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Evaluation of Climatic and Hydroclimatic Resources to Support the US Army Corps of Engineers Regulatory Program

Kent H. Sparrow, Joseph L. Gutenson, Mark D. Wahl, and
Kayla A. Cotterman

September 2022



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Evaluation of Climatic and Hydroclimatic Resources to Support the US Army Corps of Engineers Regulatory Program

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Abstract

Short-term climatic and hydrologic interactions, or *hydroclimatology*, are an important consideration when delineating the geographic extent of aquatic resources and assessing whether an aquatic resource is a jurisdictional water of the United States (WOTUS) and is therefore subject to the Clean Water Act (CWA). The now vacated 2020 Navigable Waters Protection Rule (NWPR) required the evaluation of precipitation and other hydroclimatic conditions to assess the jurisdictional status of an aquatic resource based on normal hydroclimatic conditions. Short-term hydroclimatic conditions, such as antecedent precipitation, evapotranspiration, wetland delineation, and streamflow duration assessments, provide information on an aquatic resource's geographic extent, hydrologic characteristics, and hydrologic connectivity with other aquatic resources. Here, researchers from the US Army Corps of Engineers, Engineer Research and Development Center (ERDC) evaluate tools and data available to practitioners for assessing short-term hydroclimatic conditions. The work highlights specific meteorological phenomena that are important to consider when assessing short-term hydroclimatic conditions that affect the geographic extent and hydrologic characteristics of an aquatic resource. The findings suggest that practitioners need access to data and tools that more holistically consider the impact of short-term antecedent hydroclimatology on the entire hydrologic cycle, rather than tools based solely on precipitation.

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Preface

This study was conducted for the US Army Corps of Engineers, Wetlands Regulatory Assistance Program under project 2020-ERD-0700-0003, “Typical Year,” funding account U4382480, AMSCO 088893. The technical monitor was Mr. Kyle Gordon.

The Hydrologic Systems Branch (HSB) of the Flood and Storm Protection Division (FSPD), US Army Engineer Research and Development Center—Coastal and Hydraulics Laboratory (ERDC-CHL), performed the work. At the time of publication, Dr. Hwai-Ping (Pearce) Cheng was chief, Hydrologic Systems Branch; Dr. Cary A. Talbot was chief, Flood and Storm Protection Division. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty Wamsley.

COL Christian Patterson was the commander of ERDC, and Dr. David W. Pittman was the director.

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1 Introduction

1.1 Background

The term *waters of the United States* (WOTUS) defines the scope of geographic jurisdiction for federally regulated aquatic resources under the Clean Water Act (CWA; EPA 2020). The US Environmental Protection Agency (EPA) and the Department of the Army have the ultimate responsibility for defining WOTUS, and the definition has fluctuated through time (EPA 2021a). The US Army Corps of Engineers (USACE) is responsible for conducting or verifying jurisdictional determinations on a case-by-case basis. However WOTUS is defined, recent hydroclimatic conditions, including antecedent precipitation and evapotranspiration, provide important information on an aquatic resource's geographic extent, hydrologic characteristics, and hydrologic connectivity to other aquatic resources. All of these factors could affect an aquatic resource's jurisdictional status. For example, the use of certain wetland hydrology indicators for identifying and delineating wetlands requires an evaluation of precipitation normalcy (USACE 2008). Considering normal streamflow conditions is also useful when assessing streamflow duration (Fritz et al. 2020).

Site-specific hydrologic data are limited; therefore, the EPA and USACE most often use data from NOAA's Global Historic Climatology Network, which integrates climate data from more than 20 sources. The agencies evaluate normal precipitation conditions based on three discrete 30-day periods preceding the assessment date. For each period, a weighted condition value is assigned by determining whether the 30-day precipitation total falls within, above, or below the 30th and 70th percentiles for totals from the same date range over the preceding 30 years. The agencies determine whether the period is *normal*, *wetter than normal*, or *drier than normal* based on the weighed sum of conditional values. While the agencies generally use this method to implement this final rule, the agencies also recognize there may be other accurate and reliable measurements of normal precipitation conditions and adjust the approach as is scientifically warranted. The agencies may also consider alternative methods that are developed and appropriately validated, including different statistical percentiles, evaluation periods, or weighting approaches for condition values.

To facilitate rapid, consistent, and accurate determinations of precipitation normalcy, USACE developed the Antecedent Precipitation Tool (APT; Gutenson and Deters 2022; USACE 2021a) to evaluate whether normal climatic or precipitation conditions exist during observations or measurements of flow conditions and surface water connections. This ensures that those observations are representative of typical-year conditions when assessing the jurisdictional status of certain features. An APT analysis can estimate precipitation normalcy for any “point-in-time” resources, which are sources of information that reflect flow or surface water conditions at a specific location on a specific date (e.g., aerial photographs or data collected during a site visit).

Evaluating short-term antecedent climatic conditions when determining the jurisdictional status of water bodies is not a new concept for the agencies. USACE developed the predecessor of the APT to streamline and automate the evaluation of precipitation normalcy and other climatic variables to complete wetland delineations whenever it was necessary to assess the following site-specific conditions: (1) dry season, (2) drought conditions, (3) lower than normal antecedent precipitation, or (4) greater than normal antecedent precipitation (USACE 2008). The APT automates an existing methodology for evaluating 30-day rolling totals of precipitation using the *Engineering Field Handbook’s* weighting factors (NRCS 1997), which are useful for evaluating normal precipitation conditions (i.e., *precipitation normalcy*) for individual dates at an individual site (Sprecher and Warne 2000; Gutenson and Deters 2022).

Though now vacated, at the time of this report, the Navigable Waters Protection Rule (NWPR) provides the most current definition of WOTUS (Federal Register 2021). Under NWPR, the hydrologic flows and surface water connections that occur under “typical year” conditions, as they vary throughout the year, inform the jurisdictional status of certain waterbodies. As defined by the NWPR, typical year conditions are those that occur when precipitation and other climatic variables are within the normal periodic range (i.e., between the 30th and 70th percentiles) for the geographic area of the applicable aquatic resource based on a rolling 30-year period. The NWPR requires an evaluation of typical year conditions when determining whether certain aquatic resources are jurisdictional (Gutenson and Deters 2022). Some locations in the US have ample data to determine normal climatic conditions as needed to assess typical high and low flow conditions or surface water connections in a typical year.

However, many locations lack the requisite data for determining normal climatic conditions.

Regardless of the definition of WOTUS, the climatologic and hydrologic context, or *hydroclimatology*, of an aquatic resource is an important consideration for regulatory practitioners. This technical report identifies data sets and tools that are available to practitioners when evaluating normal climatic and hydroclimatic conditions and highlights gaps in knowledge and data. The technical report reconstitutes the definition of typical year to be aquatic resource conditions that occur when climatologic or hydrologic variables are within the normal periodic range (i.e., between the 30th and 70th percentiles) for a geographic area of interest. Although this technical report is specific to typical year assessments in support of WOTUS jurisdictional determinations, the findings and concepts, as well as any future work relative to an evaluation of climatic conditions associated with WOTUS determinations, may have utility in other regulatory applications. As such, the term typical year is used throughout this report to describe normal climatologic and hydrologic conditions.

1.2 Objectives

The objective of this report is to provide an assessment of climatologic and hydroclimatic support and the tools used by the USACE Regulatory program to assess typical year for aquatic resources. This effort informs the regulatory practitioner about when and where climatologic and hydroclimatic tools are available for determining normal, wetter than normal, and drier than normal conditions, and it identifies sources of data that are readily available for analyzing the short-term antecedent climatologic and hydroclimatologic conditions that can affect the hydrologic characteristics of an aquatic resource at a given time and date. The research team also evaluates the capability of the APT to identify typical year conditions as needed to assess the hydrologic characteristics (e.g., flow regime and hydrologic connectivity) of streams in the US. This evaluation will help identify knowledge gaps for areas of future research and when other tools might be necessary for assessing typical year conditions.

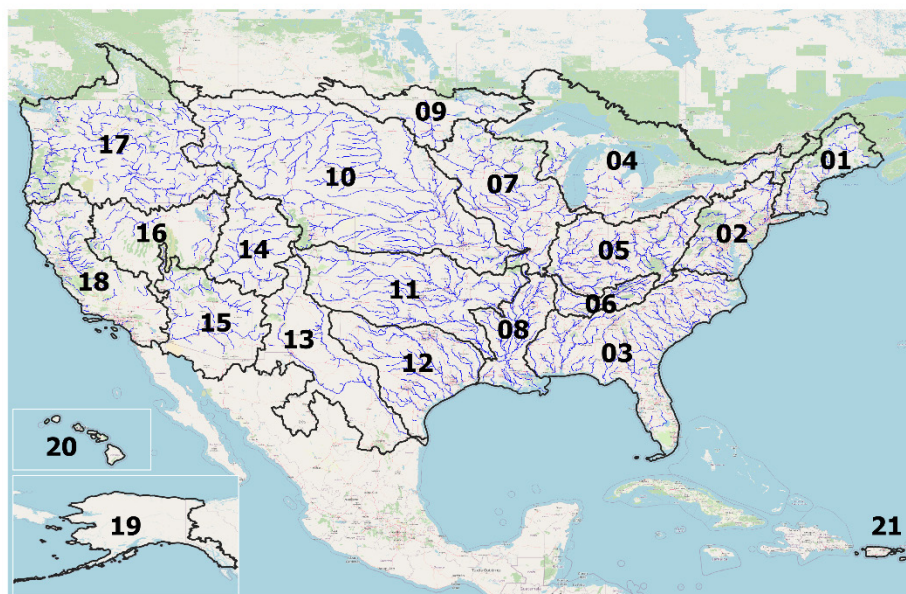
1.3 Approach

This work involved a survey of existing tools, data, and methodologies available to regulatory practitioners for assessing typical year for a given aquatic resource. This report is intended to help determine where, how,

and when these tools, data, and methodologies are useful for typical year determination.

An assessment of current APT functionality provides insights on the effectiveness of the tool for providing typical year assessments of streams. For over two decades, the APT's underlying methodology has proven useful for determining precipitation normalcy for wetland identification and delineation (Sprecher and Warne 2000; Vepraskas et al. 2019). However, the use of precipitation alone negates the physical, spatial, and temporal components of the hydrologic system and the other elements of the hydrologic cycle that can impact aquatic resources (Wu et al. 2021; Li and Quiring 2021). The additional components of the hydrologic system are likely to affect wetlands and streams differently. To assess the capacity of the APT's underlying methodology for identifying streamflow normalcy, USGS daily streamflow percentiles are considered representative of a typical year for streams with gages with 30 or more years of data (Falcone 2011). Therefore, Antecedent Precipitation Scores (α) generated with the APT (Gutenson and Deters 2022) in accordance with the standard practice are compared with USGS gage observations from the corresponding time period at regional Hydrologic Unit Code (HUC) 2 levels (Figure 1). This HUC classification divides the US into 21 geographic areas that share the same drainage area of a major river or the combined drainage area of a series of rivers (Seaber et al. 1987). Two-digit HUC classifications were a logical division, given their division by major drainage areas and the fact that the software used in the analysis, Ulmo (Github 2021), uses this division to group USGS gage numbers. The assessment of the APT's underlying methodology provides a benchmark of the capacity of existing tools to estimate typical year at streams with limited site-specific hydrologic data.

Figure 1. Hydrologic Unit Code (HUC) 2 level regions across the United States.



2 Survey of Existing Tools and Data to Support Typical Year Evaluation

This section contains an evaluation of existing tools, data, and techniques for evaluating climatic and hydroclimatic typical year conditions. The intent is to assess the current capacity of tools that practitioners can employ when evaluating typical year conditions. Table 1 lists the tools and data that are available to practitioners. Each tool is evaluated in a subsection that follows.

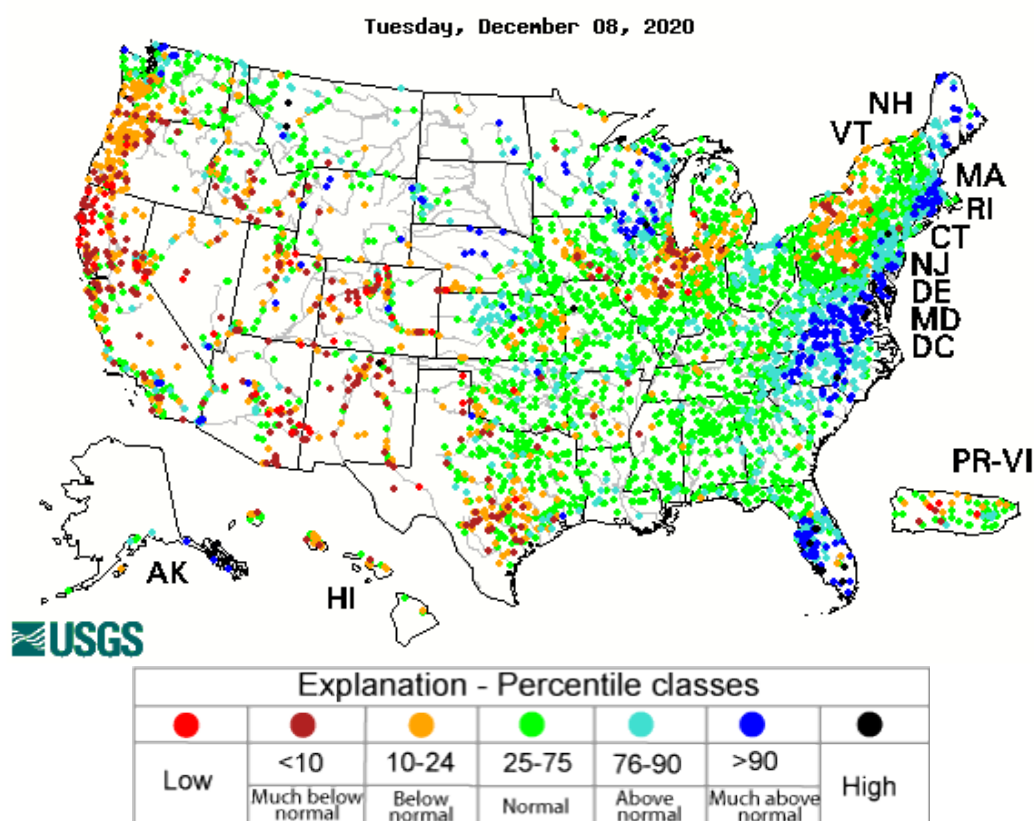
Table 1. Tools and data that are available to evaluate typical year.

