**NASA DEVELOP National Program**

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*Summer 2015*

Navajo Nation Climate II

Monitoring Drought Conditions in the Navajo Nation Using NASA Earth Observations

https://lh3.googleusercontent.com/4nD1xqiL_iH48aHoQQvktZbPnEEiWJFaLGqVIHECOYnzHWGIQHt6cHJztTZFLvnE-ay593X0nBVziVAT2EwGivvi1ZmFHdCc_Ehevg09U5yD-VbIgFpMOKPn-hOLjNlE0oYZKMdPVb-A**Technical Report**

Final Draft – August 6, 2015

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# I. Abstract

The Navajo Nation, a 65,700 km² Native American territory located in the southwestern United States, has been increasingly impacted by severe drought events and changes in climate. These events are coupled with a lack of domestic water infrastructure and economic resources, leaving approximately one-third of the population without access to potable water in their homes. Current methods of monitoring drought are dependent on state-based monthly Standardized Precipitation Index (SPI) maps calculated by the Western Regional Climate Center. However, these maps do not provide the spatial resolution needed to illustrate differences in drought severity across the vast Nation. To better understand and monitor drought events and drought regime changes in the Navajo Nation, this project created a geodatabase of historical climate information specific to the area, and a decision support tool used to calculate average SPI values for user specified areas. The tool and geodatabase use Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) observed precipitation data and Parameter-elevation Relationships on Independent Slopes Model (PRISM) modeled historical precipitation data, as well as NASA’s modeled Land Data Assimilation Systems (NLDAS) deep soil moisture, evaporation, and transpiration data products. The geodatabase and decision support tool allow resource managers in the Navajo Nation to utilize current and future NASA Earth Observations data for increased decision-making capacity regarding future climate change impact on water resources.

**Keywords**

Navajo Nation, drought, remote sensing, Standardized Precipitation Index (SPI), water management, TRMM, GPM

**II. Introduction**

**2.1 Background**

The Navajo Nation (NN), located in the southwestern United States, is the largest Native American territory in the country in terms of land area and population, with an area of 65,700 km2, and a population of 173,667 (US Census, 2010). Historically, precipitation trends in the NN exhibit two rainy seasons a year: one in the winter (December-March), and one in the summer (July-September), with dry seasons in spring (April-June) and fall (October-November). The two rainy seasons are distinctly different in precipitation mechanism and distribution. Winter precipitation brings low-intensity precipitation evenly over large areas, whereas summer precipitation brings intense, often-localized precipitation over small areas (Crimmins, 2013). The periodic oscillations between wet and dry seasons create a complex environment for monitoring drought and water resources.

