THE OHIO STATE UNIVERSITY

SCHOOL OF
EARTH SCIENCES

Discovering Drought: Emerging Remote Sensing Approaches

Navajo Nation Water resources

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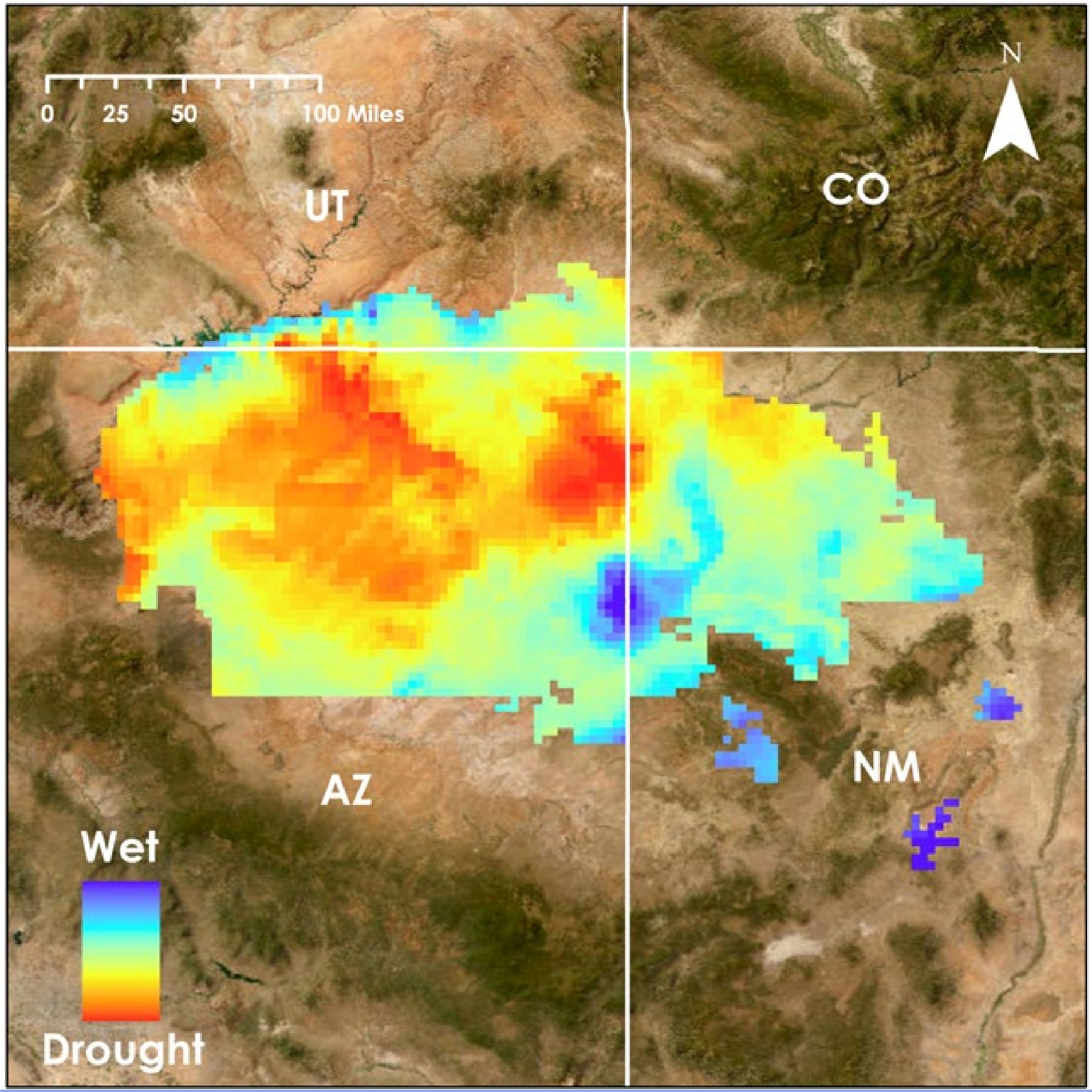


Supplementary Materials

NAVIGATION

Image Credit: Dr. Barbara Mann

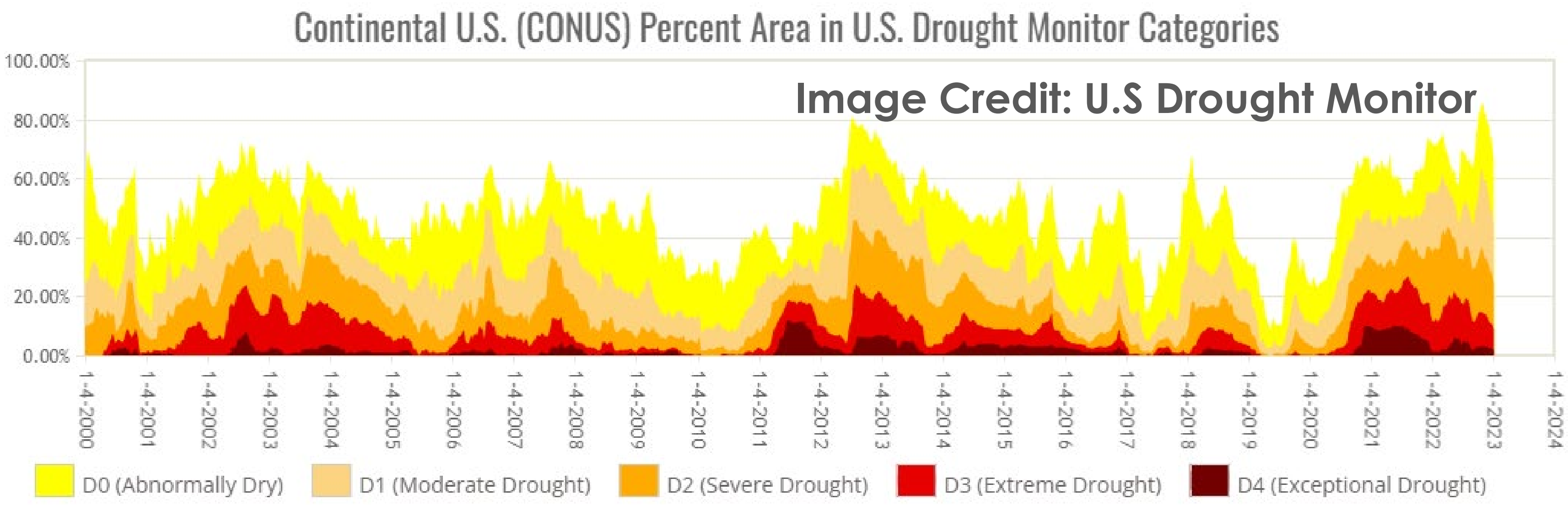
The Ohio State University occupies is the ancestral and contemporary territory of the **<u>Shawnee, Potawatomi, Delaware, Miami, Peoria, Seneca, Wyandotte, Ojibwe, and Cherokee peoples</u>**. I want to honor the resiliency of these tribal nations and recognize the historical contexts that have and continue to affect the Indigenous peoples of this land.

The Region of Interest for this project is the traditional homelands of various indigenous populations. The original peoples of **<u>New Mexico, Arizona, and Utah – Pueblo, Navajo, and Apache</u>** – since time immemorial, have deep connections to the land and have made significant contributions to the broader community statewide. I honor the land and those who steward the land throughout the generations and acknowledge my committed relationship to Indigenous peoples.