Name	Where to Access	Limitations	Type
USGS WaterWatch	https://waterwatch.usgs.gov/?id=ww_current	Limited gage network, especially in the western CONUS.	Streamflow
NOAA Stage IV	https://water.weather.gov/precip/download.php	Regional biases exist in estimates. Not an easily accessible climatology.	Precipitation
National Water Model (NWM)	https://www.nohrsc.noaa.gov/pub/staff/keicher/NWM_live/web/static_images/streamflow_anomaly/analysis_assim/	No retrospective data available. Model does not account for anthropogenic influences.	Streamflow
Streamflow Prediction Tool (SPT)	https://umip.erd.c.dren.mil/apps/streamflow-prediction-tool/	Requires some GIS background to visualize data. Does not provide specific scores or percentile categories for streamflow.	Streamflow
SNODAS	https://nsidc.org/data/g02158	No model validation. Does not perform well under forest canopy. Only useful in areas with significant snowpack.	Snow
United States Drought Monitor (USDM)	https://droughtmonitor.unl.edu/	Does not account for above average flow or wetter than normal conditions.	Precipitation/ streamflow/ soil moisture
Climate Prediction Center (CPC)	https://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/smp.shtml	Product resolution is coarse and may be locally imprecise.	Soil moisture/run off
PRISM	https://prism.oregonstate.edu/	Useful primarily in mountainous areas.	Precipitation
GridMET	https://www.climatologylab.org/gridmet.html	Struggles to capture microclimates.	Precipitation

2.1 USGS WaterWatch

The USGS maintains the National Streamflow Network (NSN) that, as of 2018, provides continuous surveillance of streamflow at more than 8,200 gages (Eberts et al. 2019). For a subset of the NSN, the USGS WaterWatch application provides historic context for current streamflow conditions at locations across the United States where streamflow records span at least 30 years (USGS 2020a). This context includes an assessment of daily streamflow conditions relative to mean historic conditions on that same day. USGS specifies that the normal range of streamflow for a given day is between the 25th and 75th percentiles. Figure 2 contains an example of this daily assessment.

Figure 2. An example of a daily streamflow assessment provided by USGS. Image reproduced from USGS WaterWatch (USGS 2020a).



USGS WaterWatch provides an assessment of normalcy of streamflow for a given day that coincides with the typical year concept as it applies to streamflow normalcy on a given day. If daily streamflow falls within the range of normal USGS WaterWatch conditions, the waterbody is likely within a typical year; if streamflow conditions are above or below normal,

the waterbody is likely not within a typical year. While high and low flows are categorized as being above or below normal, it is not uncommon for streamflow to fluctuate well outside of the normal percentile class throughout the year. Streamflow categorized as above normal could indicate recent rainfall in the area, with a return to normal conditions shortly after.

The inherent limitation of applying USGS WaterWatch to a typical year assessment is the spatial gaps in the gage network coverage. USGS WaterWatch does not evaluate many small, ungaged streams and waterbodies. Although there are more than 8,200 gages in the NSN, aquatic resources that require assessment are often located in areas far from these gaged locations. The gages are distributed across 8.4 million miles of streams (USGS 2017; Anderson and Rea 2020), meaning there is one gage for every 2,625 miles of stream.

2.2 NOAA Stage-IV rainfall

NOAA's Stage-IV data set is a quantitative precipitation estimate (QPE) of liquid precipitation and is derived from a suite of sources composed mostly of radar and rain gauge estimates (Lin and Mitchell 2005; Nelson et al. 2016). This data set was originally created to validate and improve rainfall forecasts. The National Weather Service River Forecast Centers (RFCs) obtain the precipitation data from raw observations and perform quality control edits. The National Center for Environmental Prediction then mosaics the data from RFC domains (Figure 3) into a single gridded data set for the entire contiguous United States (CONUS). The data are archived on timescales that range from hourly to annual and can be accessed via the Advanced Hydrologic Prediction Service*, which is maintained by the National Weather Service.

Because Stage IV QPE is used by various scientific organizations (e.g., NOAA, USGS, and the United States Drought Monitor [USDM]) to assess precipitation amounts for river forecasting, drought monitoring, and rainfall forecast validation, it can be quite useful in the assessment of typical year precipitation. Stage IV retrospective data can be used to generate an average precipitation amount for months or seasons and to compare to current conditions to assess normalcy.

* <https://water.weather.gov/precip/download.php>

Figure 3. River Forecast Center (RFC) domains. Image reproduced from National Weather Service (2019).



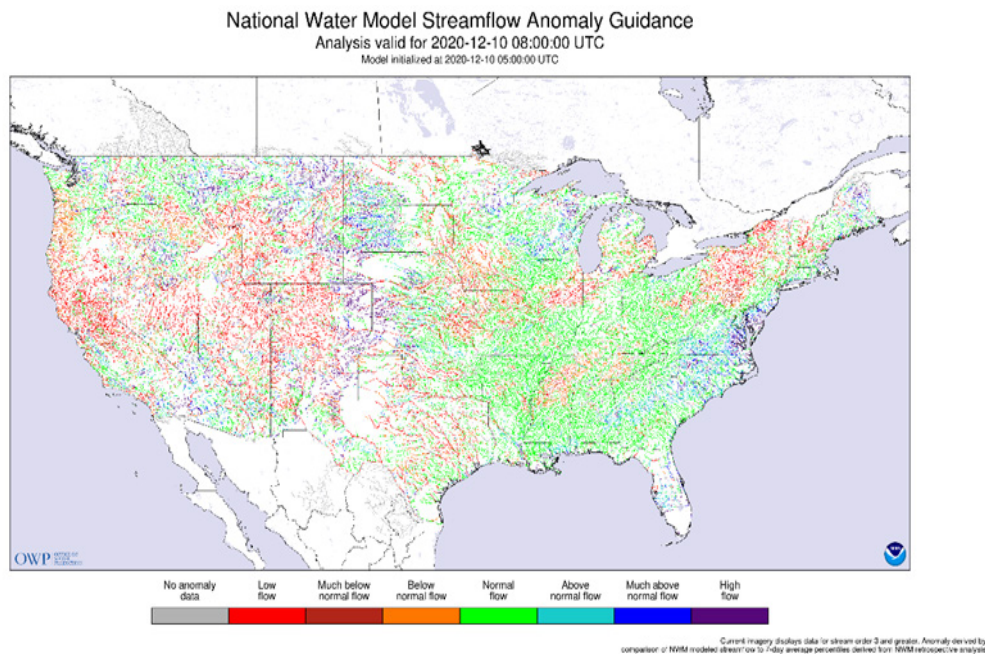
2.3 National Water Model (NWM)

The National Water Model (NWM) is an operational, large-scale, distributed hydrologic model that was developed by NOAA's National Water Center (NWC) and its collaborators. The NWM converts both meteorological reanalysis and forecast data into streamflow guidance for the CONUS and Hawaii. Meteorological reanalysis data provide the most complete understanding of past weather and climate and are a blend of observed and modeled data (ECMWF 2020). For CONUS, streamflow guidance from the NWM is available for all 2.7 million river reaches within the National Hydrography Dataset–Plus (NHDPlus), version 2, medium resolution data set (USGS 2020b). One intent of the NWM is to provide complementary forecast guidance at ungaged stream reaches within the United States (NOAA n.d.c).

Though the NWM functions mainly to support hydrologic forecasting, the NWC developed experimental NWM streamflow anomaly visualizations that adopt components of the USGS WaterWatch methodology and apply the methodology to the NWM and NHDPlus stream reaches in CONUS. Figure 4 is an example of the NWM streamflow anomaly product distributed by the NWC.

To initialize forecast cycles, the NWC performs hourly NWM runs using observed meteorological conditions and USGS NSN streamflow observations to estimate current streamflow conditions. There are two types of NWM spin up that differ based on the quality of observed precipitation data injected into the model. For every hour in the day, besides 1900 UTC, the standard NWM analysis and assimilation cycle uses gage-adjusted, Multi-Radar/Multi-Sensor System (Zhang et al. 2016) and radar-only observed precipitation products. For the 1900 UTC NWM analysis and assimilation run, the precipitation product upgrades to the Stage-IV national mosaic of RFC QPE precipitation data (Nelson et al. 2016). RFC Stage-IV rainfall undergoes a manual quality control of multisensor (radar and rain gauge) precipitation estimates. The NWC computes the anomalies depicted in Figure 4 by comparing NWM estimates of streamflow at the hour specified to the monthly average flow values taken from the NHDPlus Enhanced Runoff Method (EROM) tables (McKay et al. 2012).

Figure 4. An example of hourly streamflow anomaly assessment provided by the National Water Model (NWM) streamflow anomaly guidance. Image reproduced from NOAA (n.d.c).



The NWM anomalies graphics can substitute for USGS WaterWatch in ungaged stream reaches in CONUS for typical year determinations. However, their utility is limited by the current availability of the NWM anomaly data. The NWM anomaly graphic depicted in Figure 4 is the only product currently available to the public. The NWM anomaly graphic estimates that streams depicted as green are under normal streamflow conditions;

those in orange, red, and maroon are estimated to be experiencing below normal streamflow conditions; and those in light blue, royal blue, or purple are estimated to be experiencing above normal streamflow conditions. The NWM can be used to assess streamflow conditions in the same way as USGS WaterWatch because they use similar percentile thresholds to categorize stream conditions. The main difference between the NWM streamflow anomaly graphic depiction of streamflow conditions and those of the USGS WaterWatch is that NWM streamflow anomaly percentiles are based on EROM monthly normal, while USGS WaterWatch is based on daily percentiles calculated for each USGS gage.

The NWC currently only maintains a 5-day archive of previous NWM anomaly graphics, which only allows for the evaluation of streamflow normalcy immediately prior to or following a site visit. There is currently no publicly available retrospective data set. In addition, the NWM anomaly graphics are currently only available for CONUS locations.

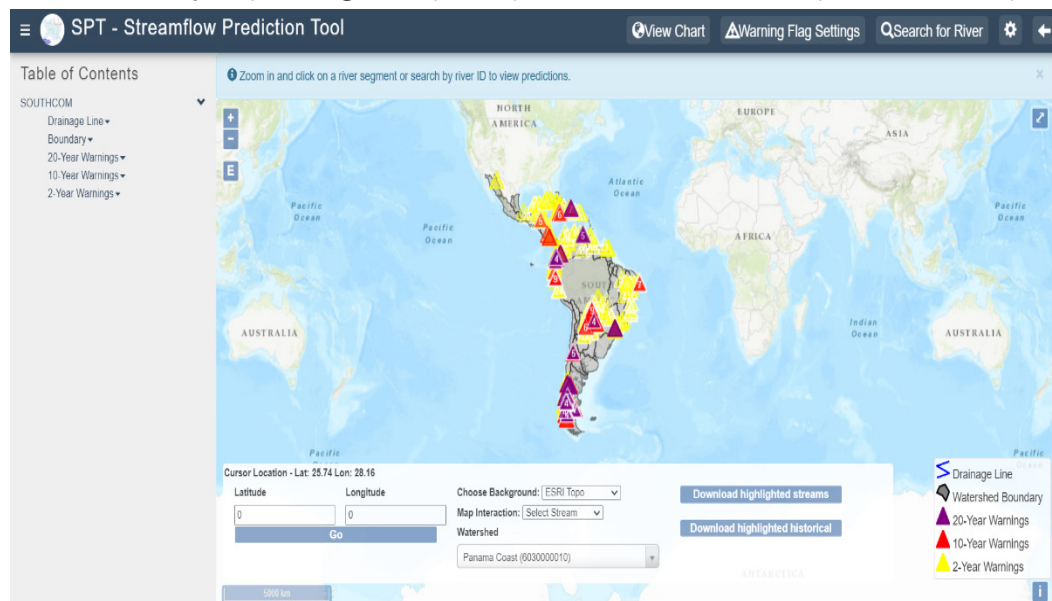
2.4 Streamflow Prediction Tool (SPT)

The SPT is an operational streamflow forecasting tool developed by the Engineer Research and Development Center (ERDC) and its collaborators to support outside CONUS (OCONUS) military and intelligence operations (Wahl et al. 2016). Figure 5 is an example of the SPT interface*, which can be accessed via common access card (CAC). The SPT currently has both a reanalysis and forecast component based on the European Centre for Medium-Range Weather Forecasts meteorological and hydrological simulations (Balsamo et al. 2009, 2015). The historic reanalysis data provide a streamflow hydroclimatology and add context to the magnitude of streamflow forecasts (Snow et al. 2016).

The SPT does not currently provide the context necessary to assess typical year. The current version of the SPT illustrates potential locations of current and forecasted high streamflow and flood conditions and then archives those analyses. The current version of the SPT does not differentiate between normal and low streamflow conditions. However, the SPT could be adapted to assess streamflow normalcy in a manner similar to USGS WaterWatch and the NWM anomaly.

* <https://umip.erd.c.dren.mil/apps/streamflow-prediction-tool/>

Figure 5. An example of the Streamflow Prediction Tool (SPT) interface. Image reproduced from US Army Corps of Engineers (USACE) Model Interface Platform (Wahl et al. 2016).



