lower end of the 90-percent confidence interval range for the 100-year/24-hour NOAA Atlas 14 estimate) (Figure 10-5). The blue columns in the plot show a higher number of events per decade that were greater than 4.2 inches occurred after the 1990s than occurred in previous decades. The exception to this was the 1940s and 1970s. The black columns show two significant events in the last decade, which had not occurred since the 1940s.

Figure 10-5 **Number of Events that Exceed NOAA Atlas 14 50-Percent Probability and the Lower Range of the 1-Percent Probability of the 100-Year/24-Hour Event**

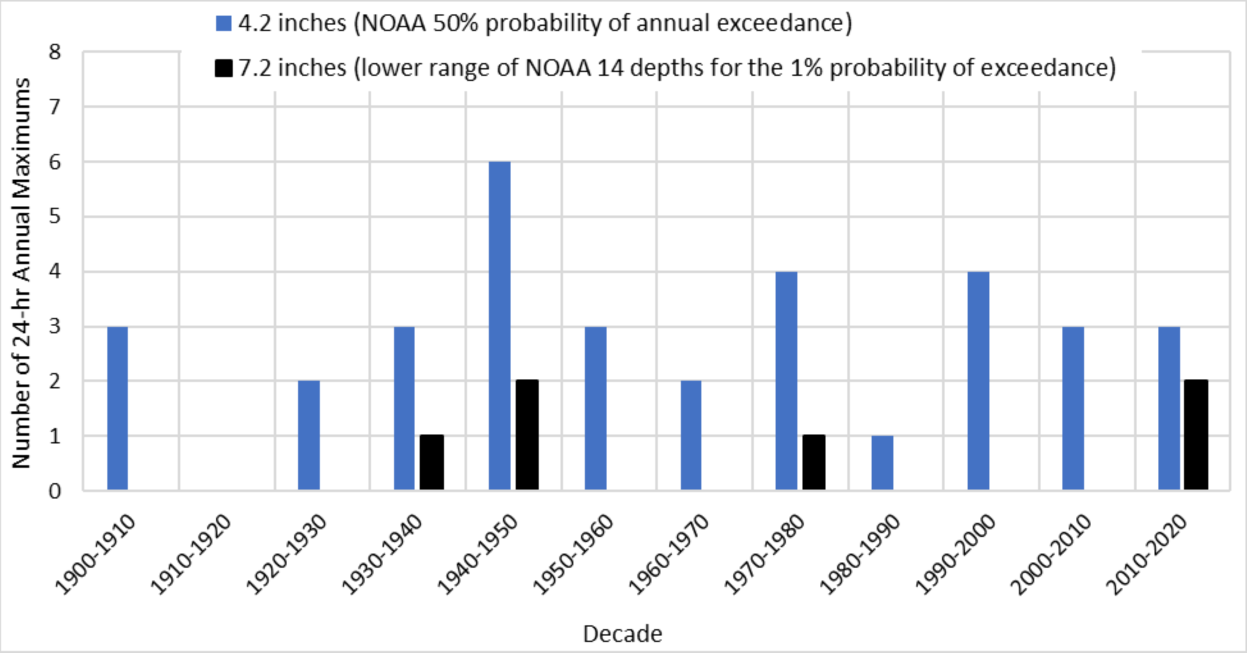
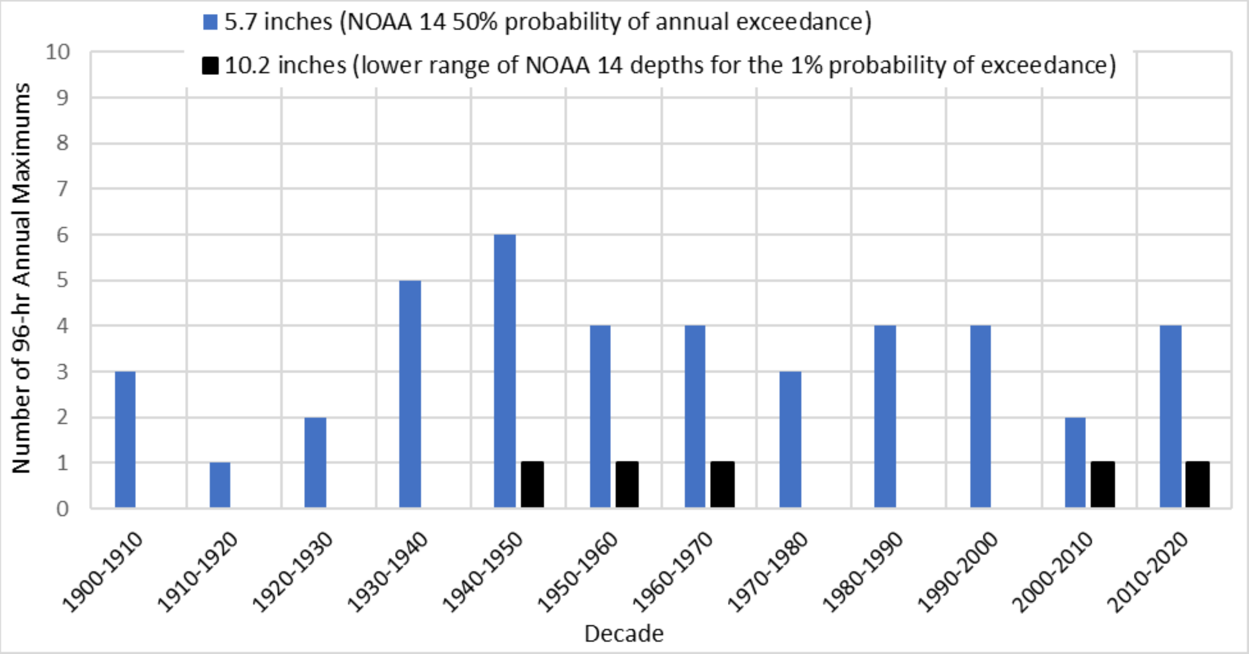


