Navajo Nation Drought Severity Evaluation Tool (DSET)

USER GUIDE

Contents

Navajo Nation Drought Severity Evaluation Tool (DSET) Overview

Yá'át'ééh! The Drought Severity Evaluation Tool (DSET) is a co-developed web-based platform designed to meet the needs of water resource managers from the Navajo Nation (N.N.). DSET is a spin-off of Climate Engine (CE), a Google Earth Engine (GEE) based web application that enables users to process, visualize, download, and share global and regional climate and remote sensing products on-demand. The use of this tool allows for the science to influence the natural resource management decision-making process. The user-centric design focuses on the ability to conduct analyses and generate visualizations, such as customizable maps and time series, that can be directly imported into drought reports. Through the use of hands-on exercises this user guide focuses on visualizing, analyzing, and interpreting remote sensing data. The exercises in this guide will demonstrate methods of applications in the areas of drought monitoring, agriculture, meadow restoration, and snowpack.

Co-development of DSET with the Department of Water Resources (N.N. DWR), the Desert Research Institute (DRI), and NASA's Western Water Applications Office (WWAO) has created an opportunity for a diverse understanding of climate conditions on the N.N. The contribution of N.N. ground-based data has created a unique opportunity to take global data and tailor it to produce meaningful data analyses that can be used for drought reporting. With DSET, water managers will have access to quickly calculate indicators of drought for various time periods. More, importantly DSET allows these drought indicators to be calculated down to the five N.N. Agency boundaries and 110 Chapter boundaries. Figure 1 displays the enhanced Standardized Precipitation Index (SPI) drought index calculation produced by DSET that provides a more detailed outlook on the six-month period for July 2020.
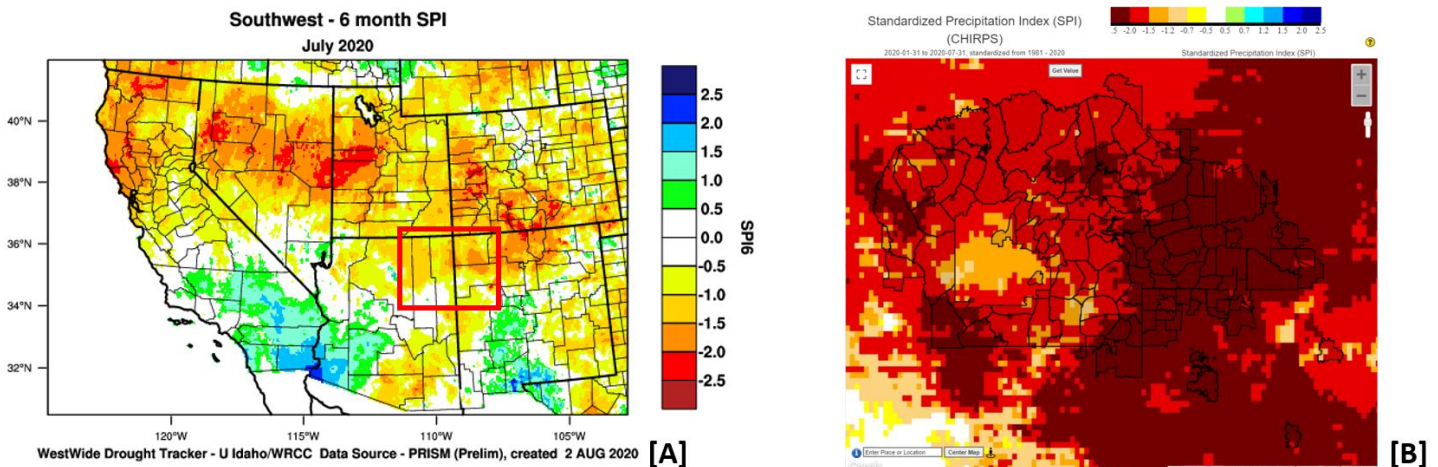
Figure 1. The 6-month Standardized Precipitation Index (SPI) from the WestWide Drought Tracker via PRISM (A) and the 6-month SPI from DSET via CHIRPS (B) from July 2020. DSET has the added features of the Navajo Nation administrative boundaries, and as will be explored in this user guide, the ability to calculate area-averaged maps for these regions.

DSET Feature Overview

Make Map Interface
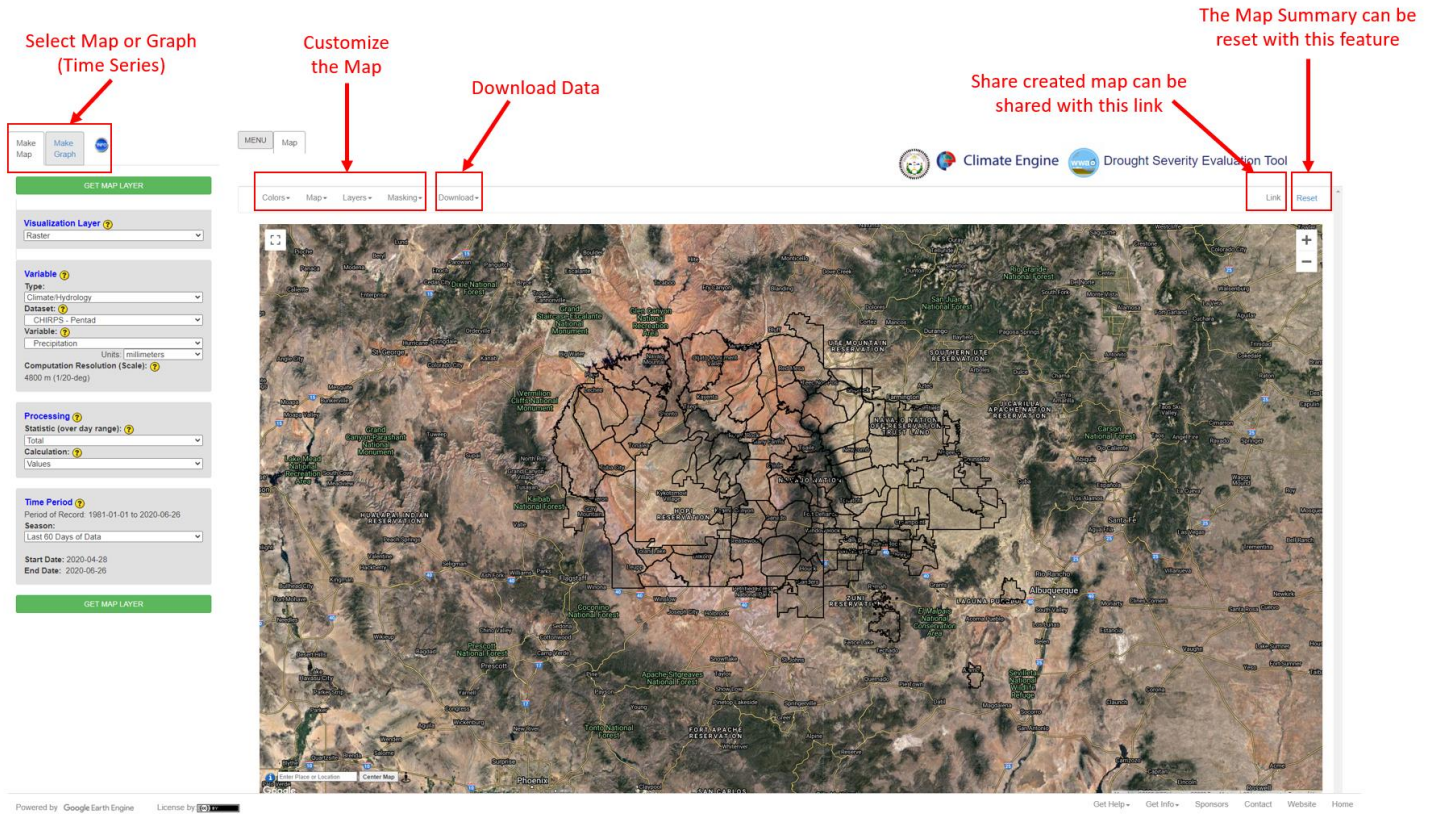
Figure 2. This figure identifies the general Make Map interface that will help in understanding how to navigate the major components of DSET.

Make Graph Interface

Select raw time series, summary series, or two-variable scatterplot.

Customize the graph.

Download Data

One variable or two variable analysis

Specific points, polygons, N.N. Boundary, N.N. Agencies, N.N. Chapters, N.N. rain gauges, or N.N. mountain ranges.

One or two variables with similar options as map interface

Figure 3. This figure identifies the major components of the Make Graph interface that will help navigate in creating time series with DSET.

Make Map Interface Features

Figure 4. These twelve identified components of the Make Map interface that will be set to create the map summaries in DSET. A brief explanation of each feature will be identified in Table 1.

Table 1. Brief explanation of the Make Map interface features identified in Figure 4.

Make Map Panel

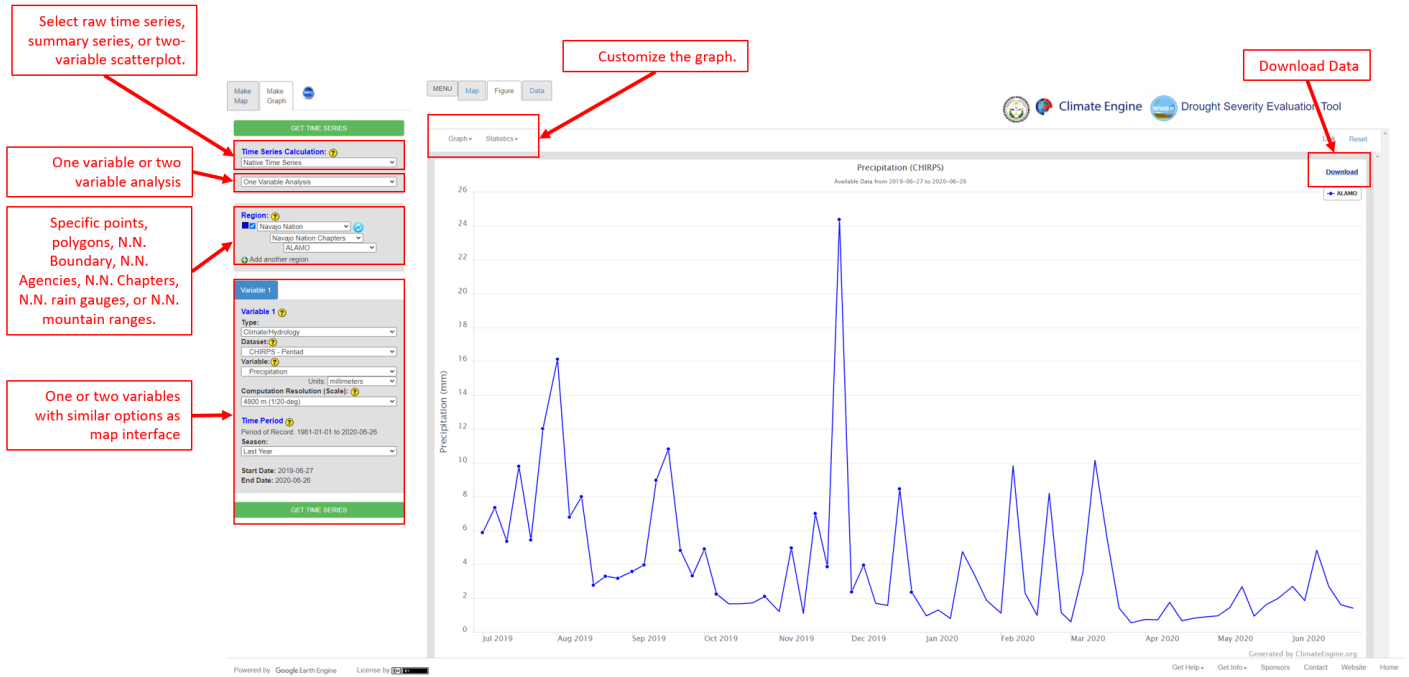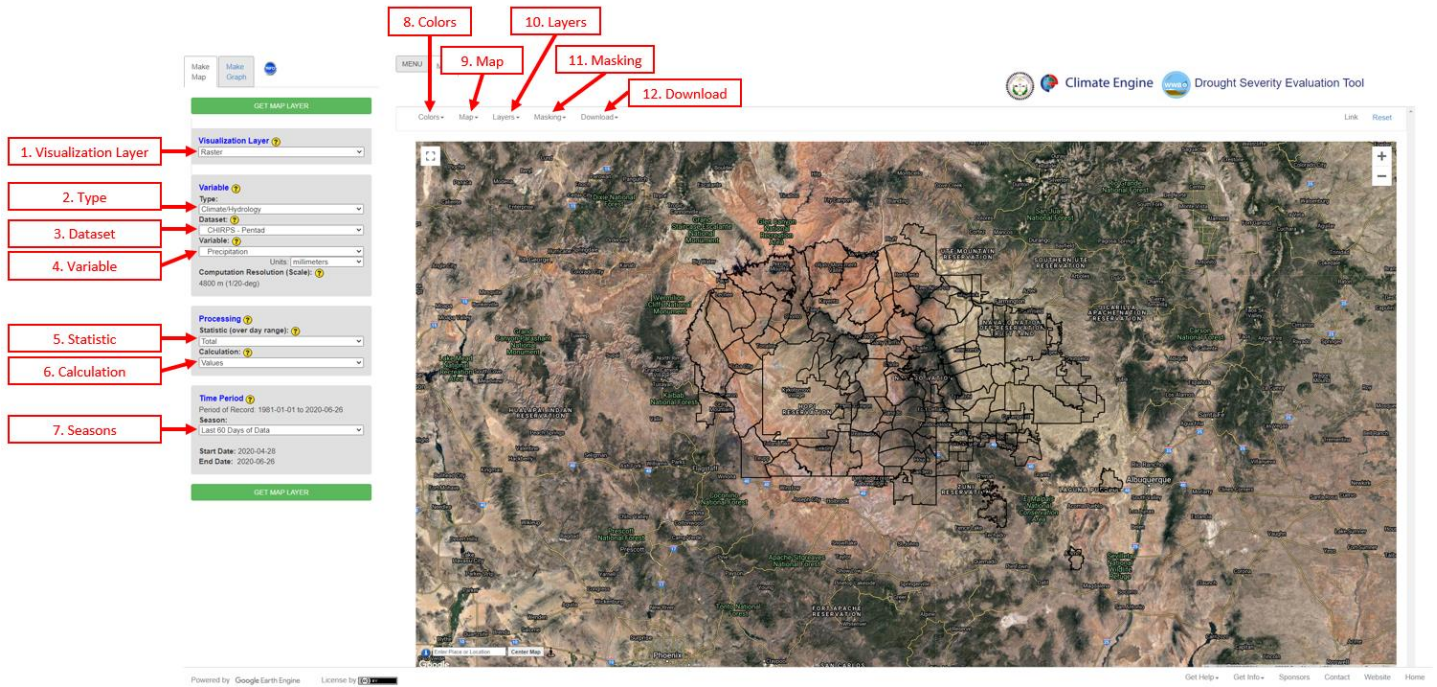|		
1	**Visualization Layer**	This feature allows you to choose the type of visualization you would like to see. There is an option to create maps specifically for the Navajo Nation or over a larger region. The two visualization layer options are raster and area averaged polygons.

	Variable	
2	Type	The two options for this section are remote sensing and climate/hydrology. The product type will either be remote sensing or meterological dataset from Google Cloud. Depending on the type selected a variety of datasets and variables will populate. The type selcted will ultimately produce map summary.
3	Dataset	The data available through this web tool were created using Google's geospatial tool, the Google Earth Engine using the data being stored on the Google Cloud.
4	Variable	A variety of indicies can be selected for drought, climate, vegetation, water, and snow. Access to Google Earth Engine's satellite image and meteorological collections allow for efficient near real-time drought monitoring through statistical analyses of surface temperature, vegetation, precipitation, snow cover, surface water, soil moisture, evapotranspiration, and simple water balances.

	Processing	
5	Statistic	Statistics are applied to the raw data that is populated over the selected range of days.
6	Calculation	The calculation for the map summary is based on the selection based on the variable, statistic, and time period. The calculation options are values, average conditions, differnce from average, percent difference from average conditions, percent of average conditions, slop of trend (Sen's Slope), and correlation of trend (Kendall Tau-b).

	Time Period	
7	Season	The date range is slected based on the desired data request to process for the map summary. A general pre-determined or custom date range can be chosen.

Top of Map

8	Colors	The colors of map summary values can be changed to meet the desired display outcome.
9	Map	The base map background properties can be changed.
10	Layers	Different map layers concerning the Navajo Nation can be selected and unselected. There is also an option for U.S. layers that can be selected.
11	Masking	A mask can be applied to conceal pieces of the map layer.
12	Download	The map can be downloaded as a geotiff or as a PDF.

Helpful Tips

While working with DSET keeping these tips in mind. They will help with completing the hands-on exercises.

- DSET works best on Google Chrome.
- DSET works best on a fast network.
- Zoom into area of interest to help with calculations. Zooming into the area will limit the processing power needed to generate the map.
- If continued error persists during a DSET calculation try resubmitting the calculation buy using the Reset feature. By resetting the tool you will have to start over and conduct the previous steps again.
- Time of day may help with time out analysis errors in DSET. Working in the early mornings, late nights, or weekends may result in less time out errors.
- In the case study exercises of this User Guide, a color-coding system is used to help with navigation of the DSET features. For example, the section heading **Visualization Layer**, matches the color of the wording you will find on the DSET webpage under the Make Map panel.

DSET Application Case Studies

Case Study 1: Drought

Introduction
As temperatures rise under a warming climate, drought risk increases, especially in arid to semi-arid regions like the Navajo Nation (N.N.). Drought is experienced when an area faces prolonged shortages of water supply. A lack of precipitation can lead to not only environmental impacts, but social and economic hardships as well. The length and severity of drought can also lead to varied impacts.

The various types of droughts include: meteorological, ecological, hydrological, and agricultural. Meteorological droughts are local events and are characterized by low precipitation (in comparison to long-term averages) in the region affected. Ecological droughts caused by reduced rainfall can have impacts on the ecosystem such as loss of plant growth, increase in fire outbreaks, altered rates of nutrient and water cycling and more leading to local species extinction. Lack of precipitation in Hydrological droughts affect streamflow, soil moisture, reservoir and lake levels, and groundwater recharge. Agricultural droughts occur when available water supplies are not able to meet crop water demands.

Short-term droughts are seasonal, while long-term droughts can last decades. On the N.N. short-term droughts can impact the water supply provided by surface water. The impact on groundwater levels can come as a result of long-term drought. Water resource managers can mitigate issues of drought impacts on water supply thorough measures of temporary water conservation, water transfers, and increased use of groundwater.

The Drought Severity Evaluation Tool (DSET) can help in understanding the extent and severity of drought in order to conduct drought assessments that can be used for mitigation decision-making. The data available on DSET provide opportunities to create place-based and near real-time drought assessments. Understanding these drought risks can help the N.N. prepare responses to water supply impacts on agriculture, availability of water for livestock, rangeland vegetation health, and community access to water.

Components of Analysis
- Datasets: METDATA/gridMET
- Variable: Precipitation (PPT) and the Standardized Precipitation Index (SPI)

Objectives
- Use the DSET to develop a drought assessment by evaluating patterns of precipitation for the Last Northern Water Year (Oct – Sept). In this example the time period for the Last Northern Water Year was from 2018-10-01 to 2019-09-30.

Depending on the year this exercise is completed the dates for the Last Northern Water Year will change.

- Map the daily precipitation totals in millimeters and calculate the difference from average for the Last Northern Water Year (Oct – Sept) the Navajo Nation using METDATA/gridMET - Daily calculations.
- Calculate the METDATA/gridMET - Daily precipitation Percent of Average conditions for the Navajo Nation for the Last Northern Water Year (Oct – Sept).
- Evaluate drought across the Navajo Nation using the Standardized Precipitation Index (SPI) for the Last Northern Water Year. This example uses the METDATA/gridMET dataset standardized precipitation index (SPI) calculations for the Custom Date Range start date of 2018-10-01and end date of 2019-09-30, the Last Northern Water Year.
- Calculate the six-month and twelve-month gridMET SPI for the Navajo Nation Nageezi Chapter using the Area Averaged Region for dates from 2018-12-31 to 2020-01-01.

Helpful Tips

- DSET is optimized for Google Chrome, please use Chrome.
- Faster networks are preferred when using DSET.
- Zoom to area of interest before submitting map requests to help with re-computing data.
- Resubmission and reset of DSET can help with fail requests that produce a server error.
- The figures included in this case study will help you navigate the DSET to locate the features associated with each step. It is suggested that you use the figure to ensure your selections are correct prior to completing each major step within the exercise.
- In the case study exercise, a color-coding system is used to help with navigation of the DSET features. For example, the section heading **Visualization Layer**, matches the color of the wording you will find on the DSET webpage.

Estimated Time for Completion for the Drought Case Study: **38 Minutes**

This exercise for Case Study 1: Drought is divided into two sections. The first section is Part 1: Daily Precipitation for the Last Northern Water Year and the second is Part 2: Drought Index for the Navajo Nation.

