



Pacific Drought Knowledge Exchange

Climate Change, Climate Variability, & Drought Portfolio

Puu Waawaa Forest Reserve, Hawaii



Pacific Drought Knowledge Exchange

Climate change, climate variability, and drought (CCVD) will exert a growing impact on Hawaii's ecosystems, agriculture and communities in the future. While resource managers are tasked with preparing for this with the best available information, it is hard to know what data, research and recommendations are available. The Pacific Drought Knowledge Exchange (PDKE) program focuses on facilitating knowledge exchange between the research community and resource managers and stakeholders, thereby expanding the utility of climate and drought-related scientific products.

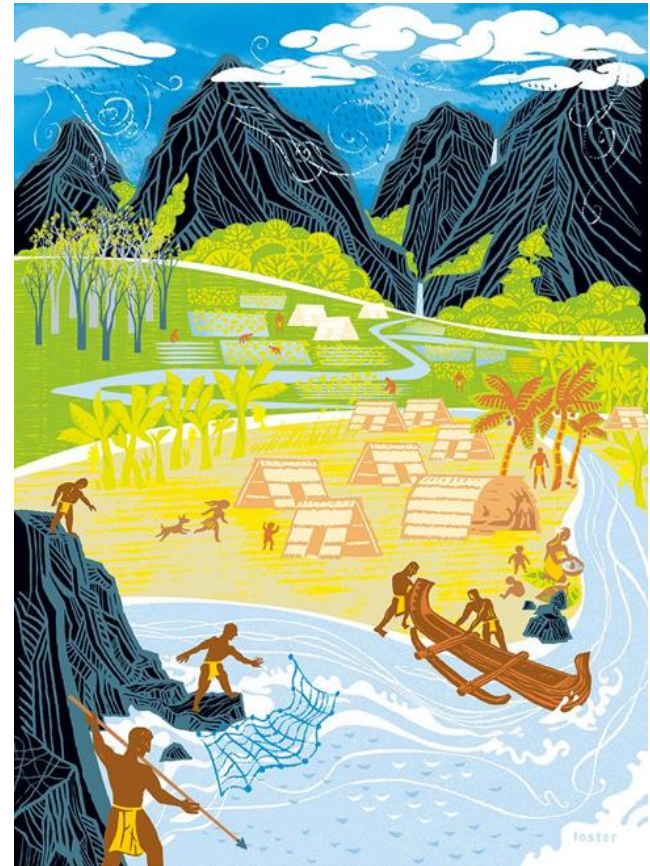
This CCVD portfolio is a comprehensive synthesis of climate and drought information developed specifically for Puu Waawaa Forest Reserve (Puu Waawaa). It is designed to provide relevant climate and drought information needed to inform land management and guide future research and extension. While we try to include a wide range of useful site-specific data products, we also recognize that every site is unique and PDKE is happy to collaborate on producing additional drought products beyond the CCVD portfolio to meet stakeholder needs.

The PDKE program was piloted in November of 2019 with funding from the Pacific Islands Climate Adaptation Science Center (PICASC). Subsequent PDKE activities and updates to the CCVD portfolio have been funded by PICASC, the East-West Center, and the National Integrated Drought Information System (NIDIS).

Part 1: Describing the Area

In describing any area of management in Hawaii, it is important to present both traditional and contemporary knowledge. Traditional Hawaiian landscape divisions are well-documented and were established largely following geological features and the natural flow of resources throughout the landscape.

This portfolio provides a brief description of Puu Waawaa in context of traditional Hawaiian landscapes, as well as contemporary knowledge on elevation and current landcover.



Credit: Matt Foster

Hawaiian Land Divisions

There are three types of traditional Hawaiian landscape divisions available as GIS layers and presented here for Puu Waawaa. The land divisions are shown in red and Puu Waawaa is shown in blue.

Mokupuni



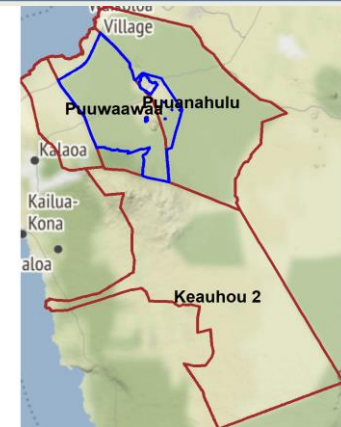
Mokupuni is the largest land division and refers to entire islands. Puu Waawaa is in the mokupuni of Hawaii.

Moku



Within mokupuni are smaller divisions called moku. Puu Waawaa is in the moku of Kona.

Ahupuaa



Within each moku are several ahupuaa which commonly extend from uplands to the sea. Puu Waawaa is situated within 4 ahupuaa - primarily Puuwaawaa; Puuanahulu; and Keauhou 2.

Elevation

Puu Waawaa is located on the Island of Hawaii and covers a vertical elevation range of 6083 ft. In Hawaii, climate gradients can change significantly over short distances due to changes in elevation, topography, and orientation to the prevailing winds.

Elevation Puu Waawaa

Minimum = 52 ft

Mean = 2239 ft

Maximum = 6135 ft

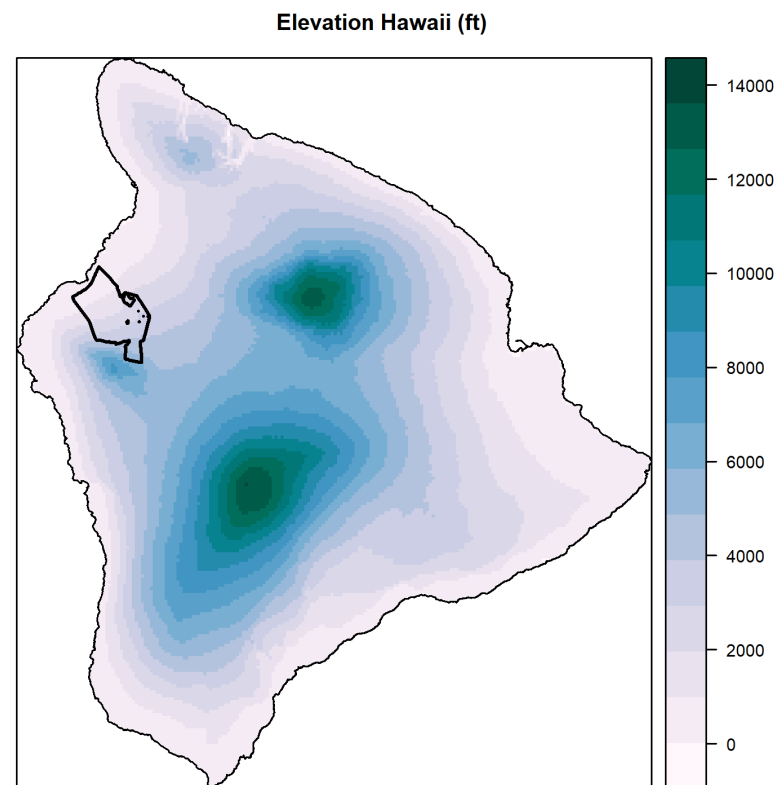


Figure 2. Elevation for the Island of Hawaii with Puu Waawaa outlined in black.

Landcover

The three most common types of landcover in Puu Waawaa are Grass/Shrub, Tree Cover, and Barren. Each landcover type exhibits different climate change impacts and management needs.

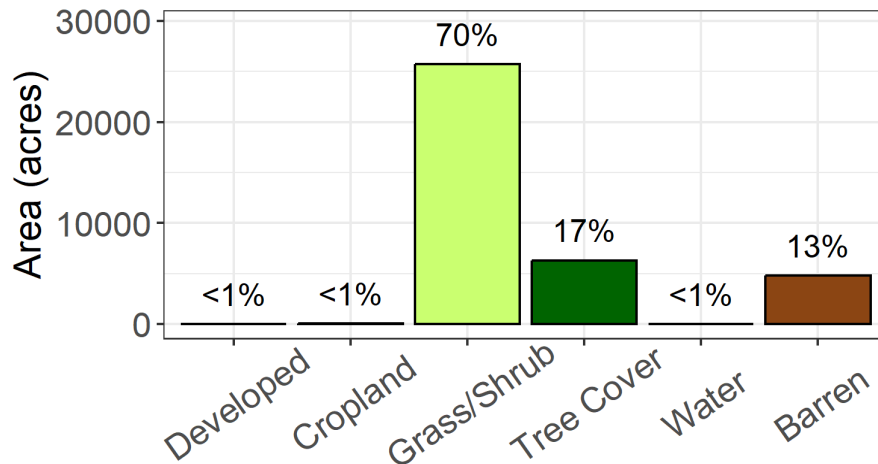


Figure 3. Bar graph showing amount and percent of each landcover type within Puu Waawaa.