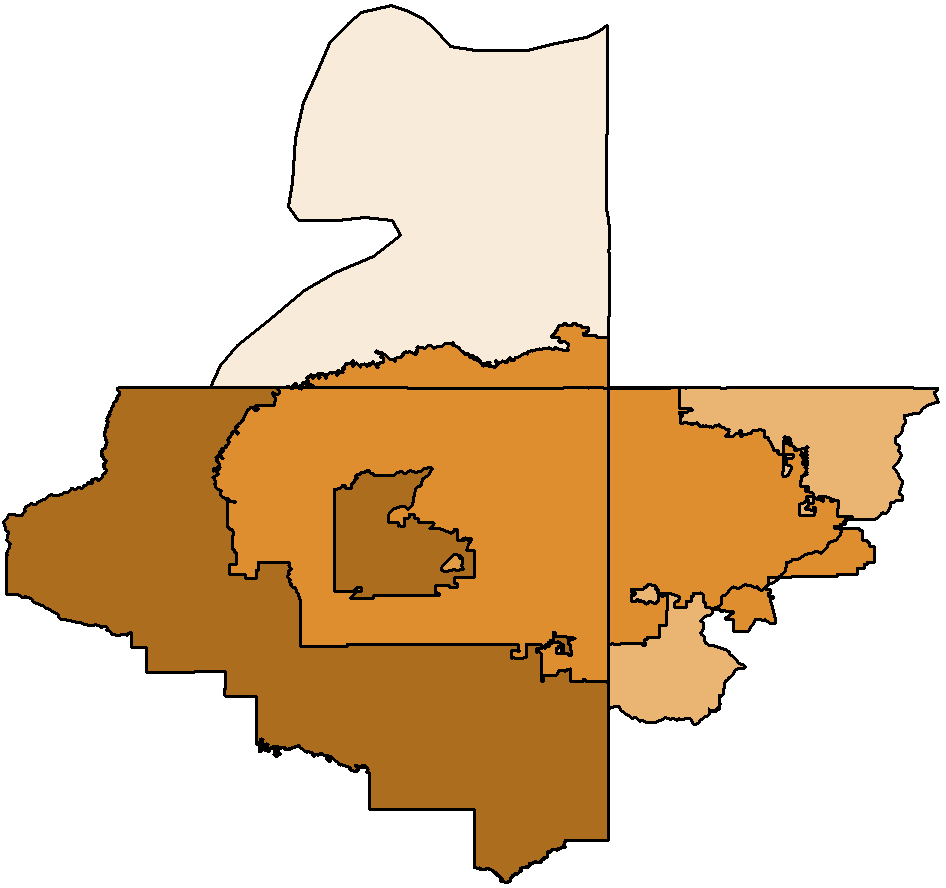
The NN has been experiencing nationwide drought since 1994. It was officially declared a state of emergency in 2011, with this status renewed in 2012 and 2013 (NNDWR, 2011; Nania et al., 2014). Between 1901 and 2010, annual average temperatures in the southwest have increased by 1.6 °F +/- 0.5 °F (Hoerling et al., 2013). Climate change is predicted to continue trends of high temperatures, high aridity, and low snowpack (Redsteer et al., 2011). In addition, droughts such as the current one are predicted to become more common in the second half of this century as a result of climate change (Gershunov et al., 2013).

At least 70,000 people in the Nation (approximately one-third of the population) are without direct access to potable water in their homes(US Census, 2000; NNDWR, 2011). Public water systems do not have the infrastructure to meet the demand in rural areas, leaving a significant percentage of residents dependent on water hauling to meet their needs. This process is economically unsustainable, costing as much as $43,000 per acre-foot of water, compared to the $600 typically paid in surrounding regions (NNDWR, 2011). No other region in the US has such a large percentage of its population lacking the basic necessity of potable tap water in their homes (NNDWR, 2011). This lack of access puts additional pressure on Navajo water resource managers.

**2.2 Current Water Conditionsand Monitoring**

The Navajo Nation Department of Water Resources (NNDWR) currently monitors water conditions using a network of 88 rain collection cans, 8 stream gages, and 9 climate stations (NNDWR, 2003). However, limited government funding, as well as staff and infrastructural constraints have made it difficult to consistently collect these data and maintain an accurate record of rainfall.

Quantifying drought intensity is necessary to monitoring water resources. To determine the Nation’s drought status, the NNDWR uses the Standardized Precipitation Index (SPI), an internationally used probability-based indicator of abnormally wet or dry time periods. The NN currently relies on SPI values that are calculated by the Western Regional Climate Center (WRCC). However, these SPI values represent the region in three large footprints, lacking the spatial detail needed to provide a consistent understanding of the drought regime within the Nation’s regional boundaries (Figure 1). The NN does not currently calculate the SPI for its specific region, and does not collect or process any remotely sensed data for management purposes (personal communication, Feb. 11, 2015). The use of NASA Earth observation data can provide coverage and spatial resolution to calculate SPI for the reservation to better monitor drought conditions in the NN.