Part 1: Daily Precipitation for the Last Northern Water Year

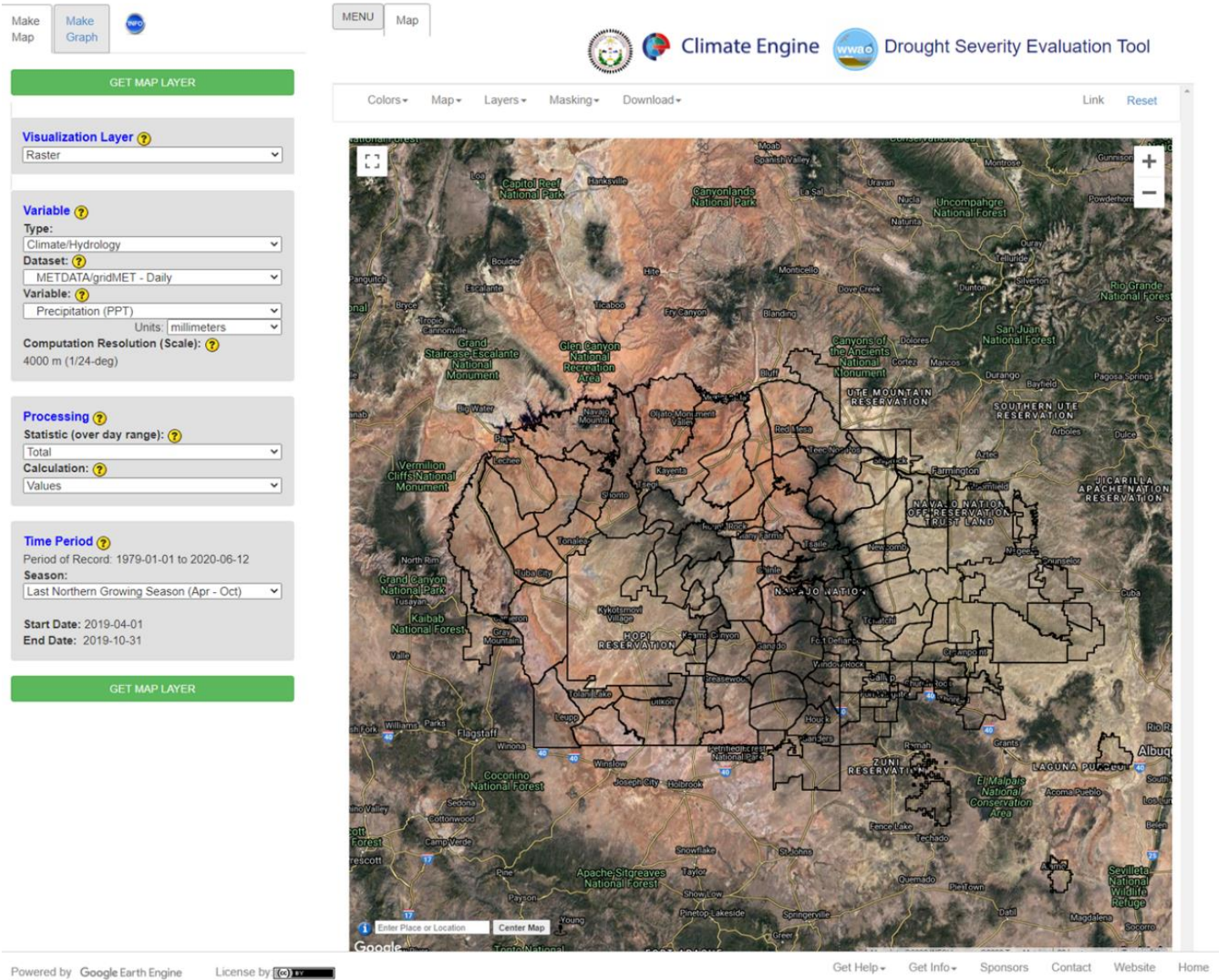- Objective: Find the daily precipitation totals for the last northern water year across the Navajo Nation.

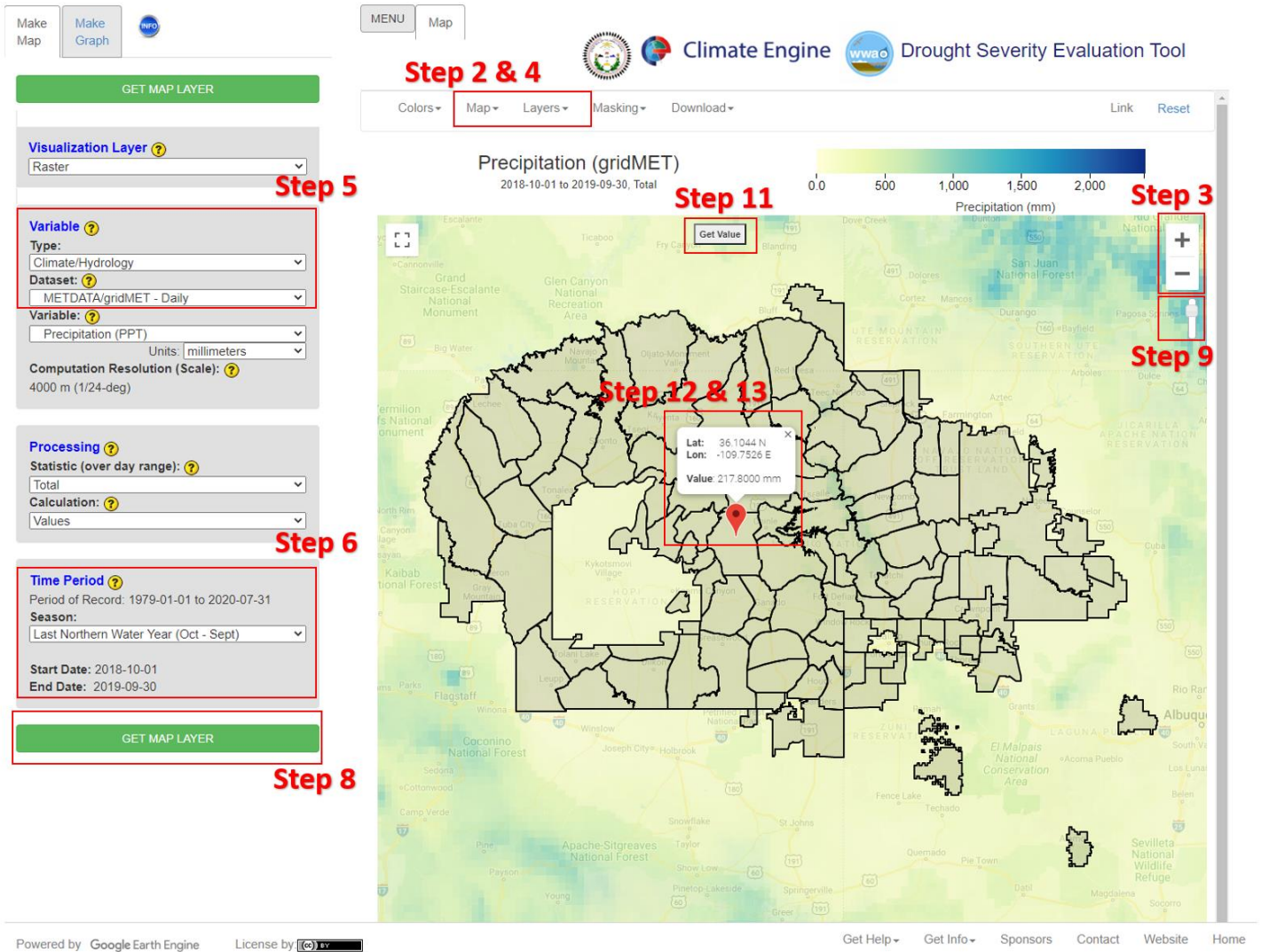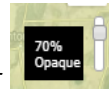Figure 5. The DSET home screen displaying the entire Navajo Nation.

Figure 6. METDATA/gridMET - Daily calculations for the Navajo Nation for the Last Northern Water Year displaying the precipitation (mm). Guidance for steps 2 through 13 are indicated in this figure.

1. Go to the DSET website using this link https://app.climateengine.org/dset.
2. Under the **Layers** tab along the top, ensure that the **Navajo Nation Chapters** boundary is selected and displayed on the map.
    a. Note: The Navajo Nation Chapter boundaries should appear as the default.
3. Zoom into the Navajo Nation reservation boundary using the "+" sign along the top right.
4. Click on the **Map** tab along the top, which hosts the map options, and select the **Road map**.
5. Located on the Make Map panel on the left side of the webpage, under the **Variable** section leave the **Type** parameter as the default (**Climate/Hydrology**), and change the **Dataset** parameter to **METDATA/gridMET-Daily**.
6. Under the **Time Period** section located on the same panel, change the **Season** to **Last Northern Water Year (Oct– Sept)**.
    a. Selecting the Last Northern Water Year (Oct– Sept) will change the start date to **2018-10-01** and end date to **2019-09-30**. Depending on the year of analysis the Water Year (WY) will change. For example, if this exercise is done in the year 2022, the Last Northern Water Year (Oct—Sept) will have a start date of 2020-10-01 and an end date of 2021-09-30.
7. Leave all other options on the panel as default.
8. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.
9. Once the processing is complete, the map will automatically display the data. The **transparency** may be decreased or enhanced to better see the results. On the top right of the map, move the opacity slider down to 70% Opaque.
10. Your map should look like Figure 6 (above). Notice that the precipitation values are similar except for the higher elevation regions along the Chuska Mountain which has values above 500 mm.
11. Now let's examine the precipitation value at a specific point on the Navajo Nation. Click on the **Get Value** box located on the top center of the map.
12. For this analysis, we are interested in the precipitation for the **Tselani Chapter** area. Click the **Get Value** pop-up box and drag the **red geo marker** to the Tselani Chapter boundary (see Figure 6 for where the Tselani Chapter is located).
13. Click on the blue **Show Value** box, wait for the request to be processed. The value calculated is the total precipitation for the Last Northern Water Year.

The result of this analysis shows that the Precipitation (PPT) variable in the METDATA/gridMET -Daily data set shows that the entire Navajo Nation for the Last Northern Water Year had less than 500 mm of precipitation (Figure 6), except for the higher elevation regions. Through DSET's layer capabilities N.N. Chapter analysis is available. For this example, in Figure 6 the Tselani N.N. Chapter showed that for the Last Northern Water Year the chapter area had around 217.8 mm of precipitation. Please be mindful that the value of precipitation will vary with latitude and longitude location within a chapter boundary. The 217.8 mm value for this exercise may be different from

the value you calculate. The reason for this variability is the value for the exact location you place the geo marker. To verify if your value is similar to this case study exercise use the precipitation value scale for reference located above the map. The next steps in this drought case study will be to understand the precipitation values more and how they correlate to drought conditions.
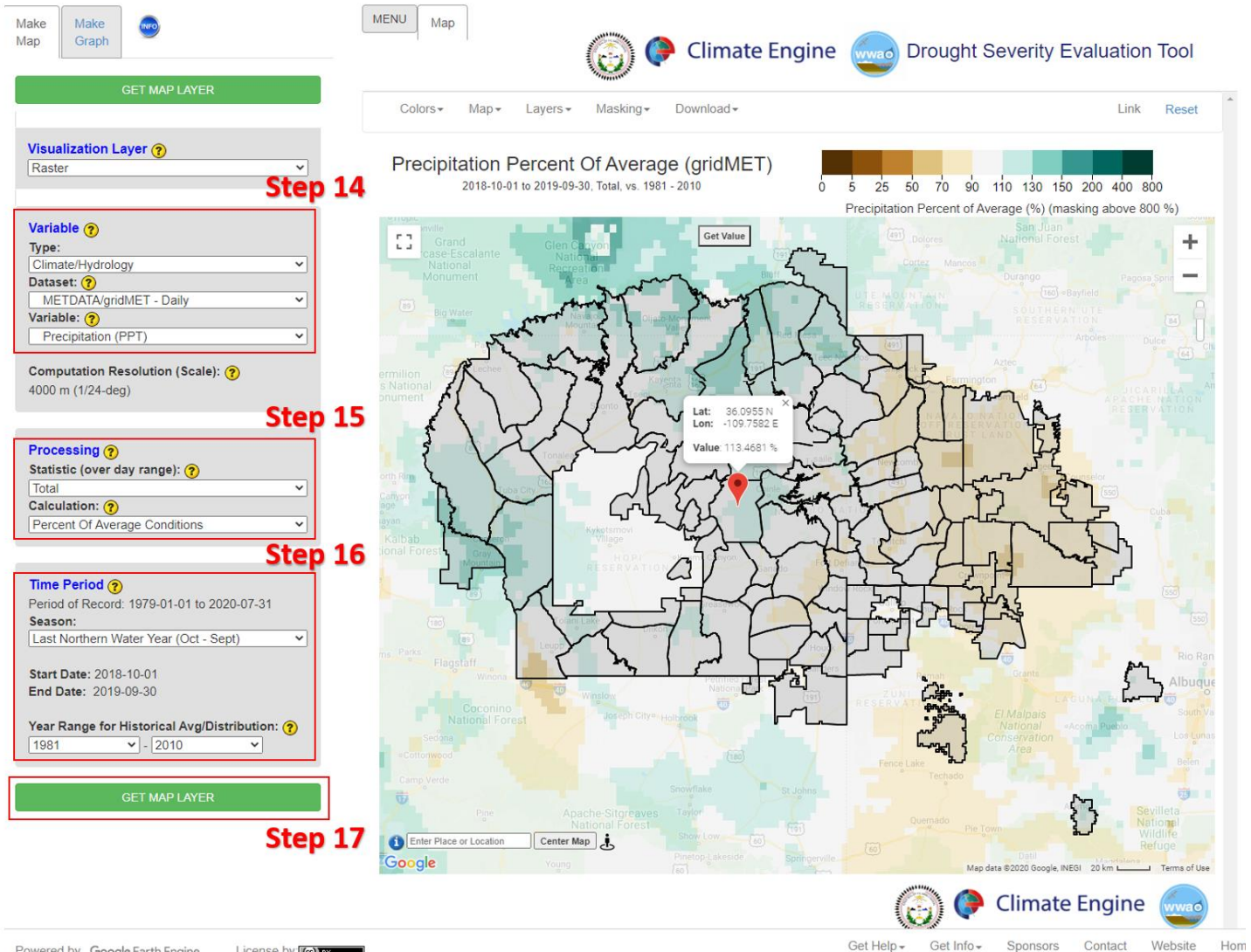

Figure 7. METDATA/gridMET -Daily precipitation percent of average conditions for the Navajo Nation for the Last Northern Water Year. Guidance for steps 14 through 17 are indicated in this figure.

14. Leave the **Variable** dataset as **METDATA/gridMET** and the **Variable** a **Precipitation (PPT).**
15. On the Make Map panel to the left under the **Processing** section and click on the drop-down arrow next to **Calculation** and select **Percent of Average Conditions**.
16. Keep the **Time Period** **Season** as the **Last Northern Water Year (Oct– Sept).**

a. Note that by selecting the **Percent of Average Conditions**, the **Time Period** section now includes the **Year Range for Historical Avg/Distribution**. The default years for the historical average range is from **1981 to 2010**, this is the standard climatology. Leave the default years in place for this case study analysis.

17. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request. If you should get a **Sever Error or Time Error**, click **Cancel Processing** and click on **Get Map Layer** again. If the error persists, try to **Reset** DSET and run the analysis again (Steps 14 through 16).

18. Follow **Steps 11 through 13**, to get the value for the Tselani Chapter Percent of Average Conditions calculation.

Using the Percent of Average Conditions calculation takes the total precipitation in the Last 60 days and divides it by the "Average Conditions" that is multiplied by 100%. For the Tselani Chapter area selected previously the percent was found to be 113.47% (Figure 7). The Percent of Average Conditions are indicators of drought conditions. Although in this example some areas of the N.N. were found to be above 100% other areas were not. Over a longer time period these values could differ to show long-term drought. Keep in mind the percentage value in this case study exercise may be different from the exact percentage you calculate. Use the precipitation percent of average value scale to see if your percentage calculated correlates to this case study exercise.

Part 2: Drought Indices for the Navajo Nation

- Objective: Develop a map displaying drought severity on the Navajo Nation using the SPI index.

The SPI is a drought index that provides more comprehensive understanding of meteorological drought, or precipitation deficits, on the Navajo Nation.

1. Go to the DSET website using this link https://app.climateengine.org/dset or click on **Reset** to start over if you are already on the website.
2. Under the **Layers** tab along the top, ensure that the **Navajo Nation Chapters** boundary is selected and displayed on the map.
   a. Note: The Navajo Nation Chapter boundaries should appear as the default.
3. Zoom into the Navajo Nation reservation boundary using the "+" sign along the top right.
4. Click on the **Map** tab along the top, which hosts the map options, and select the **Road map**.
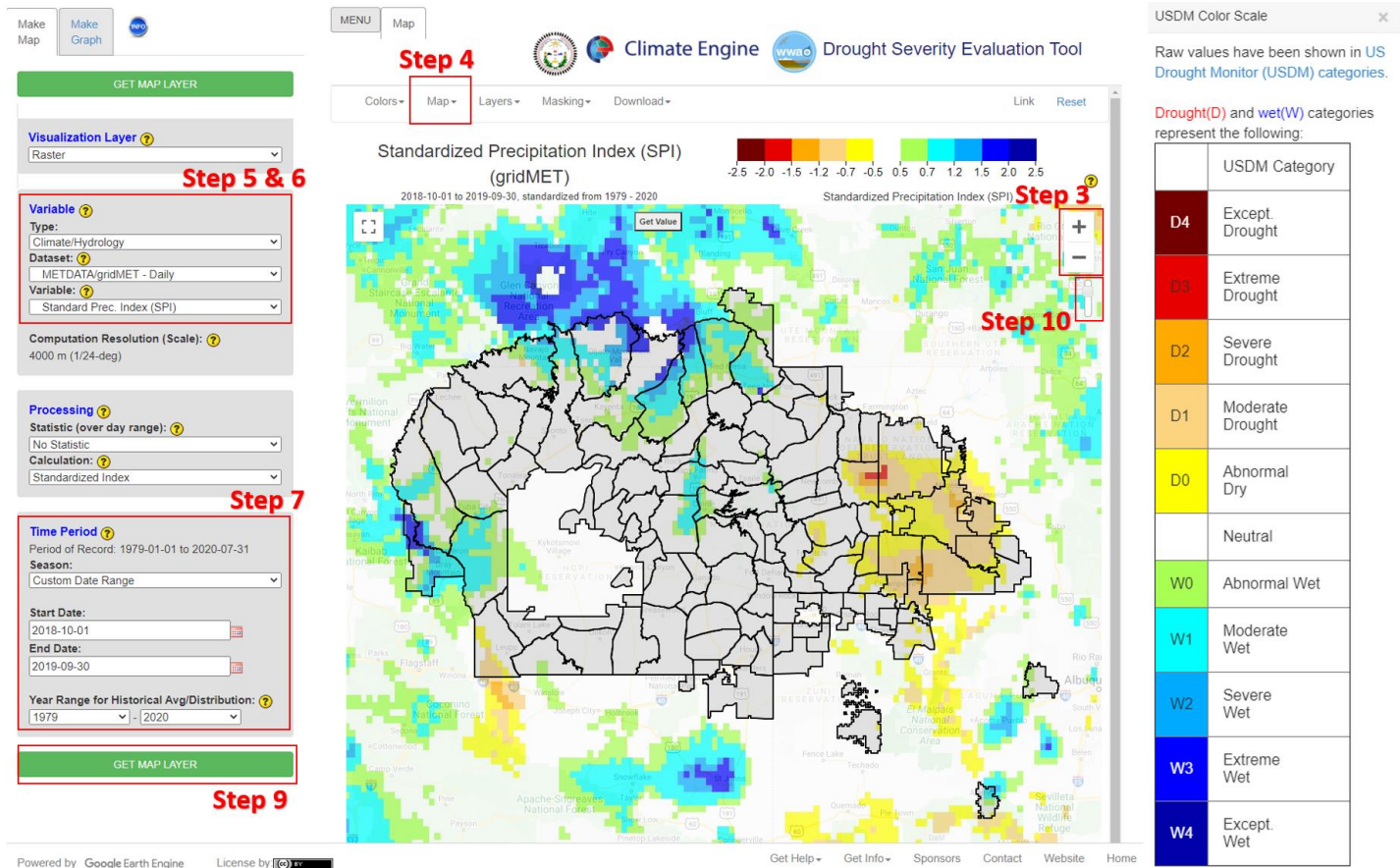
Figure 8. METDATA/gridMET standardized precipitation index (SPI) calculations for the Custom Date Range start date of 2018-10-01and end date of 2019-09-30, the Last Northern Water Year. The SPI is scaled according to the U.S. Drought Monitor Classification that categorizes the drought conditions. Guidance for steps 3 through 10 are indicated in this figure.

5. Located on the Make Map panel to the left of the screen, change the **Variable Dataset** to **METDATA/gridMET**.

6. In the **Variable** drop-down, select the **Standard Prec. Index (SPI)**.

   a. Click on the yellow question mark 🟡 for a description of the SPI. You can also view the details on all the other available data layers here. The Navajo Nation uses a 6-month SPI value of ≤**-1.5** to declare a drought emergency.

7. In the **Time Period** section use the **Season** drop-down to select the **Custom Date Range**. Change the **Start Date** to **2018-10-01** and the **End Date** to **2019-09-30**. These dates will provide the map display for the Last Northern Water Year.

8. Leave all other parameters as default.

9. Click on **Get Map Layer**, wait for the map to load. Again, give the DSET a moment to process your request.

10. As in Part 1, you can change the opacity slider to help you visualize the data better.

    a. Once the processing is complete, the map will automatically display the data. The **transparency** may be decreased or enhanced to better see the

results. On the top right of the map, move the opacity slider down to 70% Opaque.