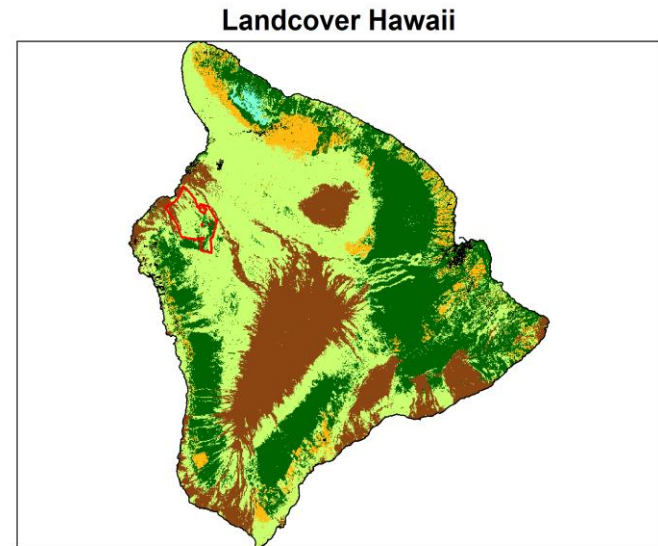
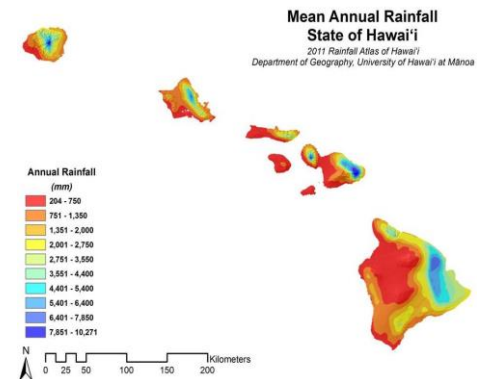
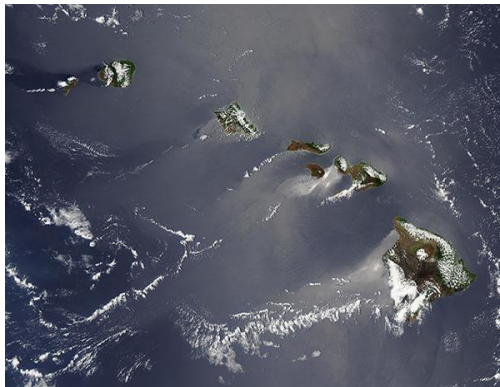


Figure 4. Landcover mapping for the island of Hawaii with Puu Waawaa outlined in red. The maps shown in the following slides will be for the Puu Waawaa area only.

Part 2: Climate Characteristics

Puu Waawaa

In developing this Portfolio, we relied on several gridded climate products available for the State of Hawaii. Annual and monthly estimates of rainfall were obtained from the Hawaii Climate Data Portal (HCDDP). Gridded estimates of other climate variables were obtained from the UH Manoa Climate of Hawaii data page. We retrieved all the data points that fell within the boundaries of Puu Waawaa from our 250 meter resolution state-wide maps to support the presented analyses.



Rainfall Station Locations

Rainfall data for this portfolio were estimated based on measurements made by hundreds of stations across the state.

The closest station to Puu Waawaa is KiholoRainGage, part of the USGS climate station network.

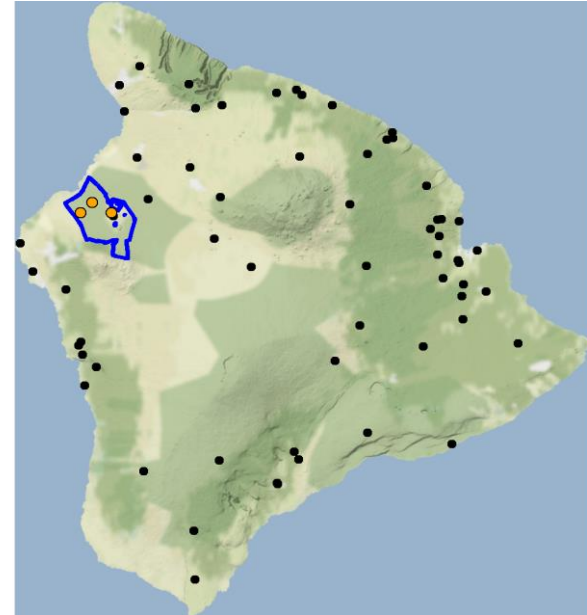


Figure 5. Rainfall station locations across Big Island with Puu Waawaa outlined in blue and three closest stations in orange.

Station.Name	Network	Website
KiholoRainGage	USGS	https://waterdata.usgs.gov/hi/nwis/current/
Mamalahoa	HIPPNET	http://www.hippnet.hawaii.edu/
KAUPULEHU LAVA FLOW	RAWS	https://raws.dri.edu/wraws/hiF.html

Figure 6. Three closest stations to Puu Waawaa with links to more information on the station network. If there are more than three stations at the site, only three will be listed here.

Annual Climate Characteristics

Climatic conditions in Hawaii can vary greatly across the landscape. These maps show the variation in select climate variables across Puu Waawaa and the table below has min. and max. values taken from the maps.

Climate Variable	Min	Max
Rainfall (°F)	10.00	29.00
Air Temperature (°F)	53.10	74.70
Relative Humidity (%)	71.00	86.00
Solar Radiation (W/m2)	174.00	210.00
Soil Moisture (Ratio)	0.17	0.52
Evapotranspiration (°F)	4.00	27.00
Windspeed (mph)	1.80	6.80

Table 1. Minimum and maximum average annual values for selected climate variables from within Puu Waawaa.

Giambelluca et al. (2013;2014)

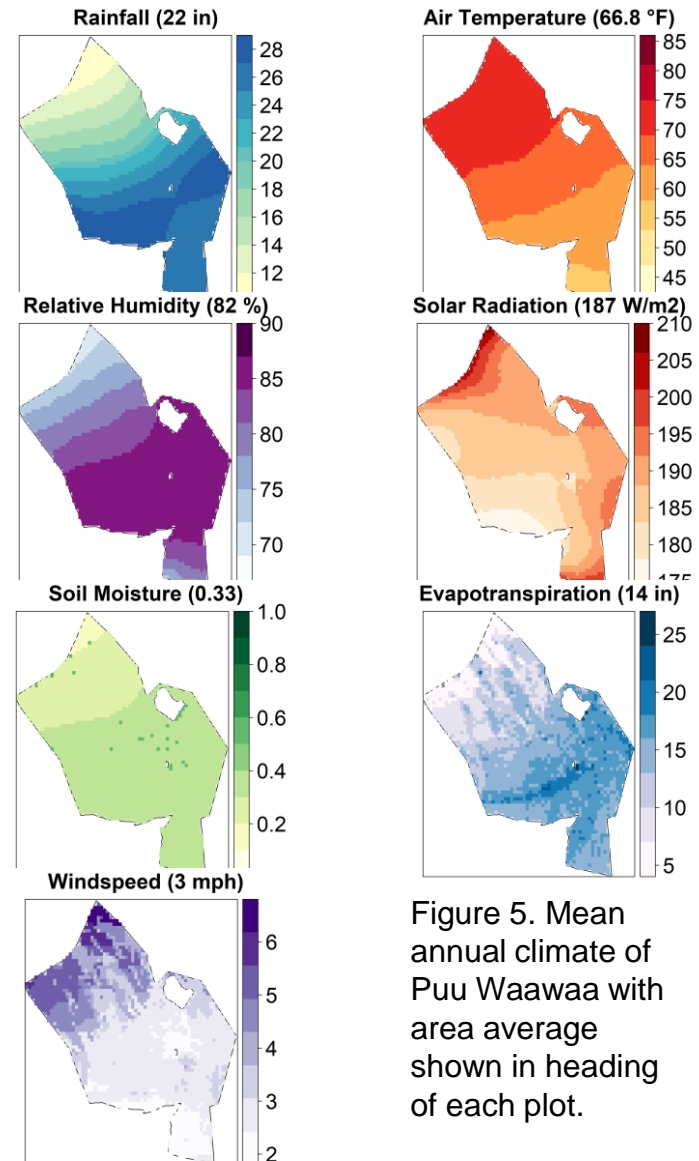


Figure 5. Mean annual climate of Puu Waawaa with area average shown in heading of each plot.

Average Monthly Rainfall

Average monthly rainfall patterns vary over the course of the year. At Puu Waawaa, the highest monthly rainfall is received in January (3 in.) and the lowest monthly rainfall is received in August (1 in.).