Image Credit: Navajo Nation

BACKGROUND INFORMATION

- Emergency planning is the act of preparing for emergencies to reduce losses, human and environmental.
- Current drought occurrences within North America and the magnitude of drought impacts reveal the persistent vulnerability of the United States to drought, specifically in the indigenous community

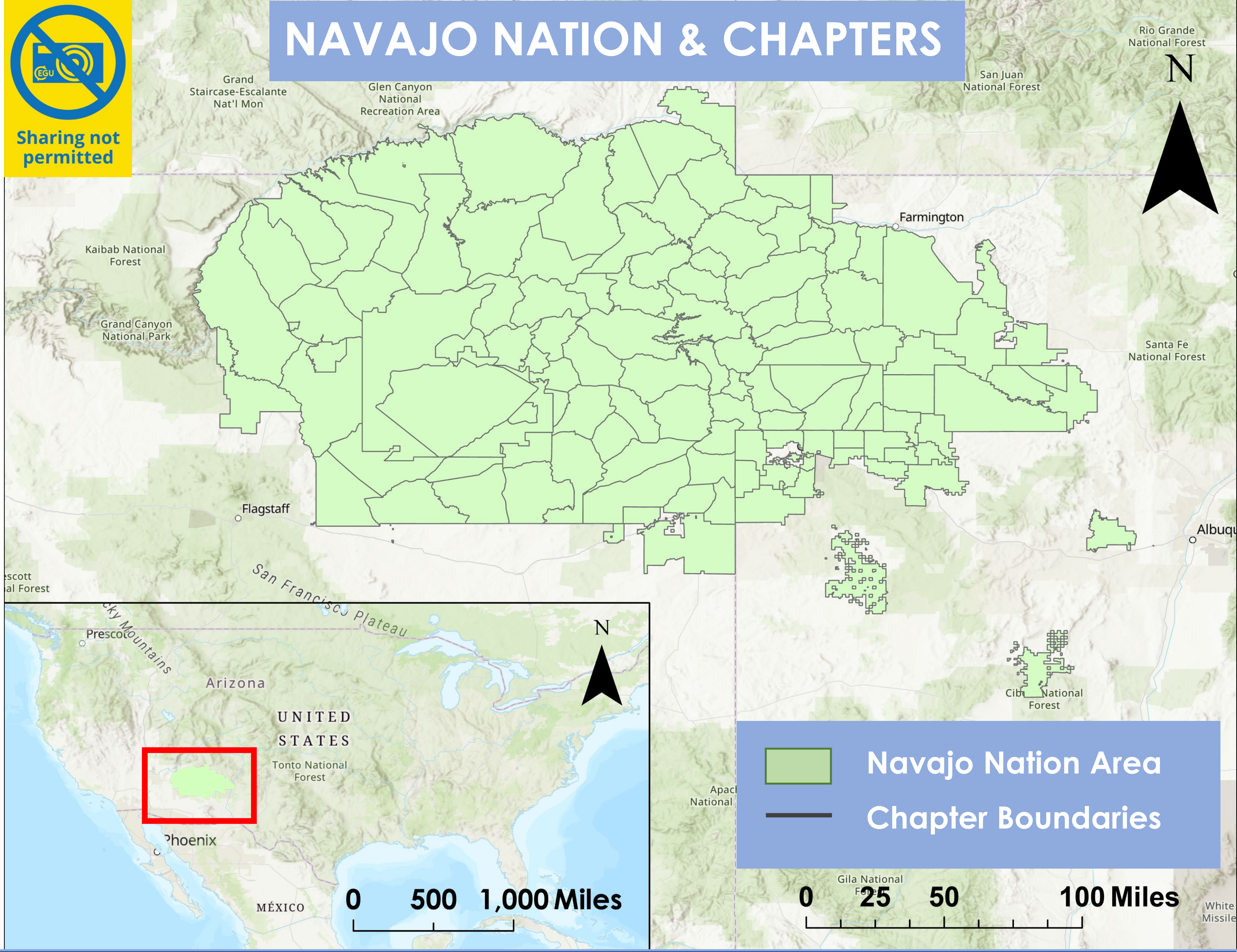


STUDY AREA

Location: Navajo Nation

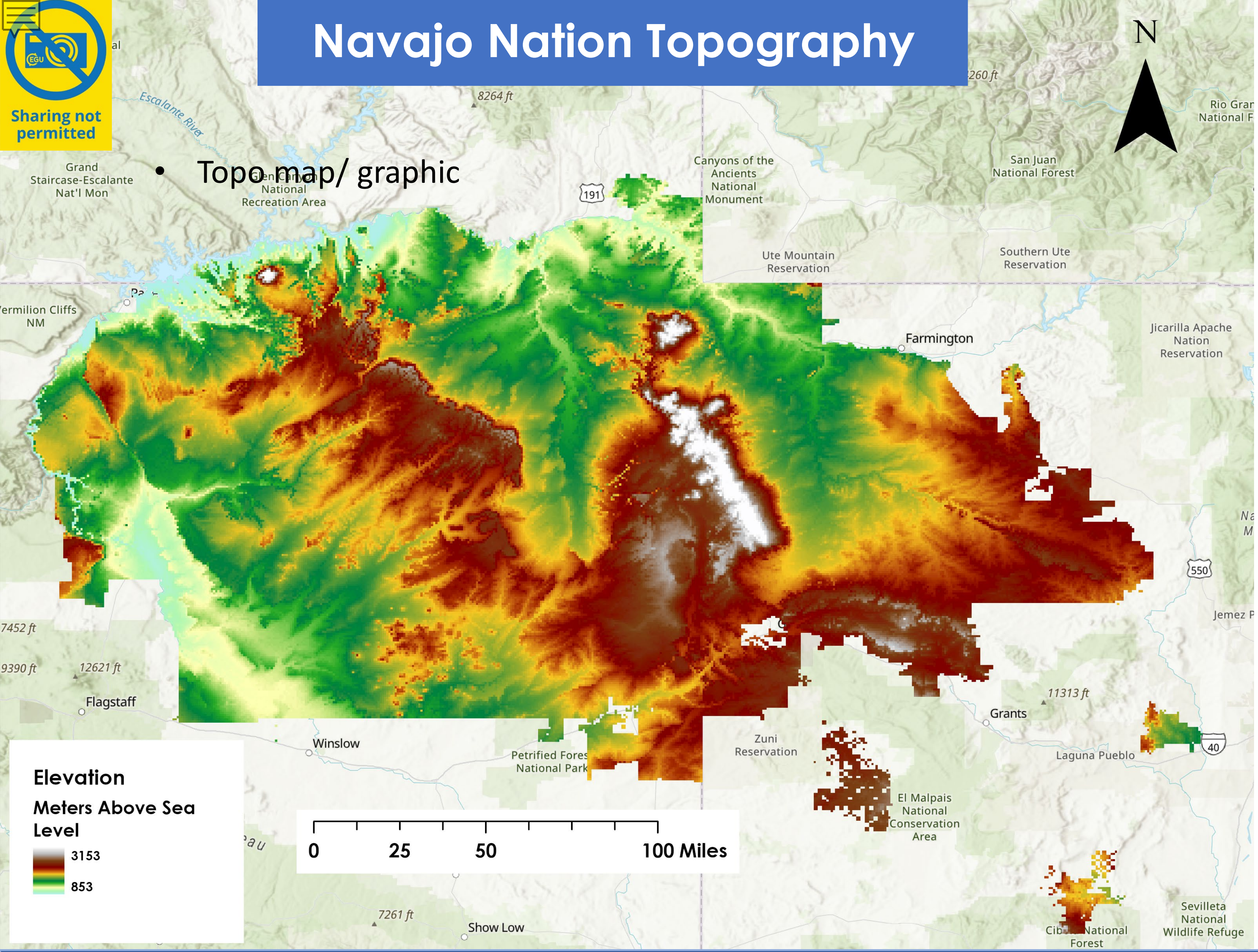
Study Period: 2000 - 2020

This area is a region of flat-lying sedimentary rock formations which has been gently but quickly uplifted over the last few million years.



Navajo Nation Topography

- Topo map/ graphic



STUDY AREA

Elevation

- Roughly 800 meters to 3,300 meters in elevation

Spanning 15 million acres of desert land and due to orographic influence, climatological factors varies across the Navajo Nation.