Figure 10-6 shows a similar plot as above for the 96-hour duration. Although seeing a clear trend is difficult, taking the average number of event occurrences divided by the number of decades results in higher frequency of extreme events for the decades after 1990 than for the decades before.

Figure 10-6 **Number of Events that Exceed NOAA Atlas 14 50-Percent Probability and the Lower Range of the 1-Percent Probability of the 100-Year/96-Hour Event**



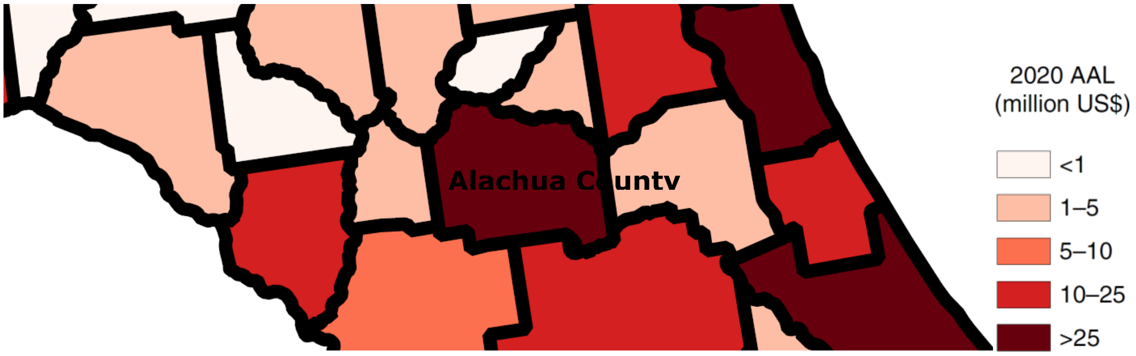
We performed the above analysis using readily available composite data from Gainesville stations. More data are needed to complete a thorough Countywide analysis. Although the data show some signs of increased extreme precipitation events in the last few decades, significant events have also occurred in the 1940s and 1960s. A thorough analysis of the effects of climate change on extreme rainfall events would require a more complex analysis (Wright, Bosma, & Lopez-Cantu, 2019).

10.1.3 LITERATURE REVIEW: FUTURE CHANGES TO FLOOD RISK

The Jones Edmunds Team also reviewed available literature on changes to flood risk to assess the possible shift in frequency of the current 1-percent event. The Federal Emergency Management Agency (FEMA), water management districts, and local jurisdictions typically conduct flood studies and flood risk predictions using hydrologic and hydraulic (H&H) models that use established design storm events. Wing et al. (2022) argues that these flood risk tools fail to recognize that the nature of floods is changing, and to plan for the long-term permitting should consider the increased future risk. This study used a one-dimensional (1D) and two-dimensional (2D) hydraulic model for all the contiguous United States (Bates et al., 2020) and a future precipitation change-factor approach based on downscaled GCMs and stochastic simulations of hurricanes under climate change scenarios. The study developed probabilistic depth-damage functions to determine the average annual losses (AAL) for the climate conditions of 2020 and 2050 under the lower emissions RCP4.5 climate change scenario.