The SPI indicates that the majority of the N.N. was in a drought for the Last Northern Water Year. The western region of the reservation was experiencing severe/extreme drought. The SPI is scaled according to the U.S. Drought Monitor Classification (USDM) that categorizes the drought conditions as identified in Figure 8. The deep red colors of USDM represent exceptional and extreme drought. The cool deep blue colors in USDM represent exceptional and extreme wet areas. DSET has the ability to also calculate the SPI for area-averages for the Chapters across the reservation as well as the Agency level. The N.N. Chapters Burnham and Huerfano were the only two chapters during this time period that had extreme drought. After becoming familiar with SPI calculations setting up your parameters let's **Reset** the tool to run this analysis. For this analysis let's calculate the SPI area-average for a Chapter.
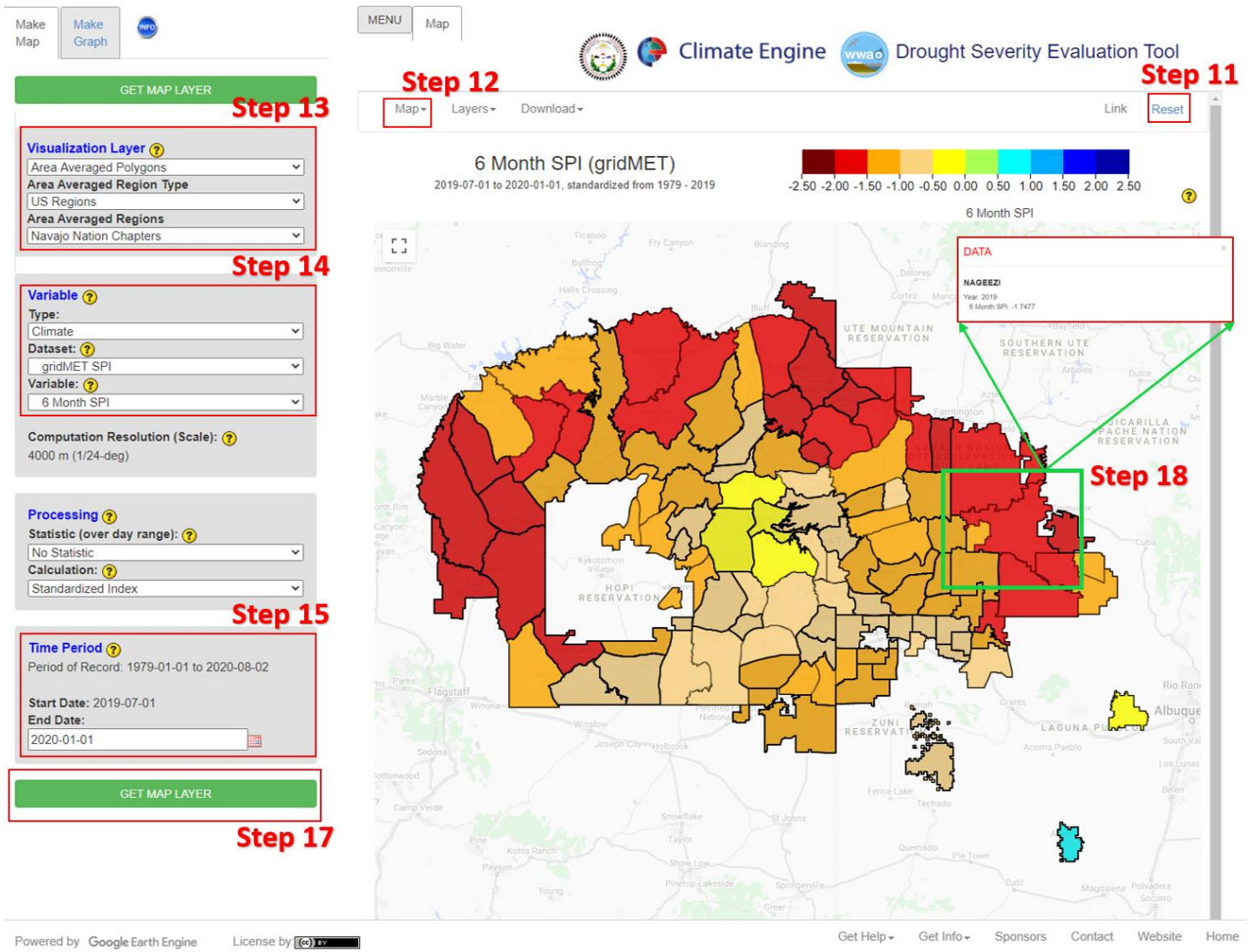
Figure 9. Navajo Nation Chapter six-month gridMET SPI values with a start date of 2019-07-01 and an end date of 2020-01-01. Through the use of the gridMET SPI dataset and Area Averaged Regions specific six-month values are calculated for each N.N. Chapter. In this example, Nageezi was found to have a drought emergency value for the six-month SPI of -1.7477. Guidance for steps 11 through 18 are indicated in this figure.

11. At the top right corner of the map, click **Reset**.
12. To visualize the polygons better for this analysis you have the option of changing the base map. Click on the **Map** tab along the top, and select the **Light Political Style**.
13. In the Make Map panel on the left, in the **Visualization Layer** drop-down select the **Area Averaged Polygons**. Then, ensure that the **Navajo Nation Chapters** are listed under **Area Averaged Regions** (this should be the default).
14. Under the **Variable** section, in the **Dataset** drop-down, select the **gridMET SPI - Daily**. The **6 Month SPI** should then be displayed as the default under **Variable**.
15. In the **Time Period** section, change the **End Date** to be **2020-01-01**. This will automatically change the **Start Date** to six-months prior (2019-07-01).
16. Leave all other parameters as the default.

17. Click on **Get Map Layer** and allow the DSET a few minutes to process your request.

18. Your map should now look similar to Figure 9 above. You now have the option to click on any Chapter boundary and get the 6-month SPI value. Click on any Chapter on the Navajo Nation to display the 6-month SPI value. For example, **Nageezi Chapter** has a 6 Month SPI value of -1.7477, as shown in Figure 9. As mentioned previously, a SPI value below -1.5 would trigger a drought emergency on the Navajo Nation.

    a. If your SPI value for the chapter of your interest does not display, you may have to **Reset** DSET again and run the analysis again by repeating steps 12-19 from this section (Part 2).
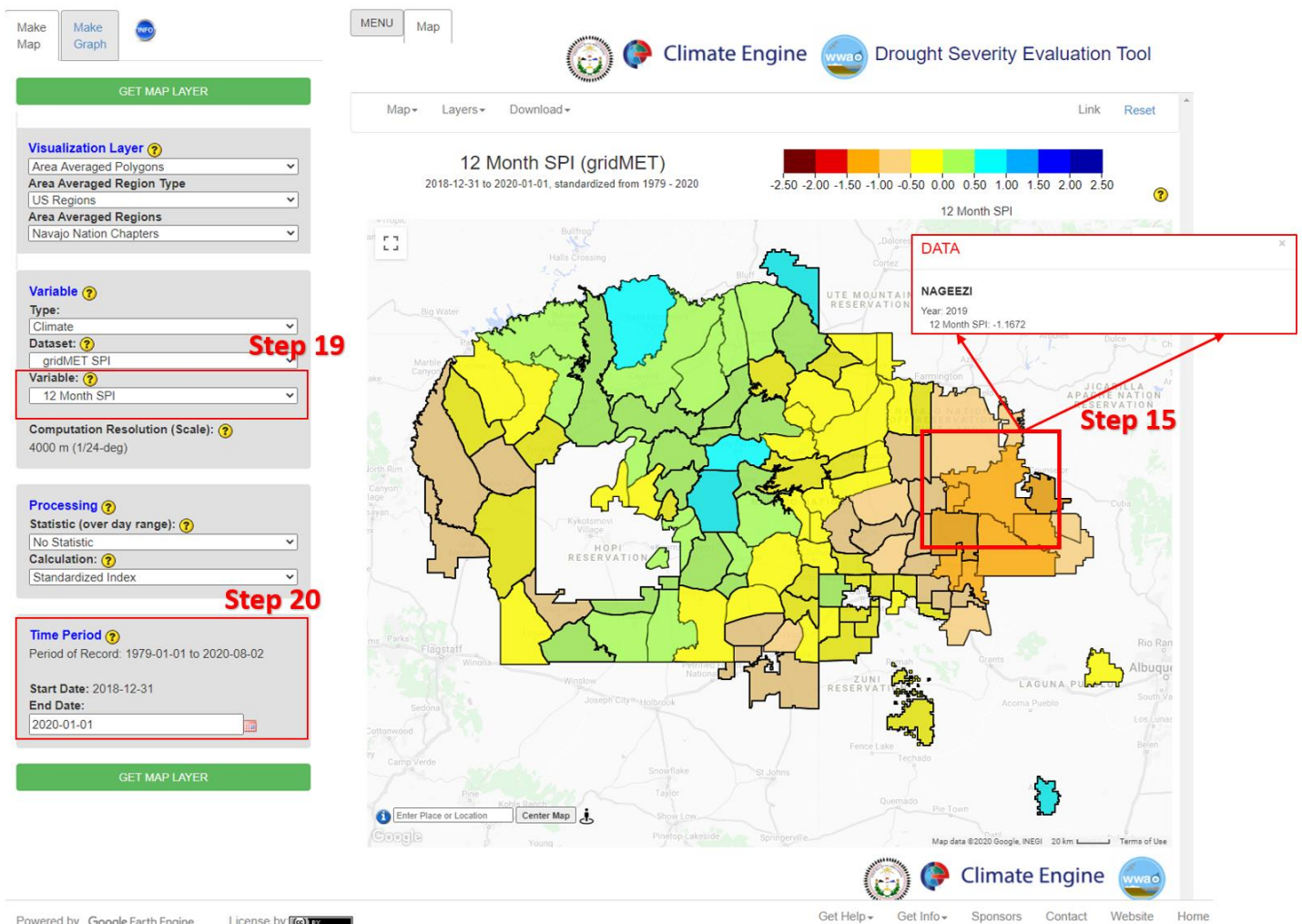

Figure 10. Navajo Nation Chapter 12-month gridMET SPI values. In this example, Nageezi was found not to have a drought emergency (-1.5) value for the six-month SPI of -1.1672. However, Nageezi for the time period of 2018-12-31 to 2020-01-01 was one of the N.N. Chapters with the highest SPI value.

Let's consider the SPI for a year (12-month) compared to the 6-month value for Nageezi Chapter.

19. Change the **Variable** of the **6 Month SPI** to the **12 Month SPI value**.
20. Remember to keep the **End Date** of **2020-01-01**. on **Get Map Layer** and allow the DSET a few minutes to process your request. For this example, the Nageezi Chapter 12-month SPI value was -1.167.
    a. If your SPI value for the chapter of your interest does not display, you may have to **Reset** DSET again and run the analysis again by repeating steps 12-20 from this section (Part 2).

Figures 9 and 10 display the average SPI value for half a year (6-month SPI) and a full year (12-month SPI) for each N.N. Chapter. For the 6-month SPI (Figure 9) there are numerous N.N. Chapters under Extreme Drought. However, when displaying the 12-month SPI values for the N.N. Chapters you will notice a distinct difference in the drought conditions. When displaying the 12-month SPI values there are no Chapters under Extreme Drought conditions, and large portions of the reservation are under Abnormal Wet drought conditions compared to the climatological average (1981-2010). For the Nageezi N.N. Chapter there was a noticeable difference in SPI values from -1.7477 (6-month) to -1.167 (12-month).

Analyzing drought at multiple timescales can help managers understand the differences in short-term (meteorological) vs. and long-term drought (hydrological or ecological). For example, under meteorological drought conditions there is a deficit in precipitation which may impact surface water conditions, but under prolonged droughts, like a hydrological drought, the impacts may be observed on soil moisture and groundwater.

Case Study 2 –Agriculture

Introduction

On the Navajo Nation, enterprises such as the Navajo Agriculture Products Industry (NAPI) have been established to continue in the legacy of Navajo farming. NAPI has a large agricultural production region near Farmington, New Mexico. Agriculture in semi-arid to arid regions is vulnerable to drought. Large scale agricultural enterprises rely on dependable water access for the health of their crops. The consistency of water access provides greater chances of a successful harvest. Agricultural droughts occur when available water supplies are not able to meet crop water demands. Although this crop analysis case study will be focused on NAPI, similar assessments can be established for other known agriculture areas on the Navajo Nation and can be assessed on an Agency and Chapter House boundary level through the use of the Drought Severity Evaluation Tool (DSET).

DSET can help in understanding crop health through the use of drought and vegetation indices related to agricultural drought. Indices and climate variables such as the Normalized Difference Vegetation Index (NDVI), precipitation, and evapotranspiration (ET) can help in assessing crop health. The NDVI is a measure of vegetation vigor or health though the use of a ratio of the reflection of red and near-infrared wavelengths. Healthy vegetation reflects green wavelengths (this is why we see most healthy plants as green) and strongly reflects near-infrared wavelengths. Therefore, the greater the NDVI value, the healthier the plant. Lower NDVI values indicate less healthy vegetation. Declines in precipitation also impacts the growth and productivity of vegetation.

Components of Analysis
- Datasets: Landsat 4/5/7/8 Surface Reflectance and Climate Hazards Group InfraRed Precipitation with Station (CHIRPS)
- Variables: Normalized Difference Vegetation Index (NDVI) and Precipitation (PPT)

Objectives
- Use the Last Northern Growing Season (Apr – Oct) for this example 2019-04-01 to 2019-10-31 to calculate the NDVI value.
- Use the calculated NDVI value to create a time series for a NAPI crop plot for the past 20 years.
- Use CHIRPS –Pentad PPT measurements and NDVI values of a NAPI crop plot to see the influences of drought and irrigation on agricultural production.

Helpful Tips
- DSET is optimized for Google Chrome, please use Chrome.
- Faster networks are preferred when using DSET.
- Zoom to area of interest before submitting map requests to help with re-computing data.

- Resubmission and reset of DSET can help with fail requests that produce a server error.
- The figures included in this case study will help you navigate the DSET to locate the features associated with each step. It is suggested that you use the figure to ensure your selections are correct prior to completing each major step within the exercise.
- In the case study exercise, a color-coding system is used to help with navigation of the DSET features. For example, the section heading **Visualization Layer**, matches the color of the wording you will find on the DSET webpage.

Estimated Time for Completion for the Crop Analysis Case Study: **33 Minutes**

This exercise for Case Study 2: Crop Analysis is broken up into two sections. The first section is Part 1: NDVI Crop Analysis for the Last Northern Growing Season and the second is Part 2: NAPI Field Data Time Series.

Part 1: Crop Analysis for the Last Northern Growing Season

- Objective: Use the Last Northern Growing Season (Apr-Oct) for this example those dates are 2019-04-01 to 2019-10-31 to calculate the NDVI value.

NDVI uses the ratio of reflection of red and near-infrared wavelengths to measure vegetation health. The equation for calculating the NDVI values using the red and near-infrared wavelengths is $NDVI = \frac{(NIR)-(Red)}{(NIR)+(Red)}$. The scale values for NDVI range from +1.0 to -1.0. A high NDVI value is an indicator of an area with dense vegetation. In this exercise a higher NDVI value represents NAPI crops at their peak growth state.

Figure 11. The darkest green colors represent the crops with the highest amounts of chlorophyll, thus displaying a high NDVI value. Some of the crops with lighter green may be less green, or not as heavily irrigated. The darker the shade of green is representative of the greater density of vegetation. Guidance for steps 11 through 18 are indicated in this figure.

1. Go to the DSET website using this link https://app.climateengine.org/dset.
   a. If you are conducting this Case Study for Crop Analysis after working on Case Study 1, at the top right corner of the map, click **Reset**.

2. Under the **Layers** tab along the top, ensure that the **Navajo Nation Chapters** boundary is selected and displayed on the map.
    a. Note: The Navajo Nation Chapter boundaries should appear as the default.
3. Zoom into the Navajo Nation reservation boundary using the "+" sign along the top right.
4. Click on the **Map** tab along the top, which hosts the map options, and select the **Hybrid map**.
    a. Note: The Hybrid map should appear as the default.
5. Located on the Make Map panel on the left side of the webpage, under the **Variable** section select the **Type** parameter to be **Remote Sensing**, and change the **Dataset** parameter to **Landsat 4/5/7/8 Surface Reflectance.**
6. For the **Variable** select **NDVI (Vegetation Index)** located under the **Vegetation Indices Section.**
    a. Note: The Landsat 4/5/7/8 Surface reflectance and the NDVI (Vegetation Index) should appear as the default when Remote Sensing is selected as the Variable.
7. Under the **Processing** section select the **Statistic (over day range)** to be **Median**, leave the **Calculation** to be set on **Values**.
8. Under the **Time Period** section located on the same panel, select the **Last Northern Growing Season (Apr – Oct).**
    a. Selecting the **Last Northern Growing Season (Apr – Oct)** will change the start date to **2019-04-01** and end date to **2019-10-31**. These dates will appear if this exercise is done in 2020. After 2020, the **Last Northern Growing Season (Apr – Oct)** dates will change to show the most recent growing season**.** For example, if this exercise is done in the year 2021 (before October) the dates for the Last Northern Growing Season (Apr – Oct) will have the start date 2020-04-01and the end date of 2020-10-31.
9. Leave all other options on the panel as default.
10. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.
11. Once the processing is complete, the map will automatically display the data. The **transparency** may be decreased or enhanced to better see the results. On

    the top right of the map, move the opacity slider down to 70% Opaque.
12. Your map should look like Figure 11 (above).
13. To get more information about the **NDVI (Vegetation Index)**, click on the yellow arrow next to **Variable**.
    a. If you select the a pop-up box of the **Metrics** will appear and will have to be closed manually by clicking the **x** at the top right corner of the pop-up box.
14. **Do not Reset**. The same findings for the NDVI will be used in Part 2 of this Crop Analysis Case Study.

After creating an NDVI map for the Navajo Nation to analyze for the Last Northern Growing Season (Figure 11). It is evident where areas of dense vegetation exist based on the type of landscape. For example, the Chuska Mountains are the dark green color near the center of the N.N. This is due to the high amount of chlorophyll in the vegetation present for a mountainous region. However, for areas in lower elevation on the Navajo Nation the NDVI values are less and are shown to be a light green color, where there is less dense vegetation. In the northeast corner of the reservation, you can see the NAPI fields located near Farmington, New Mexico. The darker shade of green shown for NAPI represents a greater density of vegetation in comparison to surrounding areas. Part 2 of this exercise will look more into the NDVI values of the NAPI center-pivot fields.

Part 2: Field Data Time Series

- Objective: Use the calculated NDVI values to create a time series for a NAPI field for the past 20 years.

Now in Part 2 the development of a data time series for a specific field is the goal. The data time series will show the characteristics of the NAPI fields. The characteristics that will be shown are the crop cycles and the influence of drought and irrigation on the crop outputs.
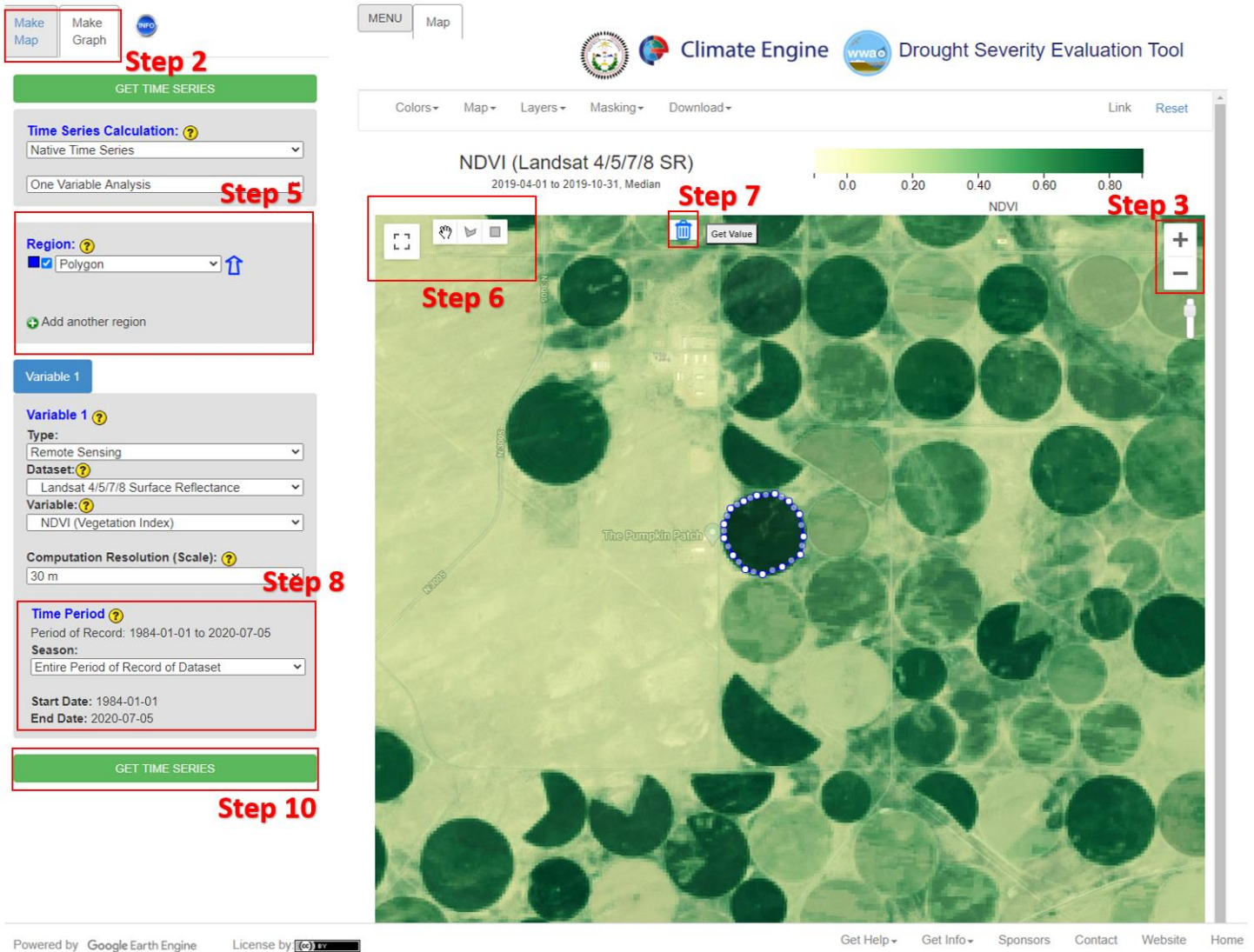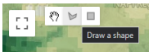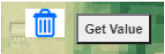
Figure 12. Specific NAPI center-pivot irrigation field near The Pumpkin Patch. This field selected as indicated by the dots encircling the field is used to provide a data time series for the values of NDVI found at this location from 1984-01-01 to 2020-07-05, the Entire Period of Record of Dataset. Guidance for steps 2 through 10 are shown in this figure.

1. Leave the **Make Map** panel as is from Part 1 of this Case Study.
2. Click on **Map Graph** tab beside the **Make Map** tab along the top left section of the DSET home screen.
3. Zoom into the Navajo Nation Chapter Boundary for Upper Fruitland, New Mexico located near Farmington, New Mexico using the "+" sign along the top right.
   a. The Upper Fruitland boundary will show NAPI fields.
4. Zoom in even closer to one specific center-pivot irrigation field that you want to analyze. For this exercise a center-pivot irrigation field near *The Pumpkin Patch* was identified.
5. Under **Region** in the panel on the left, select **Polygon** under the **Custom Polygon Regions**.
   a. Note that when you do this a pop-up will appear that describes **How to create a polygon how**. Reading through this pop-up will help in making a

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polygon.

6. Close the pop-up and click on the **Draw a Shape** icon⌣ in the top left of the map [icons] .
   a. Note that when you do this, a cross-hair symbol will appear as your cursor.

7. Click on the outer edge of one of the crop circles to start to draw your circle. Multiple clicks will be needed to enclose the circle field. Keep clicking all the way around the circle. To close the circle, click the first dot in the circle.
   a. Once you have closed the circle the polygon will flicker and then will appear as a darker shade on the map.
   b. If you are unhappy with the circle around the field, you have the option to re-draw the crop circle. Use the delete button next to the Get Value button at the top of the map [icons] .