2.5 Snow Data Assimilation System (SNODAS)

The Snow Data Assimilation System (SNODAS) data set is a product of the National Snow and Ice Data Center and the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC). This is an operational model used to conduct regional snow analyses across the CONUS. SNODAS provides integrated estimates of snow cover data from satellite and airborne surveys, numerical weather models, and ground-based observations (e.g., SNOTEL). The information provided can be used to assess the conditions of the snowpack and is most useful in mountainous regions in the western US. The following data sets are available: Snow Water Equivalent (SWE; Figure 6), Snow Depth (Figure 7), Average Snowpack Temperature (Figure 8), SWE Change, Snow Precipitation, Snow Melt, Blowing Snow Sublimation, Surface Sublimation, and Non-Snow Precipitation (Barrett 2003). The data provided by SNODAS assimilations can be used to forecast streamflow and drought conditions using SWE and snowpack temperature data.

The percent of normal SWE conditions is available through Google Earth's Climate Engine*. The product can be used on monthly or annual time scales to determine if the amount of SWE in the snowpack falls within what would be considered a typical year. Time periods of 30, 60, and 90

* <https://app.climateengine.org/climateEngine>

days can be assessed and compared to the historical SWE data set. An assessment of an above or below average snowpack prior to a melt season would allow regulators to anticipate above or below average streamflow conditions.

Figure 6. Snow Data Assimilation System (SNODAS) Snow Water Equivalent (SWE) example. Image reproduced from the National Snow Analyses tool (NOAA n.d.b).

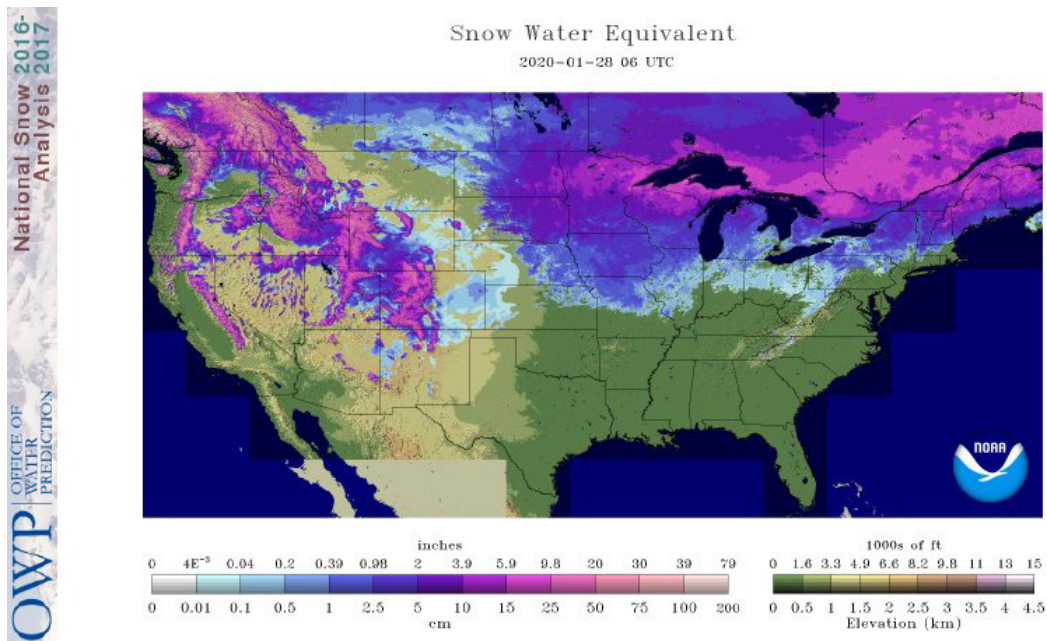


Figure 7. SNODAS Snow Depth example. Image reproduced from the National Snow Analyses tool (NOAA n.d.b).

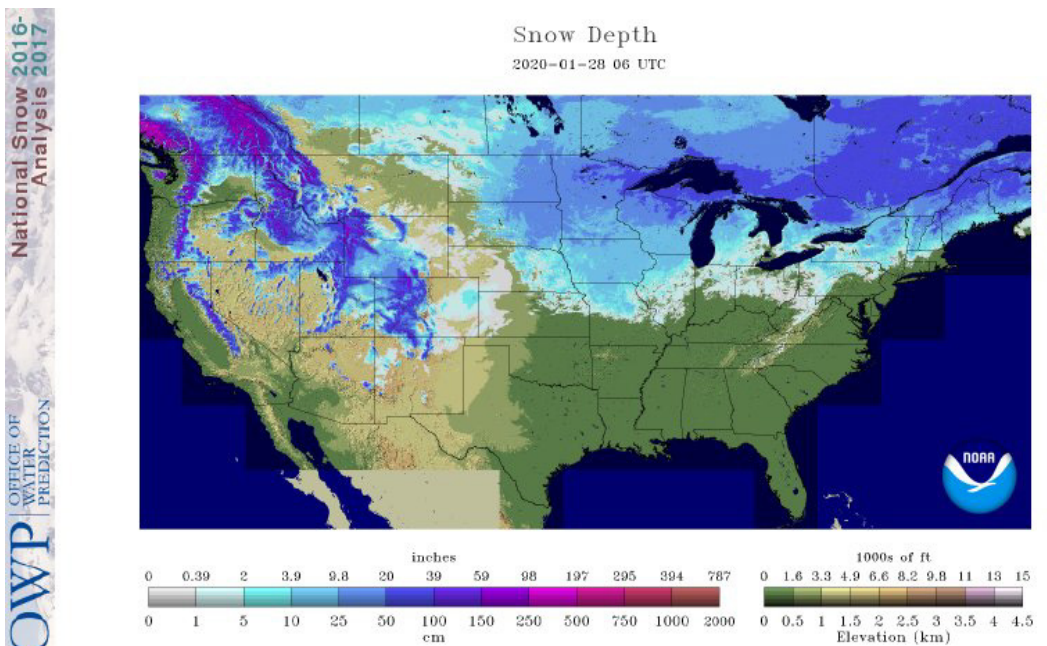
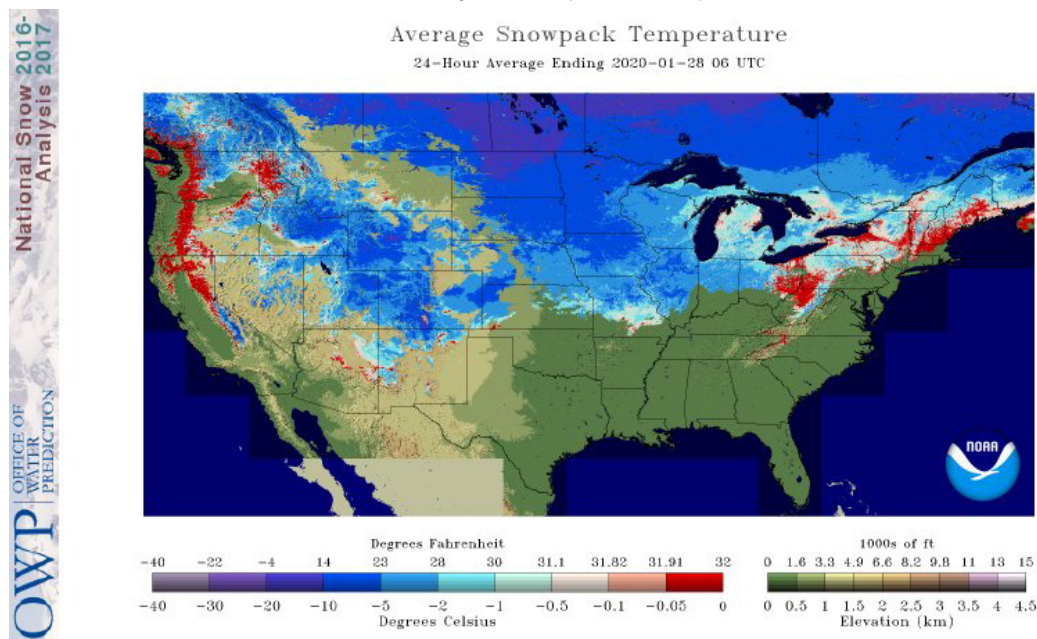


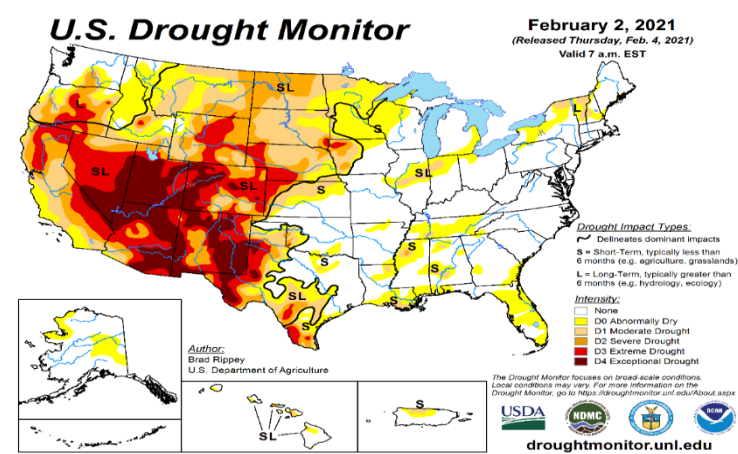
Figure 8. SNODAS Average Snowpack Temperature. Image reproduced from the National Snow Analyses tool (NOAA n.d.b).



2.6 The United States Drought Monitor (USDM)

The USDM is a partnership of drought monitor collaborators and forecasters across multiple organizations, including the National Drought Mitigation Center at the University of Nebraska–Lincoln, NOAA’s National Integrated Drought Information System, and the USDA. These agencies estimate drought severity using observed precipitation, soil moisture, agricultural conditions, and hydrologic data (Svoboda et al. 2002). The USDM is a valuable source for assessing meteorologic, hydrologic, and agricultural drought conditions. Drought severity is classified into five categories that range from *abnormally dry* to *exceptional drought* and is updated weekly by various drought authors (Figure 9). The information provided by the USDM is displayed in a polygon file format for each drought category. The Palmer Drought Severity Index (PDSI), which the APT queries, is used as an input in the USDM. Because the USDM has multiple inputs and is quality controlled by drought authors, this product may be used before any others when assessing drought conditions. However, the PDSI and other drought monitor inputs should be used when assessing wet conditions because the USDM product specifically categorizes the severity of drought.

Figure 9. United States Drought Monitor (USDM) drought severity example. Image reproduced from US Drought Monitor (n.d.).



Drought Severity Classification

Category	Description	Possible Impacts	Ranges				
			Palmer Drought Severity Index (PDSI)	CPC Soil Moisture Model (Percentiles)	USGS Weekly Streamflow (Percentiles)	Standardized Precipitation Index (SPI)	Objective Drought Indicator Blends (Percentiles)
D0	Abnormally Dry	- Going into drought: - short-term dryness slowing planting, growth of crops or pastures - Coming out of drought: - some lingering water deficits - pastures or crops not fully recovered	-1.0 to -1.9	21 to 30	21 to 30	-0.5 to -0.7	21 to 30
D1	Moderate Drought	- Some damage to crops, pastures - Streams, reservoirs, or wells low, some water shortages developing or imminent - Voluntary water-use restrictions requested	-2.0 to -2.9	11 to 20	11 to 20	-0.8 to -1.2	11 to 20
D2	Severe Drought	- Crop or pasture losses likely - Water shortages common - Water restrictions imposed	-3.0 to -3.9	6 to 10	6 to 10	-1.3 to -1.5	6 to 10
D3	Extreme Drought	- Major crop/pasture losses - Widespread water shortages or restrictions	-4.0 to -4.9	3 to 5	3 to 5	-1.6 to -1.9	3 to 5
D4	Exceptional Drought	- Exceptional and widespread crop/pasture losses - Shortages of water in reservoirs, streams, and wells causing water emergencies	-5.0 or less	0 to 2	0 to 2	-2.0 or less	0 to 2

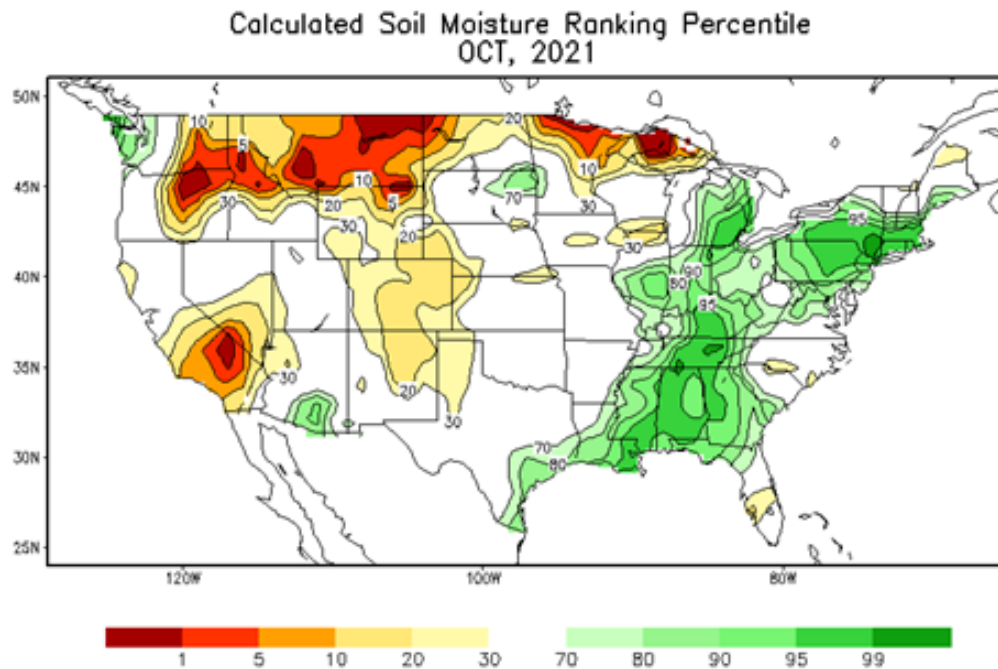
Short-term drought indicator blends focus on 1-3 month precipitation. Long-term blends focus on 6-60 months. Additional indices used, mainly during the growing season, include the USDA/NASS Topsoil Moisture, Keetch-Byram Drought Index (KBDI), and NOAA/NESDIS satellite Vegetation Health Indices. Indices used primarily during the snow season and in the West include snow water content, river basin precipitation, and the Surface Water Supply Index (SWSI). Other indicators include groundwater levels, reservoir storage, and pasture/range conditions.