NAVAJO NATION

Image Credit: PixBay

- The Navajo Nation was established in 1868 with the promise of **<u>both land and water resources</u>**

- In 2002, the Navajo Nation developed a drought contingency plan but within the past 20 years no adaptation has occurred

Water Basin Background

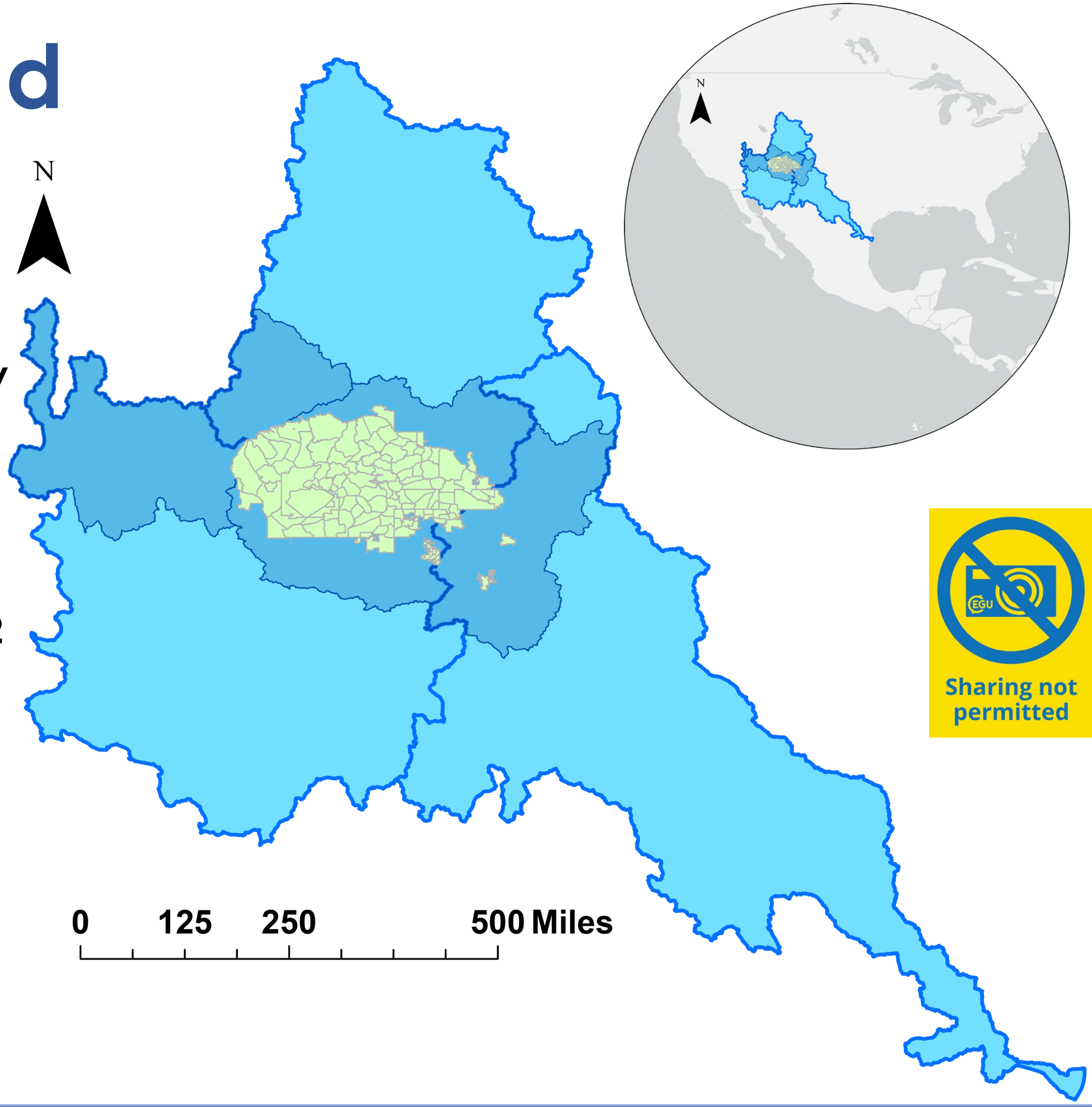
The Navajo Nation is located almost entirely within the Colorado River Basin.

However, they are currently denied access to the Colorado River.

Navajo Nation Boundary

Sub-basins HUC Level 2

Colorado River Basin
HUC Level 4



Sharing not permitted

The Hydrologic cycle

Mass Balance: Input – Output = Change in Storage, A water budget can be used to help manage water supply and predict where there may be water shortages.

Water Balance Equation:

$$\boxed{P} - Q - ET - \Delta S = 0$$

P = **Precipitation**
Q = **streamflow**
ET = **Evapotranspiration**
ΔS = **Change in Storage**

What happens when this does not equal 0 and is negative ?

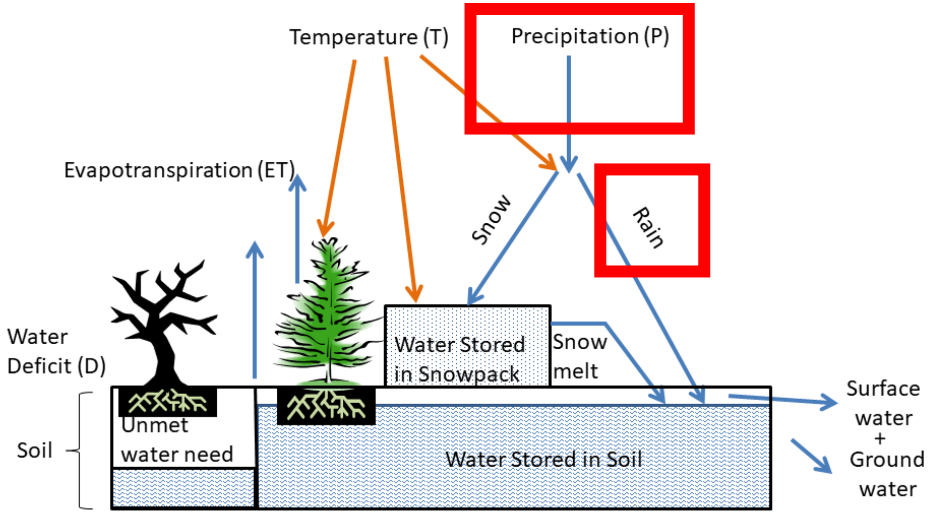


Image Credit: NPS/David Thoma

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DROUGHT

1 Climate Natural Disaster: Drought is characterized by severity, the area affected, duration, and timing.

2 Four main categories of drought

"A period of abnormally dry weather sufficiently long enough to cause a serious ***hydrological imbalance***."

American Meteorological Society Definition

DROUGHT

Meteorological:
- ❑ Precipitation Decrease
- ❑ Evaporation Increase

Agricultural:
- ❑ Soil Water Content Decrease
- ❑ Vegetation Stress

Hydrological:
- ❑ Surface Water Flow Decrease
- ❑ Inflow to water bodies

Socioeconomic:
- ❑ Resources Decrease
- ❑ Social & Economic Changes

Anomalies are a departure from the long-term climatological mean values

Drought indices are mathematical representation of water deficit (and excess) compared to historical data

Indices can be used to access these anomalies - indicate dry or wet conditions compared to the climatological condition

The Standardized Precipitation Index (SPI)

The Standard Precipitation Index (SPI) is a drought index singularly based on precipitation, displaying the probability of precipitation for a chosen time scale.

X = long term precipitation
Xm = mean precipitation
σ = standard deviation

$$SPI = \frac{X - Xm}{\sigma}$$

Previous studies have shown that drought, however, cannot be monitored singularly in the context of precipitation.

The current Drought Contingency plan in place by the Navajo Nation utilizes ONLY the SPI index and primarily at a 6-month time scale, large spatial resolution context.

RESEARCH GOALS ?

- Does the SPI accurately capture drought across the Navajo Nation?
- Is there an index that is better than the SPI?