8. Once you are happy with the polygon, change the **Time Period** section to have the **Season** select the **Entire Period of Record of Dataset**.
   a. Note that for this exercise the Entire Period of Record of Dataset includes the start date of 1984-01-01 and the end date of 2020-07-05. Depending on when this exercise is conducted the end date will vary to include the Entire Period of Record of Dataset up until when this exercise is being completed by the user.

9. The **Variable 1** section can be left as is with the selected **Type, Dataset, and Variable**.

10. Click on **Get Time Series** and wait for your figure to load.
    a. Again, if your time series does not appear after a few minutes you may have to **Reset** DSET again and run the analysis. Due to the large amount of data loading for the entire period of record, the figure may time a few minutes to load. If needed, you could choose a shorter **Time Period** in the **Custom Date Range** to resolve the issue.

11. When the time series appears there should be numerous peaks showing the trends from to 1984 to the present date that was created for the end date (in this example the end date is 2020-07-05).
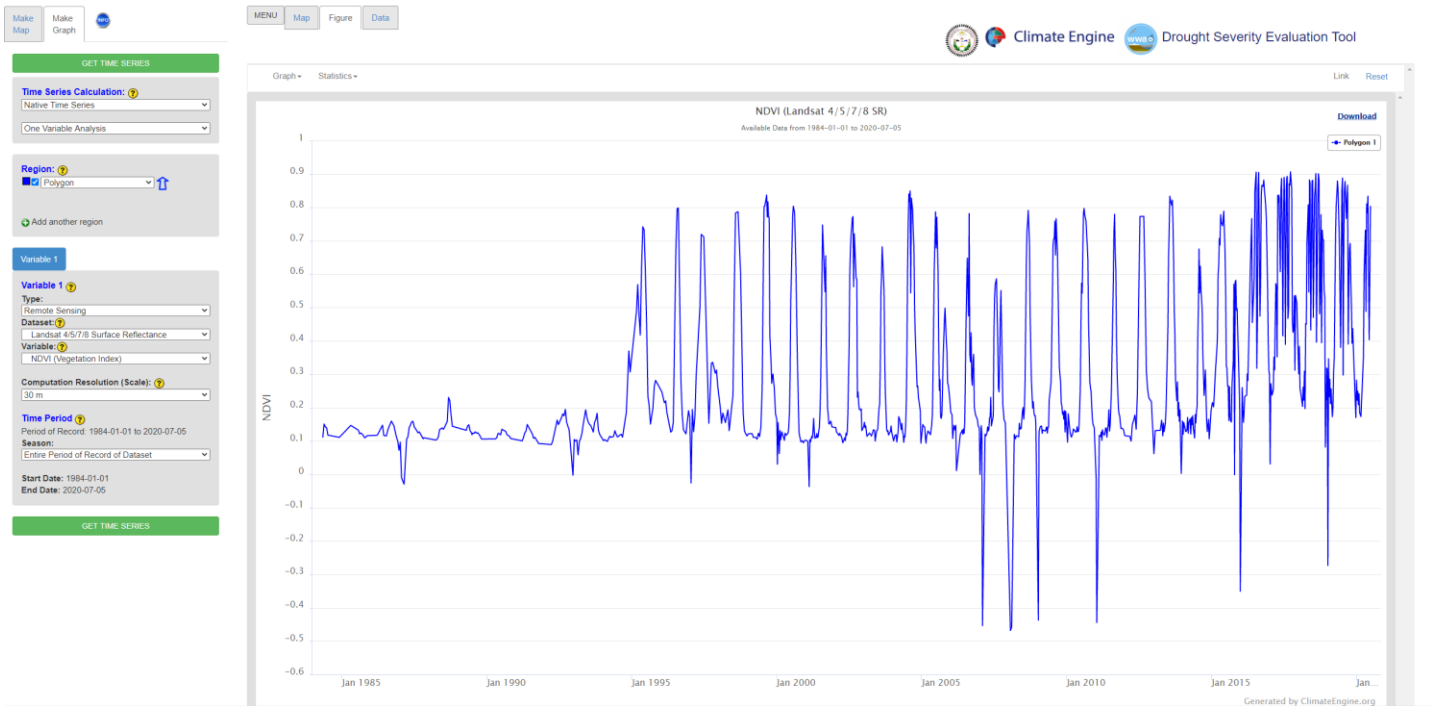
Figure 13. The NDVI data time series for the selected center-pivot irrigation field located near the NAPI Pumpkin Patch. The data time series for the values of NDVI found at this location are from 1984-01-01 to 2020-07-05, the Entire Period of Record of Dataset. The time series shows that irrigation for this field likely started around 1994, with low NDVI values prior to this date and much higher NDVI values after this date. After 1994, this field appears to have multiple cuttings per year, as indicated by the steady increases in NDVI and the sharp declines when cutting occurred.

12. Click on the map around 2013 and drag your mouse to about 2019. As you do this, a blue box ▮ will appear over the years selected and indicates where you are zooming into. This will automatically zoom into those years on your time series.

Figure 14. Zooming into a shorter time frame the harvest of a specific year for this center-pivot irrigation field is shown. In this time series example from 2013 to 2019 the NDVI values provide an understanding of the crops and harvests for a particular year. In 2017, there were multiple cuttings which is usually an indication for Alfalfa.

The time series of NDVI values displays patterns in the data that show crop signatures. For example, in Figure 13 for 2013 there was a single peak that indicates an annual crop with a greater growth time. An example of an annual crop is corn. In 2015, the center-pivot irrigation field in this exercise had a perennial crop with two harvests. In 2017, there were multiple cuttings for this year which is a typical signature of alfalfa.

13. Click on the small **Reset Zoom** box right under **Polygon 1** on the top right of the figure.
14. In the Make Map panel, under **Time Series Calculation**, select **Summary Time Series**.
15. Under **Year Statistic** for Variable 1, select **Mean**
16. Under the **Time Period** section, leave the first option as Entire Period of Record of Dataset, and for the second drop-down, select **Northern Growing Seasons (Apr – Oct)**.
17. Make sure the **Year Range** is 1984—to the current year the exercise is completed. In this example, the years selected are from 1984—2019. However, if you are running through this exercise in the year 2021 the years for the **Year Range** would be 1984—2020.
18. Click on **Get Time Series** and wait for the time series to load.
    a. Remember if you should get an error DSET can be **Reset** and the analysis can run the process again.
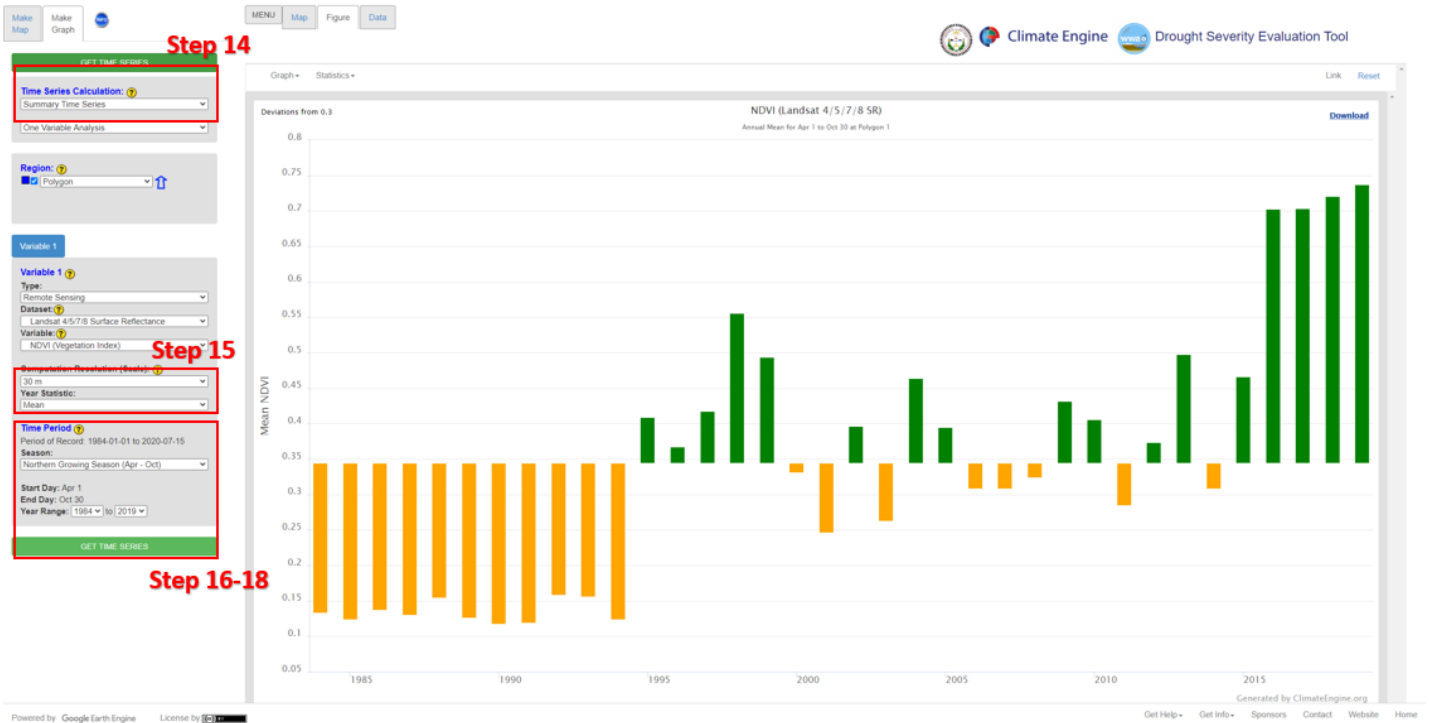
Figure 15. The center-pivot irrigation field located near the NAPI Pumpkin Patch used in this example appears to have not been irrigated until the mid-1990s. This assumption is made based on the low NDVI values from the mid-1980s to about 1995. Guidance on DSET inputs are indicated in this figure for Steps 14 through 18.

Prior to the mid-1990s the center-pivot irrigation field used in this example appears to not have been irrigated. From 1995 to 2019 it appears that irrigation was initiated with the increase of NDVI values for this center-pivot irrigation field. However, with one variable it is difficult to be certain if irrigation was the cause of this increase of NDVI values. Precipitation for this area may have also increased after 1995. Adding a precipitation values as a second variable to this analysis will help determine the impact of irrigation.
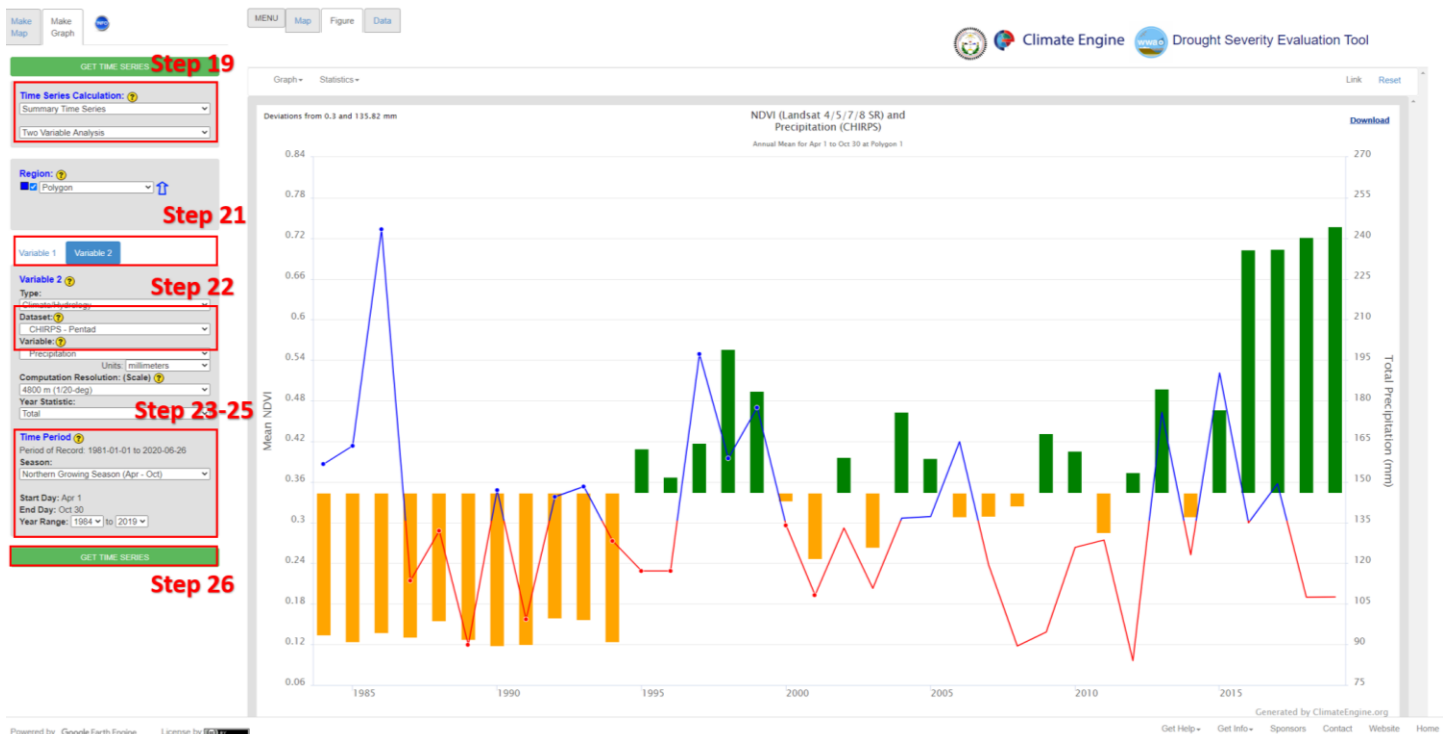
Figure 16. Precipitation and NDVI values are the two variables displayed in this time series. The CHIRPS-Pentad precipitation data is shown as the red and blue line, and the NDVI values are shown as the yellow and green bars. The irrigation of the center-pivot field is shown to have increased the NDVI values based on the precipitation data shown. Steps 19 through 26 are indicated in this figure for location guidance on DSET inputs.

19. Under **Time Series Calculation,** change the second drop-down to **Two Variable Analysis**
20. Don't make any changes to **Variable 1**.
21. Click on **Variable 2,** we are adding precipitation data to understand the influence of irrigation on the center-pivot irrigation field used in this example.
22. Under **Variable 2** for the **Dataset** section, select **CHIRPS – Pentad**, this dataset should be the default.
23. Under **Time Period**, for the first option select Entire Period of Record of Dataset, and for the second drop-down, select the **Northern Growing Seasons (Apr – Oct)** option.
24. Also, under the **Time Period** section change the **Year Range** to 1984 – 2019.
    a. However, keep in mind when making your own analysis like has been done in this exercise you will need to change the years to match your time period of interests. For example, if you are running through this exercise in the year 2021 the years for the **Year Range** would be 1984 – 2020.
25. **Check** to make sure the **Time Period** is the same for **Variable 1** and **Variable 2**.
26. Click on **Get Time Series** and wait for the map to load.

From the mid-1980s to mid-1990s there were peaks of precipitation above average that were not shown to increase NDVI values. The blue section of the precipitation data value line indicates above average whereas the red represents below average. It

would be assumed that an increase of precipitation would also indicate an increase of NDVI values. However, although we observe above average precipitation and increased NDVI values in the late 1990s, NDVI values remain higher than the values prior to 1995, even during periods of below-average precipitation. Therefore, it was be assumed that the consistently higher NDVI values came as a result of irrigation. This is particularly evident from 2007 – 2012, where precipitation was below average and NDVI values remained high.

Case Study 3 – Wildfires and Meadows

Introduction

On the Navajo Nation, meadow ecosystems are important for carbon and nitrogen storage, mediation of surface water flow, recharge ground water, sediment filtration and can also serve as natural refugia for local plant and animal species. Meadows depend on the supply of water through the water table but also rely on surface water from springs and seeps as well as precipitation. Therefore, they are highly vulnerable to changes in hydrological regimes associated with wildfires and climate change.

DSET can contribute to a better understanding of the impacts and changes to meadows. This particular case study will look at the conditions and responses to meadows in the Chuska Mountains pre- and post-Asaayi Lake Fire. The Asaayi Lake Fire occurred during the summer of 2014 and burned over 14,000 acres. Managers interested in understanding wildfire impacts can use satellite-derived vegetation indices such as the Burned Area Index (BAI) and the Normalized Difference Vegetation Index (NDVI) from Landsat and MODIS. These indices identify vegetation stress, loss, and regrowth in meadow ecosystems, such as those associated with the Asaayi Lake Fire in 2014 in the Chuska Mountains.

The BAI uses the near-infrared and shortwave infrared wavelengths to identify burned areas after the fire. NDVI is calculated using reflectance of vegetation in the red and near-infrared wavelengths. Calculations of NDVI result in a value between -1 and 1 with larger values representing greater density of green leaves. Using the NDVI values we can identify areas of stressed vegetation that may require a closer look at for restoration post-fire. NDVI can also be used to identify regions that may also be affected by activities such as overgrazing.

Components of Analysis
- Datasets: MODIS Terra Daily and Landsat 4/5/7/8 Surface Reflectance
- Variables: Burned Area Index (BAI) and Normalized Difference Vegetation Index (NDVI)

Objectives
- Identify the burn scar area in the Chuska Mountains caused by the Asaayi Lake Fire using the MODIS BAI.
- Develop a custom polygon to create a time series of the Asaayi Lake Fire burn scar to compare BAI and NDVI values pre- and post-fire to monitor meadow restoration.
- Create Landsat NDVI Percent Difference from Average value maps for the same time period on three separate years (2013, 2014, and 2019) to see the vegetation health pre- and post-fire.

Helpful Tips
- DSET is optimized for Google Chrome, please use Chrome.
- Faster networks are preferred when using DSET.

- Zoom to area of interest before submitting map requests to help with re-computing data.
- Resubmission and reset of DSET can help with fail requests that produce a server error.
- The figures included in this case study will help you navigate the DSET to locate the features associated with each step. It is suggested that you use the figure to ensure your selections are correct prior to completing each major step within the exercise.
- In the case study exercise, a color-coding system is used to help with navigation of the DSET features. For example, the section heading **Visualization Layer**, matches the color of the wording you will find on the DSET webpage.

Estimated Time for Completion for the Drought Case Study: **28 Minutes**

This exercise for Case Study 3: Climate Sensitivity of Meadows and Wildfire is broken up into three sections. The first section is Part 1: Asaayi Lake Fire Burned Area Index (BAI), the second is Part 2: BAI and NDVI Time Series, and the third section focuses on Part 3: NDVI Percent Difference from Average values for the Asaayi Lake Fire.

Part 1: Asaayi Lake Fire Burned Area Index (BAI)

- Objective: Identify the burn scar area in the Chuska Mountains caused by the Asaayi Lake Fire in the time period of May 10 to August 10, 2014 using the MODIS BAI variable.

Prior to the Asaayi Lake Fire this area in the Chuska Mountains had similar BAI values. Using the BAI, the burn scar created in 2014 will become apparent and stand out from the surrounding area.
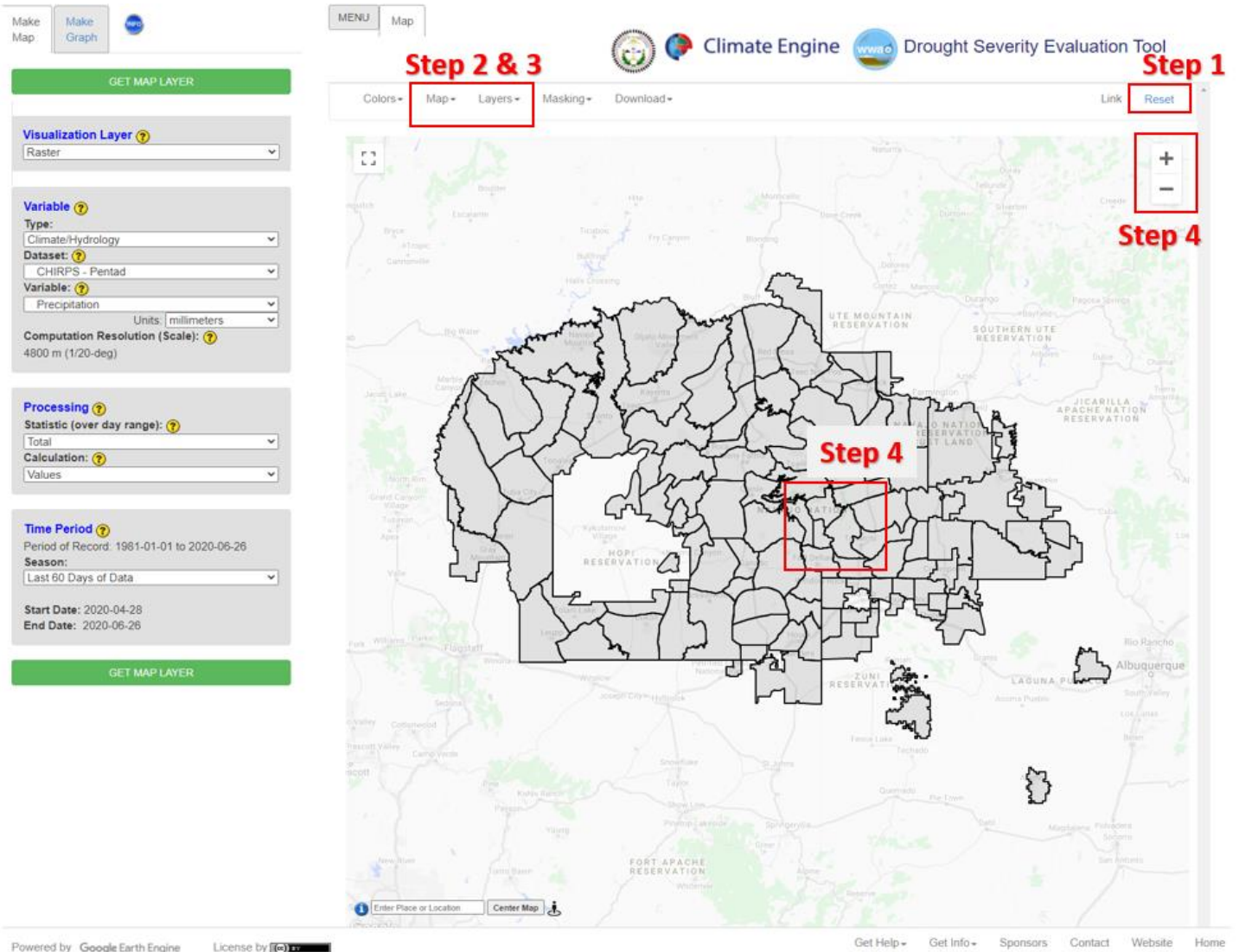
Figure 17. Steps 2 through 4 are displayed in the figure as a help to set DSET up to analyze the BAI values for the Asaayi Lake Fire burn scar in the Chuska Mountains.