2.7 Climate Prediction Center (CPC)

The National Weather Service's Climate Prediction Center (CPC) collects and produces maps and time series data of climatic variables that are used for drought monitoring by the National Integrated Drought Information System. The data include soil moisture, runoff, evaporation, precipitation, and temperature (Xia 2012). The data are provided as daily and monthly means, daily and monthly anomalies, and monthly percentiles. The soil moisture, evaporation, and runoff parameters are derived from the North American Land and Data Assimilation System (NLDAS) and the Leaky Bucket model. The Leaky Bucket hydrologic model calculates these parameters using observed temperature and precipitation, which are compared to a 28-year climatology to derive anomalies and percentiles (Huang et al. 1996; van den Dool et al. 2003). This model currently runs two different configurations that produce (1) daily and monthly precipitation and soil moisture updates for 344 US climate divisions from the National Climate

Data Center and (2) daily and monthly soil moisture and surface air temperature over a 0.5×0.5 -degree resolution global domain. The daily and monthly updates make this a useful tool for near-real-time evaluations of hydrologic conditions. Figure 10 displays an example of calculated soil moisture percentiles produced by the Leaky Bucket model.

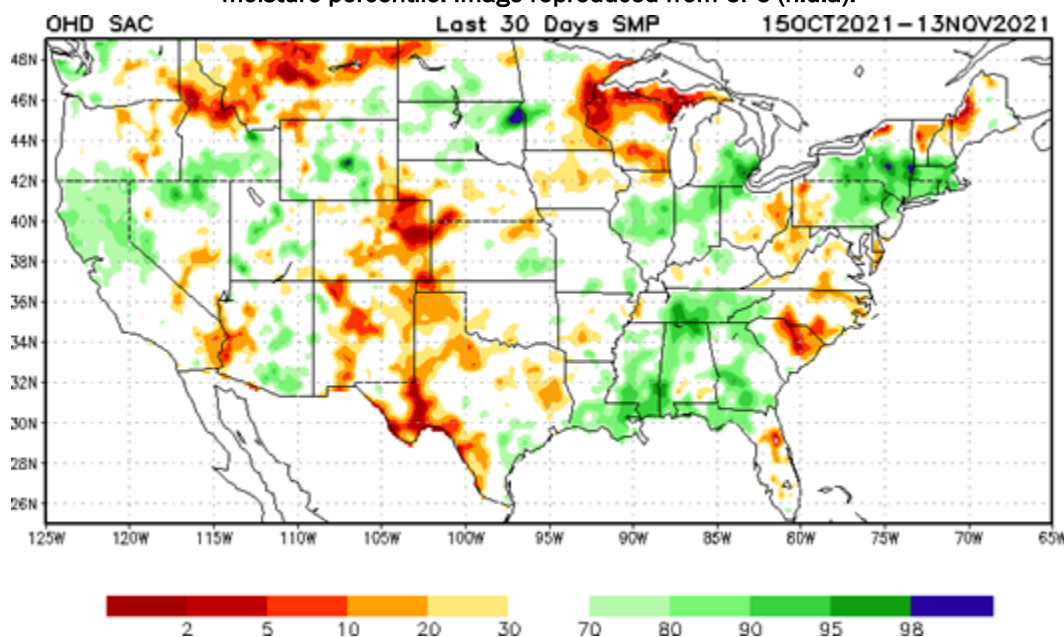
Figure 10. Climate Prediction Center (CPC) calculated soil moisture ranking percentile. Image reproduced from CPC n.d.b).



The CPC also uses NLDAS to produce experimental near-real-time drought monitor data, including soil moisture and runoff (Xia 2012). The anomalies and percentile categories produced are derived by comparing current conditions to a 28-year climatology (1980–2007). The anomalies and percentiles are provided in daily to monthly time scales. The anomalies are calculated by comparing each grid cell value to the mean grid cell value for the same date or dates in the climatology. Percentiles are based on a moving 5-day window to smooth out the data. A single value is created for each day and is compared to the corresponding days in the climatology. NLDAS currently runs near real time, with a 4-day lag on a $1/8$ of a degree grid in hourly time steps. Figure 11 displays an example of NLDAS soil moisture percentiles.

CPC products use a rather coarse resolution and may be inaccurate at local scales. However, these CPC products can be useful for assessing the normalcy of hydrologic conditions on daily, monthly, and seasonal time scales.

Figure 11. CPC North America Land and Data Assimilation System (NLDAS) calculated soil moisture percentile. Image reproduced from CPC (n.d.a).

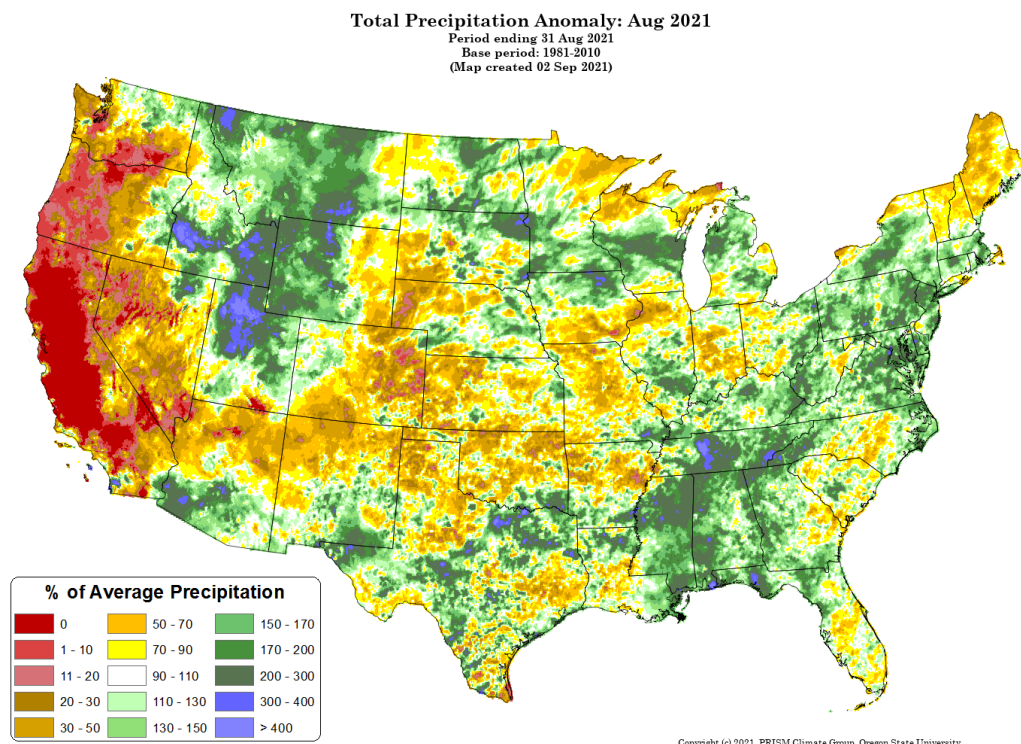


2.8 Parameter-elevation Regressions on Independent Slopes Model (PRISM)

The Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group uses multiple networks of observed temperatures, precipitation, and dewpoint (Daly et al. 2002, 2008; Figure 12). Observations of these variables are ingested into PRISM, where a weighted regression is performed to account for many local effects associated with topography and microclimates. Quality control measures are performed on these data to generate gridded data sets that can be used to assess the normalcy of current climatological conditions (Daly n.d.). The data are publicly available on a 4 km grid but can be purchased at higher resolutions. The relatively high spatial resolution of this product makes it useful in rugged terrain or complex climate regimes. Given this product's popularity as an input across multiple drought indicators, it is likely to be useful when assessing precipitation normalcy. Deviations from long-term precipitation averages can be assessed by comparing total monthly precipitation to PRISM's 30-year norms, which are based on climatological data from 1981

to 2010. While conditions can only be assessed on 30-day or greater time scales, PRISM can provide regulators with the percent of average precipitation when assessing precipitation normalcy for specified monthly, seasonal, or annual time scales.

Figure 12. Parameter-elevation Regression on Independent Slopes Model (PRISM) percent of average precipitation example. Image reproduced from the Northwest Alliance for Computational Science and Engineering (2022).



2.9 Gridded Surface Meteorological (gridMET)

The Gridded Surface Meteorological (gridMET) data set is a 4 km gridded data set of climate variables, including wind, temperature, precipitation, short-wave radiation, and humidity. GridMET is composed of a blend of climate data from PRISM and NLDAS-2 (Abatzoglou 2013). The wide range of data available from gridMET can be used as inputs for ecologic, hydrologic, and agricultural models. These data cover the CONUS from 1979 to the present and are updated daily. This data set is another relatively high spatial resolution product that has the potential to be useful when assessing the normalcy of precipitation.

The overview of existing tools and data sets that were discussed in this chapter can be used for evaluating climatic and hydroclimatic typical year conditions. The tools should be considered by practitioners to evaluate

typical year conditions under circumstances in which the accuracy of the APT is in question due to specific weather or climatic conditions discussed in Chapter 3. The suggested data sets are not intended to replace APT evaluations but, rather, to be used in conjunction with the APT to make more thorough evaluations. These data sets were selected because they provide direct measurements of streamflow conditions, model derived streamflow conditions, or account for multiple hydrologic components that can be used to assess the normalcy of aquatic resources.

3 Meteorological Phenomena to Consider When Assessing Climatological and Hydrological Normalcy

This section contains a discussion of weather and climatological factors to consider when assessing typical year for a given aquatic resource. Each section discusses how weather and climate patterns can result in extreme precipitation and streamflow anomalies. These patterns warrant further analyses or multiple lines of evidence when assessing typical year for aquatic resources.

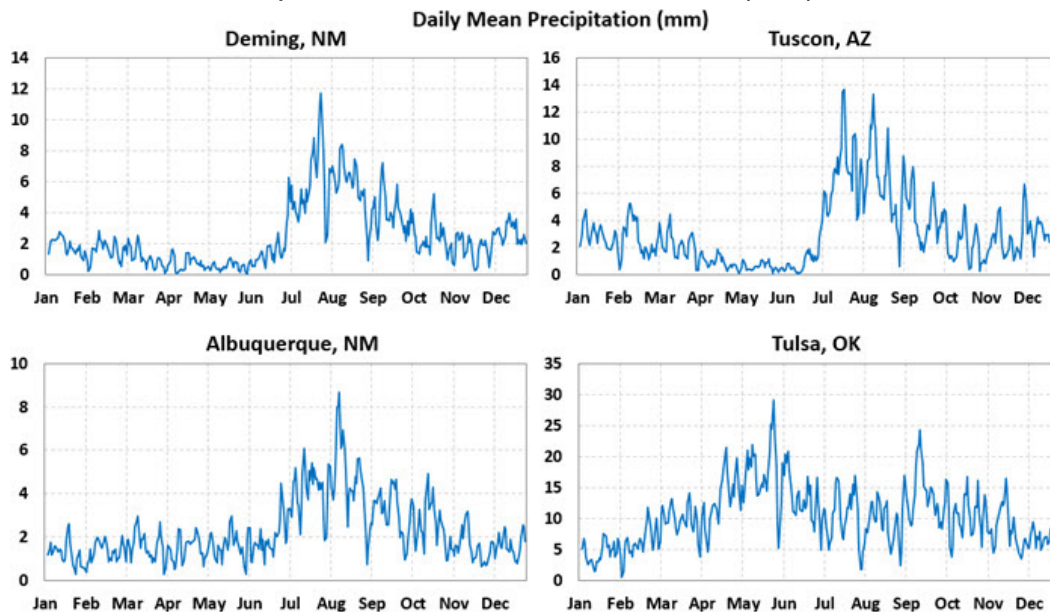
3.1 The North American Monsoon

The North American Monsoon is part of an atmospheric circulation that affects the weather over a large portion of the western CONUS (Adams and Comrie 1997). The monsoon season occurs when a reversal in the flow of this circulation brings influxes of moisture from the Gulf of California, the eastern Pacific Ocean, and the Gulf of Mexico (CPC 2004). The change in wind direction occurs because of the temperature gradient that develops between the land and the Pacific Ocean during the summer months. The transport of moisture into the upper and lower levels of the atmosphere can bring significant regional increases in sporadic convective precipitation. The southwestern US typically sees precipitation increases associated with the monsoon between June and September (Figure 13). In addition to a general precipitation increase during the monsoon season, extreme flash flood events can occur where streamflow conditions change rapidly (Yang et al. 2019).

Due to the isolated nature of convective precipitation during the monsoon season, it might be necessary to deviate from the methodology underlying the current version of the APT (version 1.0) to assess typical year streamflow conditions. The rapid change in streamflow that can occur following a localized rain event means that a 30-day average of rainfall will not provide an accurate representation of stream conditions. During such events, USGS stream gages, the NWM, or the SPT would be beneficial for assessing the normalcy of streamflow conditions. The data from these three products are a direct representation of streamflow, rather than an assessment of precipitation as a proxy for streamflow. This would provide a potentially more accurate representation of hydroclimatic conditions when

the correlation between streamflow and precipitation is low in convective precipitation events. If precipitation data are necessary, a gridded data set (e.g., Stage IV) would be more useful than the site-specific station data discussed in Section 2.2.

Figure 13. Example of the effects of a monsoon on daily mean precipitation. Image reproduced from National Weather Service (n.d.a).