Monthly Rainfall: Puu Waawaa

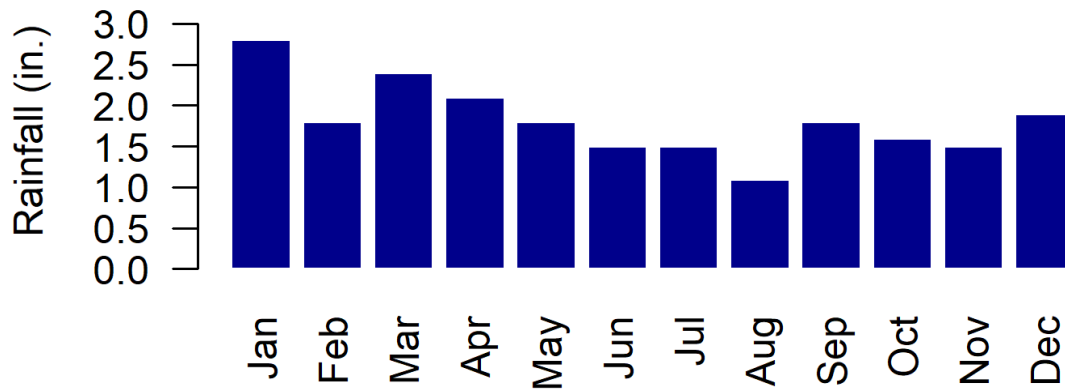
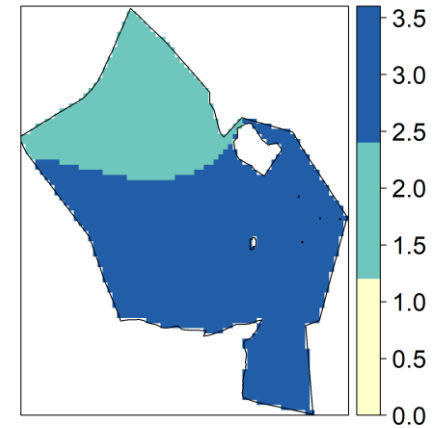


Figure 6. Mean monthly rainfall at Puu Waawaa.

January Rainfall (in.)



August Rainfall (in.)

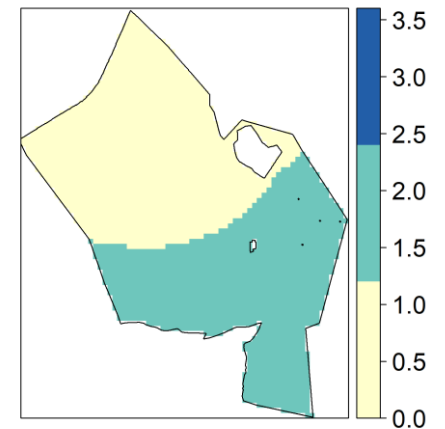


Figure 7. Monthly rainfall maps for the wettest (top) and driest (bottom) months.

Average Monthly Temperature

Average monthly air temperature patterns vary over the course of the year. At Puu Waawaa there is a 6.8 °F annual variation in temperature, with the warmest month of August (70 °F) and the coolest month in February (63 °F).

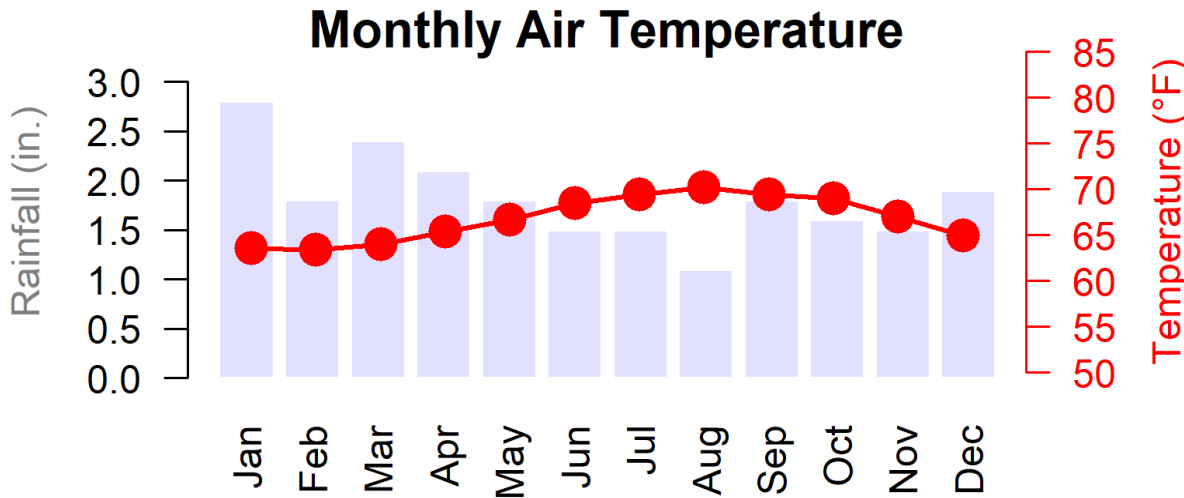


Figure 8. Mean monthly air temperature at Puu Waawaa with monthly rainfall in the background.

Giambelluca et al. (2013;2014)

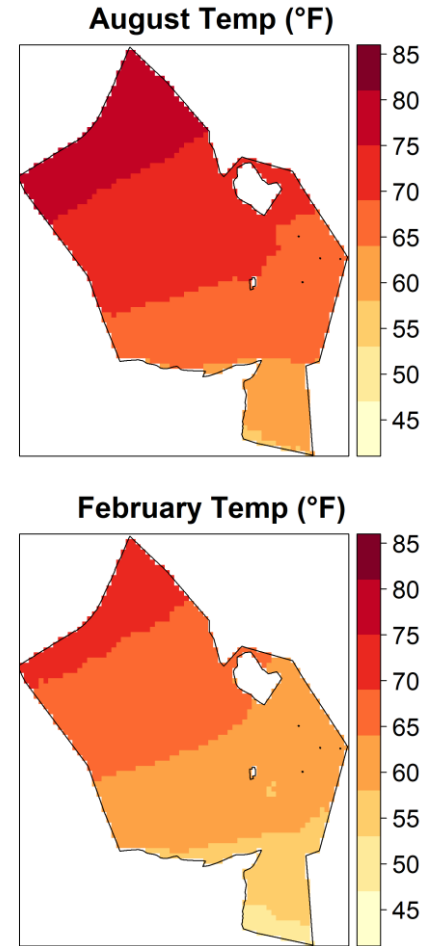
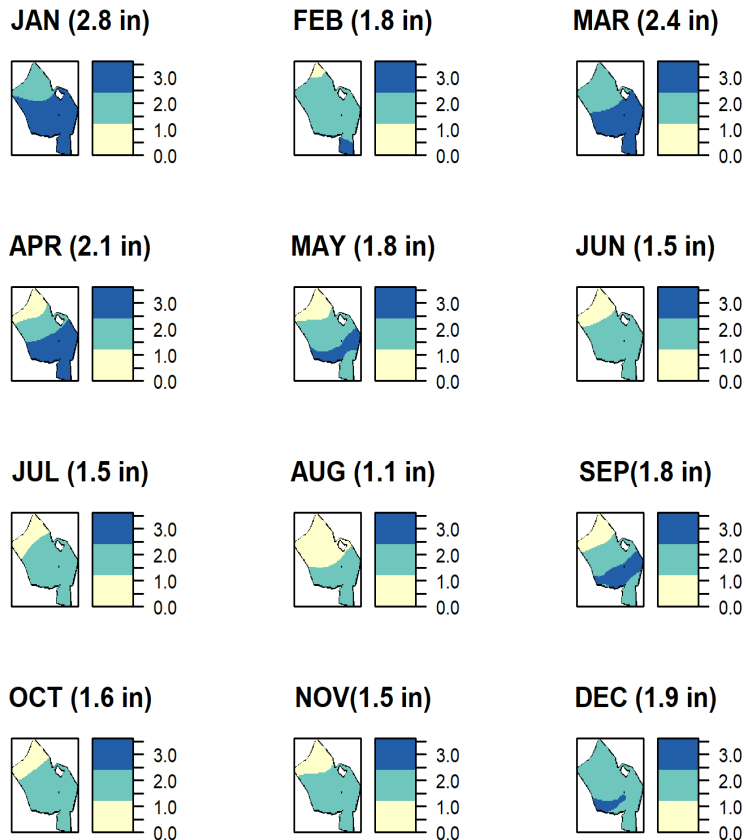


Figure 9. Monthly air temperature maps for the coldest (top) and hottest (bottom) months.

Average Monthly Climate

Monthly Rainfall: Puu Waawaa



Monthly Temperature: Puu Waawaa

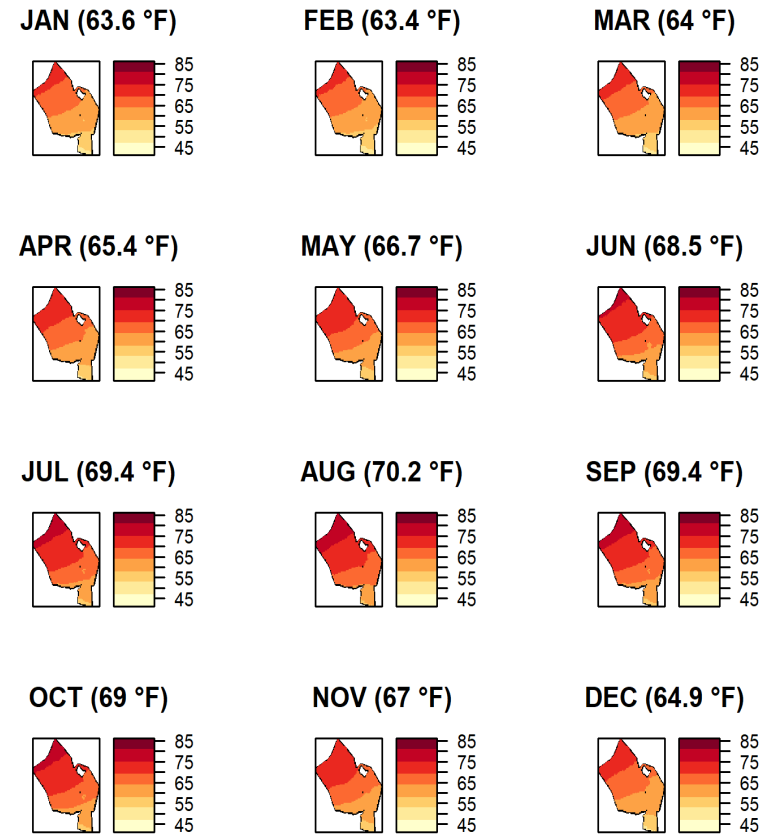


Figure 10. Mean monthly rainfall Puu Waawaa with area average shown in heading of each plot.