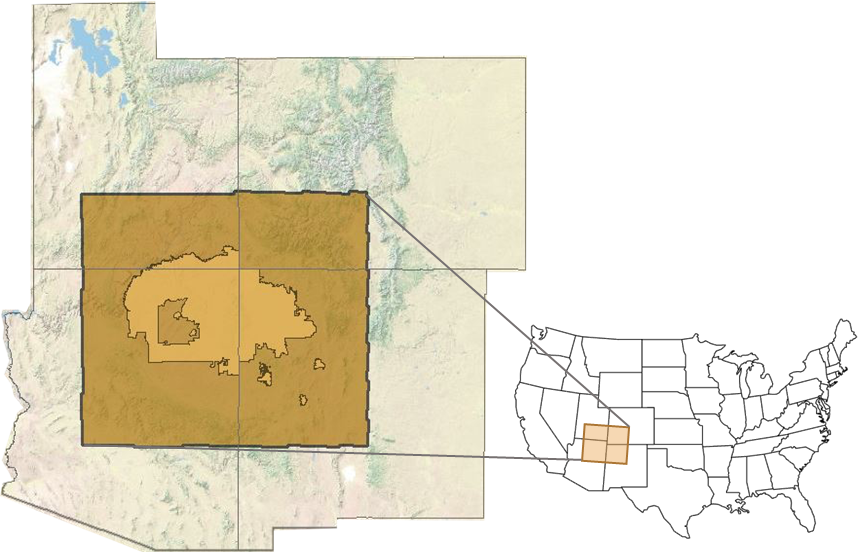
*Fig. 1 – The Navajo Nation currently uses SPI values calculated by the Western Regional Climate Center. The SPI values, represented by the three footprints, do not provide adequate spatial detail.*

**2.2 Project Objectives**

This project phase was the conclusion of a two-term project focusing on water resources in the NN and the role of NASA Earth observation data in water management and drought mitigation. The previous term focused on data collection, and the examination of methodologies of a rasterized SPI calculation. This term focused on creating an SPI tool in the open source statistical program R to allow the NN to generate SPI values specific to chosen boundaries within the Nation.

**2.3 Study Area**

The NN is a 65,700 km2 (25,350 mi2) Native American territory located at the intersection of Arizona, New Mexico, and Utah. The project created a bounding box, using a 62 km buffer around US Geological Survey (USGS) Hydrologic Unit Code 8 (HUC 8) watershed boundaries that intersect the political boundary of the NN in order to accommodate original TRMM data resolution. This buffer defines the study area (Figure 2). This method was used in order to more accurately represent hydrologic processes within a watershed, making the total area of study 150,705 km2.



*Fig. 2 - Study area, Navajo Nation boundary*

**2.4 Project Partners**

This project partnered with the Navajo Nation Department of Water Resources: Water Management Branch, and the Navajo Technical University.

**III. Methodology**

**3.1 Data**

Data were collected from three sources to create a geodatabase of historical and current precipitation data.

Parameter-elevation Relationships on Independent Slopes Model (PRISM) data from 1901-2000 were downloaded from an FTP server hosted on the Northwest Alliance for Computational Science and Engineering (see Appendix A). A model was created in ArcGIS ModelBuilder to convert the data from BIL to TIFF format. The model then projected the data for use in the NN and clipped the data to the study area boundary.

Monthly rainfall rate data 3B43 from the Tropical Rainfall Measuring Mission (TRMM) were downloaded from NASA’s Precipitation Processing System (PPS STORM) data portal. A model was created in ArcGIS ModelBuilder to define the projection of the original data, convert average rainfall rate (mm/hr) into monthly accumulated rainfall (mm/month), re-project, and resample the TRMM data to spatially match the PRISM data’s footprint. In order to maintain data integrity while projecting the originally undefined TRMM data into the same projected coordinate system used by the Navajo Nation, cell values were represented as centroid points, projected, transformed into a triangulated network, and then interpolated back into a raster, using a bilinear resample to match the resolution of the historical precipitation data.