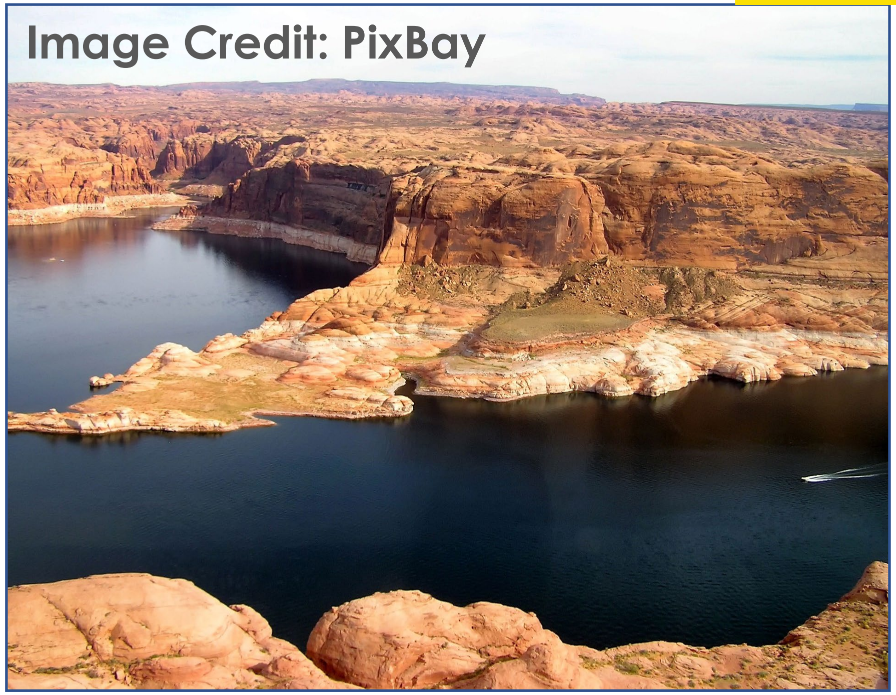
DRIVING QUESTION:

How can the advancement of remote sensing be used to advance drought monitoring and identification?

Null Hypothesis ?

The standard precipitation index accurately assesses drought both spatially and temporally across the Navajo Nation.

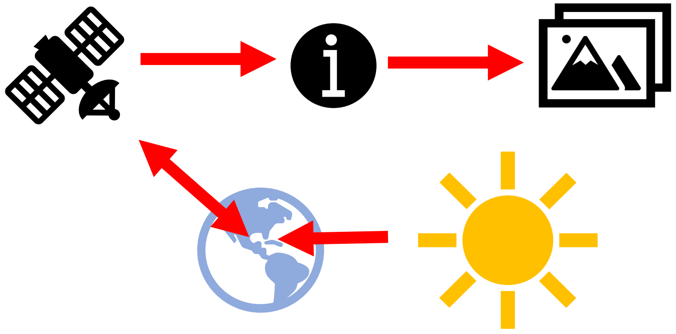
- Current science understands that drought is a complex natural hazard where no singular index can adequately capture the impacts across the main categories of drought.

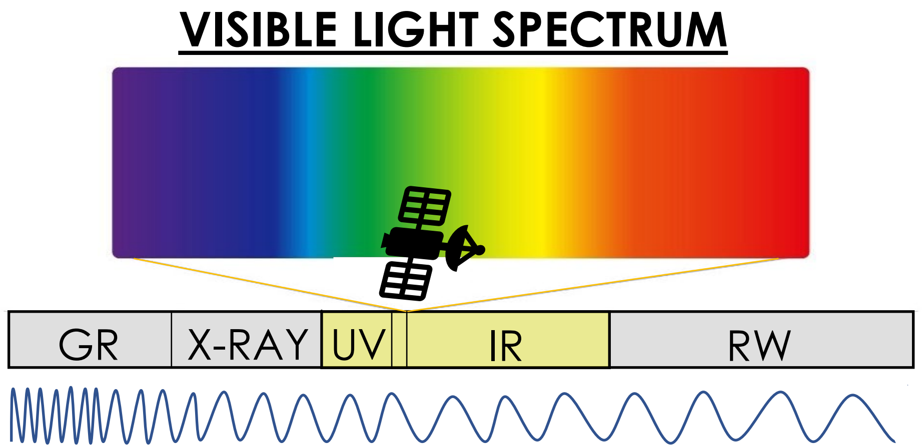


Remote Sensing Refresher

- **Remote Sensing** - obtaining information about an object from a distance

- **Electromagnetic Spectrum**- full range of wave frequencies of solar radiation



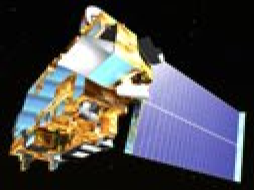


Satellites and Sensors

Image Credit: PixBay

Landsat 8 OLI
(Collection 2)
surface reflectance

TRMM
(PR, TMI)
Tropical rainfall measuring mission

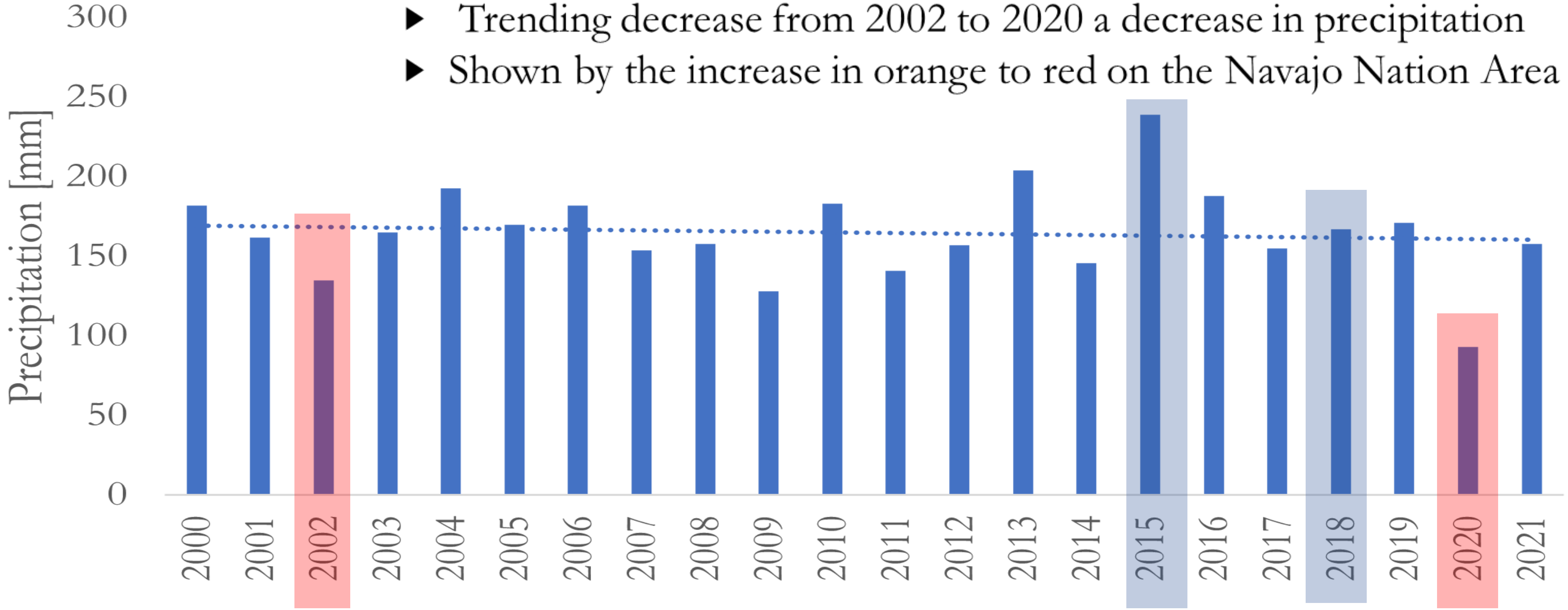


TERRA & AQUA
(MODIS, ASTER)
precipitation and thermal

- Passive remote sensors measure radiant energy reflected or emitted by the Earth atmosphere system or changes in gravity from the Earth.
- Radiant energy is converted to biogeophysical quantities such as temperature, precipitation, and soil moisture

Precipitation

- Each annual value is below the threshold for drought
- Trending decrease from 2002 to 2020 a decrease in precipitation
- Shown by the increase in orange to red on the Navajo Nation Area