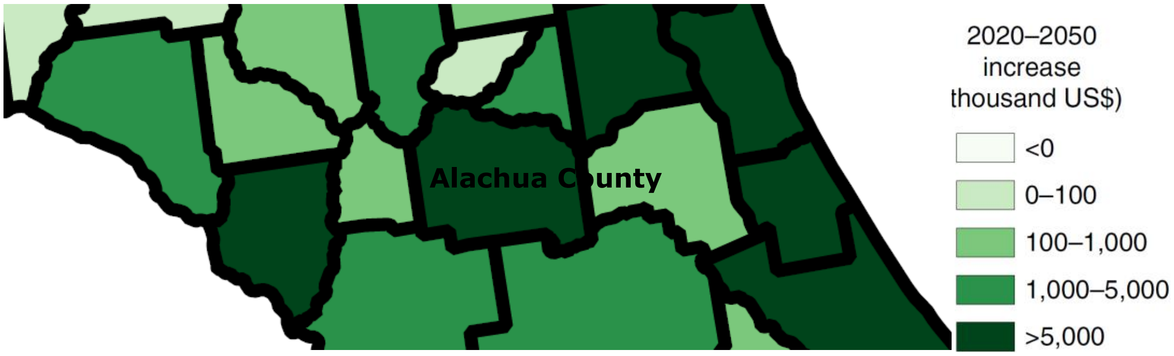
Figure 10-7 and Figure 10-8 show the zoomed views of Alachua County, depicting the estimated AAL for 2020 and 2050, respectively, extracted from Wing et al. (2022). The authors predicted over 25 million in AALs for Alachua County under current (2020) climate conditions and land use, similar in magnitude to coastal communities. The AAL includes all economic costs associated with flooding, such delays in traffic, relocation costs, and repair costs.

Figure 10-7 Absolute AAL in 2020



Extracted from Wing et al. (2022).

Figure 10-8 Absolute AAL Increase from 2020 to 2050



Extracted from Wing et al. (2022).

According to the estimated projections, between 2020 and 2050, the AAL will increase by over 5 million.

We did not review the model used by Wing et al. (2022) for Alachua County. However, the authors of that model noted that their methodology includes some simplifications. For example, the model approximates stream geometry when modeling riverine systems (with more than 20 square miles of contributing area) based on a return-period-discharge-capacity estimate resulted in up to a 29-percent error for the 100-year flows. Also, the Wing et al. (2022) model uses a rain-on-grid approach to map more local flooding (less than 20 square miles of contributing area). Although the model results compare favorably with FEMA flood models (a 78-percent similarity, [Bates et al., 2020]) and historical observations (an 87-percent similarity [Wang et al., 2021]), none of the validation sites reported are in Florida.

Moreover, the Wing et al. (2022) analysis does not consider groundwater dynamics. In Alachua County, precipitation frequency and intensity are the principal drivers that result in flood conditions. However, regional groundwater dynamics can play an important role, particularly in areas near zones of high connectivity between surface water and groundwater bodies and in closed basins, where percolation is the main drainage pathway. Changes to groundwater resource management, such as decreased groundwater abstractions and water quality/ecological protection policies, may lead to higher groundwater levels than were assumed during design. These changes could increase flood risk without a change in rainfall.

10.2 WHAT WILL THE FUTURE 100-YEAR STORM DEPTH BE?

Change Factors (CFs) are multipliers that flood management and stormwater professionals can apply to current design storm rainfall depth estimates to approximate future design rainfall depths. The Jones Edmunds Team has reviewed available studies on rainfall CFs.

10.2.1 CHANGE FACTORS FOR ALACHUA COUNTY

The best available data on CFs for Alachua County is a statewide study performed by Florida International University (FIU) titled *Updating the Statewide Extreme Rainfall Projections*. (Obeysekera et al., 2021) The study provides change factors for five climate divisions within

Florida. Figure 10-9 shows that Alachua County is in Climate Division 2, referred to as the North Florida Climate Division.

Figure 10-9 NOAA Climate Divisions in Florida

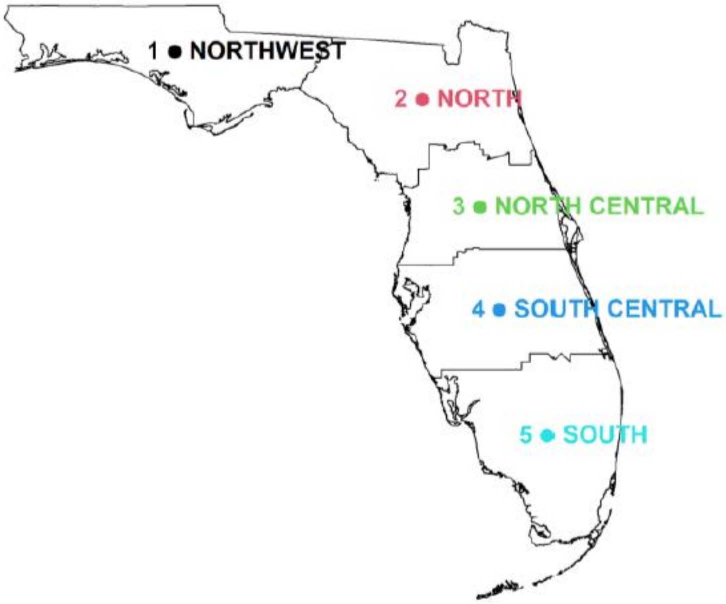


Figure copied directly from FIU report *Updating the Statewide Extreme Rainfall Projections*, June 2021 (Obeysekera, Sukop, Troxler, & John, 2021).