The tool also uses two forms of data from the Global Precipitation Measurement (GPM) mission. The Integrated Multi-satellitE Retrievals for GPM (IMERG) monthly accumulated precipitation data product is highly calibrated using constellation satellites, and a network of ground climate stations, but these data have a 3 month latency period. In order to accommodate for processing time, while still creating a tool supports decision making based on current conditions, the CMB data product from GPM was also included. This product combines observations from both the GPM Microwave Imager and the Dual-Frequency Radar to produce monthly precipitation data products within two weeks of the month's end. As the more fine-tuned IMERG products become available, they will replace the coarser CMB files in the geodatabase.

**3.2 Selecting drought index**

With no single accepted definition of drought, and multiple existing drought types, defining and characterizing drought can be a difficult task. Drought indices serve to transform raw climatic data into a meaningful quantity in order to allow for monitoring, documentation, and comparison (Paulo et al., 2006; Zagar et al., 2011). The SPI is a well-known, internationally-used index to characterize meteorological drought (McKee et al., 1993). It is useful because it is a relatively simple index calculated exclusively using precipitation data, can quantify abnormally wet as well as abnormally dry periods, and does not require calculating the entire study area’s water balance (Magyari-Saska et al., 2009; Zargar et al., 2011).

**3.3 Standardized Precipitation Index**

An SPI can be calculated for varying timescales, depending on user needs. For example, a 6-month SPI has been shown to be a good indicator of seasonal precipitation trends, while a 24-month SPI may give insight to watershed cycles and aquifer recharge (Zagar et al., 2011). The SPI compares precipitation at a time of interest to historical average precipitation, and is calculated using the following equation (Bhuiyan et al., 2006):

\*\*\*Will fix equation\*\*\*\*

Where:

= accumulated precipitation over months of interest

= historical average accumulated precipitation over months of interest

= standard deviation

The SPI is based on comparing precipitation deviations using the normal distribution to find the likelihood of a given precipitation amount compared to the historical average in that area over a specified period of time. However, as precipitation is not a normally distributed variable, data must first be transformed using a Gamma function. The series is then transformed into a normal distribution, the standard deviation is identified, and the SPI value for the location and time is calculated, indicating severity of abnormality (Table 1).

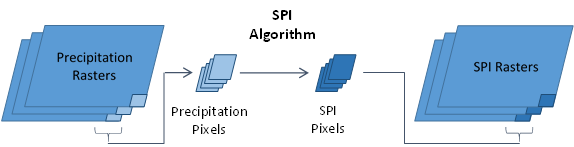
|  |  |  |
| --- | --- | --- |
| SPI Value | Precipitation Intensity | Probability of occurrence (%) |
| 2.00+ | Extremely wet | 2.3 |
| 1.5 to 1.99 | Very wet | 4.4 |
| 1.0 to 1.49 | Moderately wet | 9.2 |
| -0.99 to 0.99 | Near normal | 68.2 |
| -1.00 to -1.49 | Moderately dry | 9.2 |
| -1.5 to -1.99 | Severely dry | 4.4 |
| -2.00 | Extremely dry | 2.3 |

Table 1- SPI values, corresponding precipitation intensities, and corresponding probabilities of occurrence as defined by McKee et al.1993. This enables comparison of both wet and dry periods relative to the historical trend for a set of months at a specific location.