3.2 Lake effect snow

Lake effect snow is a common occurrence during the late fall and winter months in the Great Lakes region but can occur near the shoreline of large waterbodies anywhere in the mid to high latitudes. This process occurs when cold air moves over warmer waters, causing water vapor to rise and condense (Peace and Sykes 1966). When condensation occurs, clouds form and bands of snow develop (Figure 14). This can sometimes lead to heavy snowfall and very sharp gradients in snowfall amounts across short distances (Steenburgh and Campbell 2017). The orientation of the land and moisture source relative to the wind direction can have a significant effect on the amount and inland extent of lake effect snow (Villani et al. 2017). These events can be identified on the National Snowfall Analysis map, where sharp gradients in snowfall amounts occur along lake shorelines. Figure 15 displays an example of this along the eastern shoreline of Lake Erie.

During the lake effect snow season, it is often necessary to deviate from the APT's underlying methodology for evaluating typical year. Extreme

precipitation in one area can influence stream conditions in neighboring areas that experienced little to no precipitation. Therefore, a 30-day rolling total of precipitation for a specific location would not be an accurate representation of stream conditions following a lake effect snow event. It is also likely that there will be a lag between heavy snowfall precipitation events and higher streamflow conditions because runoff from snowmelt occurs later in time. This scenario is more likely in higher latitudes, where temperatures can remain below freezing for an extended period of time in the winter months.

Figure 14. Favorable conditions for lake effect snow. Image reproduced from National Weather Service (n.d.c).

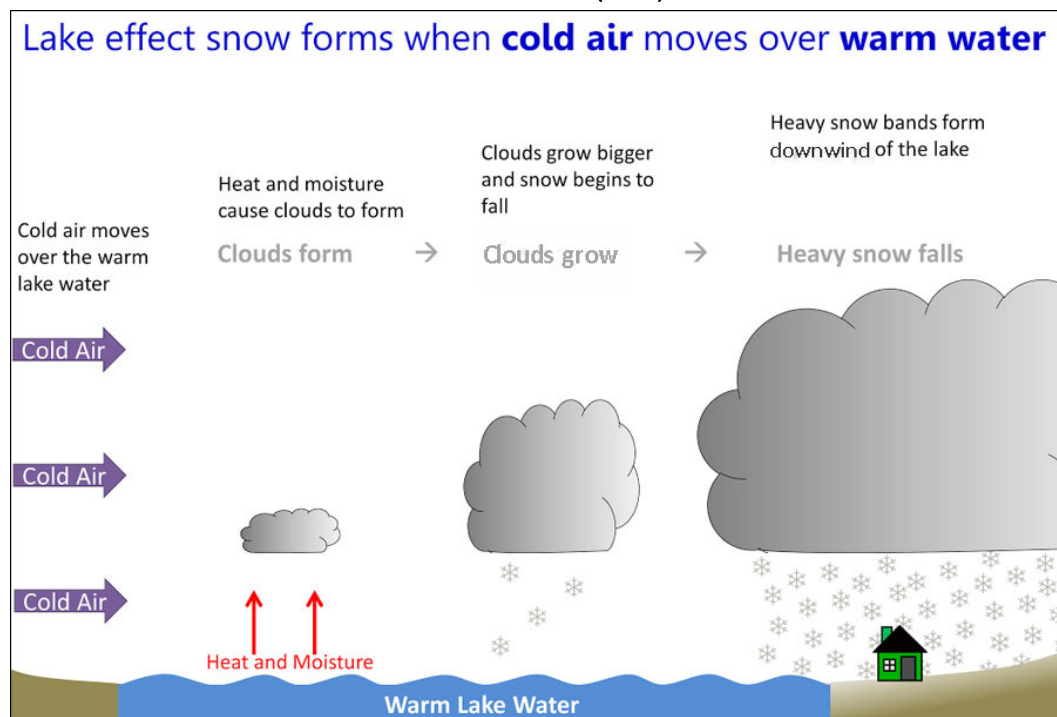
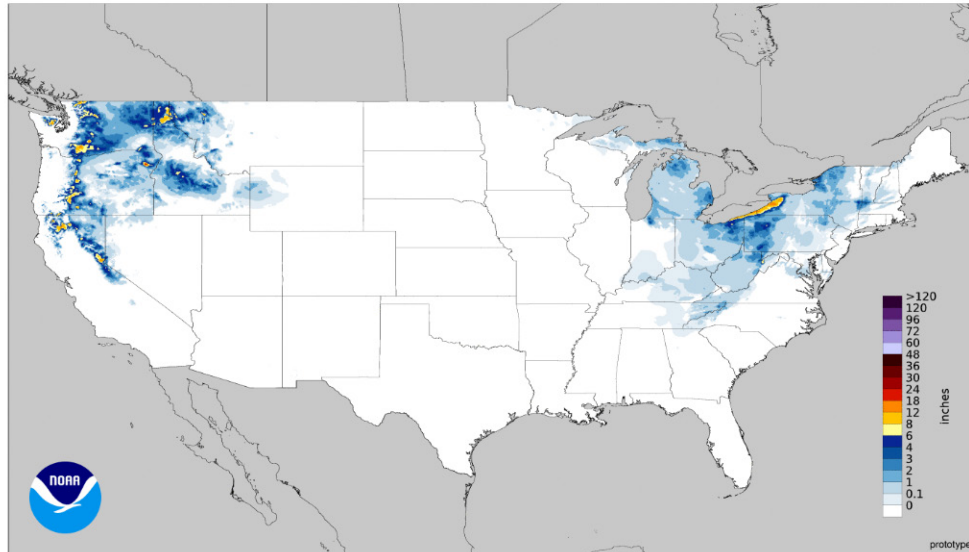


Figure 15. Lake effect snow example. Image reproduced from the National Gridded Snowfall Analysis (NOAA n.d.a).

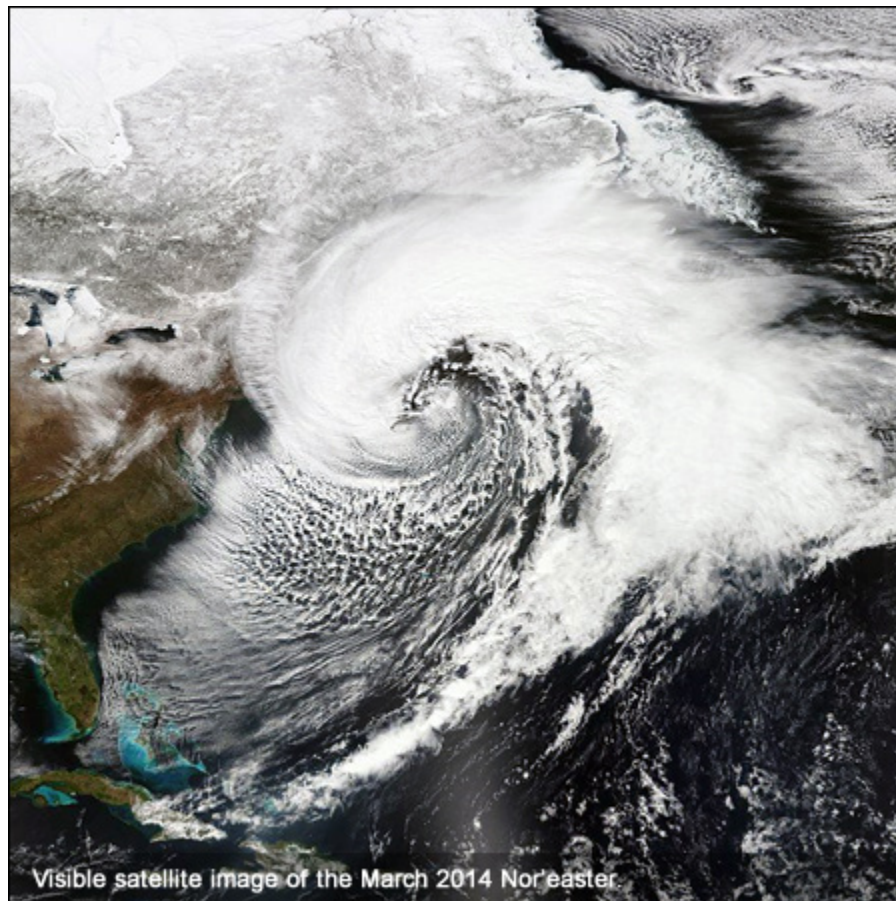
National Snowfall Analysis: 24-hour accumulation ending 2020-12-26 12 UTC
5041 reports; issued 2020-12-26 21:34:10 UTC



3.3 Nor'easters

Nor'easters form from midlatitude cyclones that move along the East Coast of the US and Canada (Figure 16). They are given the name due to the strong northeast wind that typically occurs along the backside of the low-pressure circulation as they move along the coastline. They can bring heavy rain, river flooding, snowfall, blizzards, coastal flooding, and dangerous sea conditions (Beardsley et al. 2013). Nor'easters most frequently occur between the months of September and April, when the polar jet stream transports arctic air southward toward the Atlantic Ocean (Davis and Dolan 1993). Cold air moves over the relatively warm waters of the Gulf Stream, and this difference in temperature can cause the low-pressure system to strengthen rapidly. Nor'easters often impact the heavily populated areas along the East Coast between Washington, DC, and New England, where they bring significant disruptions to life and cause major property damage each year.

Figure 16. Satellite imagery of a nor'easter. Image reproduced from National Weather Service (n.d.b).



It is often necessary to deviate from the APT's underlying methodology when evaluating a typical year in the event of a nor'easter due to the extreme weather that is likely to occur. A rapid rise in streamflow due to heavy precipitation and sharp gradients in precipitation amounts can be expected. Weather observation stations in close proximity to each other can have drastically different precipitation totals. Stream gage data or gridded precipitation data are the most useful for assessing the normalcy of conditions in the event of a nor'easter. This is especially true if the location in question has a tight gradient in precipitation amounts. Heavy precipitation events also might affect typical year calculations for 90 days. Saturated soil could result in excessive runoff and high-flow conditions that might not be captured by the APT.

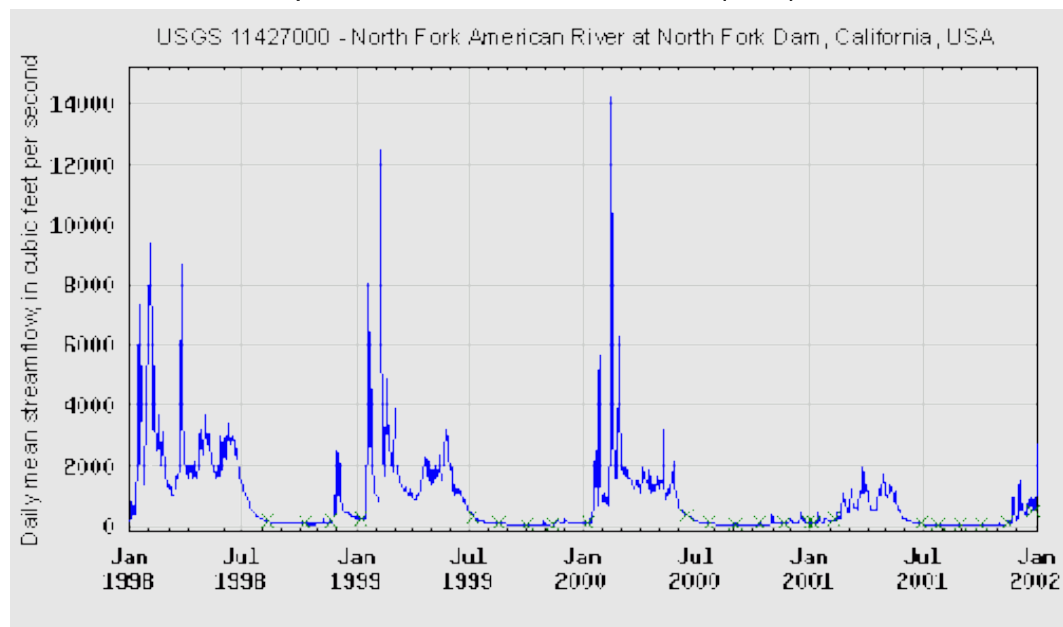
3.4 Snowpack melt

In the CONUS, melt season is typically during February, March, and April (Kent, 1972). Rapid snowpack melt can cause abnormally high streamflow

and flooding, and APT's underlying methodology might have difficulty capturing such events. Rapid snowpack melt takes place when there is a rapid increase in the temperature of the snowpack. Large variations in discharge are possible throughout melt seasons and between seasons. This is evident on the hydrograph displayed in Figure 17.

During melt seasons, it is likely that resources other than the methodology used in the APT will be needed to assess the normalcy of stream conditions. The SNODAS products that indicate the amount of SWE and the temperature of the snowpack (Section 2), hydrologic models (e.g., the NWM or SPT), or USGS stream gages should be used to assess stream conditions during melt seasons. While the APT's underlying methodology might be useful for determining if a normal amount of precipitation has occurred, it is not likely to be useful when large temperature fluctuations cause rapid snowpack melt and changes in streamflow.

Figure 17. Hydrograph example of spikes in streamflow from rapid snowmelt. Image reproduced from Water Science School (2019).



4 Assessing the Capacity of the Antecedent Precipitation Tool (APT) for Approximating Daily Streamflow Conditions

Because practitioners sometimes use the APT to determine if streamflow conditions observed during a field visit or in aerial imagery are representative of normal, dry, or wet conditions for the stream, this section details an initial comparison of daily APT α , monthly PDSI from NOAA's Climate Divisional Database (nClimDiv), and observed daily USGS streamflow percentiles. Both the APT α and nClimDiv PDSI are provided to the user in each APT output. The intention of the initial analysis was to ascertain if the APT α and nClimDiv PDSI accurately and precisely measure streamflow conditions on a given day. A list of all USGS gage locations used in the analysis can be found in the Appendix.