WET YEARS

DRY YEARS

GOOGLE EARTH ENGINE UTILIZATION

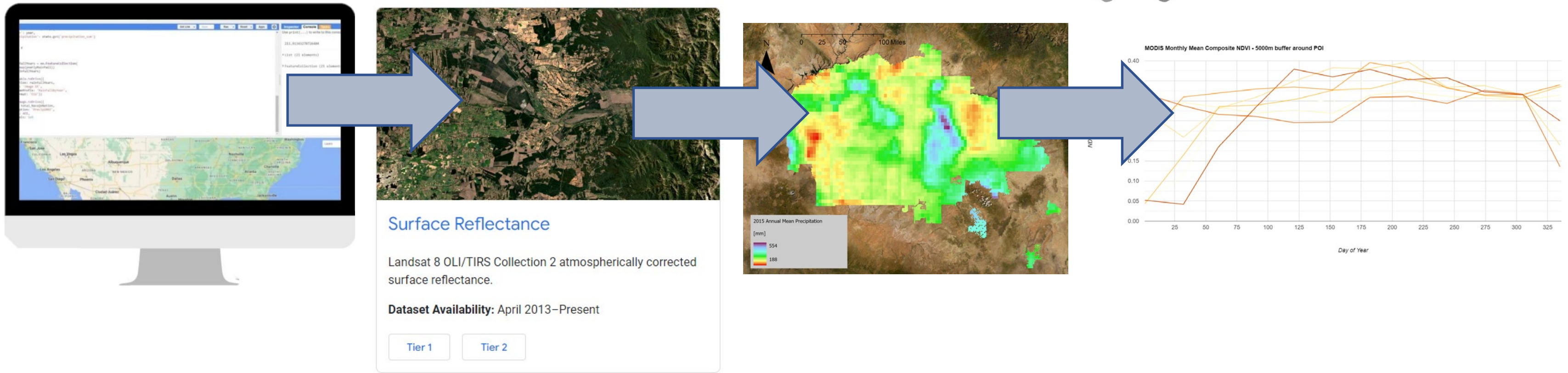
1 Access an Imagery Data

2 Apply Algorithm (Index)

3 Map Over The Image or a Collection of Images

4 Reduce If Necessary

5 Compute Statistics

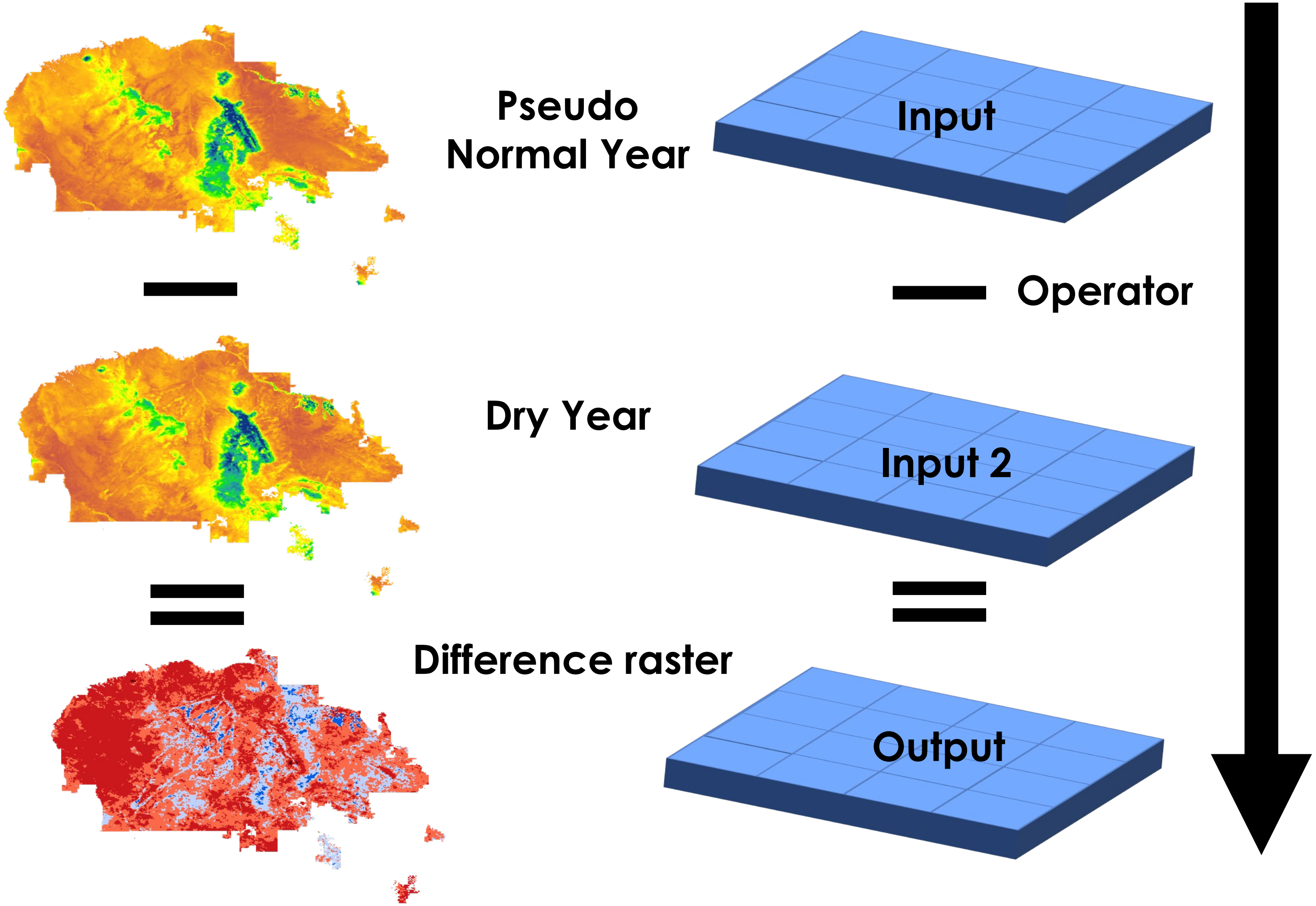


Raster Analysis

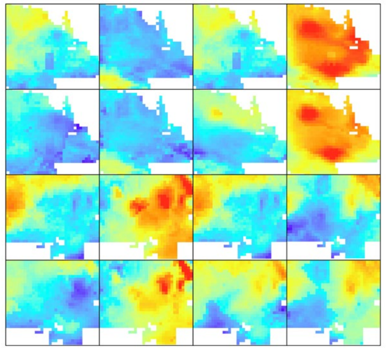
Pinpoint cells or areas with the greatest difference

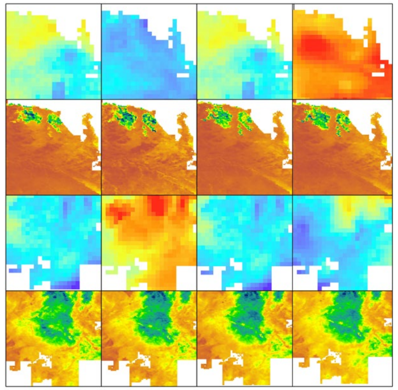
Cell-By-Cell Map Algebra: Raster directly stacked on top of one another. Then, the function applies to cells aligned with each other.