Figure 11. Mean monthly temperature at Puu Waawaa with area average shown in heading of each plot.

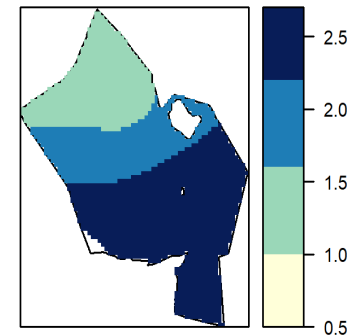
Average Seasonal Rainfall

Hawaii has two distinct 6-month seasons of rainfall: hooilo (Wet season: November to April) and kau (Dry season: May to October). Average Wet season monthly rainfall across Puu Waawaa is 2.1 in and Dry season is 1.6 in. These monthly values are in the 24 and 11 percentiles for rainfall across the whole state, respectively.

Management plans should anticipate and minimize negative impacts of these seasonal rainfall variations.

Monthly Rainfall: Puu Waawaa

Wet Season (NOV-APR) 2.1 in



Dry Season (MAY-OCT) 1.6 in

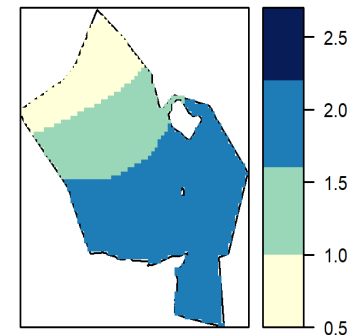


Figure 12. Average monthly rainfall maps for the wet (top) and dry (bottom) seasons. Puu Waawaa.

Average Monthly Climate Table

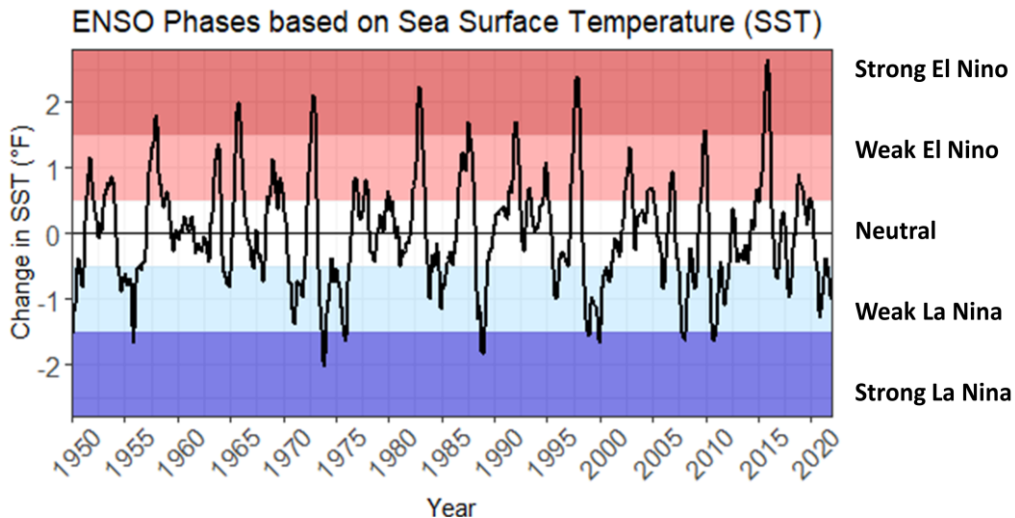
Puu Waawaa

Variable	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
RF [in]	2.8	1.8	2.4	2.1	1.8	1.5	1.5	1.1	1.8	1.6	1.5	1.9	22.0
Min TA [°F]	56.0	55.9	56.6	58.0	59.2	60.9	61.9	62.6	62.0	61.2	59.9	57.6	59.4
Mean TA [°F]	63.6	63.4	64.0	65.4	66.7	68.5	69.4	70.2	69.4	69.0	67.0	64.9	66.8
Max TA [°F]	73.2	72.8	73.2	74.1	75.1	76.9	77.9	78.8	78.6	77.8	75.9	74.1	75.8
RH [%]	80.0	80.0	82.0	84.0	84.0	84.0	83.0	82.0	83.0	83.0	81.0	81.0	82.0
CF [%]	43.0	51.0	58.0	57.0	54.0	53.0	48.0	43.0	43.0	47.0	48.0	46.0	49.0
ET [in]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	14.0
SM [%]	38.0	38.0	37.0	37.0	34.0	31.0	29.0	26.0	29.0	32.0	31.0	33.0	33.0
S [W m/2]	175.0	184.0	183.0	198.0	201.0	196.0	208.0	207.0	196.0	179.0	161.0	158.0	187.0

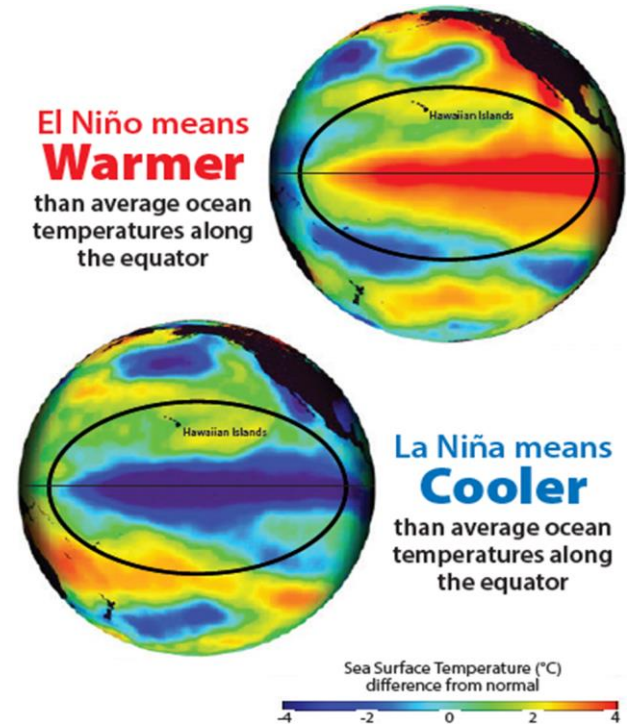
Table 2. Average monthly climate variables characteristics at Puu Waawaa Forest Reserve. Where, RF is rainfall; Min TA is average minimum air temperature Mean TA is average air temperature; Max TA is average maximum air temperature; RH is relative humidity; CF is cloud frequency; ET is evapotranspiration; SM is soil moisture; S is shortwave downward radiation; ANN, is annual total for rainfall and annual average for all other variables.

Part 3: Climate Variability

Rainfall and temperature in Hawaii can vary greatly from year-to-year due to natural climatic systems such as the El Niño-Southern Oscillation (ENSO). ENSO is a periodic fluctuation of ocean temperatures in the tropical Pacific, and this has a strong influence on rainfall variability. ENSO consists of five phases, as shown in the graph below.



<https://origin.cpc.ncep.noaa.gov/>



<https://www.climate.gov/enso>

Figure 13. Timeseries of changes in sea surface temperature (SST) and associated ENSO phase from 1950 - 2022. Puu Waawaa.

Seasonal Rainfall and ENSO

In Hawaii, the Warm (El Niño) phase typically brings below average rainfall during the wet season, and above average rainfall in the dry season. This pattern is reversed for the Cool (La Niña) phase.

At Puu Waawaa, the wet season during a Strong El Niño is 47% dryer than the long-term wet season average, and the dry season during a Strong La Niña is 66% dryer than average. These patterns influence drought conditions and wildfire susceptibility, and management activities can benefit from incorporating this ENSO-influenced seasonal rainfall variability.