1. Go to the DSET website using this link https://app.climateengine.org/dset.
    a. If you are conducting this Case Study for Wildfires and Climate Sensitivity of Meadows after working on previous case studies, at the top right corner of the map, click **Reset**.
2. Under the **Layers** tab along the top, ensure that the **Navajo Nation Chapters**

boundary is selected and displayed on the map.
   a. Note: The Navajo Nation Chapter boundaries should appear as the default.
3. Click on the **Map** tab along the top, which hosts the map options, and select the **Light Political Style map**.
4. Zoom into the Navajo Nation Chapter boundaries of Crystal, Mexican Springs, and Red Lake using the "+" sign along the top right. Bring the chapter boundaries center map.
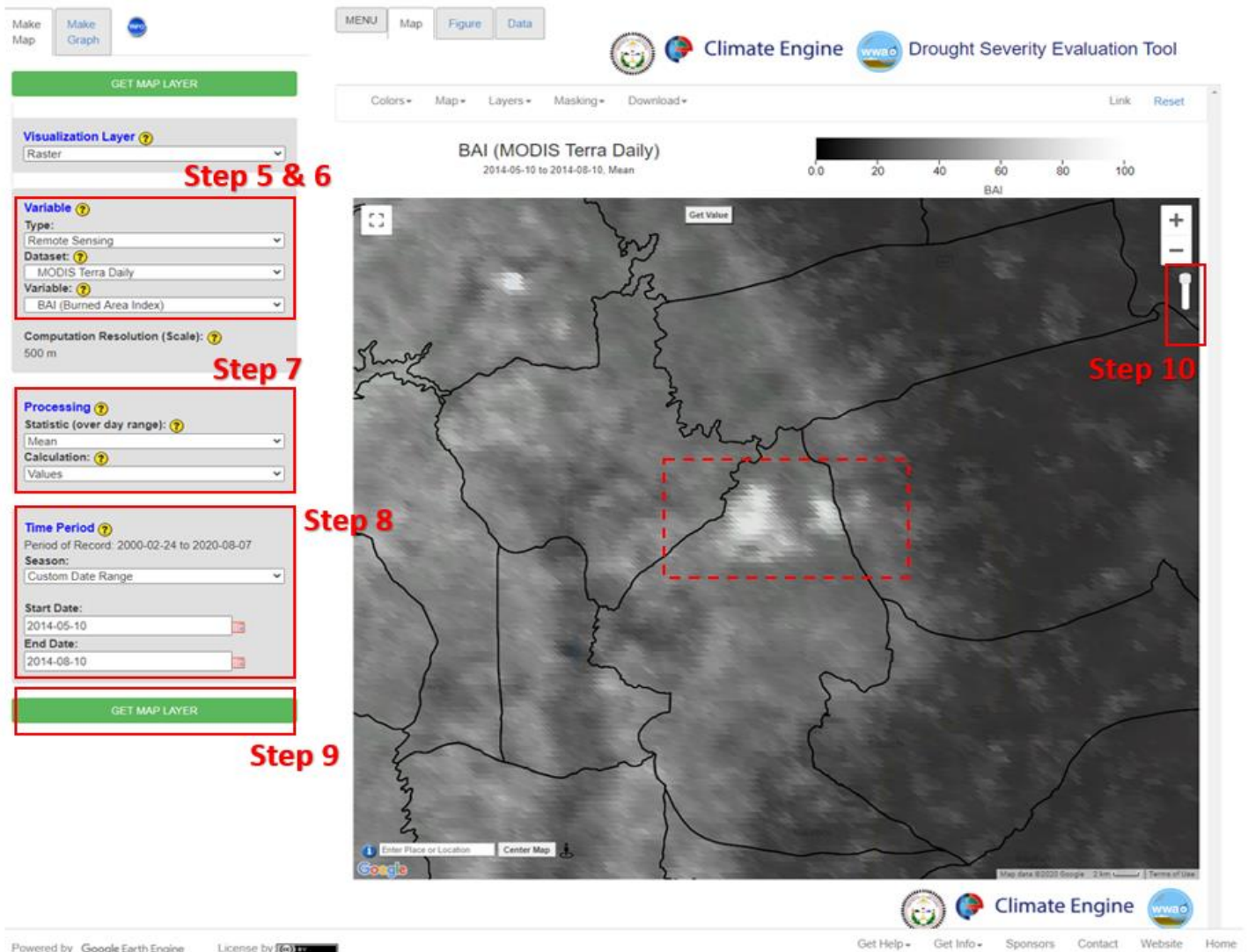   a. Reference the figure above to identify Crystal, Mexican Springs, and Red Lake Chapter boundaries.

Figure 18. The dashed red box indicates the area of the Asaayi Lake Fire of 2014 primarily located in the Mexican Springs chapter boundary. Steps 5 through 10 are displayed in the figure as a help locate the DSET features needed to complete the case study exercise.

5. Located on the Make Map panel on the left side of the webpage, under the **Variable** section select the **Type** parameter to be **Remote Sensing**, and change the **Dataset** parameter to **MODIS Terra Daily.**

6. For the **Variable** select **BAI (Burned Area Index)** located under the **Fire Indices section.**

7. Under the **Processing** section select the **Statistic (over day range)** to be **Mean**, leave the **Calculation** to be set on **Values**.

8. Under the **Time Period** section located on the same panel, select the **Custom Date Range.**
   a. Selecting **Custom Date Range** will change the **Start Date** and **End Date** options. For the **Start Date** enter **2014-05-10** and for the **End Date** enter **2014-08-10**.

9. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.

10. Once the processing is complete, the map will automatically display the data. The **transparency** may be decreased or enhanced to better see the results. On the top right of the map, move the opacity slider down to 70% Opaque.

11. The map will appear in greyscale, but you can change the colors to ensure that your burned area stands out.
12. Click on Colors, then under the Color options under Color Palette, use the drop-down to select Red-Blue Reversed under Divergent Maps. Click on **Update Map Layer**. Your map should look now look like Figure 19 (below).
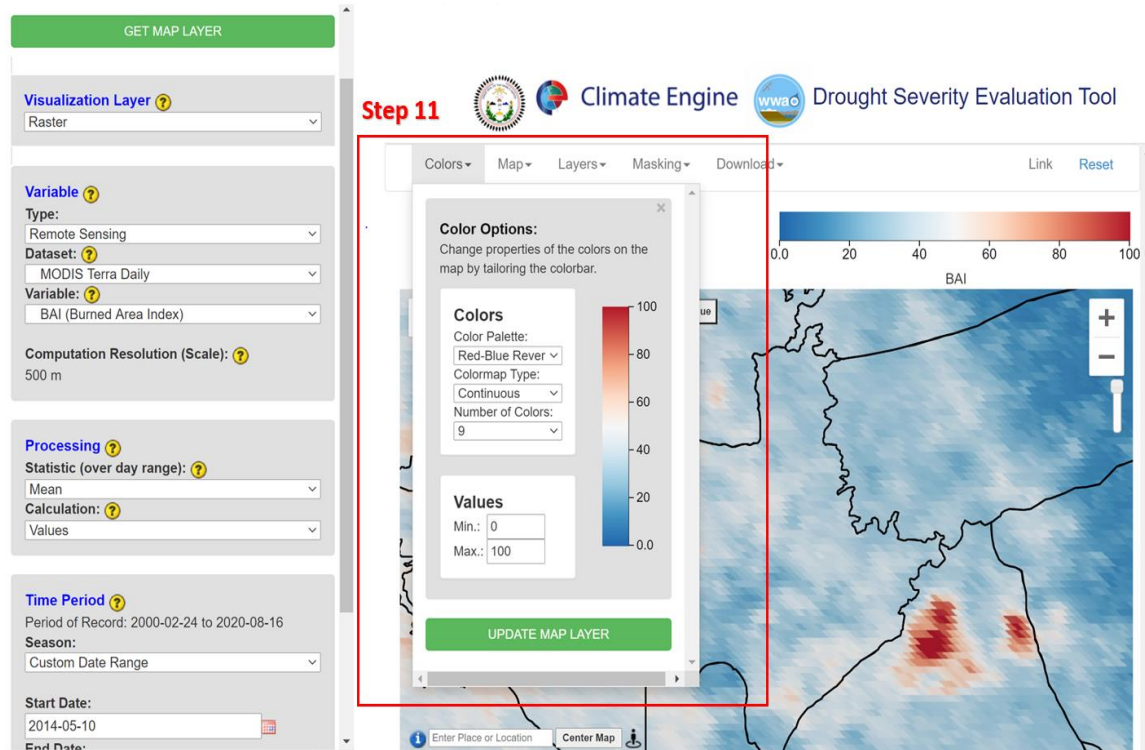

Figure 19. DSET color option feature to help in visualizing the data. Changing the color palette for the BAI values from black and white to red and blue shows the Asaayi Lake Fire clearly with the contrasting colors as described in Step 11.

13. When the process request is complete you will notice a cluster of high BAI values within the Mexican Springs Chapter boundaries that are highlighted with a dashed red box in Figure 18. These high values indicate the burned areas of the Asaayi Lake Fire.
14. **Do not Reset**. The same findings for the Asaayi Lake Fire BAI values will be used in Part 2 of this Case Study for Climate Sensitivity of Meadows and Wildfire.

Part 2: Time Series of Wildfire Indices

- Objective: Develop a custom polygon to create a time series of the Asaayi Lake Fire burn scare to compare BAI and NDVI values pre- and post-fire to monitor meadow restoration.

For this case study we are interested in the findings for the Asaayi Lake Fire. In Part 1 we identified the burn scar created in the 2014 fire. Now in Part 2 we will look further into

the data available for the Asaayi Lake Fire specifically using BAI and NDVI values to create a time series, which will include pre- and post-fire values.
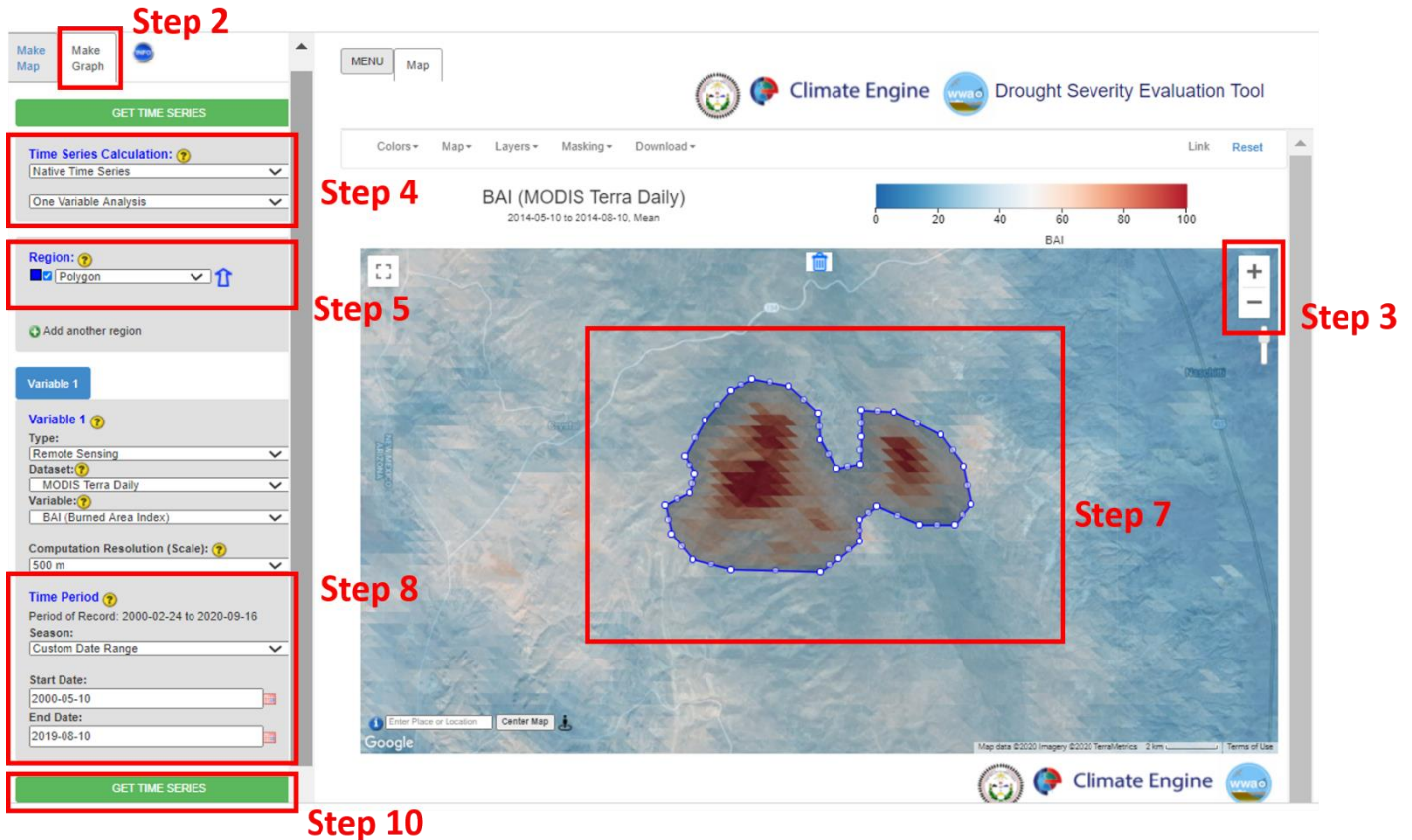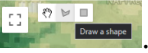

Figure 20. The custom polygon region developed and outlined for the Asaayi Lake Fire in the Mexican Springs chapter boundaries. Steps 2-10 are shown in this figure to provide support of locating DSET features to help complete this case study exercise.

1. Leave the **Make Map** panel as is from Part 1 of this Case Study.
2. Click on **Map Graph** tab beside the **Make Map** tab along the top left section of the DSET home screen.
3. Zoom into the Asaayi Lake Fire burn site located (Figure 18) in the Mexican Springs chapter boundary using the "+" sign along the top right.
4. Under **Time Series Calculation** change the first drop-down to **Summary Time Series**. Leave the second drop-down as **One Variable Analysis.**
5. Under **Region** select **Polygon** under the **Custom Polygon Regions**.
   a. Note that when you do this a pop-up will appear that describes **How to create a polygon how**. Reading through this pop-up will help in making a polygon.
6. Close the pop-up and click on the **Draw a Shape** icon in the top left of the map .
   a. Note that when you do this, a crosshair symbol will appear as your cursor.

7. Click on the outer edge of the Asaayi Lake Fire burn site to start to draw your polygon. Multiple clicks will be needed to enclose the burn site. Keep clicking all the way around the burn site. To close the polygon, click the first dot in the polygon.
    a. Once you have closed the custom burn site polygon the polygon will flicker and then will appear as a darker shade on the map.
    b. If you are unhappy with, the way the circle came out around the field you have the option to re-draw the crop circle. Use the delete button next to the Get Value button at the top of the map .
8. Once you are happy with the polygon, change the **Time Period** section to have the **Season** select the **Custom Day Range**
    a. Selecting **Custom Day Range** will change the **Start Day** and **End Day** options. For the **Start Day** select **May 10** and for the **End Day** select **August 10**. Select the **Year Range** to be from **2000** to **2019**.
9. The **Variable 1** section can be left as is with the selected **Type, Dataset, and Variable**.
10. Click on **Get Time Series** and wait for your figure to load.
    a. If your time series does not appear after a few minutes you may have to **Reset** DSET again and run the analysis. Due to the large time frame loading including many years of data this might create some issues.
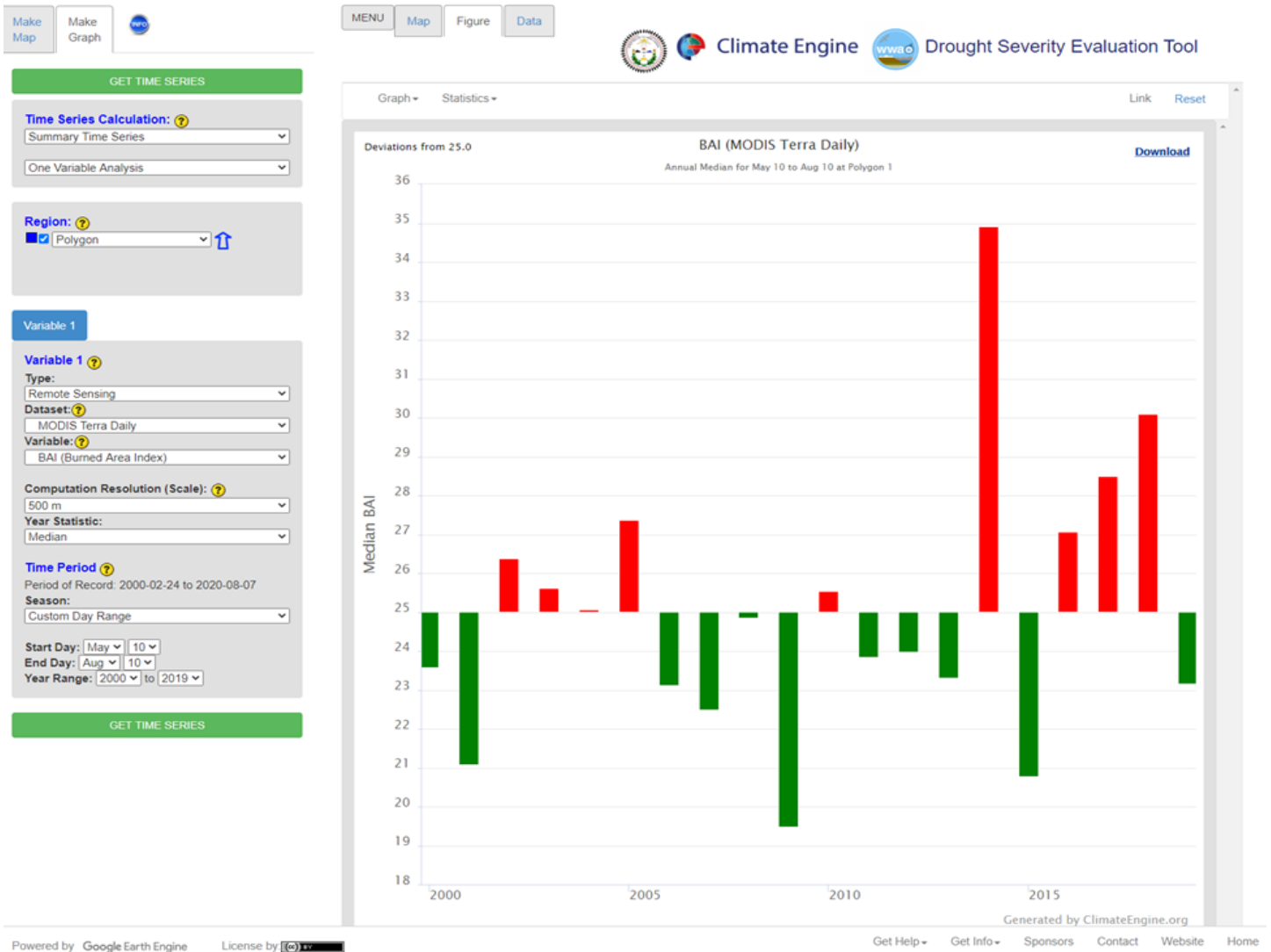
Figure 20. Time series created for the Asaayi Lake Fire BAI values pre- and post-fire for the time period of 2000 to 2019.

Looking at the time series created for BAI variable pre- and post-fire it is evident that in 2014 a land cover change occurred, that resulted in the largest increase in BAI values within the nineteen-year period of record (2000 - 2019). When a fire occurs, the BAI value increases due to a decrease in vegetation, therefore the burned area is emphasized by the post-fire images captured by MODIS. This time series (Figure 20) shows the BAI values created by the fire however, the inclusion of NDVI in this case study analysis will support the understanding of meadow restoration after a wildfire.
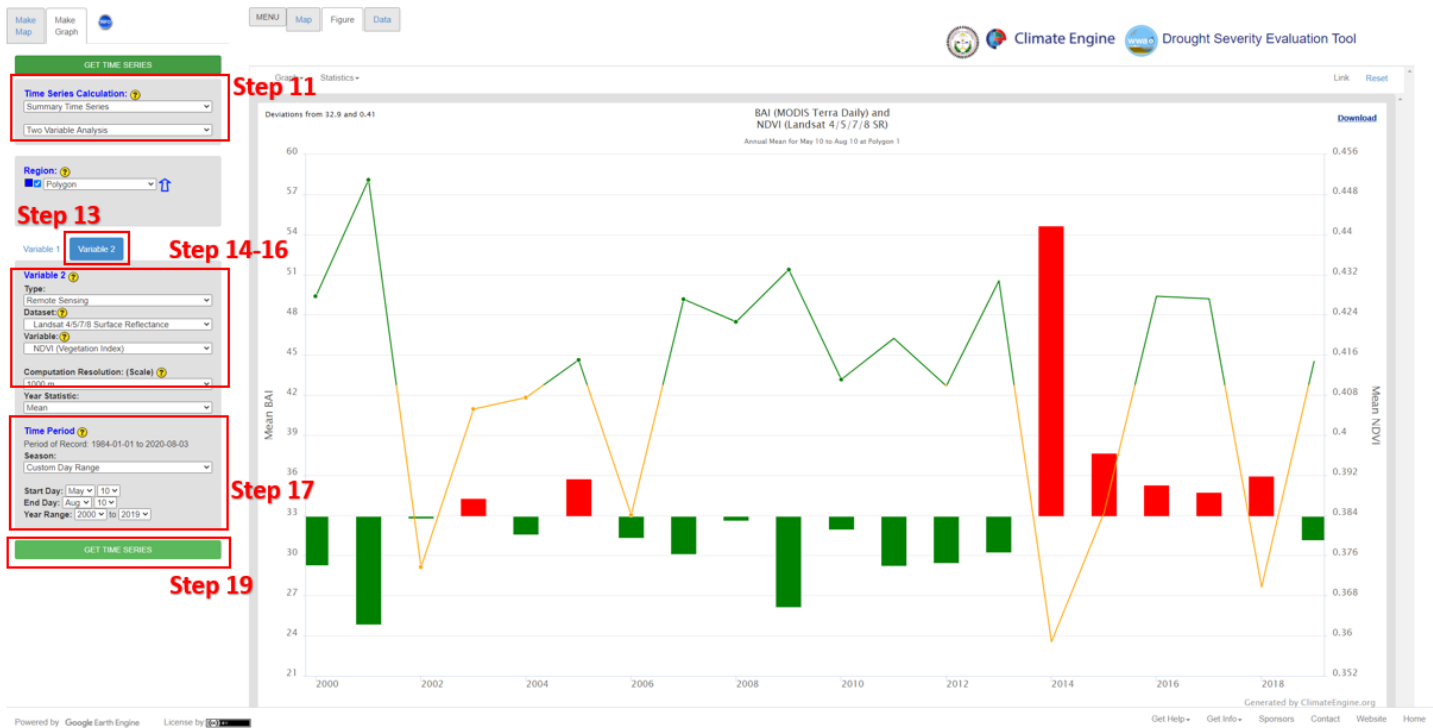
Figure 21. Time series created for the Asaayi Lake Fire mean BAI values compared to the mean NDIV values pre- and post-fire for the time period of 2000 to 2019. Steps 11-19 are also shown in this figure to provide support of locating DSET features to help complete this case study exercise.