4.1 APT, Palmer Drought Severity Index (PDSI), and USGS gage comparison

The methodology within the APT has a documented history of being useful for assessing precipitation normalcy for wetlands (Sprecher and Warne 2000; Vepraskas et al. 2019). However, no similar documentation is available for streams. To perform a preliminary assessment of the accuracy and precision with which the APT α and the nClimDiv PDSI measure streamflow conditions, the calculated daily APT (version 1.0) α and the queried monthly nClimDiv PDSI values were compared with observed daily USGS percentiles (P) for the October 2015 to September 2016 time period (i.e., the 2016 water year). Compared to the preceding 87 years, the 2016 water year ranked 12th highest in nationwide streamflow, meaning the water year was relatively wet historically (Jian et al. 2017). We limited our study to one water year due to computational time constraints associated with APT processing speed.

As detailed in Gutenson and Deters (2022), α is a single value that ranges from 6 to 18 and is a weighted sum index comparing three 30-day rolling totals of precipitation on the observation date to historical totals over the preceding 30 years. The APT has two general ways of calculating α : a single-point or watershed analysis. An APT single-point analysis generates a single α value and queries the monthly nClimDiv PDSI value for a given observation point and date. An APT watershed analysis undertakes the

same analysis as an APT single-point analysis but does so multiple times throughout a user-specified upstream watershed for the observation point. In an APT watershed analysis, the APT generates random sampling points throughout the upstream watershed, runs the equivalent of an APT single-point analysis at those upstream watershed sampling points, and averages the resulting values of α to generate the APT watershed-analysis α . Each APT run also collects PDSI data archived on a monthly time step at the climate division level in the nClimDiv data set (NOAA 2014; Vose et al. 2014; Gutenson and Deters 2022). The PDSI is a cumulative index of water balance that tends to range between positive and negative 10 (NCAR 2020; Palmer 1965). This analysis collects daily PDSI estimates from the monthly nClimDiv data set, so days falling in the same month and year will have identical PDSI values.

The Ulmo (Github 2021) software library is used to collect P . Ulmo accesses daily stream gage data available within the USGS National Water Information System (NWIS; USGS 2022). This analysis extracts the daily average of observed streamflow and the daily streamflow percentiles from NWIS, bins the daily average streamflow into a percentile category using the NWIS daily percentiles, and interpolates a streamflow percentile from this binning. We assumed that if α or PDSI are accurate and precise measures of streamflow conditions on a given day, they should correlate well with P , or with the below-normal, normal, and above-normal categories of P .

Regionalization of the analysis occurred using two-digit HUC regions. The two-digit HUC classification divides the US into 21 geographic areas that share the same drainage area of a major river or the combined drainage area of a series of rivers (Seaber et al. 1987). Two-digit HUC classifications were a logical division, given their division by major drainage areas and the fact that the software used in the analysis, Ulmo (Github 2021), uses this division to group USGS gage numbers.

Assessment of the APT single-point analysis occurred for a sample of USGS gage locations within each two-digit HUC. The researchers chose the USGS gage locations in each HUC by having Ulmo list 40 stream gages within each division. The number of USGS gages chosen in each two-digit HUC varied according to the number of successful APT simulations that encapsulated the entire October 2015 to September 2016 period. For each USGS gage location, the researchers calculated an APT single-point α and

collected a monthly nClimDiv PDSI value for each day in the study period (366 days because the chosen period encompassed a leap year). The researchers also collected a daily P and the size of the upstream watershed from USGS NWIS. The selection of USGS gages did not consider the representativeness of the gages in comparison to the rest of the two-digit HUC, the watershed size, or the degree of regulation. If gages listed in the Appendix do not have a drainage area, NWIS did not report a drainage area.

Daily calculations of APT single-point α and PDSI were compared to daily P in two ways. First, values for α , PDSI, and P were classified into one of three categories: dry (i.e., below normal), normal, or wet (i.e., above normal). Table 2 identifies those categories. The methodology underlying the calculation of α denotes the categories applied to α (Gutenson and Deters 2022; NRCS 1997). PDSI categories are specified based on NOAA's visual categorizations of the data (NOAA 2022). P categories align with the categories of below normal, normal, and above normal assigned by the USGS (2011). These categories allowed the researchers to assess the accuracy of the APT single-point α and PDSI categories in reflecting observed below-normal, normal, and above-normal P conditions. Accuracy was calculated by dividing the number of hits by the sum of hits and misses. Hits were daily instances for each USGS gage where the determined category of α or PDSI aligned with categories of observed P for each gage. Misses were daily instances for each USGS gage where the determined category of α or PDSI did not align with categories of observed P for each gage. For example, a hit would be an α less than 10 on the same day that the USGS streamflow percentile was below 25%, while a miss would be an α less than 10 on the same day that the USGS streamflow percentile was above 25%. The second comparison considered daily APT single-point α and P within each two-digit HUC to assess the precision with which α measured P . Although daily percentiles are not always the same as atypical conditions for a given year, streamflow percentiles can be used to provide a consistent evaluation of the correlation between α , PDSI, and P throughout the United States. Other characterization methods, such as ordinary high water marks and bankfull streamflow, tend to vary at locations throughout the United States (Hamill and David 2021; Williams 1978).

Table 2. Assigned APT α , PDSI, and USGS WaterWatch streamflow percentiles used to assess the accuracy of the APT α and nClimDiv PDSI in reflecting USGS streamflow percentiles.

Condition	APT Antecedent Precipitation Score (α)	PDSI Value	USGS WaterWatch Streamflow Percentile (P)
Dry	$\alpha < 10$	$\text{PDSI} \leq -2$	$P < 25$
Normal	$10 \leq \alpha < 15$	$-2 < \text{PDSI} < 2$	$25 \leq P \leq 75$
Wet	$\alpha \geq 15$	$\text{PDSI} \geq 2$	$P > 75$

An assessment of the APT custom-watershed α determines if inclusion of hydroclimatology upstream of an observation point affects the accuracy of the APT. Due to the computational limitations of the APT, we limited this analysis to a single, randomly selected gage within each two-digit HUC. The EPA's Watershed Assessment, Tracking and Environmental Results System (WATERS) Web services provided the upstream delineation of watershed boundaries for each APT custom watershed analysis (EPA 2021b). The same categories for α and P identified in Table 2 were used to assess accuracy.

4.2 APT antecedent precipitation score, PDSI accuracy, and watershed size

The researchers hypothesized that watershed area would be a strong predictor of the accuracy of an APT analysis. To ascertain if a relationship exists between watershed size and APT analysis accuracy, the researchers assessed whether, according to the categories in Table 2, daily categories of APT single-point α and monthly categories of nClimDiv PDSI accurately represented daily categories of P for each stream listed in the Appendix. To accomplish this assessment, the total number of hits for each gage in the study was divided by the number of hits and misses for each gage. Figures 18 and 19 present the results for both the APT single-point α and the nClimDiv PDSI at each USGS gage in our study. Each point in the figures represents the size of the watershed upstream of each USGS gage and the accuracy of the α and the PDSI categories in estimating the corresponding category of P . The red line in each plot represents the ordinary least squares line of best fit, and the R^2 value in each plot is the coefficient of determination. Ranging from 0 to 1, R^2 is a measure of fit for the line of best fit and indicates how much of the variability in the dependent variable, in this case the accuracy of α or nClimDiv PDSI, is explained by the independent variable of watershed size. R^2 was near zero in both instances, suggesting that watershed size does not substantially affect the accuracy of

the APT or the nClimDiv PDSI. These results supported the conclusion that watershed size does not affect the accuracy of an APT analysis.

Figure 18. Comparison of daily Antecedent Precipitation Tool (APT) single-point α accuracy and upstream watershed area for each USGS gage listed in the Appendix for the October 2015 to September 2016 period.

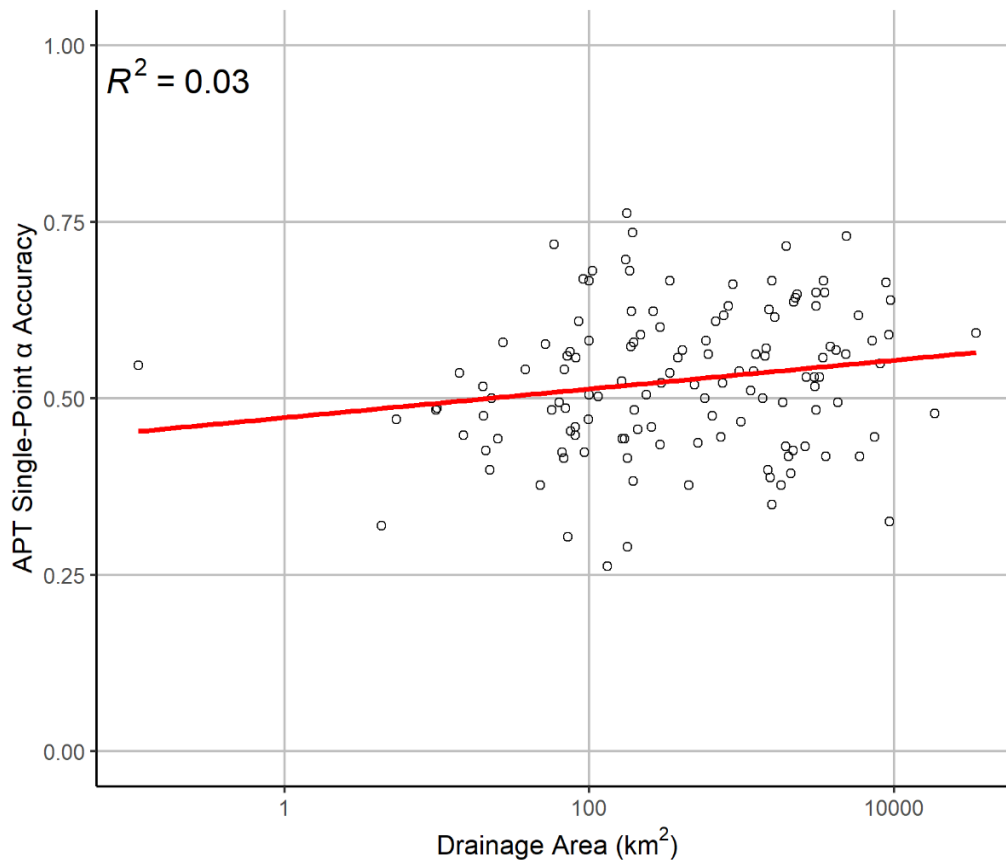
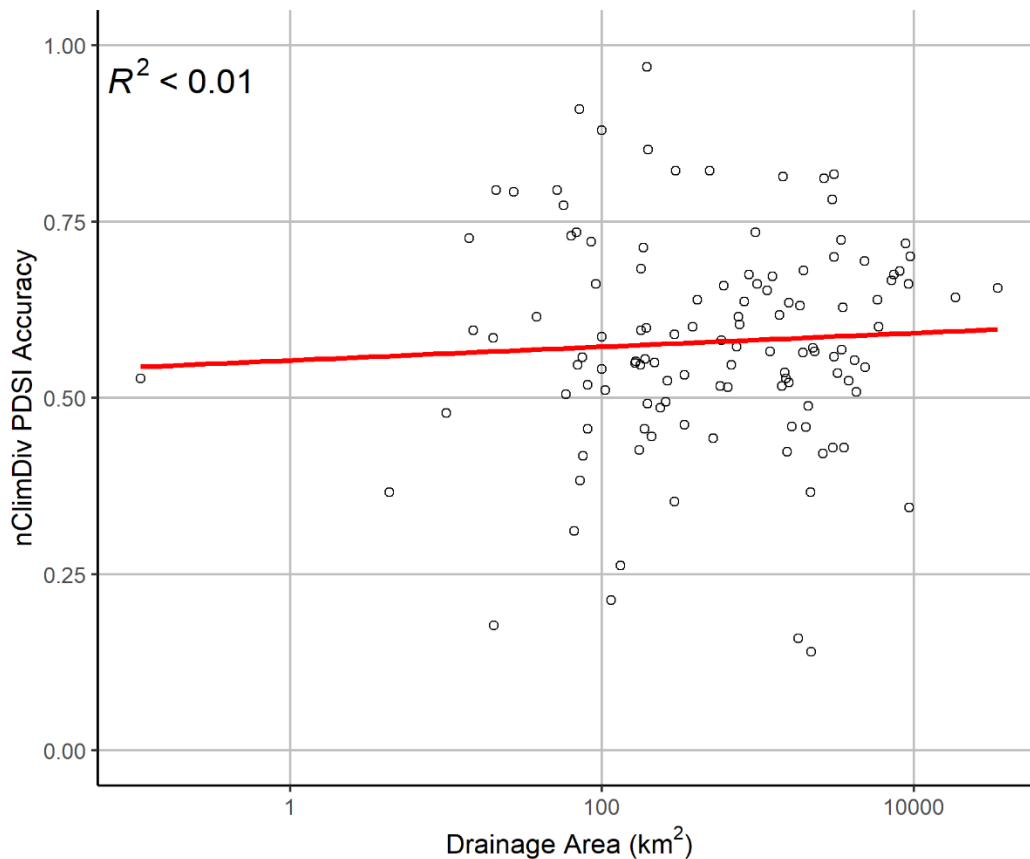


Figure 19. Comparison of daily single-point Palmer Drought Severity Index (PDSI) accuracy and upstream watershed area for each USGS gage listed in the Appendix for the October 2015 to September 2016 period.



4.3 Hydrologic Unit Code (HUC) analysis

The regional analysis of the ability of APT α and PDSI to precisely measure P and accurately assess categories of P demonstrated consistent results with only minor variations. The sections that follow illustrate the findings through three types of graphics (Figures 20 through 81).