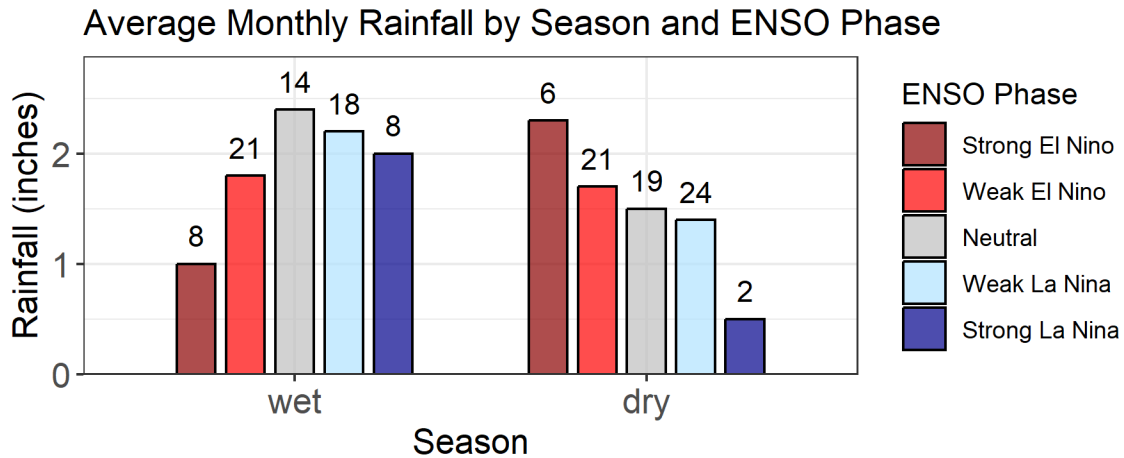


Figure 14. Barplot of average monthly rainfall grouped by season and ENSO phase. Numbers above the bars are how many seasons from 1950 to 2022 fell within each ENSO phase.

Long-Term Trends in Rainfall

Linear trends in annual and seasonal rainfall at Puu Waawaa have been calculated over three different periods since 1920 to show long, mid, and short-term trends. The directions of change for the annual plot are shown below.

Period	Trend
1920 - 2022	Decrease
1980 - 2022	Decrease
2010 - 2022	Increase

Table 3. Direction of trendline for annual average monthly rainfall over three periods within the record.

Frazier et al. (2016); Lucas et al. (2022); See Annex I

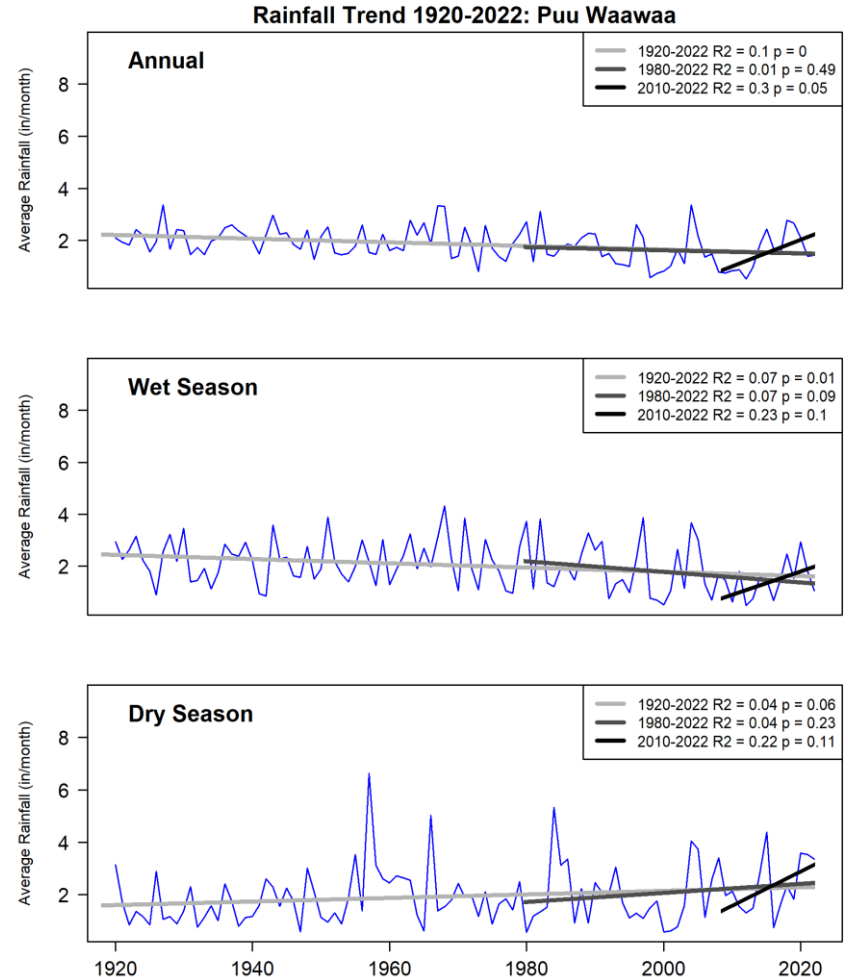


Figure 15. 102-year (1920-2022) rainfall time series at Puu Waawaa with linear trends. Trendlines with p-value < 0.05 are statistically significant.

Trends in Air Temperature

Trends in air temperature have been calculated over a 32-year record at Puu Waawaa. From 1990 to 2022 average annual air temperature has increased by 2°F.

At this site there is an average range of 25.9°F between the hottest and coldest months within a single year. The highest monthly temperature of 80.5°F was recorded in September 2015.

- Linear trend
- Average monthly
- Average annual
- Hottest month
- Coldest month

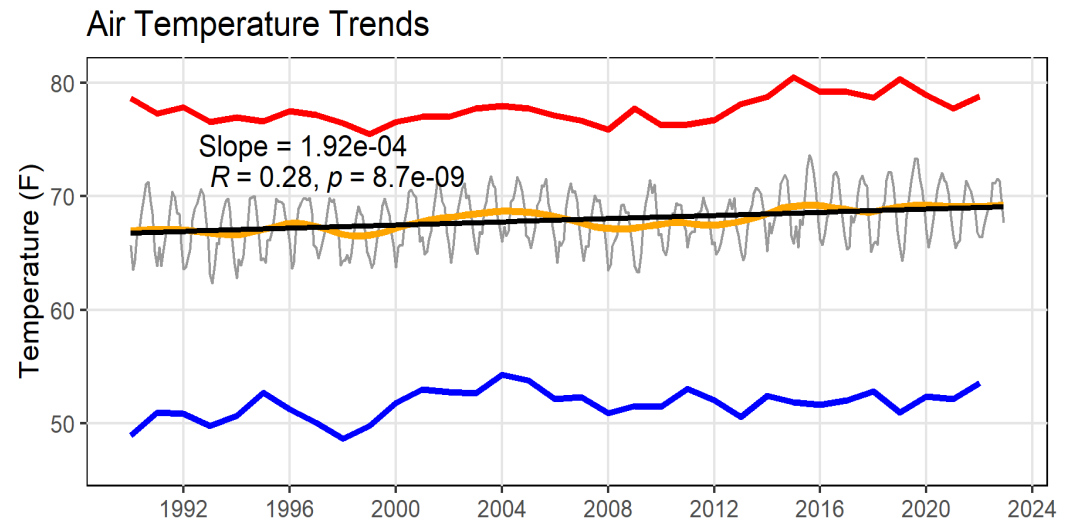


Figure 16. 32-year (1990 ?? 2022) monthly air temperature time series at Puu Waawaa. The linear trend is determined to be statistically significant when the p-value is less than 0.05.

Part 4: Drought and Fire History

Puu Waawaa

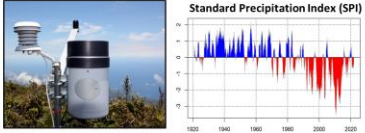



Drought is a prominent feature of the climate system in Hawaii and can cause severe impacts across multiple sectors. Droughts in Hawaii often result in reduced crop yields, loss of livestock, drying of streams and reservoirs, depletion of groundwater, and increased wildland fire activity. These impacts can cause substantial economic losses as well as long-term damage to terrestrial and aquatic habitats.




Five Types of Drought

There are five major types of drought. During droughts there is sometimes a progression from one type to the next. Depending on local factors, these drought types can also happen simultaneously and at different levels of severity.



Meteorological	Agricultural	Hydrological	Ecological
 <p><i>Climate station; Monthly rainfall measurements</i></p>	 <p><i>Dry coffee plant; Cattle grazing in drought conditions</i></p>	 <p><i>Dry stream bed; Reservoir with low water level</i></p>	 <p><i>Water-stressed plants and landscape; forest fire</i></p>
<p>Measurements of rainfall amount and duration fall below their normal amount.</p>	<p>Agricultural yield is reduced (biomass, quality) due to insufficient water.</p>	<p>Less water in streams, lakes, reservoirs, or aquifers.</p>	<p>Degradation of nature. Plant/animal mortality, wildfire, habitat change.</p>
<p>Factors of Severity:</p> <ul style="list-style-type: none"> • Natural climate variability • Climate change 	<ul style="list-style-type: none"> • Fresh water sources • Crop suitability and timing 	<ul style="list-style-type: none"> • Surface water management • Groundwater recharge 	<ul style="list-style-type: none"> • Biodiversity • Fire management

Socioeconomic	
<p>Negative impacts to social and economic systems. Increased costs, reduced public health and safety.</p>	 <p><i>Drought-stricken rural landscape; Wildfire next to residences.</i></p>
<p>Factors of Severity:</p> <ul style="list-style-type: none"> • Community awareness 	<ul style="list-style-type: none"> • National/global support

Identifying Droughts Using the Standard Precipitation Index

The Standardized Precipitation Index (SPI) is one of the most widely used indices for meteorological drought. SPI compares current rainfall with its multi-year average, so that droughts are defined relative to local average rainfall. This standardized index allows wet and dry climates to be represented on a common scale. Here, 100+ years of monthly rainfall are used to calculate SPI-12, which compares how a 12-month period compares with all 12-month periods in the record. SPI-12 is a good measure of sustained droughts that affect hydrological processes at Puu Waawaa.