11. Under **Time Series Calculation** change the second drop-down to **Two Variable Analysis.**
12. For **Variable 1** change the **Computation Resolution: (Scale)** to **1000 m.**
    a. Don't make any other changes to **Variable 1**. Note: you may need to change the Year Range to 2000 - 2019 if that does not remain the default from Part 1.
13. Click on **Variable 2,** we are adding NDVI data to understand the meadow restoration after a wildfire on the Asaayi Lake Fire burn site used in this example.
14. Under **Variable 2** for the **Type** select **Remote Sensing.** For the **Dataset** section, select **Landsat 4/5/7/8 Surface Reflectance**.
15. For the **Variable** select **NDVI (Vegetation Index)** located under the **Vegetation Indices section.**
16. Also, under **Variable 2** change the **Computation Resolution: (Scale)** to **1000 m.**
17. Under **Time Period**, select the **Custom Day Range.**
    a. Selecting **Custom Day Range** will change the **Start Day** and **End Day** options. For the **Start Day** select **May 10** and for the **End Day** select **August 10**. Select the **Year Range** to be from **2000 to 2019**.
18. **Check** to make sure the **Time Period** is the same for **Variable 1** and **Variable 2**.
19. Click on **Get Time Series** and wait for the map to graph.

Figure 21 shows us that before the Asaayi Lake Fire the NDVI values were fairly consistent in the years prior to the wildfire. After the 2014 wildfire, the BAI drastically

increases and NDVI value decreases, thus indicating vegetation loss during the wildfire. In the years following 2014, the BAI values decline and the NDVI values slowly increase, indicating some vegetation regrowth in the previously burned region. The NDVI values can also be visualized to examine these changes in the map interface. Part 3 aims to visualize the NDVI data pre- and post-fire.

Part 3: Percent Difference from Average values for the Asaayi Lake Fire

- Objective: Create Landsat NDVI Percent Difference from Average value maps for the same time period in three separate years (2013, 2014, and 2019) to see vegetation changes pre- and post-fire. This objective has the primary focus of visualizing the Landsat imagery.

The BAI values in Part 1 of this case study helped us identify the Asaayi Lake Fire burn scar. The primary goal of this section is to see the pre- and post-fire changes to vegetation density as identified by NDVI values for the years 2013, 2014, and 2019.
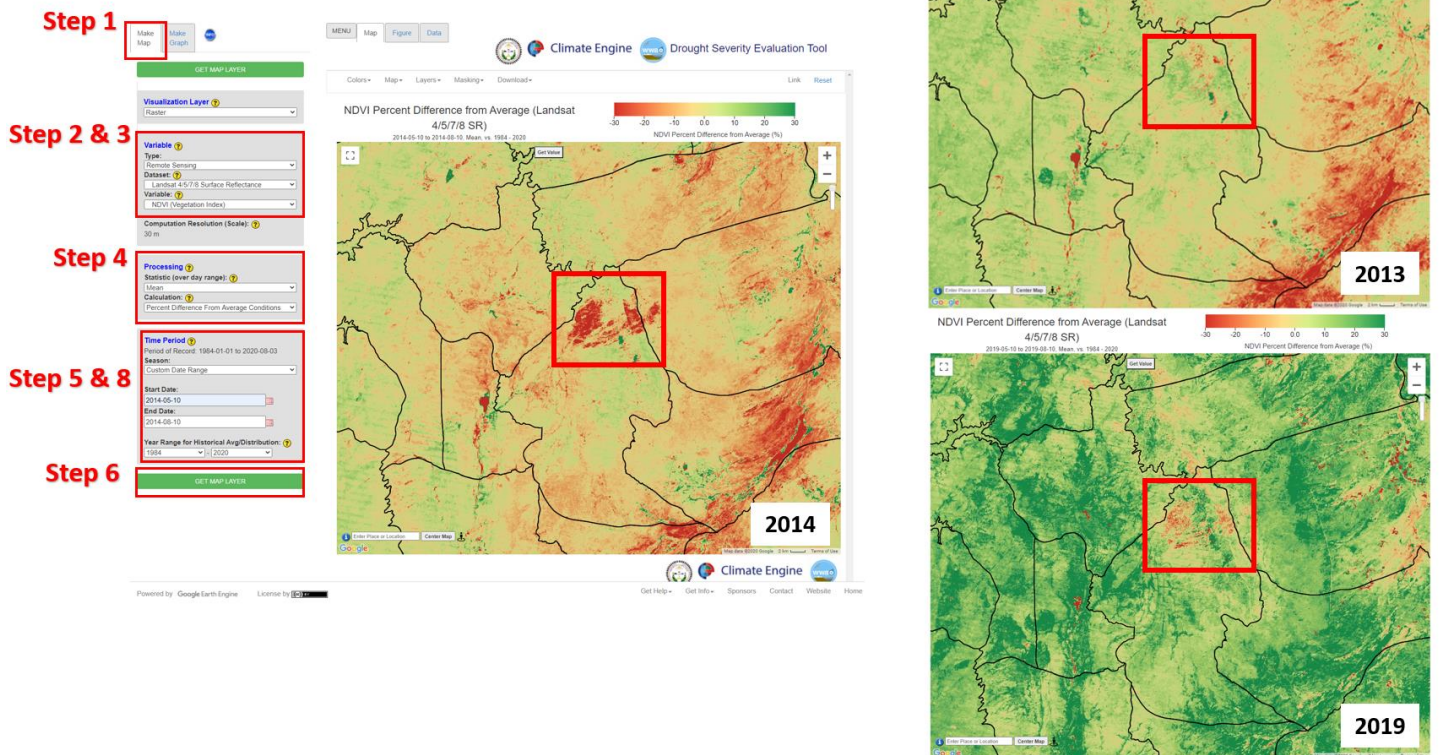

Figure 22. NDVI Percent Difference from Average values pre- and post-fire are presented for 2013 (before fire), 2014 (year fire occurred), and 2019 (five years after fire). From 2014 to 2019 based on the Landsat NDVI values it is evident that

restoration of the meadows in the burn site are recovering. Steps 1 through 8 are listed here to help complete Part 3 of this case study.

1. Leave the **Make Graph** panel and click on the **Make Map** tab along the top left section of the DSET home screen.
2. Located on the Make Map panel on the left side of the webpage, under the **Variable** section select the **Type** parameter to be **Remote Sensing**, and change the **Dataset** parameter to **Landsat 4/5/7/8 Surface Reflectance.**
3. For the **Variable** select **NDVI (Vegetation Index)** located under the **Vegetation Indices section.**
4. Under the **Processing** section select the **Statistic (over day range)** to be **Mean**, change the **Calculation** to **Percent Difference From Average Conditions**.
5. Under the **Time Period** section located on the same panel, leave the **Custom Date Range** as was entered for the **Make Graph** variables**.**
    a. Double check to make sure the **Custom Date Range** has the **Start Date** entered as **2014-05-10** and for the **End Date** entered as **2014-08-10**. The **Year Range for Historical Avg/Distribution** should be 1984 to 2020.
6. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.
7. The bright red NDVI values are within the area of the Asaayi Lake Fire burn site.
8. **Repeat Step 6** for years **2013** and **2019**. The map for 2013 will show the pre-wildfire NDVI values and the 2019 map will show the post-wildfire NDVI values.
    a. **Pre-wildfire Dates: Start Date** entered as **2013-05-10** and for the **End Date** entered as **2013-08-10**.
    b. **Post-wildfire Dates: Start Date** entered as **2019-05-10** and for the **End Date** entered as **2019-08-10**.

In this case study, the BAI and NDVI values indicate the impacts on landcover as a result of the Asaayi Lake Fire. The post- fire NDVI values reflect the restoration of the meadow and surrounding forest after the fire. The red values observed with the NDVI indicates less dense vegetation and the dark green values indicate denser vegetation cover. The red boxes on the maps are used to highlight the burn scar created in 2014. Then in 2019, the darker green regions indicate vegetation regrowth and restoration of the meadow to conditions similar to those prior to the wildfire.

Case Study 4 -Snowpack Analysis

Introduction

Snowpack accumulation in mountainous regions is important for water resources. Snowpack on the Navajo Nation melts into streams to support vegetation and wildlife. Given the importance of precipitation in this semi-arid to arid landscape, drought conditions and a changing climate are a concern to the Navajo Nation. One impact of declines in precipitation and long-term drought is desertification. Desertification is a result of land degradation or destruction of topsoil where fertile landcover is destroyed by human activity (e.g. overgrazing) and natural destruction (e.g. drought). When a vast area of desertification occurs, resultant dust deposited on snow can increase snowpack melting rates. As a prominent snow accumulation area on the Navajo Nation, the Chuska Mountains will provide a meaningful analysis for snowpack development during the winter months.

There are two snow measurements that will be included in this analysis to understand the snowpack trends on the Navajo Nation. The first snow measurement is the Snow Water Equivalent (SWE), which is a function of the snow depth and the grain size. Ultimately, it is a measurement of the total volume of liquid water contained within the snow. Most often, snow depth is of interest to measure winter precipitation. However, the SWE value is needed to calculate the snow depth. The equation for snow depth is (SWE)/(Density) = Snow Depth. The density of snow is increased by packing, melting, gravitation, and recrystallizing. The Normalized Difference Snow Index (NDSI) provides the estimation of the snow covered area. Snow is highly reflective in visible wavelengths and has low reflectance in the shortwave infrared wavelengths, thus this ratio can be used to map snow and differentiate snow from clouds. NDSI values are used to estimate snow cover area, values of ~0.5 to 1 indicate snow cover.

Components of Analysis
- Datasets: Sentinel 2 Top Of Atmosphere and SNODAS - Daily
- Variables: Normalized Difference Snow Index (NDSI) and Snow Water Equivalent (SWE)

Objectives
- Use the Sentinel 2 TOA dataset to create a map of the NDSI values for the Navajo Nation for the past 16 years covering the years 2004 – 2020.
- Use the Sentinel 2 TOA dataset to create a map of the NDSI values for the Chuska Mountains for the Last December, January, February (Last DJF) time period (2019 – 2020).
- Create a time series of SWE and NDSI values for Chuska Mountains for the Last December, January, February (DJF) time period (2019 – 2020).

Helpful Tips
- DSET is optimized for Google Chrome, please use Chrome.
- Faster networks are preferred when using DSET.
- Zoom to area of interest before submitting map requests to help with re-computing data.
- Resubmission and reset of DSET can help with fail requests that produce a server error.
- The figures included in this case study will help you navigate the DSET to locate the features associated with each step. It is suggested that you use the figure to ensure your selections are correct prior to completing each major step within the exercise.
- In the case study exercise, a color-coding system is used to help with navigation of the DSET features. For example, the section heading **Visualization Layer**, matches the color of the wording you will find on the DSET webpage.

Estimated Time for Completion for the Drought Case Study: **16 Minutes**

This exercise for Case Study 4: Snowpack is broken up into two parts. The first part will specifically focus on NDSI values for the Navajo Nation and the Chuska Mountains for a 16-year time period, and then an evaluation of NDSI values for the Last DJF. The second part of this case study will focus on developing a time series for multiple variables for the Last DJF within the Chuska Mountains. Part 2 of this case study will center around the interpretation of SWE and NDSI values.

Part 1: Snowpack Analysis

- Objective: Develop an NDSI analysis for short term and long-term snowpack. A time period of 16-years will show the NDSI values for the entire Navajo Nation. A three-month time period will be used to evaluate NDSI values for the Chuska Mountains.

The intensity of the snowpack created by winter snowstorms on the Navajo Nation will indicate the impact wintertime precipitation can have on drought conditions. The Chuska Mountains are a single mountain range that has the highest rates of snowpack accumulation on the Navajo Nation.
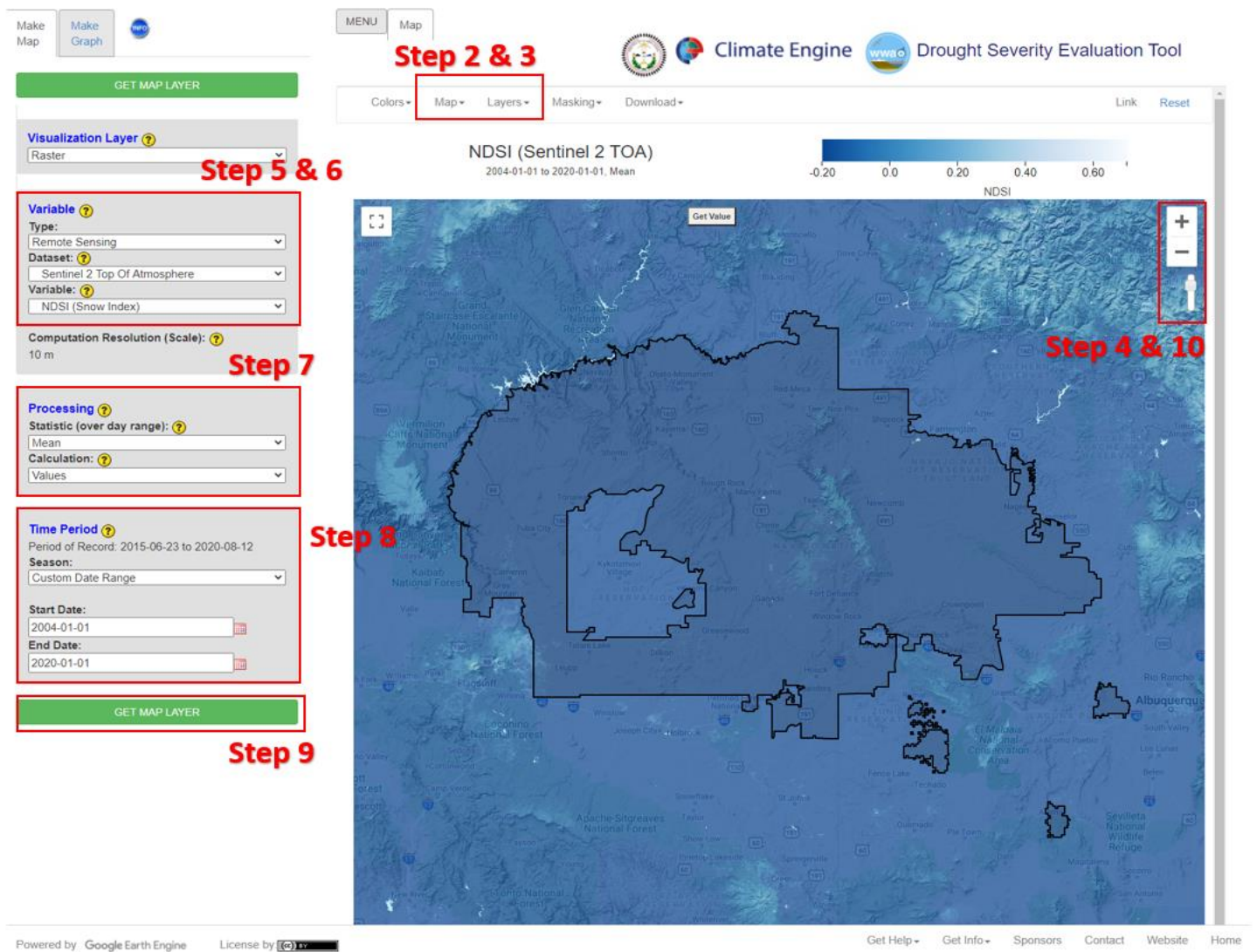

Figure 23. NDSI values using the Sentinel 2 TOA dataset are displayed in this figure for the entire Navajo Nation from 2004 - 2020. The NDSI values appear to show extremely low snow levels. The mountain ranges on the Navajo Nation appear to have slightly increased NDSI value. Guidance for DSET feature location are included for Steps 2-10.

1. Go to the DSET website using this link https://app.climateengine.org/dset.
   a. If you are conducting this Case Study for Snowpack Analysis after working on previous case studies, at the top right corner of the map, click **Reset**.
2. Under the **Layers** tab along the top, select the **Navajo Nation Boundary** and deselect the Navajo Nation Chapters.
   a. Note: The Navajo Nation Chapter boundaries will appear as the default, but for this exercise we will be looking at the Navajo Nation as a whole.
3. Click on the **Map** tab along the top, which hosts the map options, and select the **Terrain map**.
4. Zoom into the **Navajo Nation Boundary** using the "+" sign along the top right. Bring the reservation boundary to center map.
5. Located on the Make Map panel on the left side of the webpage, under the **Variable** section select the **Type** parameter to be **Remote Sensing**, and change the **Dataset** parameter to **Sentinel 2 Top Of Atmosphere.**
6. For the **Variable** select **NDSI (Snow Index)** located under the **Snow Indices section.**
7. Under the **Processing** section select the **Statistic (over day range)** to be **Mean**, leave the **Calculation** to be set on **Values**.
8. Under the **Time Period** section located on the same panel, select the **Custom Date Range.**
   a. Selecting **Custom Date Range** will change the **Start Date** and **End Date** options. For the **Start Date** enter **2004-01-01** and for the **End Date** enter **2020-01-01**.
9. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.
10. Once the processing is complete, the map will automatically display the data. The **transparency** may be decreased or enhanced to better see the results. On

   the top right of the map, move the opacity slider ![70% Opaque] down to 70% Opaque.
11. Your map should look like Figure 23 (above).

The NDSI values that indicate the estimation of snow covered area for the past 16-years have been minimal. The majority of the Navajo Nation has values of less than 0.20 on the NDSI scale (Figure 23). The minimal snow cover estimation provided through the NDSI values indicate the consistent drought conditions impacting precipitation activity year-round. In Figure 23, the Chuska Mountains shows the greatest NDSI values over the

16-year period. The next few steps will look deeper into the NDSI specially for the Chuska Mountains.
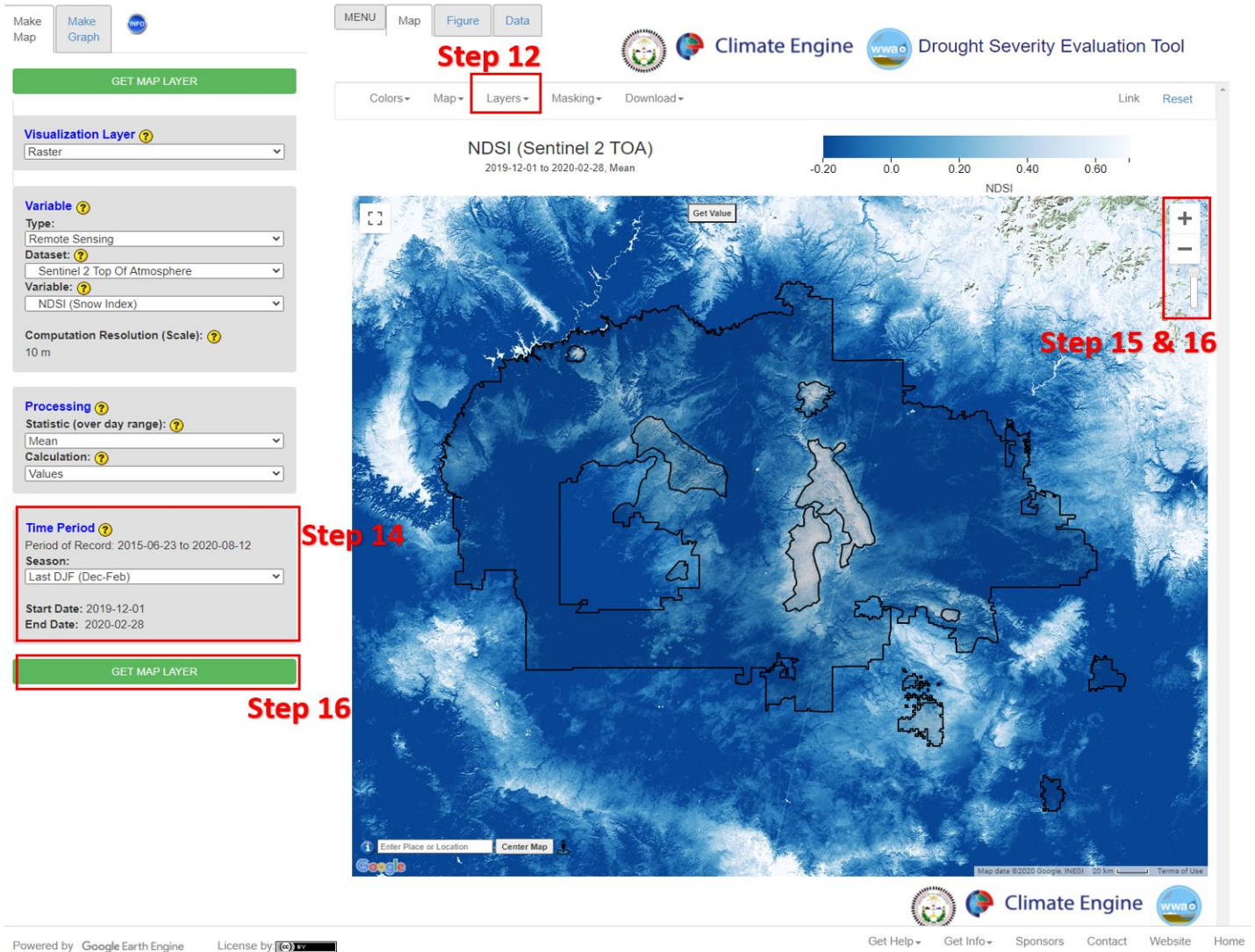

Figure 24. NDSI values for the Last DJF (2019-2020) for the Navajo Nation. The red box in the middle of the Navajo Nation encompasses the Chuska Mountains. This region generally has the highest NDSI values. Included on this figure are Steps 12 -16 that locate DSET features to help navigate the tool to complete this case study.