**3.4 Calculating Standardized Precipitation Index Rasters**

*R Methodology:*

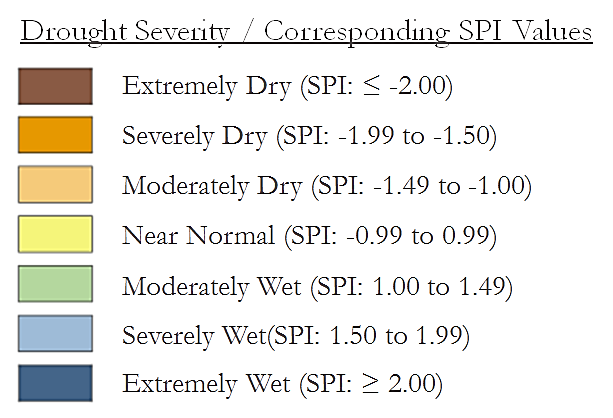
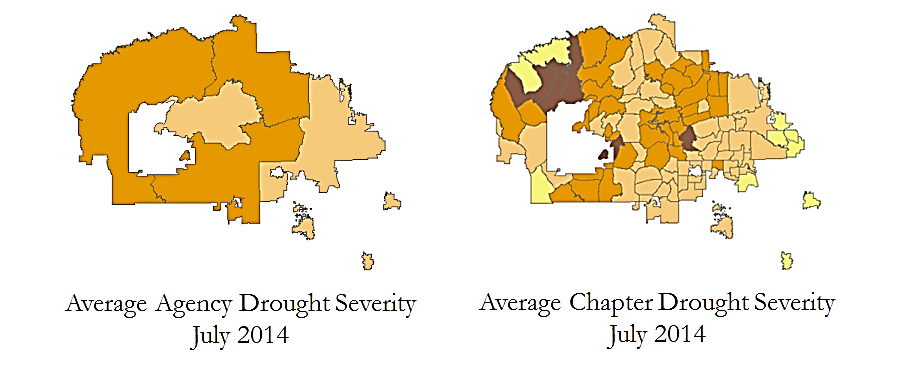
SPI rasters were created by first producing a time series of precipitation data from TRMM and PRISM. SPI values were then calculated for each pixel across the time period. Effectively, this produced rasters of SPI values for each time step in the time period (Figure 3).



*Fig. 3: A flowchart for calculating the SPI for each raster.*

**3.5 Single SPI Values for Specified Boundaries**

Summary statistics were calculated by collecting all pixels contained within a designated “zone.” These zones were defined by a polygon (shapefile), such as an agency, chapter, watershed, or ecoregion. For the selected zone and time period, summary statistics were calculated from all pixels. It is important to note that zonal statistics are produced only from the SPI values in a single time step, not across all time steps.



*Fig. 4 - Examples of Agency and Chapter specific SPI maps*

**IV. Results & Discussion**

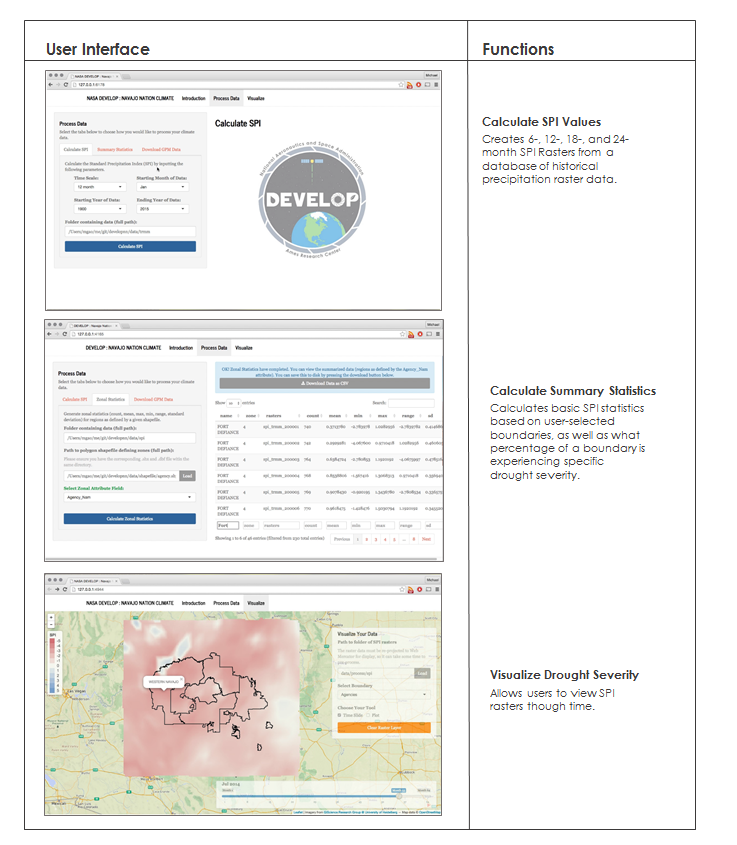
The Drought Severity Assessment - Decision Support Tool (DSA) integrates both SPI raster and single SPI value calculation. Through an interface utilizing R Shiny, the user will have access to three core functions: (Figure 4)