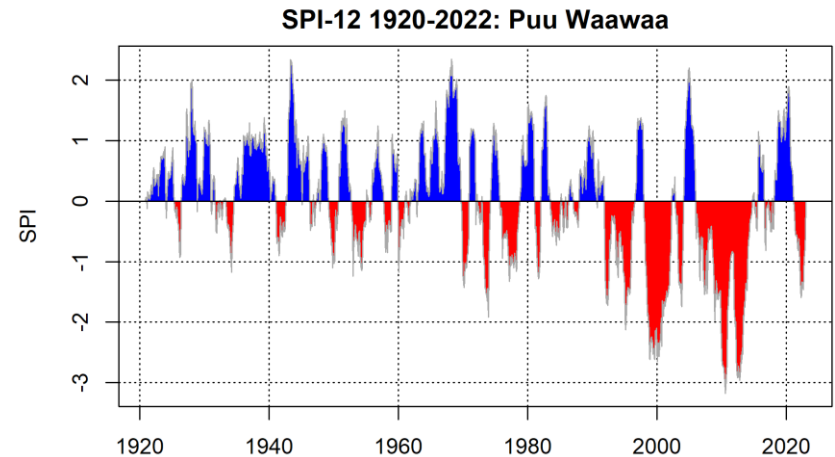


Figure 18. 102-year (1920-2022) SPI-12 time series at Puu Waawaa. Positive SPI (blue) indicate wet periods, negative SPI (red) indicate dry periods.

A 100+ Year History of Drought

Negative SPI values (dry periods) are inverted to show a complete drought timeseries at Puu Waawaa. Dashed lines and corresponding color coding indicates instances of Moderate (SPI > 1), Severe (SPI > 1.5), and Extreme (SPI > 2) drought.

A total of 13 droughts were observed over the entire record with a total of 6 drought events of severe strength or greater. The longest drought lasted for a total of 106 months (see Annex III).

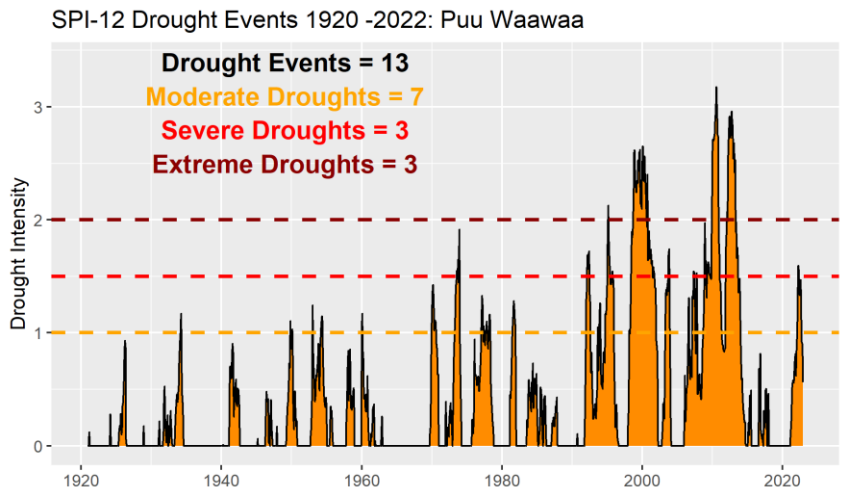


Figure 19. 102-year (1920-2022) SPI time series (reversed axis) at Puu Waawaa. Dashed lines show, moderate (yellow), severe (red), and extreme (dark red), drought thresholds.

Short-term vs Long-term Droughts

SPI-3 Drought Events 1990-2022: Puu Waawaa

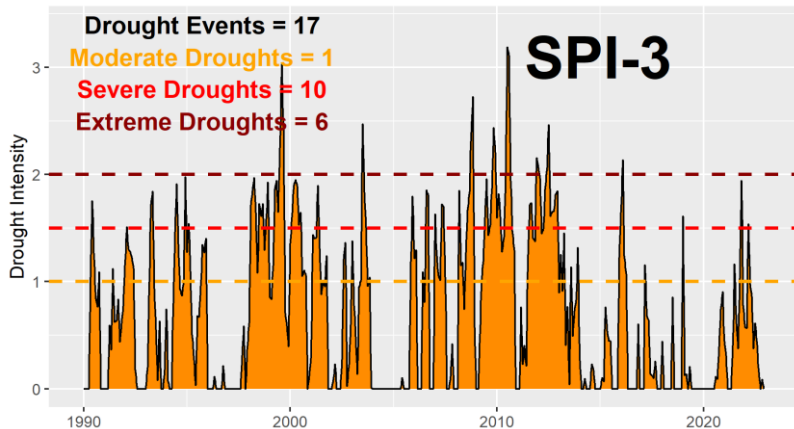


Figure 20. SPI-3 time series (reversed axis) at Puu Waawaa Forest Reserve.

SPI-12 Drought Events 1990-2022: Puu Waawaa

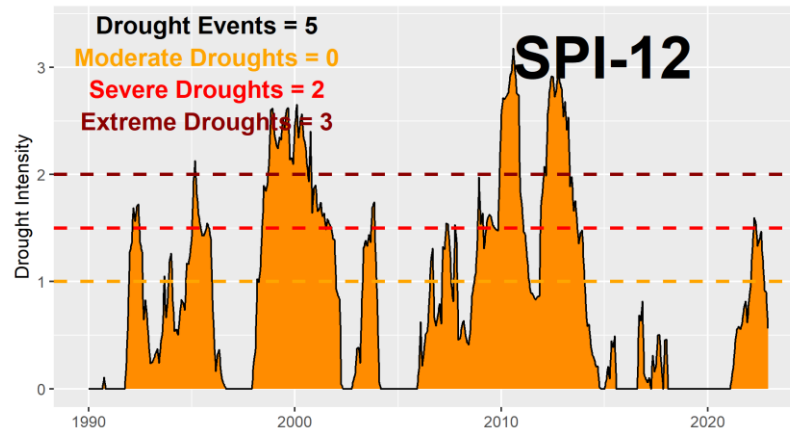


Figure 21. SPI-12 time series (reversed axis) at Puu Waawaa Forest Reserve.

SPI-3 provides a comparison of rainfall over a specific 3-month period and reflects short-term conditions. SPI-12 provides 12-month comparisons and reflects long-term conditions. It is important to consider both timescales for planning.

As of December 2022 the most recent drought events are as follows:

SPI-3: Currently not in drought. Most recently there was severe drought from Jun 2021 - Sep 2022. Current SPI-3 value 0.

SPI-12: Currently in severe drought since Apr 2021. Current SPI-12 value -0.6.

Fire Occurrence in Hawaii

Ecological drought often drives an increase in wildfire occurrence. In Hawaii, wildfires are most extensive in dry and mesic non-native grass and shrublands. During drought events, wildfire risk in these areas increases rapidly. Currently, agricultural abandonment is resulting in increased grass and shrublands. This combined with recurring incidences of drought is expected to increase the risk of future wildfire in Hawaii.

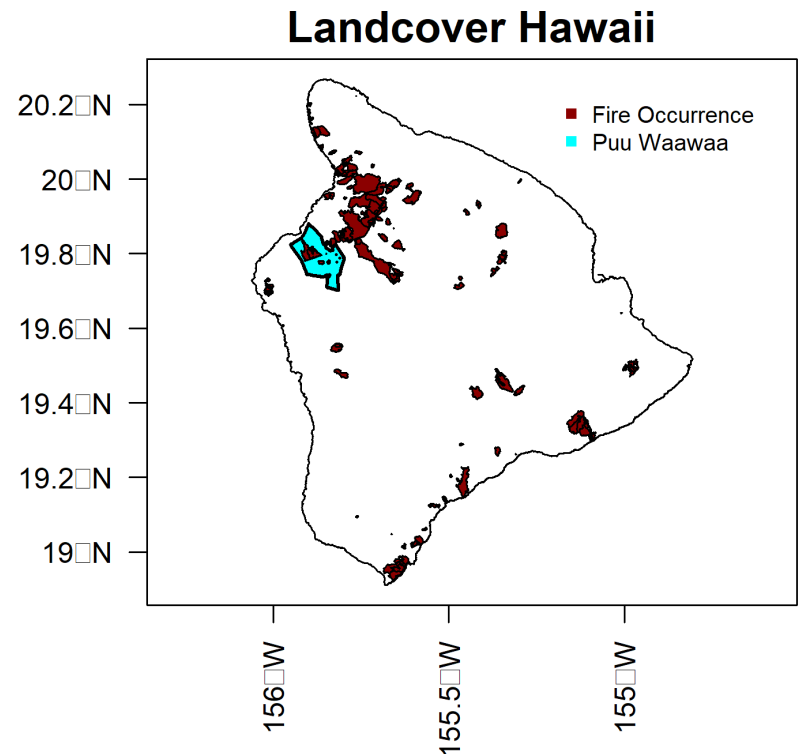


Figure 22. The map shows wildfires that have occurred on the island of Hawaii between 1999 and 2020.