A similar study was also completed by South Florida Water Management District (SFWMD) and the United States Geological Survey (USGS) but only developed CFs for Climate Divisions 4 and 5 (Irizarry-Ortiz and Stamm, 2021). Obeysekera et al. (2021) and Irizarry et al. (2021) used similar methodology and datasets (Obeysekera et al., 2021).

Obeysekera et al. (2021) projected derived CFs based on the NOAA Atlas 14 Depth-Duration-Frequency (DDF) curves and the following three separate downscaled GCM datasets:

- Coordinated Regional Downscaling Experiment (CORDEX), dynamically downscaled.
- Localized Constructed Analogs (LOCA), statistically downscaled.
- Multivariate Adaptive Constructed Analogs (MACA), statistically downscaled.

The CFs were provided separately for each downscaled model (CORDEX, LOCA, and MACA) and provided a possible future rainfall based on multiple climate scenarios and simulations. The climate scenarios included with each of the downscaled models in the study include datasets representing RCP4.5 (median greenhouse gas [GHG] emissions scenario) and RCP8.5 (high GHG emissions scenario). Additional details regarding the specific methods and simulations considered can be found in the 2021 report.

Obeysekera et al. (2021) produced CFs for each of the following:

- Climate dataset (CORDEX, LOCA, and MACA).
- Rainfall duration (1, 3, 7, and 10 days).
- Two future periods of analysis (2030 to 2069 and 2060 to 2099, relative to the *baseline* period of 1966 to 2005).
- Florida Climate Divisions or Regions (Figure 10-9).
- Return Period (5, 10, 25, 50, 100, and 200 years).

For each combination of categories above, Obeysekera et al. (2021) report percentiles representing the 17th, 50th, and 83rd percentile to represent the variability in the data.

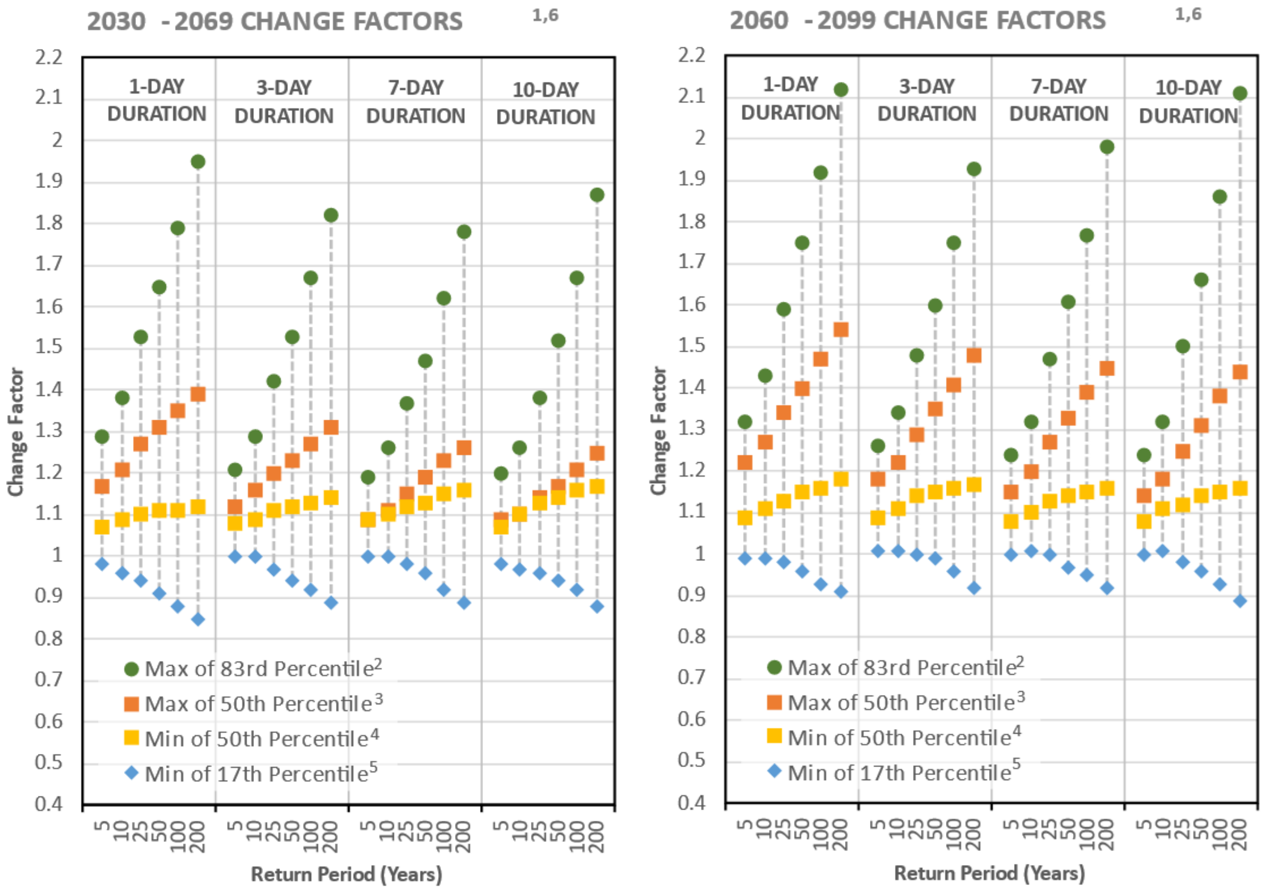
After the report's publication, the authors discovered a bias-correction error in the CORDEX dataset. As a result, USGS released a disclaimer describing the errors with the dataset. We also confirmed with Dr. Obeysekera that we should apply the same disclaimer to the FIU study:

> **USGS Disclaimer:** *A bias-correction error was recently found in the bias-corrected CORDEX data used in this project as described at https://na-cordex.org/bias-correction-error.html. The impact of this error in the computed DDF curves and change factors is not fully known. Once a corrected CORDEX dataset becomes available, the USGS will publish a new set of DDF curves and change factors for CORDEX based on the new data if necessary. Users should exercise caution when using CORDEX change factors in decision-making until the data is revised.* Irizarry-Ortiz & Stamm, 2021

In an email to the Jones Edmunds Team, Dr. Obeysekera recommended that the Team only use the LOCA and MACA data to establish future CFs until he has an opportunity to correct the CORDEX data. No timeline is set for the reanalysis and update of the FIU paper with the corrected data.

Figure 10-10 shows the 2030 to 2069 projections and the 2060 to 2099 projects created from the data presented in Obeysekera et al. (2021) for Climate Division 2 for only LOCA and MACA data. See Figure 10-10 footnotes for more detailed information regarding the data source. Obeysekera et al. (2021) recommends reviewing the range of CFs and selecting the appropriate value based on the type of project or analysis. We discussed this selection in more detail in Section 10.4. For an example of how these CFs could affect future storm depths, we applied these CFs to a NOAA Atlas 14 station in Alachua County, Gainesville 3 WSW (Figure 10-10 and Figure 10-11). In addition, Section 10.4 provides a further discussion of design criteria.

Figure 10-10 CF Data for Climate Division 2



[1] Change Factor data for Climate Division 2 from Florida International University report titled "Updating the Statewide Extreme Rainfall Projections" Obeysekera, Sukop, Troxler, & John, 2021. Change Factor data from LOCA and MACA climate model datasets only, CORDEX data was excluded due to bias correction errors (LOCA, MACA, and CORDEX are downscaled GCMs; LOCA = Localized Constructed Analogues; MACA = Multivariate Adaptive Constructed Analogs; CORDEX = Coordinated Regional Downscaling Experiment).

[2] *Max of 83rd Percentile CF = The highest 83rd percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.*

[3] *Max of 50th Percentile CF = The highest 50th percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.*