Local Operation



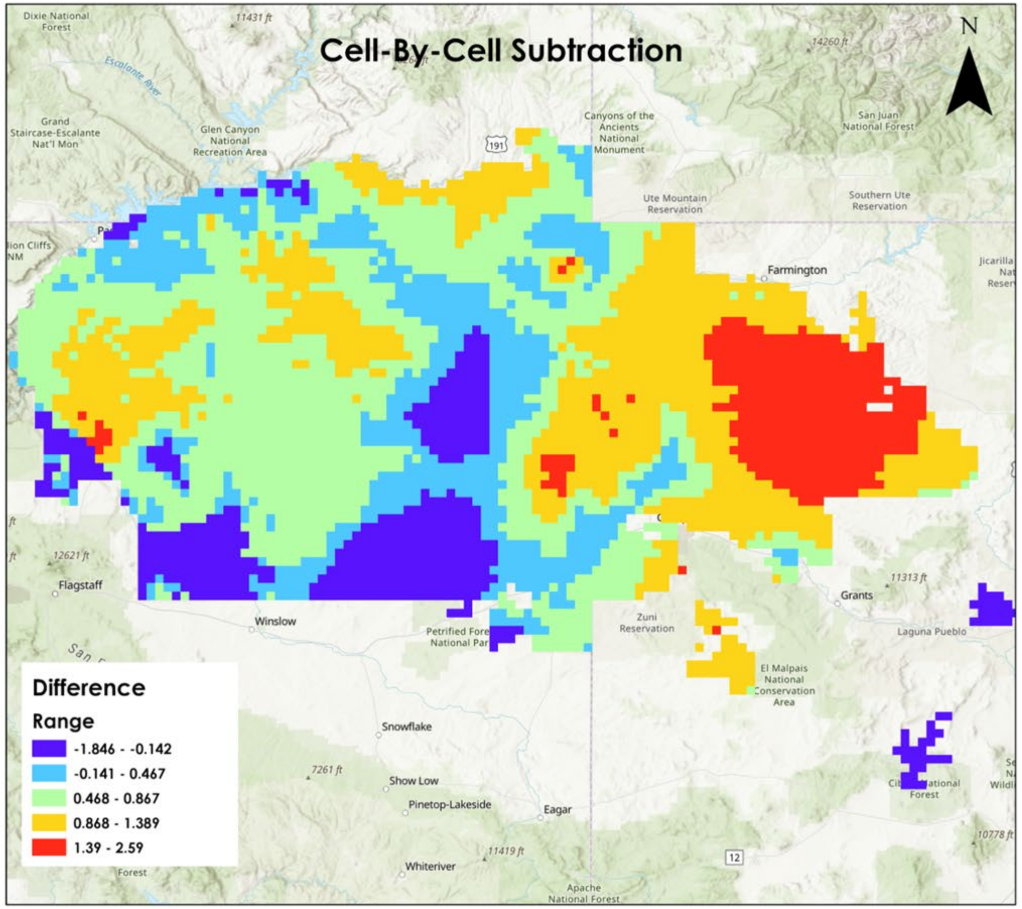
Index Comparison

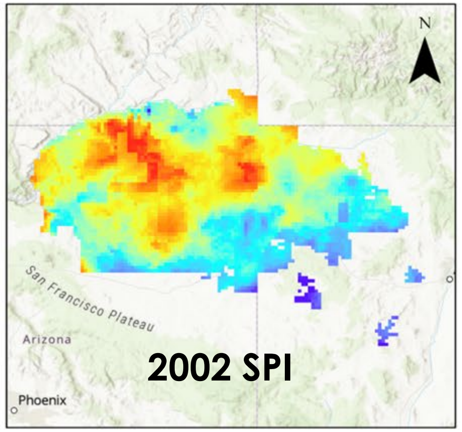


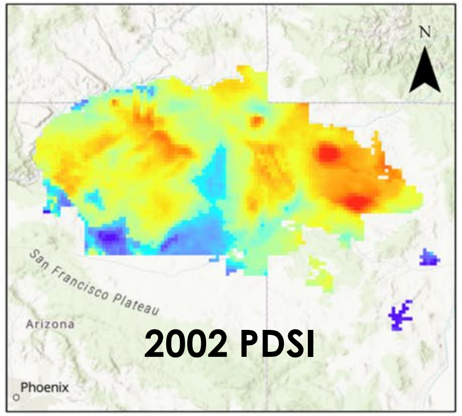


- Each index was compared to the SPI across the years of interest (2002, 2015, 2018, 2020)
- Maps were created for each index and a grid was used to highlight each index in comparison to the SPI
- From these grids, areas of significant differences were able to be highlighted for further study