12. Under the **Layers** tab along the top, the **Navajo Nation Boundary** should already be on your map now add the **Navajo Nation Mountain Ranges** to be displayed on the map.
13. Leave all the input parameters the same as you entered for Steps 1-7.
14. Under the **Time Period** section located on the same panel, select the **Last DJF (Dec-Feb).**
    a. Selecting the **Last DJF (Dec-Feb)** will change the **Start Date** to **2019-12-01** and end date to **2020-02-28**. Depending on the year of analysis the year will change. For example, if this exercise is done in the year 2022, the Last

DJF (Dec-Feb) will have a start date of 2021-12-01 and an End Date of 2022-02-28.

15. Change the **transparency** to enhance the value color scheme to better see the results. On the top right of the map, move the opacity slider up to 100% Opaque.

16. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.

17. Zoom into the **Navajo Nation Mountain Ranges** for **Chuska Mountain** using the "+" sign along the top right. Bring the Chuska Mountain boundary to center map.
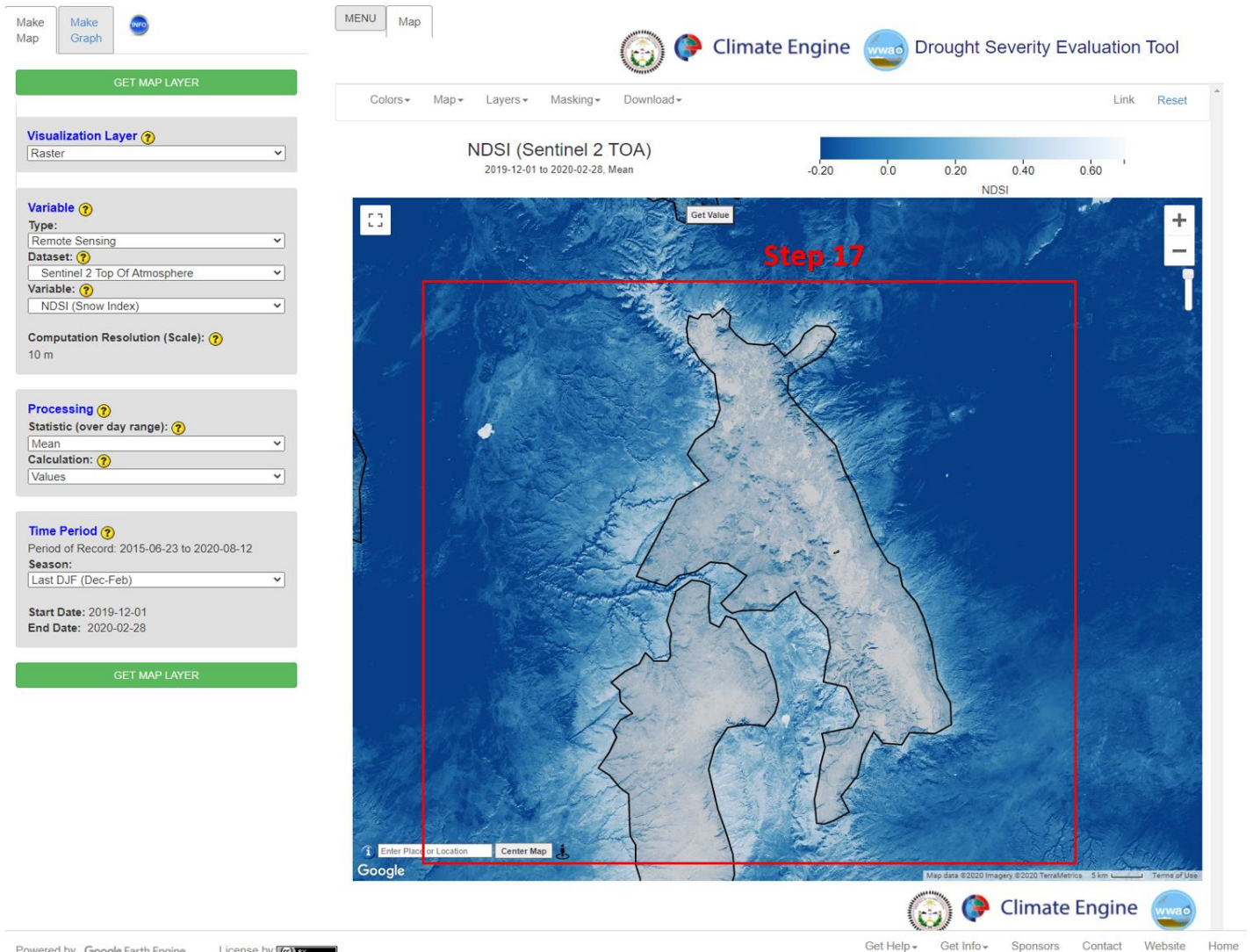
Figure 25. Following the instructions of Step 17 the Chuska mountain range brought to center map.

18. **Do not Reset**. We will use the findings from Case Study 3: Wildfires and Climate Sensitivity of Meadows, which examined BAI values with the Asaayii Lake Fire, in this next section.

Part 2: Chuska Mountain Snowpack Time Series

- Objective: Create a time series of SWE and NDSI values for Chuska Mountains for the Last December, January, February (DJF) time period (2019 – 2020).

This section of the case study is intended to look at multiple variables for snowpack over a short time period for the Chuska Mountains. The Chuska Mountains remains a region

that receives the majority of the total winter snowpack. SWE and NDSI will indicate patterns of snow density and cover.
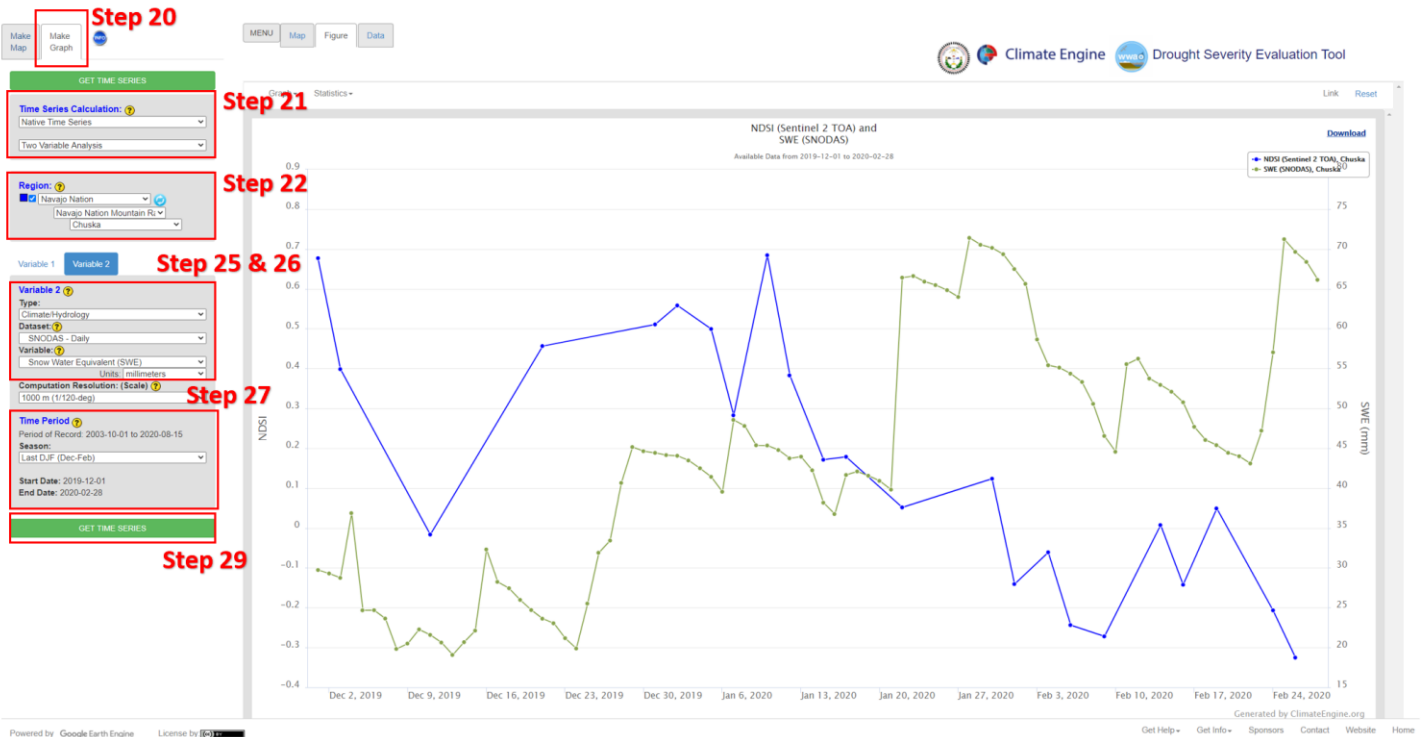

Figure 26. SWE and NDSI value comparison for the Last DFJ for the Chuska Mountain. NDSI values in this figure represent the snow cover and SWE indicates the volume of water stored in the snowpack. Steps 20-29 are included on this figure to help navigate to the DSET features to complete this case study.

19. Leave the **Make Map** panel as is from Part 1 of this Case Study.
20. Click on **Map Graph** tab beside the **Make Map** tab along the top left section of the DSET home screen.
21. Under **Time Series Calculation** leave the first drop-down on **Native Time Series**. Change the second drop-down as **Two Variable Analysis.**
22. Under **Region** select **Navajo Nation**, under the second drop-down select the **Navajo Nation Mountain Ranges**, and finally under the third drop-down select **Chuska**.
23. The **Variable 1** section can be left as is with the selected **Type, Dataset, and Variable**.
24. Click on **Variable 2**, we are adding Snow Water Equivalent (SWE) data to understand the snowpack on the Chuska Mountain.
25. Under **Variable 2** for the **Type** select **Climate/Hydrology.** For the **Dataset** section, select **SNODAS - Daily**.
26. For the **Variable** select **Snow Water Equivalent (SWE)** and leave the units in millimeters.
27. Under the **Time Period** section located on the same panel, select the **Last DJF (Dec-Feb).**

a. Selecting the **Last DJF (Dec-Feb)** will change the **Start Date** to **2019-12-01** and end date to **2020-02-28**. Depending on the year of analysis the year will change. For example, if this exercise is done in the year 2022, the Last DJF (Dec-Feb) will have a start date of 2021-12-01 and an End Date of 2022-02-28.

28. **Check** to make sure the **Time Period** is the same for **Variable 1** and **Variable 2**.
29. Click on **Get Time Series** and wait for the map to graph.
   a. If your time series does not appear after a few minutes you may have to **Reset** DSET again and run the analysis. Due to the large time frame loading including many years of data this might create some issues.

Figure 26 displays the SWE (in green) and NDSI (in blue) comparisons for the Last DJF. Generally, the two variables display similar patterns of snowpack development over the Chuska Mountains. Early in December 2019, the NDSI values are found to be higher than the SWE values. This higher NDSI values at this time indicates snow covered area. A higher snow-covered area is interpreted as fresh snow fall and the growing intensity of the winter season. By mid-January 2020, the SWE increases, indicating increased accumulation of snowpack during the coldest portion of the winter. This displays the progression of snowfall and snowpack accumulation throughout the winter season where SWE is also increasing after multiple winter storms.

Additional Exercise - Downloading DSET Data

This section of the user guide is intended to help you take any analysis you run in DSET and download data generated in the tool. The download features in DSET are highlighted in the bright red boxes in the next few figures shown in this section.
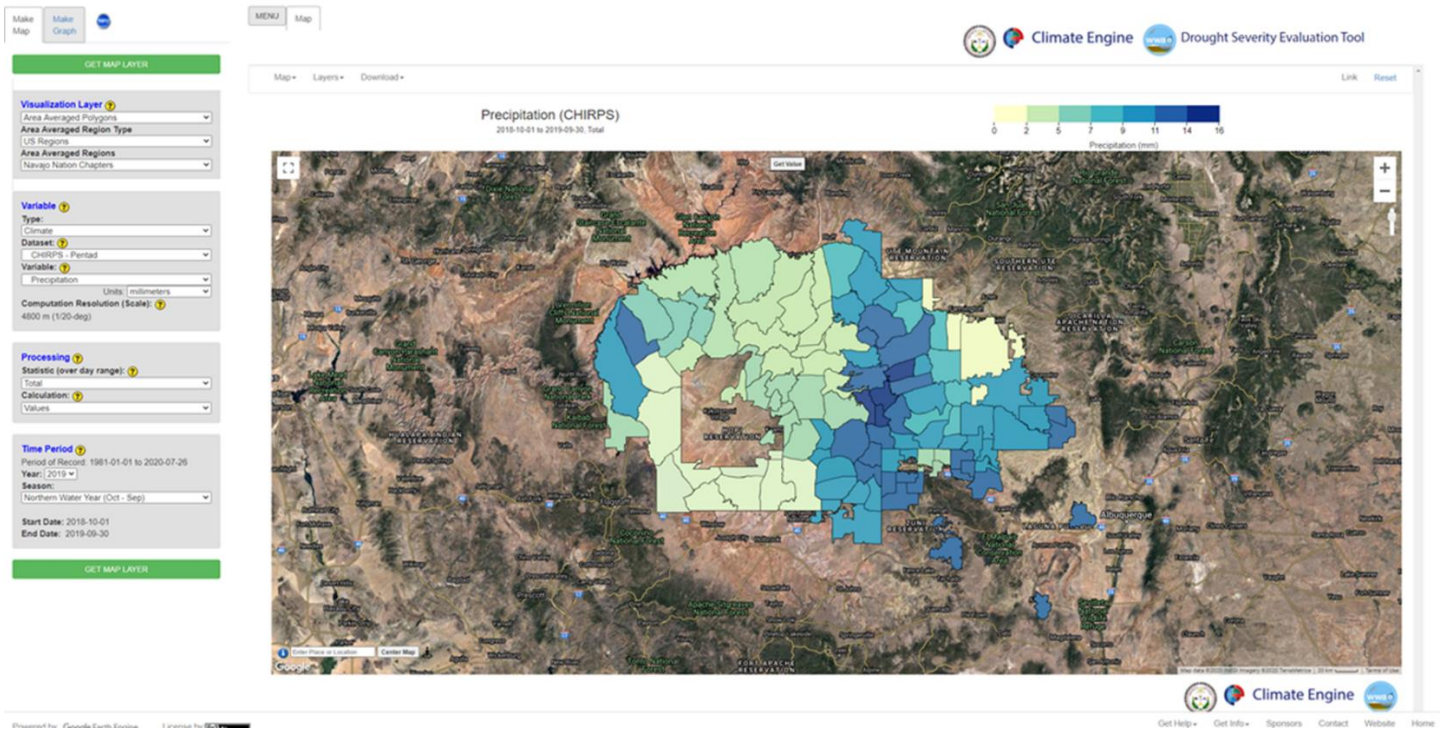
Part 1: Download Map Data

Figure 27. Screenshot of the DSET home screen base map and a CHIRPS precipitation analysis generated.

Figure 27 shows a screenshot of DSET after a CHIRPS precipitation Area Averaged Polygons analysis generated for the Navajo Nation Chapters for the 2018 – 2019 Northern Water Year (Oct – Sept). This is an example of the type of data you can download.

You can download many different types of data, if you'd like to download the example show above here are the parameters:

1. Go to the DSET website using this link https://app.climateengine.org/dset.
2. Located on the Make Map panel on the left side of the webpage, under the **Visualization Layer** select Area Averaged Polygons the top, select the
3. Under the **Variable** section keep the default selected (Type: Climate, Dataset: CHIRPS-Pentad, Variable: Precipitation, Units: millimeters)
4. Under the **Processing** section keep the default selected (Statistic (over day range): Mean, Calculation: Values)
5. Under the **Time Period** section keep the default selected (Year: 2019, Season:

Northern Water Year (Oct – Sept)

6. Click on **Get Map Layer**, wait for the map to load. The loading of the map may take a few minutes for the request to process.
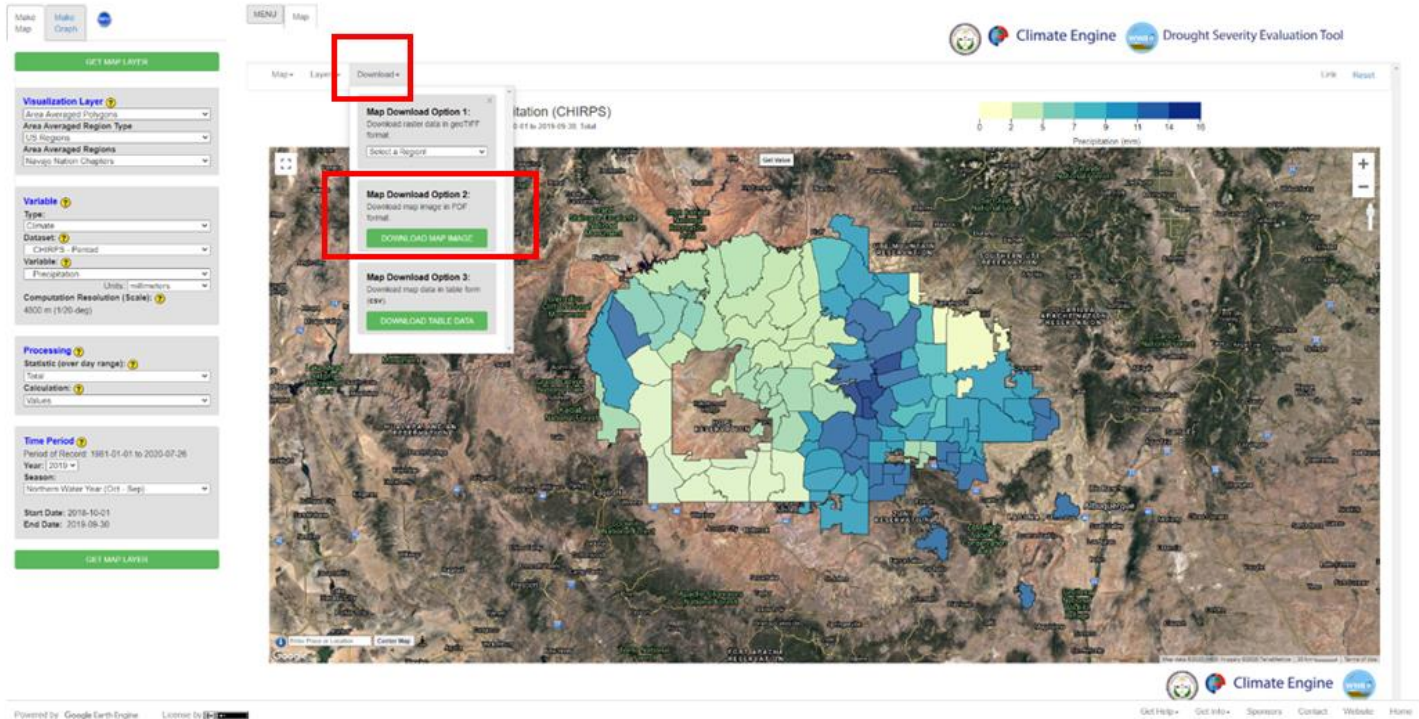

Figure 28. Three download options for this analysis is available and highlighted in the red box.

Figure 28 shows us where we can download information when we are in the **Make Map** function for DSET. The small red box is highlighting the **Download** tab that you will always find when you are in the **Make Map** function on the top left-hand side of the base map. When you **click** on this **Download** tab you will be given three options: **Map Download Option 1, Map Download Option 2, and Map Download Option 3.**

Map Download Option 1 allows you **to draw a Rectangular Region** on the base map and download the raster data as a **geoTIFF**.

Map Download Option 2 allows you **to download the entire base map** shown for the analysis. The downloaded map is **saved as a PDF**.

Map Download Option 3 allows you **to download the map data in a table format** that is **saved in the form of a csv**.
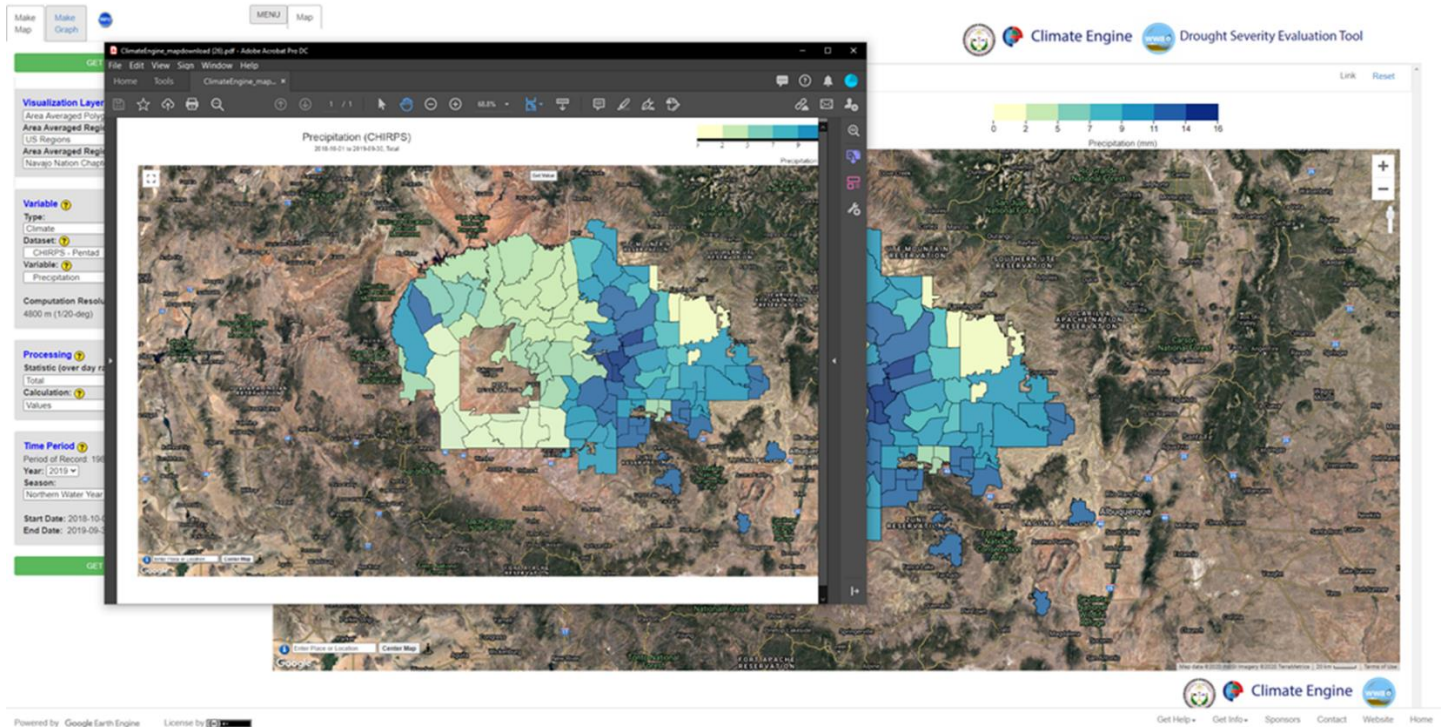
Figure 29. Map Download Option 2 allows you do download data in the format of a PDF.