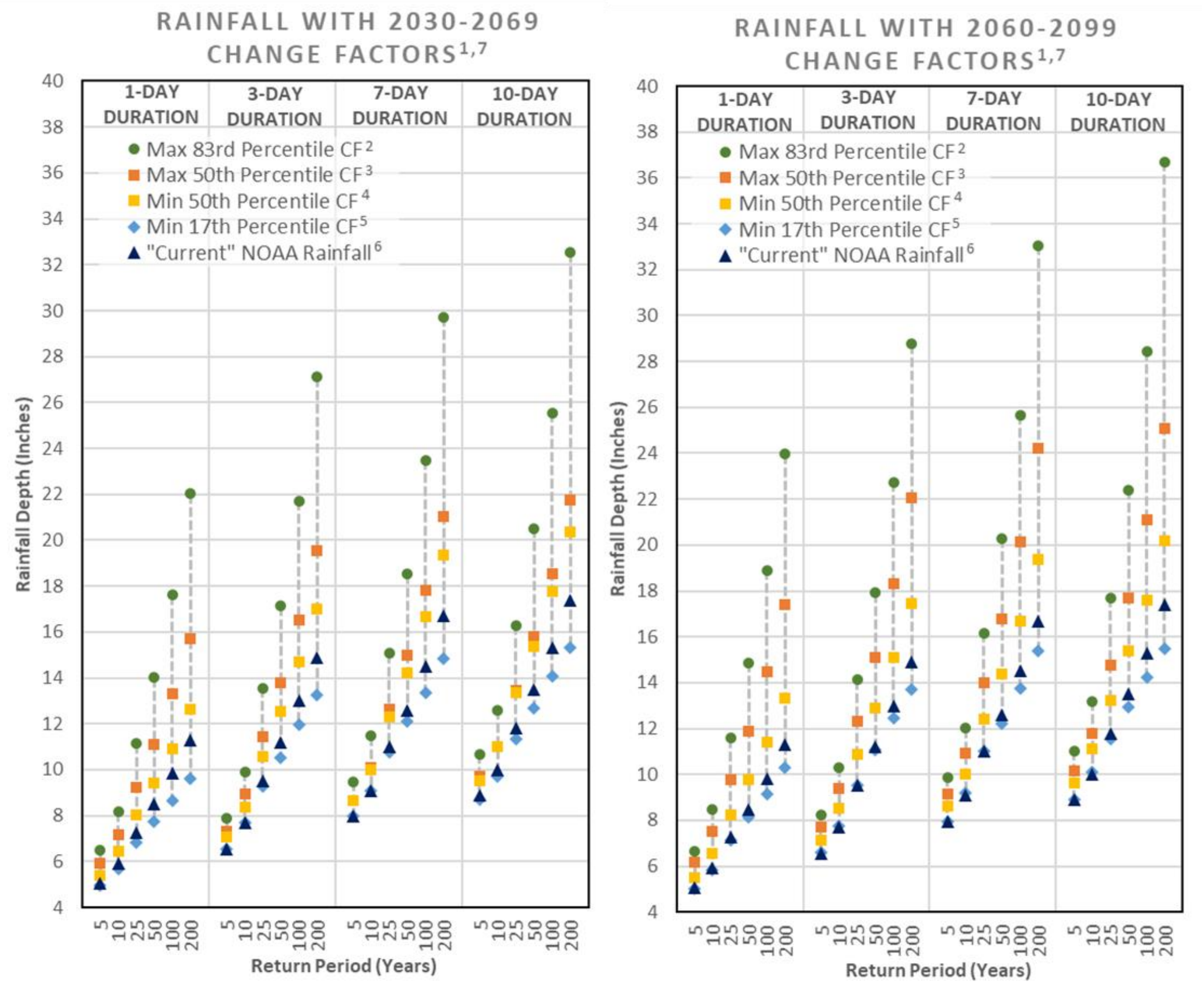
[4] *Min of 50th Percentile CF = The lowest 50th percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.*

[5] *Min of 17th Percentile CF = The lowest 17th percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.*

[6] *To selecting a change factor, Obeysekera et al (2021) recommend considering project design life, objectives of the stormwater project, size of the infrastructure, and the design return period. A higher change factor will lead to a higher design rainfall.*

From FIU report titled *Updating the Statewide Extreme Rainfall Projections* (Obeysekera et al., 2021). CF data are only representative of LOCA and MACA climate model datasets.

Figure 10-11 CFs Applied to NOAA Atlas 14 Station Gainesville 3 WSW – CF Data for Climate Division 2



[1] Change Factor data for Climate Division 2 from Florida International University report titled "Updating the Statewide Extreme Rainfall Projections" Obeysekera, Sukop, Troxler, & John, 2021. Change Factor data from LOCA and MACA climate model datasets only, CORDEX data was excluded due to bias correction errors (LOCA, MACA, and CORDEX are downscaled GCMs; LOCA = Localized Constructed Analogues; MACA = Multivariate Adaptive Constructed Analogs; CORDEX = Coordinated Regional Downscaling Experiment).

[2] Max of 83rd Percentile CF = The highest 83rd percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.

[3] Max of 50th Percentile CF = The highest 50th percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.

[4] Min of 50th Percentile CF = The lowest 50th percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.

[5] Min of 17th Percentile CF = The lowest 17th percentile value (from LOCA and MACA datasets) times "Current" NOAA Rainfall.

[6] "Current" NOAA Rainfall = NOAA Atlas 14 Volume 9 Version 2 Point Precipitation Estimates from Station Gainsville 3 WSW.