Part 5: Future Climate

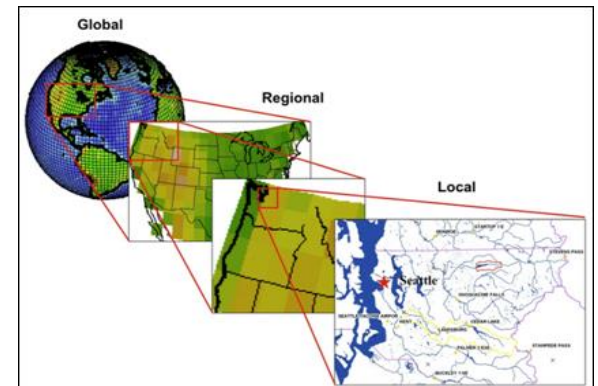
Puu Waawaa

Global Climate Models are used to predict future changes in rainfall and temperature, simulating future conditions under different scenarios for how much carbon dioxide we emit into the air. Two common scenarios are RCP 4.5 which assumes we reduce our carbon emissions, and RCP 8.5, which is an increased emissions scenario.

Data downscaling is used make these models useful at the local management level. In Hawaii, two types of downscaled projections are available:

Statistical: Available for Mid & End-of-Century

Dynamical: Only available for End-of-Century



Both downscaling projections are presented here. These two projections sometimes agree with each other, and other times they provide conflicting results. When viewing the maps, we can observe where these similarities and differences are, for example which areas show reduced rainfall under both projections.

Average Rainfall Change Mid-Century (2040-2070)

Rainfall for Years 2040-2070

Change in Annual Rainfall

-5 to -6 in/year

-24 to -29% change from present

These Statistical Downscaling maps show the projected change in rainfall under RCP 4.5 and 8.5 conditions. At Puu Waawaa, annual rainfall is projected to decrease by 5 inches (RCP 4.5), or decrease by 6 inches (RCP 8.5) by mid-century.

Changes in Annual Rainfall by Mid-Century

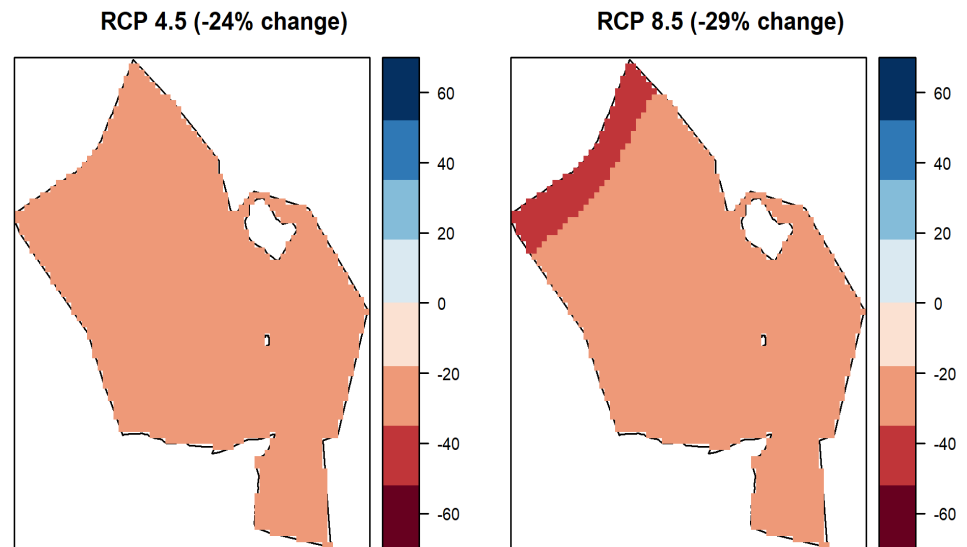


Figure 23. Downscaled future rainfall projections (% change from present) at Puu Waawaa by mid-century (2040-2070) using Statistical Downscaling. RCP 4.5 (left) and RCP 8.5 (right).

Average Rainfall Change End-of-Century (2100)

Rainfall in the Year 2100

Annual

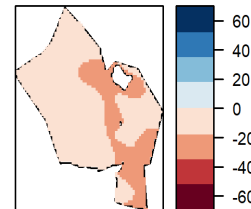
-6 to -9 in/year

-42 to -8 % change from present

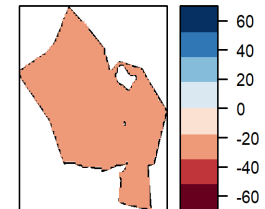
These Dynamical and Statistical Downscaling maps show the projected change in rainfall under RCP 4.5 and 8.5 conditions. At Puu Waawaa, annual rainfall is projected to decrease by 6 inches (RCP 4.5), or decrease by 9 inches (RCP 8.5) by end-of-century.

Changes in Annual Rainfall by 2100

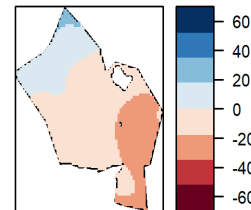
Dynamical 4.5 (-16% change)



Statistical 4.5 (-27% change)



Dynamical 8.5 (-8% change)



Statistical 8.5 (-42% change)

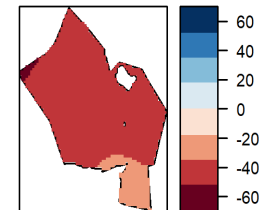


Figure 24. Downscaled future rainfall projections (% change from present) at Puu Waawaa by end-of-century (2100), using both Dynamical and Statistical downscaling. RCP 4.5 (top row) and RCP 8.5 (bottom row).

Average Air Temperature Change Mid-Century (2040-2070)

Air Temp. for Years 2040-2070

Change in Air Temperature
2.3 to 3.3°F
3 to 5% change from present

These Statistical Downscaling maps show the projected change in air temperature under RCP 4.5 and 8.5 conditions. At Puu Waawaa, air temperature is projected to increase by 2.3°F (RCP 4.5), or increase by 3.3°F (RCP 8.5) by mid-century.

Changes in Air Temperature by Mid-Century

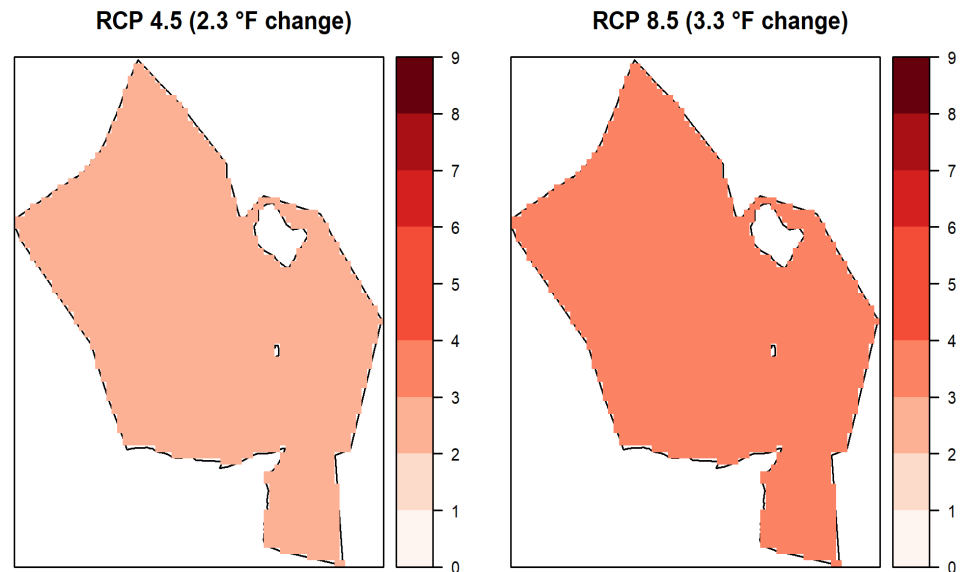


Figure 25. Downscaled future temperature projections (°F change from present) at Puu Waawaa by mid-century (2040-2070) using Statistical Downscaling. RCP 4.5 (left) and RCP 8.5 (right).

Average Air Temperature Change End-of-Century (2100)

Air Temp. in the Year 2100

Change in Air Temperature

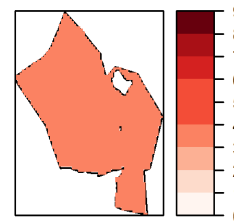
3 to 5.8°F

4 to 9 % change from present

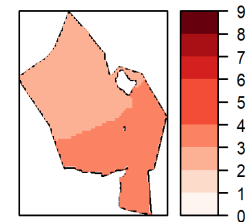
These Dynamical and Statistical Downscaling maps show the projected change in air temperature under RCP 4.5 and 8.5 conditions. At Puu Waawaa, air temperature is projected to increase by 3°F (RCP 4.5), or increase by 5.8°F (RCP 8.5) by end-of-century.