The first graphic in each section is a bar chart that illustrates the monthly accuracy of single-point α and PDSI categories in predicting the appropriate P category. Daily APT single-point analyses estimate α and query the nClimDiv PDSI. These bar charts were constructed by computing the aggregate number of hits in each month and dividing that by the aggregate sum of hits and misses in each month across all USGS stream gages in each two-digit HUC, based on correspondence with the categories expressed in Table 2. The results indicated that the single-point APT and nClimDiv PDSI are typically inaccurate and imprecise predictors of

streamflow normalcy. For significant portions of the study period, the monthly accuracy of the APT single-point α in predicting streamflow normalcy was below 0.50. This means that the APT category assigned by computing α was predictive of the P category less than half of the time for the month across all USGS gages in that two-digit HUC. The nClimDiv PDSI occasionally provided a more accurate representation of streamflow conditions (e.g., HUC 07–Upper Mississippi) than the APT single-point α , but this improvement was inconsistent (e.g., HUC 18–California). There were also isolated instances of seasonality (e.g., HUC 04–Great Lakes) in the level of accuracy. The nClimDiv PDSI data were unavailable in HUC 19–Alaska, HUC 20–Hawaii, and HUC 21–Puerto Rico.

The second graphic in each section compares the accuracy of the APT single-point α and custom-watershed α using a bar chart. Much like the first graphic in each section, the second graphic in each section expresses monthly accuracy as reflected by the correspondence between the alignment of α and P in terms of the categories listed in Table 2. However, because of the longer computational times associated with the APT custom-watershed analysis, the monthly accuracy in these plots applies to only one USGS gage in each two-digit HUC. For instance, the second graphic under HUC 01 (Figure 20) expresses the monthly accuracy for USGS gage 01011000. One notable exception to this analysis is HUC 19–Alaska, where the researchers were unable to generate a custom watershed using EPA WATERS for upstream delineation of watershed boundaries. The use of the APT custom-watershed analysis appears to offer little to no improvement in the accuracy of the APT above that of the APT single-point in predicting the appropriate category of P . For instance, Figure 54 illustrates that the average monthly APT custom-watershed accuracy for USGS Gage 08017410 is only greater than the APT single-point accuracy for 3 of the 12 months of the year and, in fact, has an accuracy of zero for 4 of the 12 months of the year. The expectation was that consideration of the entire upstream area of a stream would increase the accuracy of the APT analysis. However, this expectation was rarely met throughout all sample locations within each two-digit HUC. Thus, when compared to using only the observation point (i.e., APT single-point analysis) to analyze the hydroclimatology of a stream, the inclusion of the entire upstream area of the stream within the APT analysis offered little to no increase in accuracy.

The third graphic in each section compares the daily APT single-point α and monthly nClimDiv PDSI to P for that same location using scatterplots

and box plots. Each point in the scatterplots represents an individual day at each USGS location during the October 2015 to September 2016 period (366 points for each gage). The x -axis of the scatterplot is the APT single-point α and PDSI for that day at the USGS gage location. The y -axis of the scatterplot is the recorded P for that day at the USGS location. The *Dry/Below Normal*, *Normal*, and *Wet/Above Normal* agreement zones in the scatterplots represent the regions of the scatterplots where the α and PDSI categories should agree with the P categories (i.e., the categories in Table 2). The red line in each plot represents the ordinary least squares line of best fit, and the R^2 value in each plot is the coefficient of determination. In this instance, R^2 indicates how much of the variability in the dependent variable, in this case streamflow percentile, is explained by the independent variable, α . The higher the R^2 , the more precise the line of best fit. The box plots in this class of figures describe the spread of P observed for each APT single-point α value and the PDSI averaged to the nearest whole number. In general, the APT single-point α and PDSI had a positive correlation with P because the red line of best fit tended to slope upward.

Only one two-digit HUC, HUC 18, had a downward sloping, negative correlation with APT single-point α (Figure 73). However, the APT single-point α was not a precise predictor of daily P , with R^2 values ranging from <0.01 – 0.58 , and typically less than 0.25 , and the whiskers of each two-digit HUC box plot tending to extend across most of the spectrum of P for a given α or PDSI. If the APT single-point α or PDSI were a precise indicator of streamflow percentile, each of the scatterplots would demonstrate USGS streamflow percentiles increasing, with increases in α or PDSI, and the black data points would closely align with the red line of best fit. Likewise, the box plots would not have whiskers that ranged from nearly $P = 0\%$ to $P = 100\%$ for each α and PDSI value. However, these conditions rarely occurred. For instance, an APT single-point α of 10 – 14 indicated normal precipitation conditions. However, comparing those α to P , P typically ranged between near 0% (i.e., dry or low flow) and near 100% (i.e., wet or high flow) conditions, resulting in bands of dots in the scatterplot that corresponded to α and box plots that spanned that same range of P for each α . The same can generally be said of dry α (<10) and wet α (≥ 15), with few notable exceptions (e.g., wet α in Figure 38). The general lack of precision indicates that the APT's single-point α and PDSI skill in predicting P is unlikely to increase without reformulation.

4.3.1 HUC 01–New England

Figure 20. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 01 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 5 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 7 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

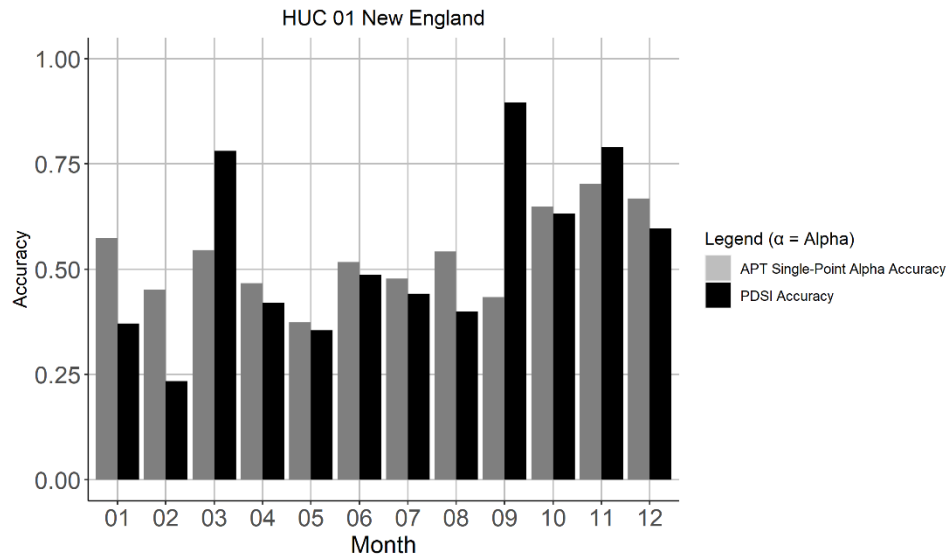


Figure 21. Comparison of APT single-point and custom-watershed α accuracy for HUC 01 at USGS Gage 01011000 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 3 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 01 Single Point and Custom Watershed Comparison at USGS 01011000

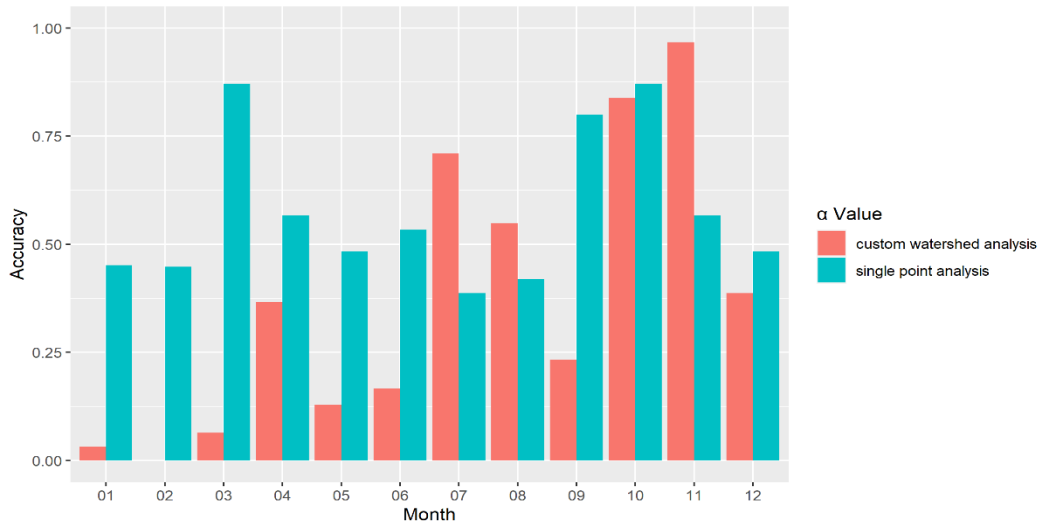
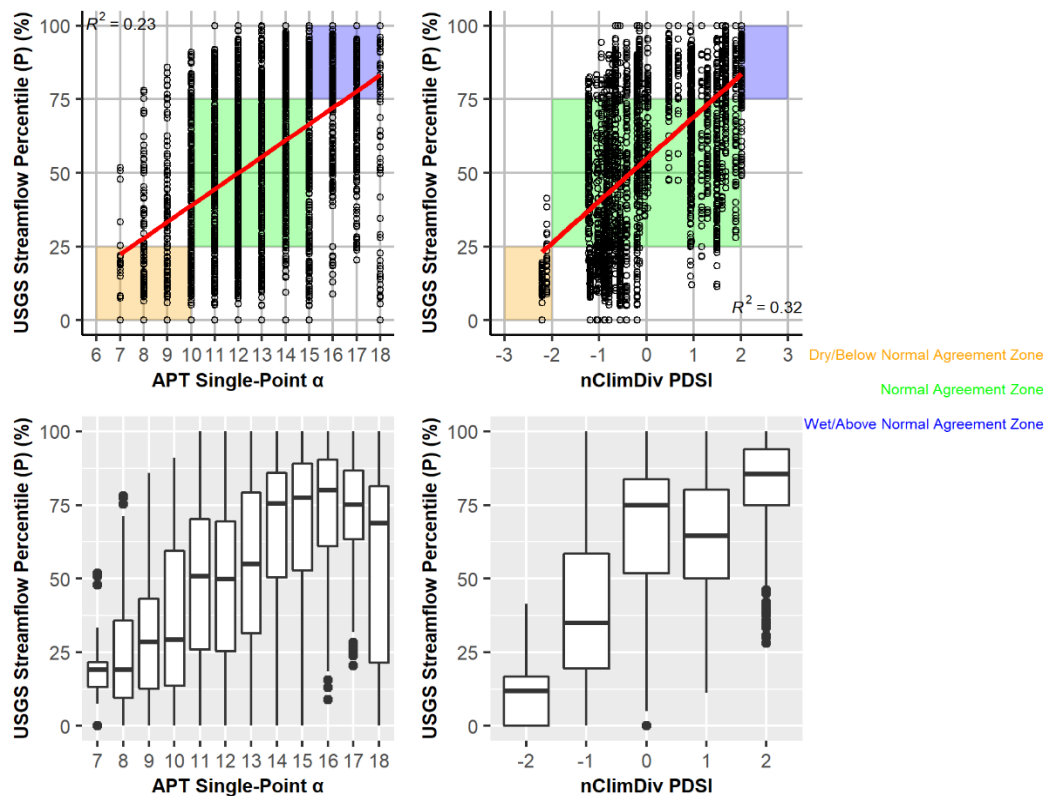


Figure 22. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 01.



4.3.2 HUC 02–Mid-Atlantic

Figure 23. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 02 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 4 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 7 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

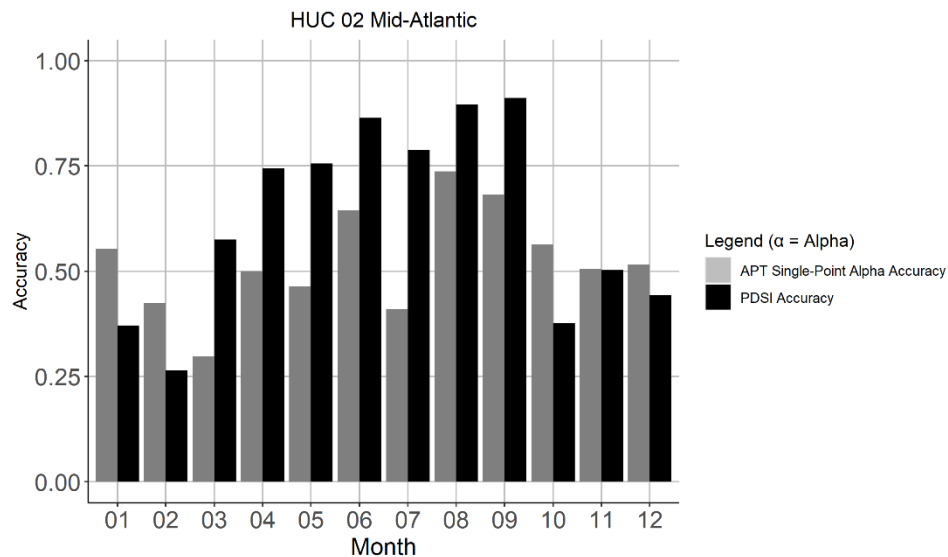


Figure 24. Comparison of APT single-point and custom-watershed α accuracy for HUC 02 at USGS Gage 01302020 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