**1) Calculate SPI Values**. The user will be able to select either a 1-month, 6-month, or 12-month SPI depending on the type of drought they want to examine. The user is then prompted to identify the time range by selecting the starting month and year, and then the ending year. (Figure 3)

**2) Calculate Summary Statistics.** Using these SPI rasters, the tool allows the user to generate and view zonal statistics for each time step within the time range for user specified boundaries, such as Navajo Nation political boundaries, USGS watersheds and EPA Level III and IV ecoregions. The tool also allows additional boundaries to be utilized.

**3) Visualize Drought Severity**. This will allow the user to visualize drought severity by viewing SPI rasters through time. The user can also view what percentage of a boundary is experiencing specific drought severity. Additionally, the tool will contain a function that allows the user to download and process up-to-date NASA Earth observation GPM data.

The tool will be accessible through GitHub, the web-based Git repository hosting service. Supplemental written and video tutorials for the tool that encompass the installation process, file structure set-up, tool functionality, and GPM processing workflow in ArcGIS will be provided.



*Fig. 4: Drought Severity Assessment - Decision Support Tool (DSA. Within this interface, the user will have access to three functions: 1) Calculate SPI Values, 2) Calculate Summary Statistics, and 3) Visualize Drought Severity.*

**V. Conclusions**

The DSA will provide water resource managers in the NNDWR the ability to create drought severity maps and monthly drought reports with finer spatial resolution and continuity. Currently, financial drought mitigation resources are allocated evenly across all agencies. With the DSA, water resource managers will be able to determine which agencies and chapters are experiencing greater drought intensity and properly allocate drought mitigation resources. By utilizing NASA Earth Observations, Navajo Nation resource managers and decision-makers will be able to monitor drought more consistently than presently possible.

**VI. Acknowledgments**

Thanks to Ramsey Seweingyawma of the Navajo Technical University for communication and potential coordination of incoming Navajo Technical University students, to Maurice Upshaw, Robert Kirk, Teresa Showa, and Jason John of the Navajo Department of Water Resources: Water Management Branch for providing project guidance and Navajo Nation in-situ GIS data, and to Amber Brooks Geoinformatics of the NASA DEVELOP Program and Eric Wittner of Esri for technical guidance in ArcGIS.

This material is based upon work supported by NASA through contract NNL11AA00B and cooperative agreement NNX14AB60A.

**VII. References**

Bhuiyan, C., R. P. Singh, F. N. Kogan (2006), Monitoring drought dynamics in the Ravalli region (India) using different indices based on ground and remote sensing data, *International Journal of Applied Earth Observation and Geoinformation*, *8,* 289-302.

Crimmins, M., N. Selover, K. Cozzetto, and K. Chief (2013), Technical review of the Navajo Nation drought contingency plan. Drought Monitoring.

Gershunov, A., B. Rajagopalan, J. Overpeck, K. Guirguis, D. Cayan, M. Hughes , M. Dettinger, C. Castro, R. E Schwartz, M. Anderson, A.J. Ray, J. Barsugli, T. Cavazos, M. Alexander (2013), Future climate change: Projected extremes, Chapter 7 in the Assessment of climate change in the Southwestern United States: A report prepared for the National Climate Assessment, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy. A report by the Southwest Climate Alliance, Island Press, Washington, DC, pp. 126-147.

Giddings, L., M. Soto, B. M. Rutherford, and A. Maarouf (2005), Standardized Precipitation Index zones for Mexico. Atmosfera 33-56.