Figure 29 shows the results of downloading data with **Map Download Option 2** in a PDF format. When you select to download the map image with **Map Download Option 2** a PDF will automatically appear on your desktop.
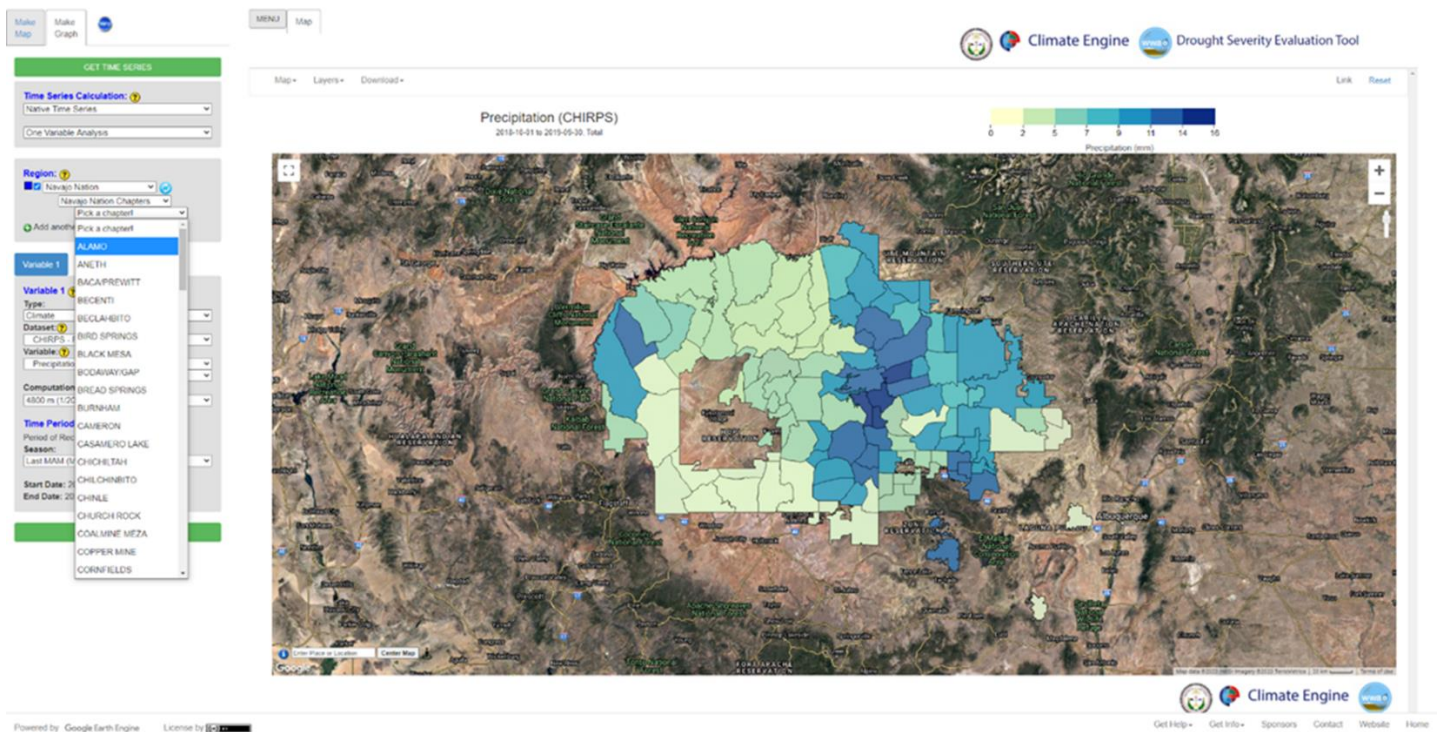
Figure 30. When in the Make Graph function of DSET more specific information in the analysis may be required. In this example we will focus on data CHIRPS precipitation data for the Alamo Chapter.

We will now walk through what you can be expected to find when you are in the **Make Graph** function of DSET and want **to download data for a Time Series**. In the Make Graph function, you may be asked to narrow down the area of focus for your analysis to generate data. In this example, we will download time series data from the Alamo Chapter.

7. Click on **Map Graph** tab beside the **Make Map** tab along the top left section of the DSET home screen.
8. Under **Region** select **Navajo Nation**, under the second drop-down select the **Navajo Nation Chapters**, and finally under the third drop-down select **Alamo**.
9. The **Variable 1** section can be left as is with the selected (Type: Climate, Dataset: CHIRPS-Pentad, and Variable: Precipitation).
10. Under the **Time Period** section located on the same panel, select the **Last MAM (Mar – May)**
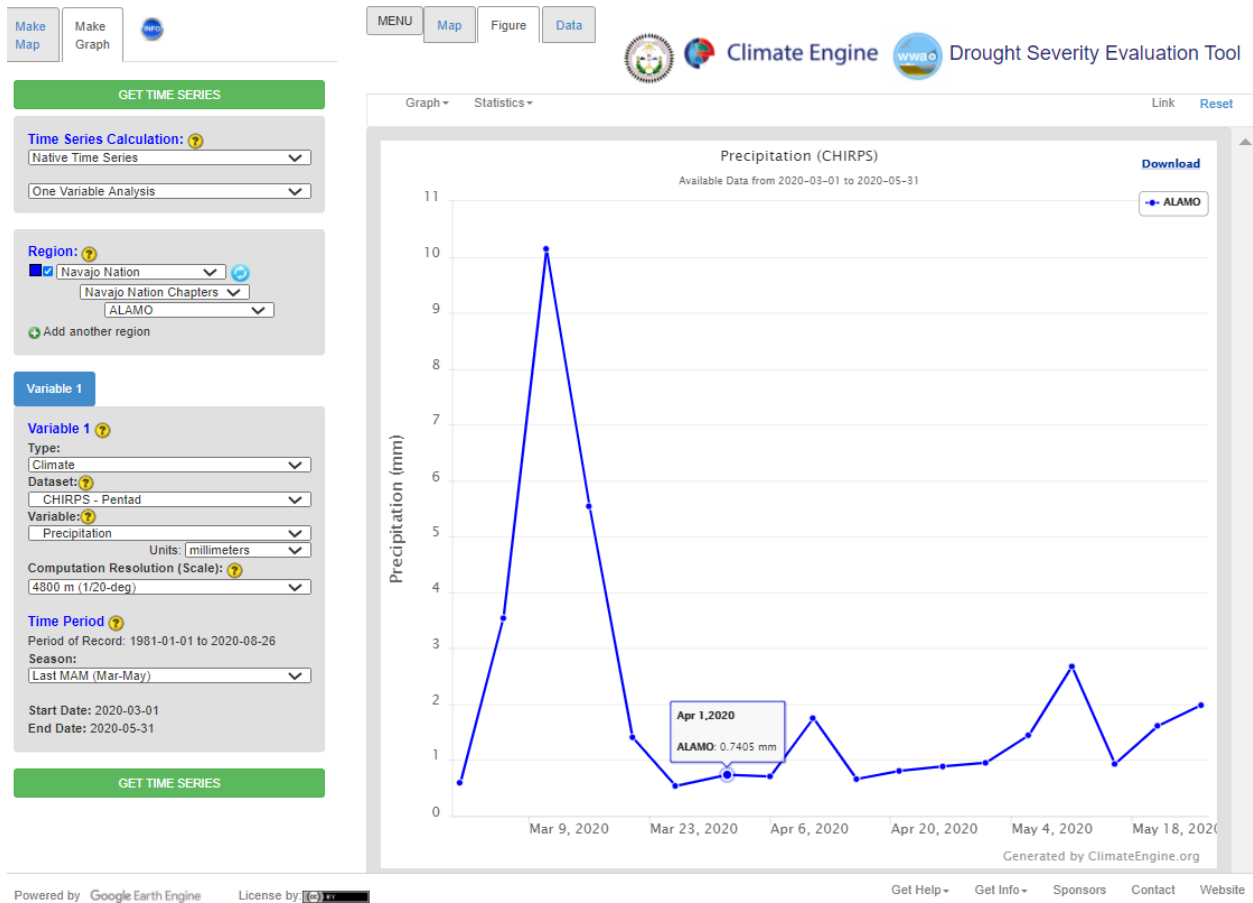11. Click on **Get Time Series** and wait for the figure to load

Figure 31. Alamo Chapter boundary displayed in the Make Graph function that will be used to create a Time Series for this example to demonstrate how to download data.
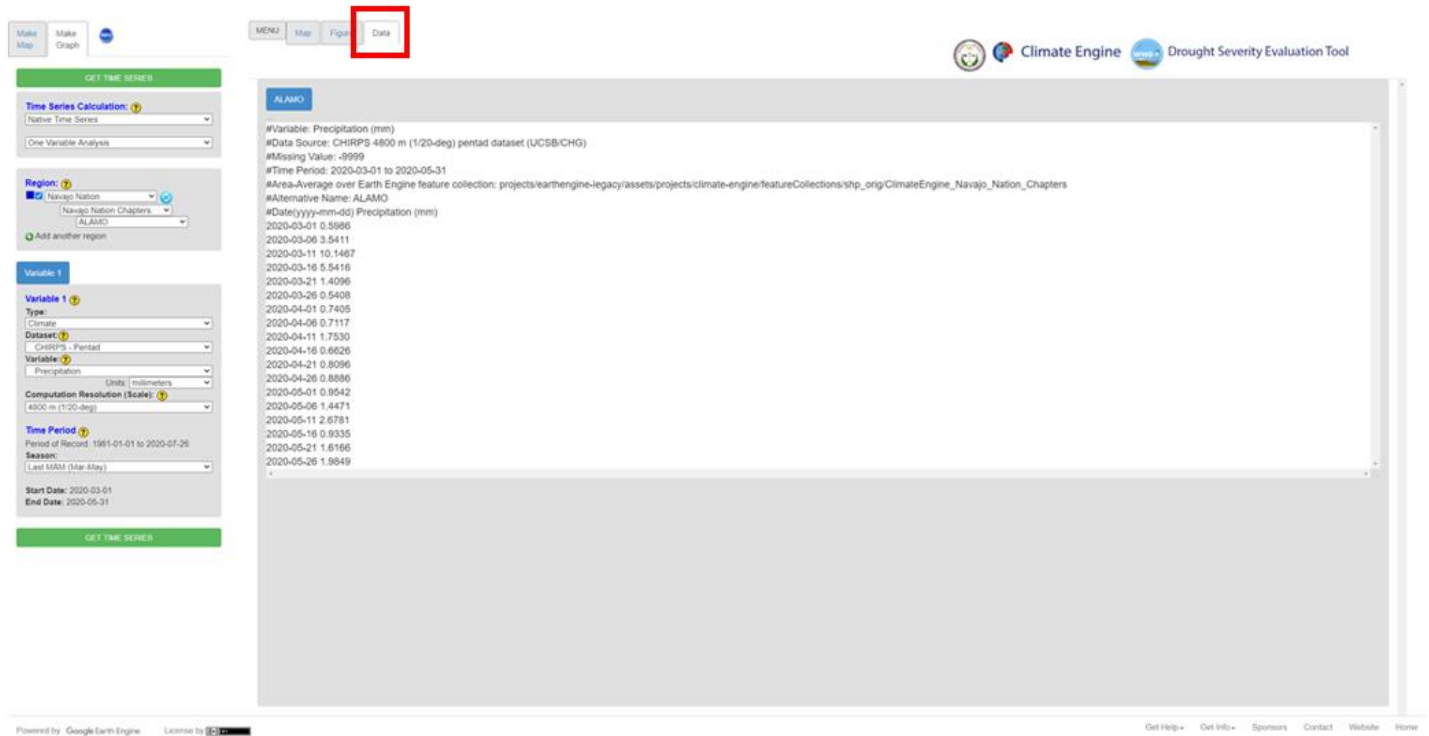
Figure 32. Data in the Make Graph function can be seen with the Data tab highlighted in the red box.

12. Click on the **Data tab** along the top panel
    a. The Data tab is highlighted in the red box in Figure 32. **By clicking on the Data tab,** you will be able to see raw data generated using DSET for your study area. In this example the data displayed in Figure 6 is the data we generated CHIRPS precipitation values for the **Last MAM (Mar – May)** in the Alamo Chapter.
13. Click back on the **Figure tab** along the top panel
14. Click on the **Download** option along the top right
    a. The six options down download data are highlighted in the red box shown in Figure 33. The options are: **Download PNG image, Download JPEG image, Download PDF Document, Download SVG vector image, Download CSV, and Download XLS.**
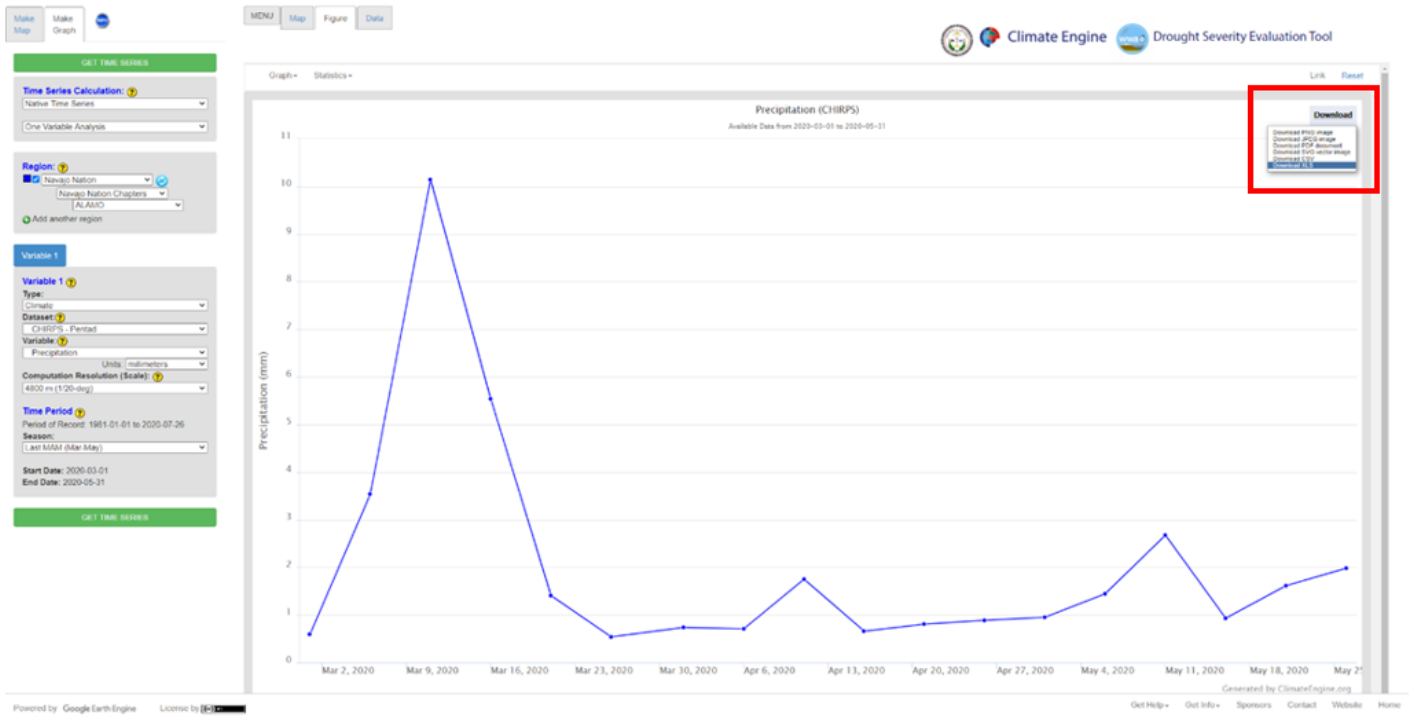
Figure 33. Alamo Chapter CHIRPS precipitation data displayed as a figure for the Time Series data generated. The download options for the Time Series data is highlighted in the red box.

15. Choose the **Download XLS** option
    a. You may receive a warning message when you open the file that reads: "*The file format and extension of 'ClimateEngine.xls' don't match. The file could be corrupted or unsafe. Unless you trust its source, don't open it. Do you want to open it anyway?*" If you have downloaded this data from DSET **click Yes** to open the file.
16. The final helpful option in DSET is the **Share Results** function. Click on the **Link** option located on the top right-hand side of the base map to open up the **Share Results option**. Generating a URL link will share your last successful Map result in DSET.
    a. The Link will provide access to the data selections and the map you have previously generated, which is helpful for sharing results with colleagues. You have **two options** when creating your link that is to create a **Short of Long Link**. You can also **Open Link in New Window** to see what the Map will look like when other people open up your link.
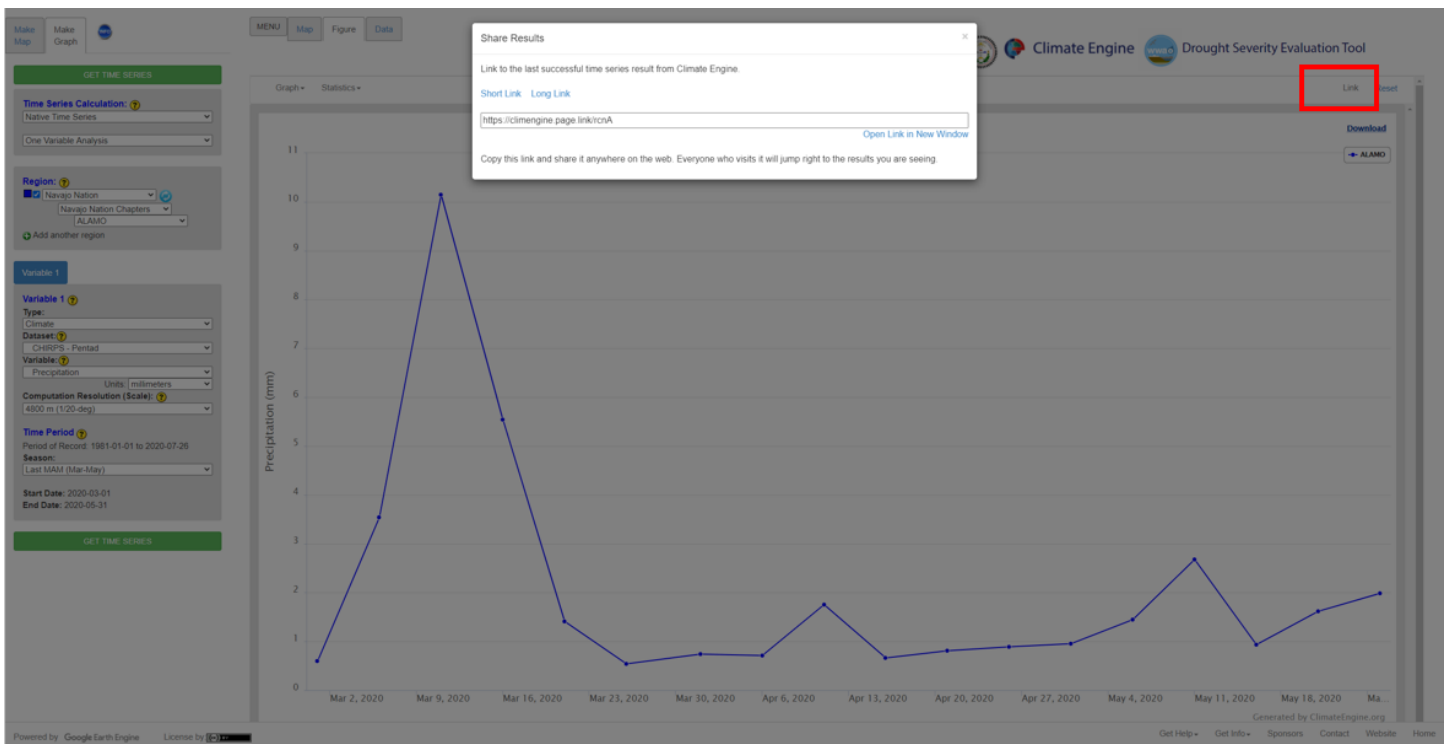
Figure 34. Share Results capability in DSET can be accessed by clicking the Link button highlighted in the red box. This share capability is available for both Make Map and Make Graph data generated.

Additional Resources

- The Applied Remote Sensing Training (ARSET) is a program that is designed to build the capacity of decision-makers to use NASA data. ARSET offers online and in-person trainings for beginners and advanced practitioners alike. Trainings cover a range of datasets, web portals, and analysis tools and their application to air quality, agriculture, disaster, land, and water resources management. http://appliedsciences.nasa.gov/arset

- The National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information provides public access to climate and weather data. This particular link provides a deeper look at drought as well as provide projections: https://www.drought.gov/drought/data-maps-tools/tools

- DSET is a spin-off of Climate Engine, a web-based platform for conducting on-the-fly climate analysis: http://climateengine.org/data