Changes in Air Temperature by 2100

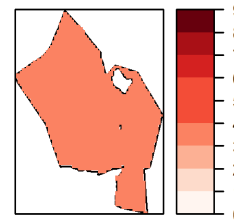
Dynamical 4.5 (3.5 °F average)



Statistical 4.5 (3 °F average)



Dynamical 8.5 (3.6 °F average)



Statistical 8.5 (5.8 °F average)

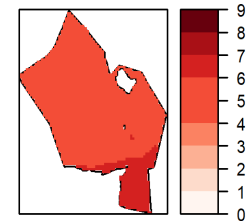


Figure 26. Downscaled future rainfall projections (% change from present) at Puu Waawaa by end-of-century (2100), using both Dynamical and Statistical downscaling. RCP 4.5 (top row) and RCP 8.5 (bottom row).

Part 6: CCVD Summary

Puu Waawaa

Puu Waawaa Forest Reserve (Puu Waawaa) is located on the island of Hawaii at mean elevation of 2239 ft (rangF: 52 to 6135 ft). Rainfall varies over the course of the year with a maximum of 3°F occurring in January and a minimum of 1°F occurring in August. On average, wet season months (Nov-Apr) receive 0.5 in more rainfall than dry season months (May-Oct). Seasonal rainfall can vary within the unit as well, with dry season rainfall ranging from 3 to 13°F and wet season rainfall ranging from 7 to 16°F across the 6083 ft elevation gradient. Rainfall can also vary considerably from year-to-year with the driest years occurring during a Strong El Niño event, when on average, 47% less rainfall is received, relative to the long-term average. The average temperature at Puu Waawaa is 66.8°F but temperature ranges from 63°F to 70°F over the course of the year. Drought is a reoccurring feature in the climate system of Puu Waawaa with a total of 13 occurring over the record which is approximately 1.3 per decade. A total of 6 drought events were at severe strength or greater and the longest drought lasted for a total of 106 consecutive months. Future projections of rainfall are uncertain, with end-of-century annual changes ranging from -42 to -8. Future projections of temperature suggest an increase of 2.3°F to 3.3°F by mid century (2040-2070) and an increase of 3°F to 5.8°F by the end of the century (2100).

External Resources

For more Information

US Drought Monitor

<https://droughtmonitor.unl.edu/>

NIDIS Current Hawaii Drought Maps

<https://www.drought.gov/states/hawaii>

State of Hawaii Drought Plan

<https://files.hawaii.gov/dlnr/cwrm/planning/HDP2017.pdf>

Hawaii Climate Data Portal

<https://www.hawaii.edu/climate-data-portal/>

ENSO Current Phase and Discussion

https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml

Pacific Drought Knowledge Exchange

<http://www.soest.hawaii.edu/pdke/>

Pacific Fire Exchange

<https://www.pacificfireexchange.org/>

Ahupuaa GIS Layer Storymap

<https://storymaps.arcgis.com/stories/1ad9fcf7f2c345a58adef0997f9e9b5d>



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For the most up-to-date version of this portfolio contact Derek Ford:
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Annex I: 100+ Year Rainfall

The 100+ year monthly rainfall dataset was drawn from two unique gridded products. We used data from Frazier et al. (2016) for the period 1920-1989 and Lucas et al. (2022) for the period 1990-2022. Given that two unique data sets and methods were used to make these two products we show the 1:1 Statistical relationship between the two products for a 23-year overlap (1990-2012) with the datasets and associated error metrics.

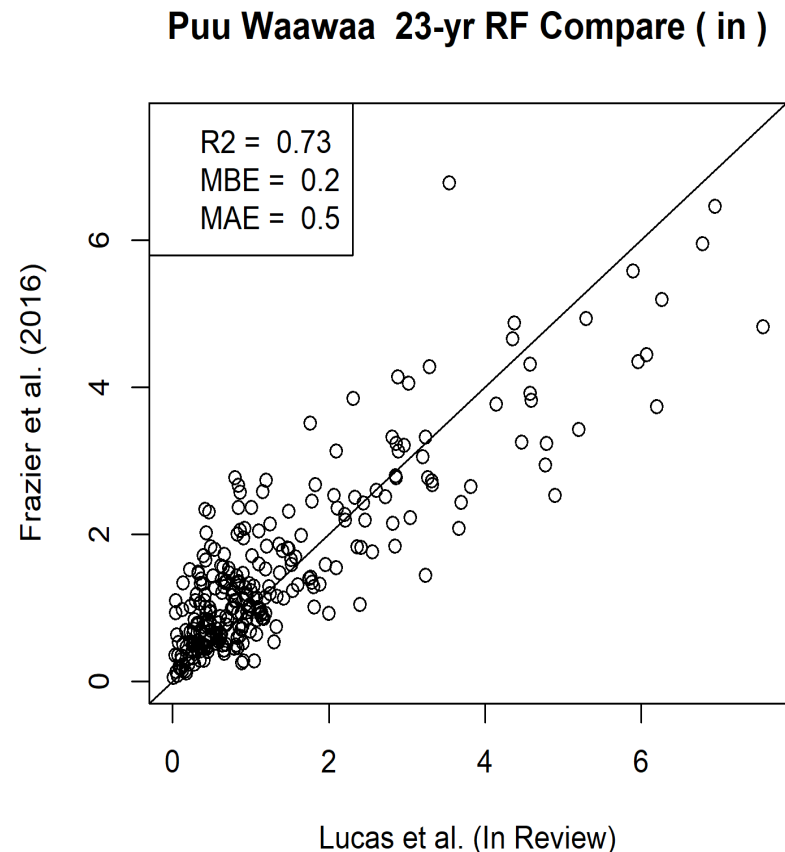
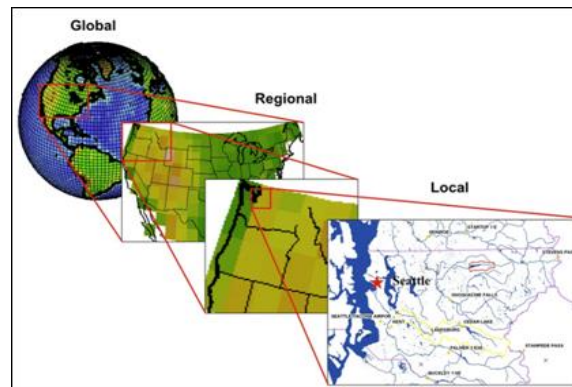


Figure A1: One to one comparison of 23-years (1990-2012) of monthly rainfall from two unique datasets for Puu Waawaa, and associated error metrics; R2, is the coefficient of determination, MBE, is the mean bias error, MAE, mean absolute error.

Annex II: Climate Downscaling in Hawaii

Two types of downscaling products were used in this analysis. Here we explain some of the nuances between the two. Dynamical Downscaling (Zhang et al., 2016), feeds GCM output into a regional model that can account for local topographic and atmospheric phenomena at much finer resolutions (e.g. 1 km). End-of-century projections (2100) encompass the period 2080-2099. Statistical Downscaling (Timm et al., 2015, Timm, 2017), develops a relationship between GCM model output and station data for a historical period and then uses this established relationship to make projections for two future scenarios. End-of-century projections (2100) encompass the period 2070-2099 (2100), Mid-century projections encompass the period 2040-2070.



Annex III: Drought Events (1920 - 2022)

Start Date	End Date	Duration (months)	Average Intensity	Peak Intensity	Magnitude
1933-06-01	1934-09-01	16	0.5169460	1.172615	8.271136
1949-05-01	1950-11-01	19	0.5218488	1.104565	9.915127
1952-11-01	1955-02-01	28	0.6327661	1.243572	17.717451
1960-02-01	1961-02-01	13	0.5369749	1.172691	6.980673
1969-11-01	1971-01-01	15	0.9178092	1.427449	13.767138
1973-02-01	1974-04-01	15	1.1094224	1.915647	16.641336
1975-10-01	1978-11-01	38	0.7087119	1.329550	26.931054
1981-04-01	1982-02-01	11	0.8567768	1.282822	9.424545
1991-12-01	1996-09-01	58	0.9275048	2.126551	53.795278
1998-02-01	2002-05-01	52	1.8343620	2.654096	95.386823
2002-12-01	2004-03-01	16	0.8925670	1.743020	14.281071
2006-02-01	2014-11-01	106	1.4680562	3.176950	155.613954

Table A1. SPI-12 drought characteristics at Puu Waawaa Forest Reserve identified in the SPI-12 timeseries. Duration is the number of months the drought persisted; Average Intensity is the average absolute SPI; Peak Intensity is the highest SPI value calculated during the drought. Magnitude is sum of absolute SPI values during the drought.

Annex III: Drought Events (1920 - 2022)

Start Date	End Date	Duration (months)	Average Intensity	Peak Intensity	Magnitude
2021-04-01		22	0.8781985	1.59582	19.32037

Table A1. SPI-12 drought characteristics at Puu Waawaa Forest Reserve identified in the SPI-12 timeseries. Duration is the number of months the drought persisted; Average Intensity is the average absolute SPI; Peak Intensity is the highest SPI value calculated during the drought. Magnitude is sum of absolute SPI values during the drought.