[7] To selecting a change factor, Obeysekera et al (2021) recommend considering project design life, objectives of the stormwater project, size of the infrastructure, and the design return period. A higher change factor will lead to a higher design rainfall.

From FIU report titled *Updating the Statewide Extreme Rainfall Projections* (Obeysekera et al., 2021). CF data are only representative of LOCA and MACA climate model datasets.

10.3 WILL DESIGN CRITERIA CHANGE AND BY HOW MUCH?

The following Section summarizes stormwater design criteria in Alachua County and possible future changes to those criteria. To determine possible changes to design criteria, the Team considered the extreme precipitation CFs (Section 10.3) and briefly reviewed available literature.

10.3.1 EXISTING STORMWATER SYSTEM DESIGN CRITERIA

The State, County, and municipalities regulate stormwater and new development in Alachua County. Depending on location, stormwater design criteria may be established by:

- St. Johns River Water Management District (SJRWMD).
- Suwannee River Water Management District (SRWMD).
- Alachua County.
- Local municipalities.
- Florida Department of Transportation (FDOT).

The design criteria discussed in this Section are specific to rainfall and the potential effects on stormwater system designs. We summarized environmental resource permitting (ERP) requirements as those that apply Countywide and are generally the minimum design criteria that projects must meet.

The ERP permitting guidance manuals for SRWMD and SJRWMD guide the selection of design storms events, rainfall depths, rainfall distributions, and antecedent moisture conditions for evaluating stormwater systems to meet ERP requirements. The criteria specified by the SRWMD and SJRWMD ERP Volume 2 guidance manuals are different. For example, the two water management districts' ERP requirements for design storm event(s) differ. Table 10-1 provides examples of the ERP design storm event(s) and rainfall volumes that may be required to be evaluated depending on the project's location.

Alachua County has adopted the FDOT Drainage Manual design rainfall depths. The FDOT Drainage Manual has adopted NOAA Atlas 14 design rainfall depths.

10.3.2 NOAA ATLAS 14 DATA

Alachua County and FDOT use precipitation estimates available from NOAA Atlas 14 (Perica et al., 2013) as their source for rainfall DDF curves. The NOAA Atlas 14 project (Hydrometeorological Design Studies Center (weather.gov)) has updated these curves with more recent rainfall data and robust statistical analyses. However, some jurisdictions still rely on older data sources, such as Technical Paper (TP)-40 and TP-49 (National Weather Service (NWS), 1961; NWS, 1964). In some cases, these older sources may result in significantly different depths than the NOAA Atlas 14 data. In addition, NOAA based their Atlas 14 data on temporal stationarity, which assumes that the extreme precipitation events do not change significantly over time and that future climate conditions can be represented by the past observed precipitation (Perica et al., 2013; NWS, 2022). However, studies show that climate change is likely to impact precipitation patterns. Accordingly, water resources planners are reconsidering the current design criteria to account for updates to historical data and climate change predictions (Underwood, et al., 2020).

Table 10-1 Examples of Design Storm Events Related to ERP Requirements in SRWMD and SJRWMD

Water Management District	Design Event[3]	Rainfall Volume associated with existing ERP manual guidance (inches)
SRWMD[1] *(Design event for Alachua County is dependent on factors specific to SRWMD ERP guidance)*	10-year/24-hour	7.92
	100-year/1-hour	4.40
	100-year/2-hour	5.40
	100-year/4-hour	6.72
	100-year/8-hour	8.00
	100-year/1-day	11.04
	100-year/3-day	13.80
	100-year/7-day	16.00
	100-year/10-day	18.00
SJRWMD[2] *(Design event for Alachua County is dependent on factors specific to SJRWMD ERP guidance)*	25-year/1-day	7.75
	25-year/4-day	11

1 - Rainfall volumes in the ERP manual are those listed for Alachua County in SRWMD's *Environmental Resource Permit Applicant's Handbook Volume II*. SRWMD provides consistent rainfall depths for Taylor, Lafayette, Dixie, Gilchrist, Levy, Bradford, and Alachua Counties. These depths are based on FDOT values through durations of 24 hours, and durations greater than 24 hours are based on the NWS TP No.49 (1964). By grouping Alachua Counties with coastal communities, SRWMD design rainfall depths significantly exceed other design rainfall depth requirements.

2 - Rainfall volumes estimated based on acceptable sources listed in the SJRWMD Permit Information Manual: NWS TPs No. 40 (1961) and No.49 (1964).

3 - The design event requirements have exceptions. We have not included all design events that a design engineer would need to consider.

Alachua County requires the NOAA Atlas 14 rainfall depths as a basis for design criteria, which aligns with the FDOT Drainage Manual. The Atlas 14 depths are also the basis of the CFs established by Obeysekera et al. (2021) and Irrizary et al. (2021). However, in some cases, the rainfall depths available from NOAA Atlas 14 are lower than those published in the SRWMD and SJRWMD ERP guidance documents.