Guttman, N. B. (1998), Comparing the Palmer Drought Index and the Standardized Precipitation Index. *Journal of American Water Resources Association. 34(1)*, 113-121.

Guttman, N. B. (1999), Accepting the Standardized Precipitation Index: A calculation algorithm. Journal of American Water Resources Association. 35(2), 311-322.

Hoerling, M.P, Dettinger M, Wolter K, Lukas J, Eischeid J, Nemani R, Liebmann B, Kunkel KE (2013), Present Weather and Climate: Evolving Conditions, Chapter 5 in the Assessment of Climate Change in the Southwestern United States: A Report Prepared for the National Climate Assessment, edited by G Garfin, A Jardine, R Merideth, M Black, and S LeRoy. A report by the Southwest Climate Alliance, Island Press, Washington, DC, pp. 74-100.

Kumar, M. N., C. S. Murthy, M. V. R. Sesha Sai, and P. S. Roy (2009), On the use of Standardized Precipitation Index (SPI) for drought intensity assessment, *Meteorological Applications.* *16:* 381-389.

Magyari-Saska, Z., I. Haidu (2009), Drought and extreme moisture evaluation and prediction with GIS software module. Proceedings of the ITI 2009 31st International Conference on Information Technology Interfaces, Cavtat, Croatia, June 22-25, 2009.

McKee, T. B., N. J. Doesken and J. Kleist (1993) The relationship of drought frequency and duration to time scales, *In Proceedings of the 8th Conference on Applied Climatology*, Anaheim, California, 17– 22 January 1993. American Meteorological Society.

Nania, J., K Cozzetto, N. Gillett, S. Duren, A. M. Tapp, M. Eitner, and B. Baldwin (2014), Considerations for climate change and variability adaptation on the Navajo Nation.

National Drought Mitigation Center, SPI DOS Program, http://drought.unl.edu/MonitoringTools/DownloadableSPIProgram.aspx

Navajo Nation Department of Water Resources (NNDWR) (2003), Navajo Nation drought contingency plan.

Navajo Nation Department of Water Resources (NNDWR) (2011), Water resource development strategy for the Navajo Nation.

Neves, J. (2012) Computer SPI Index v.1.1, <http://cran.r-project.org/web/packages/spi/index.html>

Paulo A.A. and L.S. Pereira (2006), Drought concepts and characterization. Comparing drought indices, *Water International. 31:* 37–49.

Redsteer, M. H., K. B. Kelley, H. Francis, and D. Block (2011), Disaster risk assessment case study: Recent drought on the Navajo Nation, southwestern United States, *UN Global Assessment Report 2011.*

Steinemann, A. (2003), Drought indicators and triggers: A stochastic approach to evaluation. *Journal of the American Water Resources Association 39 (5)*: 1217-1233.

US Census Bureau (2000), 2000 American Community Survey.

US Census Bureau (2010), 2010 American Community Survey.

Zagar, A., R. Sadiq, B. Naser, and F. I. Khan (2011), A review of drought indices. *Environmental Reviews 19:* 333-349.

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# VIII. Content Innovation

* [Term 1 Virtual Poster Session](http://earthzine.org/2015/04/04/arc-navajo-nation-climate/)
* [Term 2 Virtual Poster Session](http://earthzine.org/2015/07/30/beyond-a-shadow-of-a-drought-ii-monitoring-severity-from-space/)
* [Featured article in Earthzine](http://earthzine.org/2015/06/05/remote-drought-monitoring-in-the-navajo-nation-utilizing-nasa-earth-observation-data/)
* Online user interface

# IX. Appendix A

Below are the websites to download precipitation data.

**PRISM**. <ftp://prism.orgeonstate.edu>

**TRMM**. [ftp://pps.gsfc.nasa.gov/pub/trmmdata/](https://talkgadget.google.com/u/0/talkgadget/_/frame?v=1438196657&hl=en#zSoyz)

**GPM**. <ftp://arthurhou.pps.eosdis.nasa.gov/>