SPI Accuracy Analysis





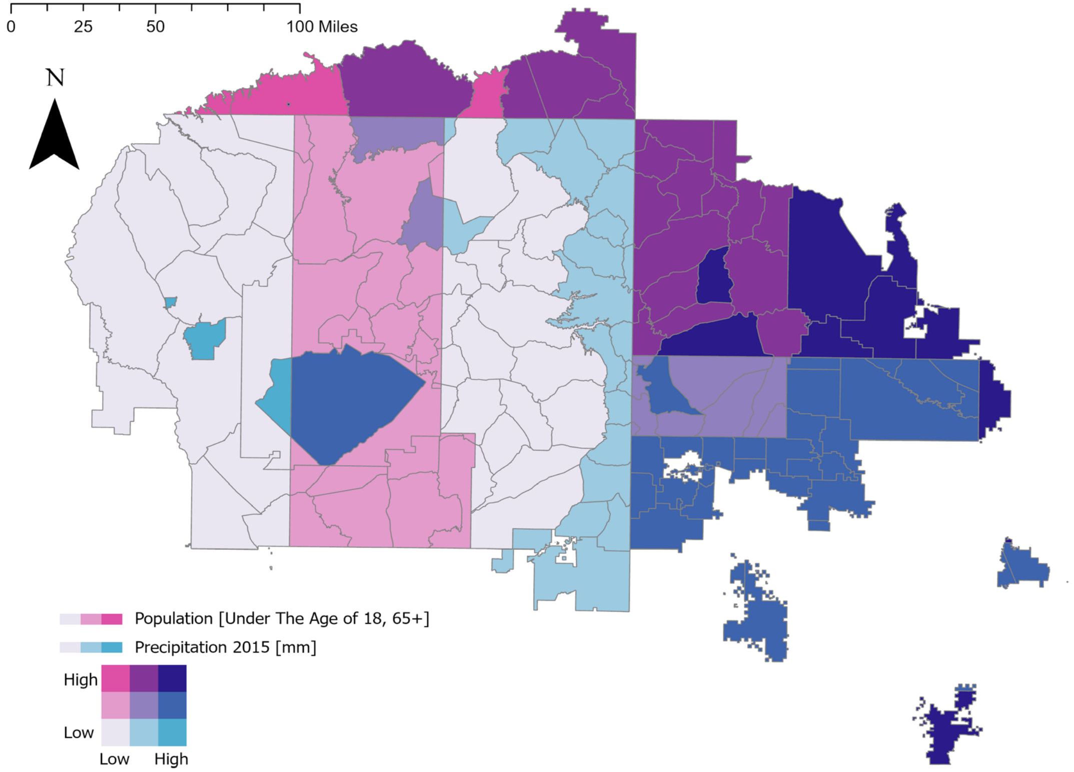


Differences in Drought can be seen in the orange to red on the left most map

Where the maps have similar values are the green to blues on the left most map

The darkest blue highlights differences in wet conditions

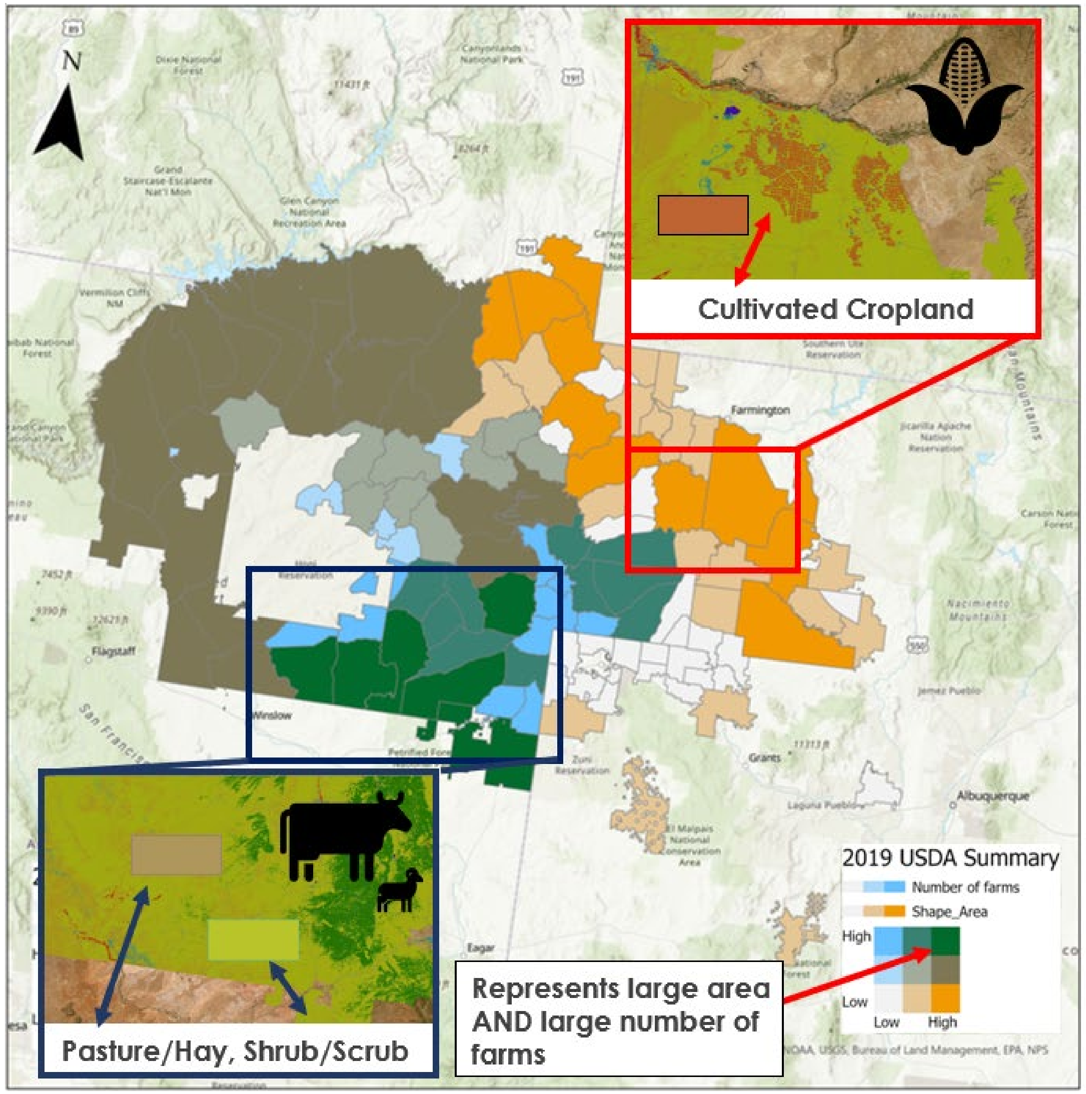
Application

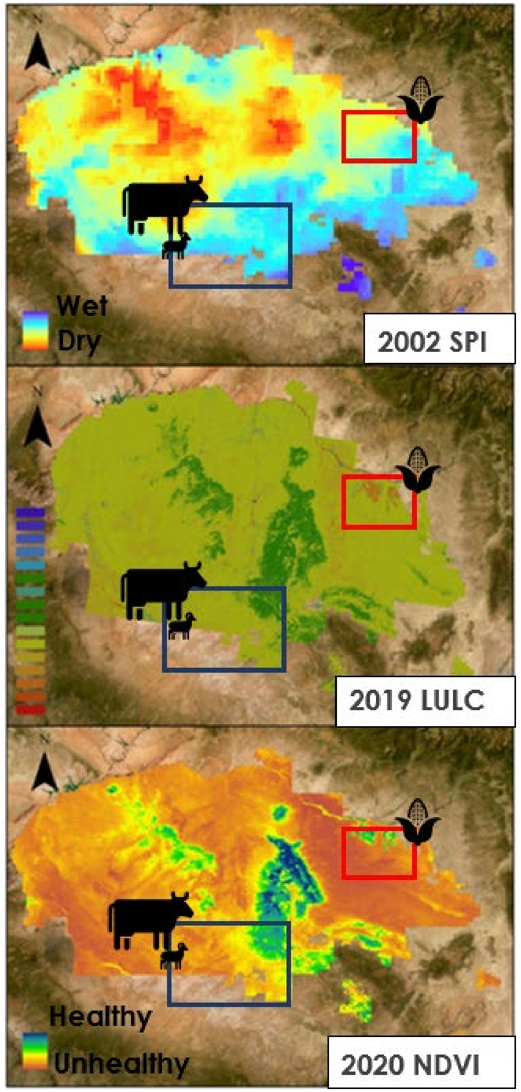


High VULNERABLE population concentration in area of severe drought not captured by the SPI

Colors to note for High Vulnerable Population and High Drought [Purples]

Application





Climate change and droughts negatively impact the productivity of agricultural sectors through low crop yield, damage to pasture/range land, and a reduction in plant growth (Hatfield et al., 2011; Kuwayama et al., 2019).

Evaporative Demand

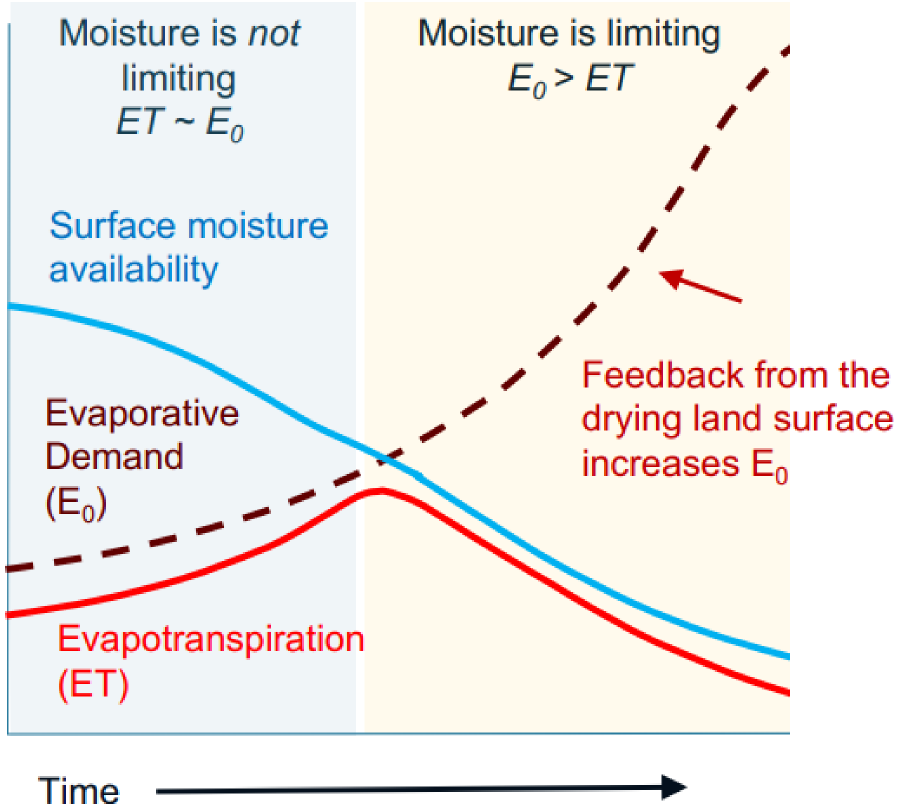


Image Credit: EDDI Team, NOAA

Looking at multiple indicators provides a "convergence of evidence", e.g., to support a drought designation

Evapotranspiration

We cannot accurately describe this change in dryness using <u>precipitation</u>. That requires an understanding of water deficit.

Evapotranspiration returns water to the atmosphere through evaporation and transpiration, which is water movement through plants. When soils dry sufficiently to limit evapotranspiration, a *climatic water deficit* occurs.

When we estimate water deficit, we incorporate these interactions into a single variable. We do this using a water balance model that describes the movement of water in nature.

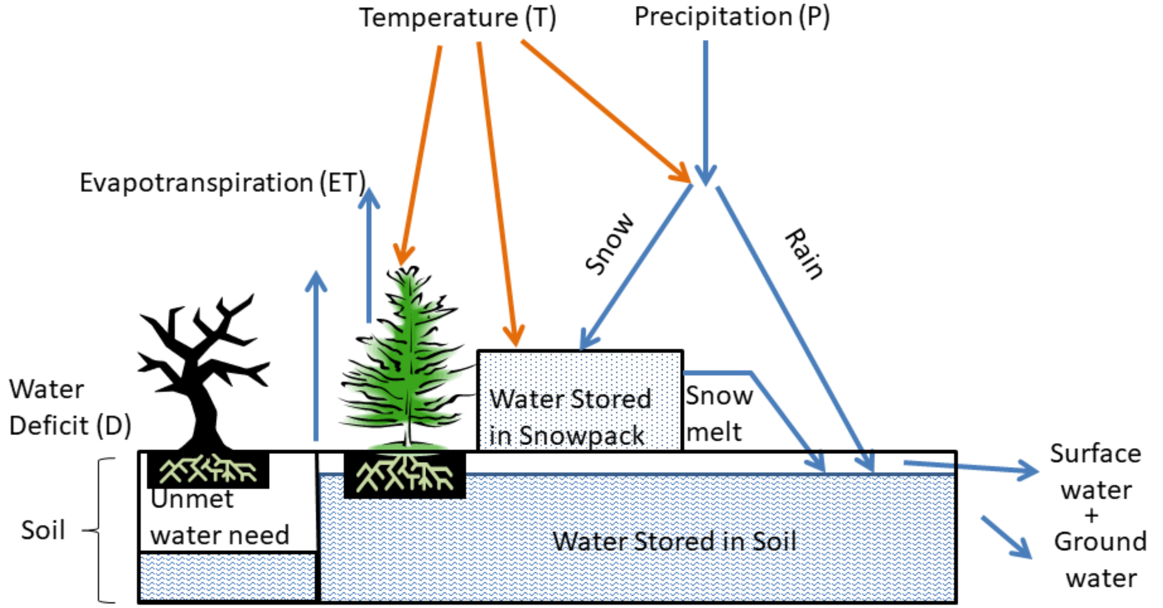


Image Credit: NPS/David Thoma

Water Availability

Drought is a problem of <u>moisture imbalance</u> at the <u>land surface:</u> Imbalance, specifically for this area ET and Temperature are critical for this budget