Based on the Jones Edmunds Team's literature review, we expect climate change will increase extreme rainfall depths within Alachua County (Obeysekera, Sukop, Troxler, & John, 2021). Rainfall CFs indicate the expected shift in rainfall volume associated with return periods (frequency) and storm durations. The literature we reviewed provided CFs for return periods with durations of 1, 3, 7, and 10 days.

Figure 10-10 and Figure 10-11 summarize rainfall volumes associated with the CFs for the near (2030 to 2069) and far (2060 to 2099) terms in Alachua County based on NOAA Atlas 14 data (Station Gainesville 3 WSW). During our literature review, the Team did not discover CFs for storm durations under 24 hours. Table 10-2 compares rainfall volumes based on ERP guidance manuals, NOAA Atlas 14 data, and rainfall CFs.

Table 10-2 Comparison of Rainfall Volumes for Existing ERP Guidance Manuals, NOAA Atlas 14 Data, and Rainfall CFs

Design Event (return period, duration	Rainfall Volume, inches			
	Associated with ERP manual guidance for SRWMD and SJRWMD[1,2]	NOAA Atlas 14, Version 2, Station: Gainesville 3 WSW		
		Current[3]	2030 to 2069: For the Range of CFs of the 50th to 83rd percentiles[4]	2060 to 2099: For the Range of CFs of the 50th to 83rd percentiles[4]
10-year/1-day	7.92	5.91	6.44 – 8.16	6.56 – 8.45
25-year/1-day	7.75	7.28	8.01 – 11.14	8.23 – 11.58
100-year/1-day	11.04	9.84	10.92 – 17.61	11.41 – 18.89
100-year/3-day	13.80	13	14.69 – 21.71	15.08 – 22.75
100-year/7-day	16.00	14.5	16.68 – 23.49	16.68 – 25.67
100-year/ 10-day	18.00	15.3	17.75 – 25.55	17.60 – 28.46

Notes:

1 - Rainfall volumes in the ERP manual are those listed for Alachua County in SRWMD’s *Environmental Resource Permit Applicant's Handbook Volume II*. SRWMD provides consistent rainfall depths for Taylor, Lafayette, Dixie, Gilchrist, Levy, Bradford, and Alachua Counties. These depths are based on FDOT values through durations of 24 hours, and durations greater than 24 hours are based on the NWS TP No.49 (1964). By grouping Alachua Counties with coastal communities, SRWMD design rainfall depths significantly exceed other design rainfall depth requirements.

2 - Rainfall volumes for 25-year/1-day estimated based on acceptable sources listed in the SJRWMD Permit Information Manual: NWS TPs No. 40 (1961) and No.49 (1964).

3 - *Current* = NOAA Atlas 14 Volume 9 Version 2 Point Precipitation Estimates from Station Gainesville 3 WSW.

4 - CF data for Climate Division 2 from the FIU report titled *Updating the Statewide Extreme Rainfall Projections* (Obeysekera et al., 2021). CF data shown is from LOCA and MACA climate model datasets only. CORDEX data were excluded due to bias correction errors (LOCA, MACA, and CORDEX are downscaled GCMs.

For the design events presented in Table 10-2, NOAA Atlas 14 *current* rainfall volumes are lower than the volumes associated with the ERP manual guidance (this may not be true for all design events, and specific design events should be evaluated if needed). As the CFs are applied to the *current* NOAA rainfall, the rainfall volumes increase for the near and far terms. As a result, the rainfall volumes are greater than those associated with ERP manual guidance (depending on the percentile selected). The literature recommends, when choosing a CF, to consider an appropriate value based on the particular setting of the project under consideration in which the setting may be characterized by design life, objectives of the stormwater project, size of the infrastructure, and the design return period (Obeysekera, Sukop, Troxler, & John, 2021). Also indicated in the literature, using a higher CF will lead to a larger than expected magnitude of extreme rainfall. Therefore, this choice may lead to a larger design but a lower risk of failure and selecting a lower CF will have the opposite effect of a smaller design and a greater chance of failure (Obeysekera et al., 2021).

We expect that regulators will consider changing stormwater design criteria, given that the rainfall CFs show an increase in the rainfall volume associated with (select) design events. Therefore, we can use the rainfall CFs to estimate how design rainfall depth requirements may change. Examples of how the design rainfall volumes may change are summarized in Table 10-2 for the 50th to 83rd percentiles.

Additionally, we expect regulatory agencies to consider changes to design criteria associated with rainfall distribution patterns, groundwater levels, and antecedent moisture as research into climate change continues and more data become available.

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