Water Balance Equation: variable values are declining

$$P - Q - \boxed{ET} - \boxed{\Delta S} = 0$$

P = Precipitation
Q = streamflow
ET = Evapotranspiration
ΔS = Change in Storage

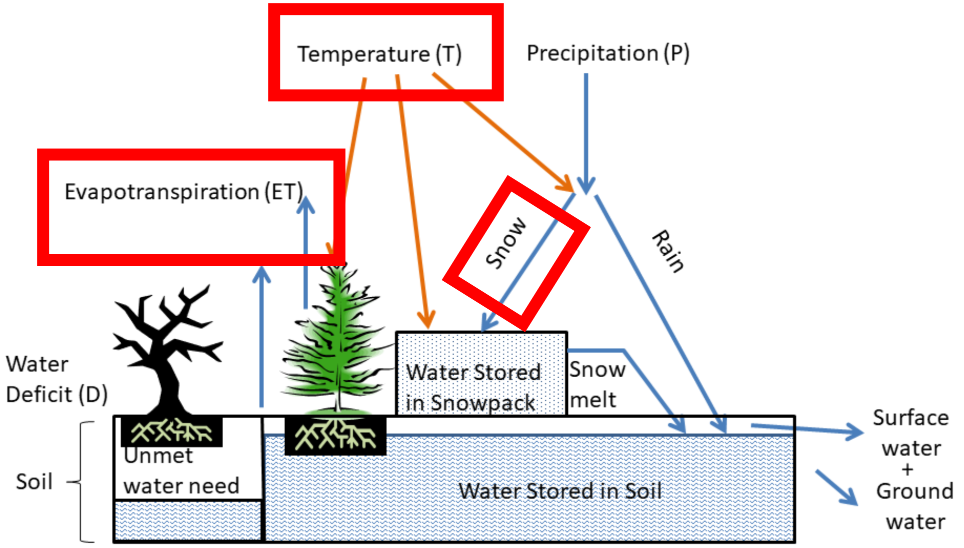
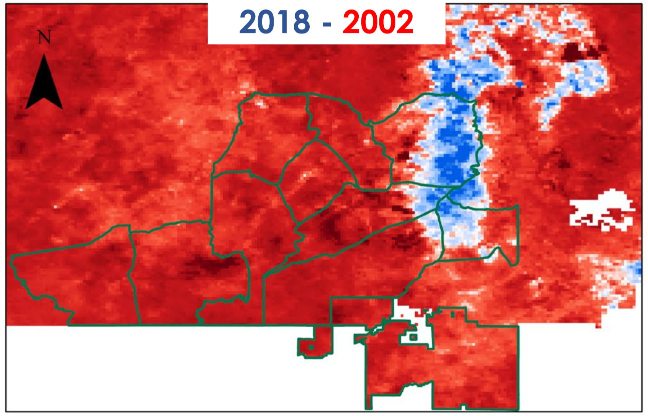
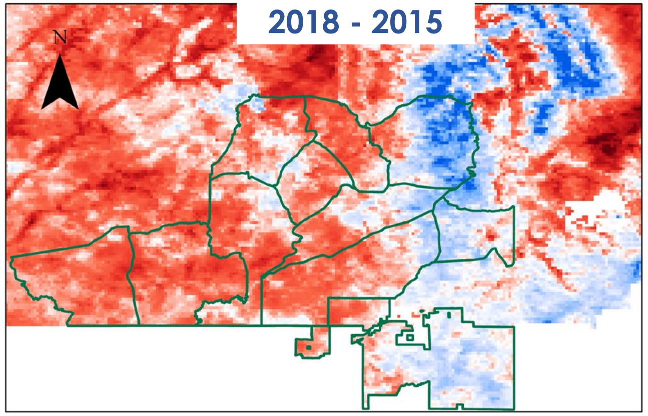


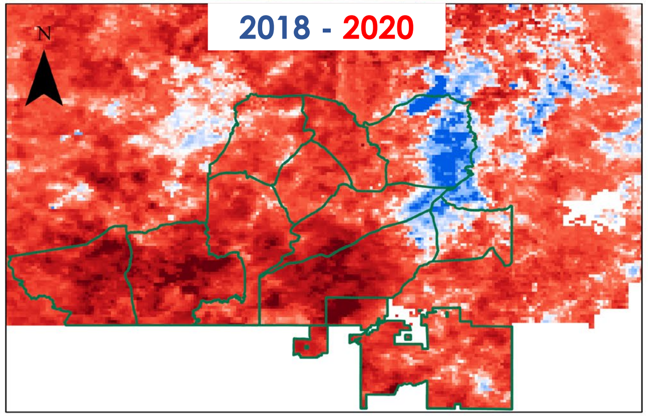
Image Credit: NPS/David Thoma

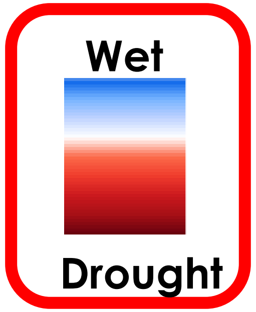
Differencing: Grazing & Pasture Areas

- As expected, due to the orographic influence, the Higher elevation areas have wetter conditions
- The change between 2015 and 2018 is less when compared to 2002 and 2020 show in the top right with a lot of white space on the map
- 2002 has the most area in overall drought
- 2020 has the most difference in intensity of drought being captured across the years









2015

2002, 2020

Agricultural Metrics Comparison

- Agricultural production has been declining
- Correlates to decline in variables in the water budget
- Future work should focus on ET imbalances capturing drought

2012

Navajo Nation	2012
Number of Farms and Ranches	14,456
Land in farms and ranches, acres	16,971,989
Market value of agricultural products sold, $1,000	$ 92,228
Crops, including nursery and greenhouse crops, $1,000	$ 73,215
Livestock, poultry, and their products, $1,000	$ 19,013
Market value of agricultural products sold, Average per farm dollars	$ 6,380
Total farm production expenses, $1,000	$ 138,772
Average age of: All operators	58

2017

Navajo Nation	2017
Number of Farms and Ranches	16,129
Land in farms and ranches, acres	212,465
Market value of agricultural products sold, $1,000	$ 87,653
Crops, including nursery and greenhouse crops, $1,000	$ 69,354
Livestock, poultry, and their products, $1,000	$ 18,299
Market value of agricultural products sold, Average per farm dollars	$ 5,434
Total farm production expenses, $1,000	$ 163,162
Average age of: All operators	59.5

Declining

Image Credit: USDA

CONCLUSIONS

Does the SPI accurately capture drought across the Navajo Nation?

No – more indices are needed

Is there an index that is better than the SPI?

Not a singular index captures drought accurately, Indexes based off multiple variables like vegetation indices are better.

- **The definition of drought is variable across place, time, and discipline.**
- **SPI is not a long-term index and may miss valuable data related to water management**
- **The addition of diverse indices provides more insight for the development of a further detailed and tailored drought contingency plan.**

Acknowledgements

- I would like to acknowledge my advisor, Dr. Michael Durand. Thank you for your mentorship and training me to be a real scientist.

- I would like to acknowledge me committee members, Dr. Ann Cook and Dr. Wendy Panero. Thank you for answering all my questions, science or not. Thank you for your mentorship.

- I would like to acknowledge my Navajo Nation supervisor Carlee McClellan. Thank you for training me to use my science skills to help people.