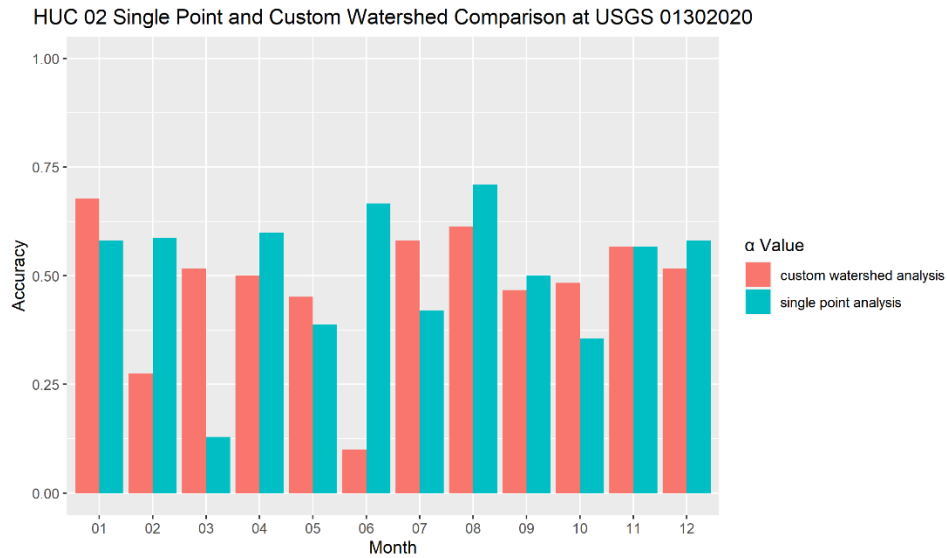
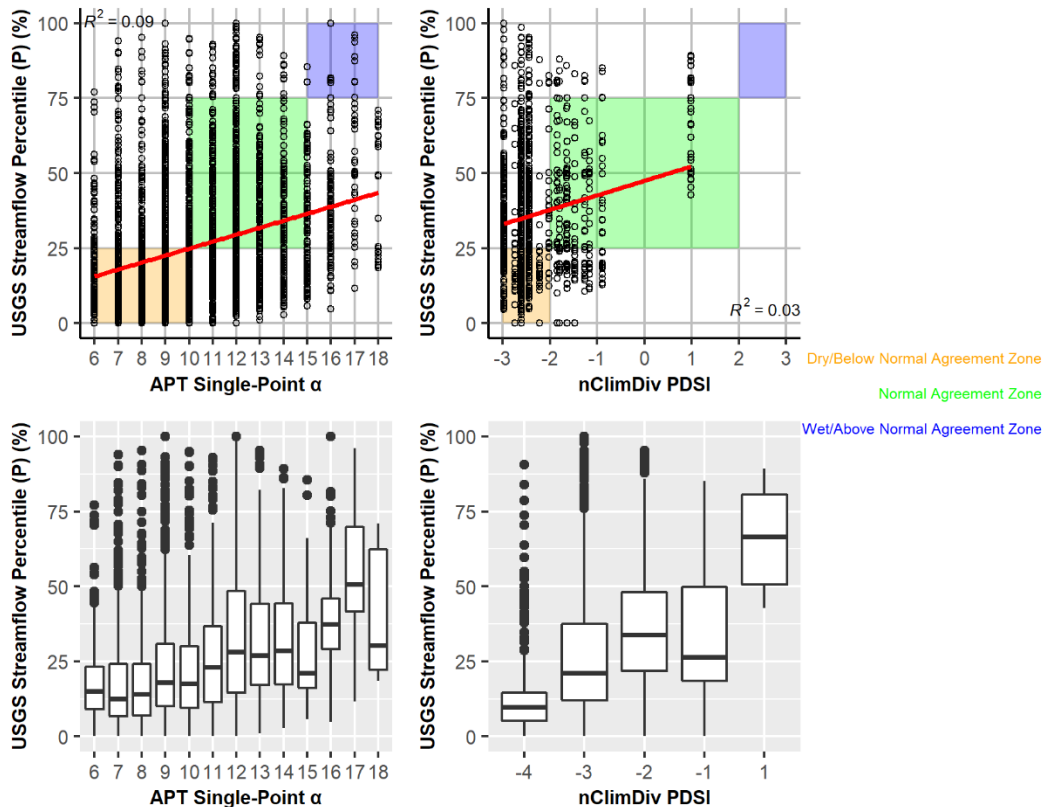


Figure 25. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 02.



4.3.3 HUC 03–South Atlantic-Gulf

Figure 26. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 03 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 6 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 2 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

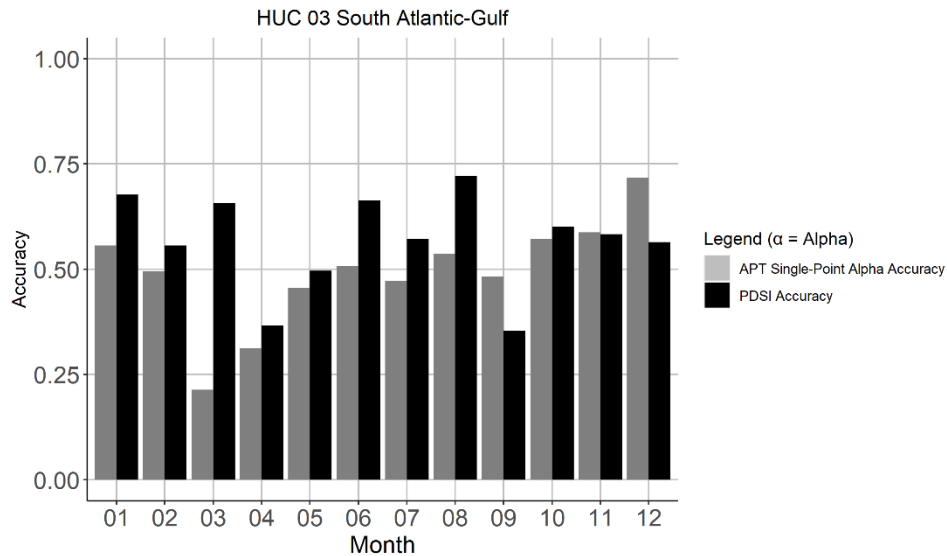


Figure 27. Comparison of APT single-point and custom-watershed α accuracy for HUC 03 at USGS Gage 02049500 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 4 of the 12 months. Months are presented according to the Julian calendar (e.g., January = 01).

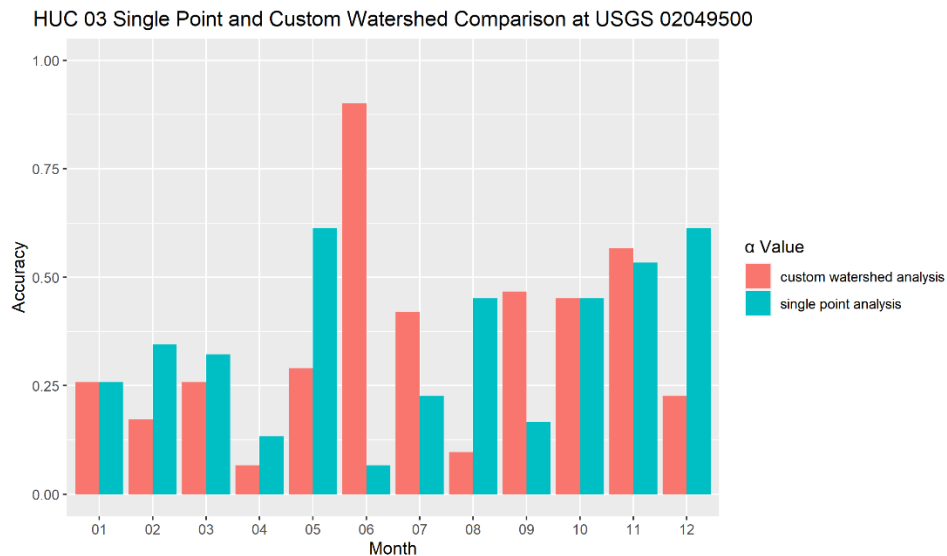
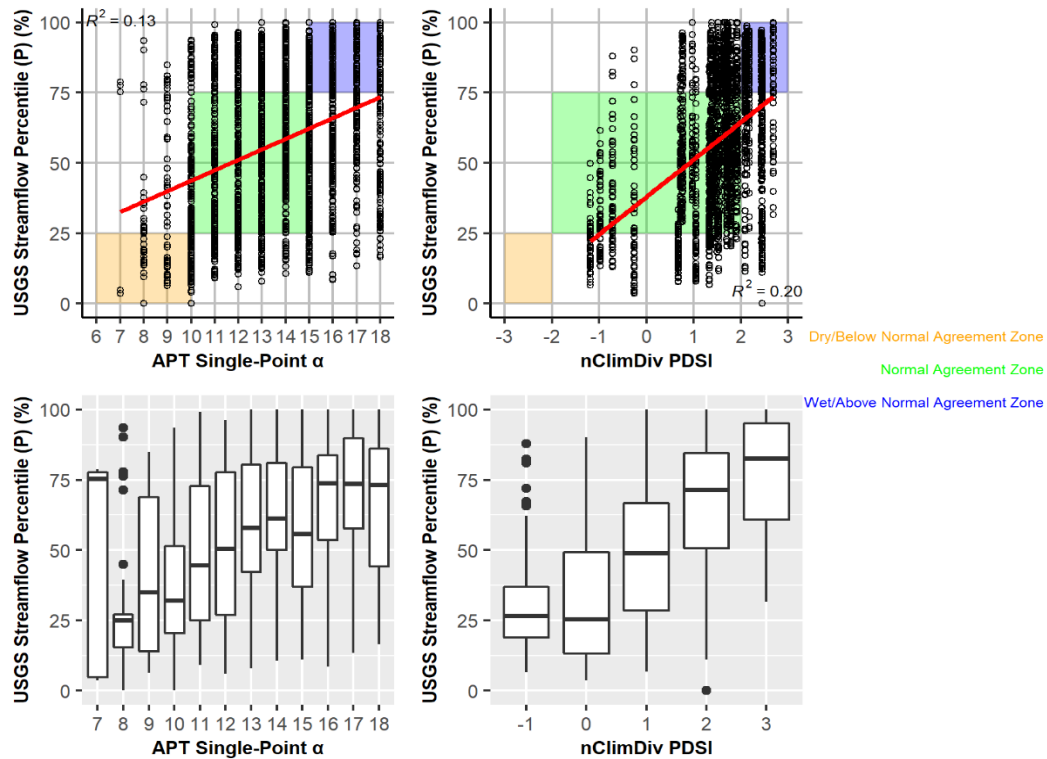


Figure 28. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 03.



4.3.4 HUC 04–Great Lakes

Figure 29. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 04 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 4 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

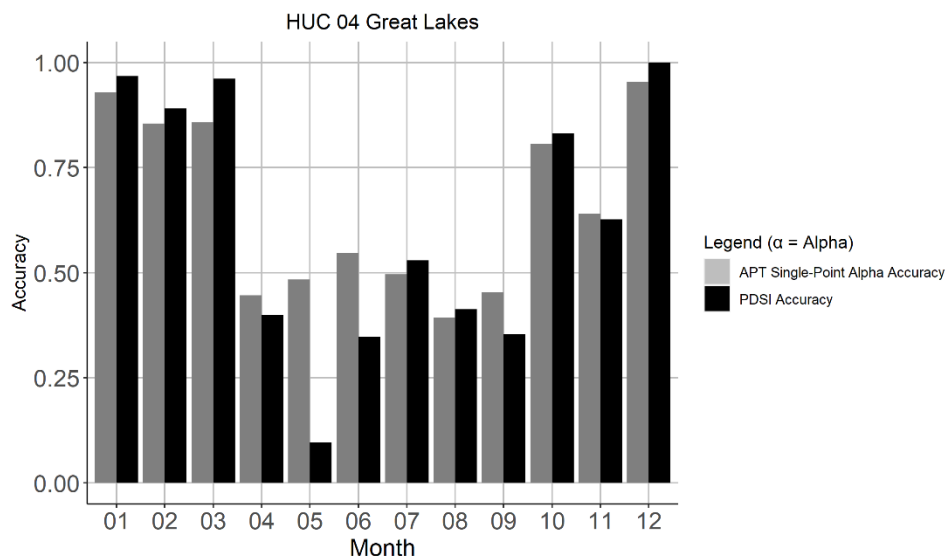


Figure 30. Comparison of APT single-point and custom-watershed α accuracy for HUC 04 at USGS Gage 04024000 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 4 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 04 Single Point and Custom Watershed Comparison at USGS 04024000

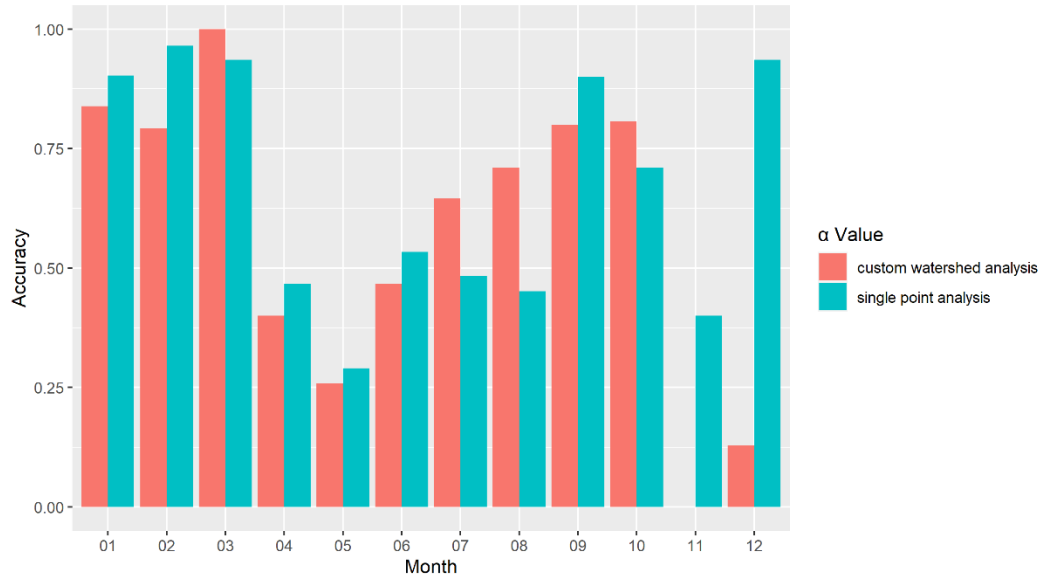
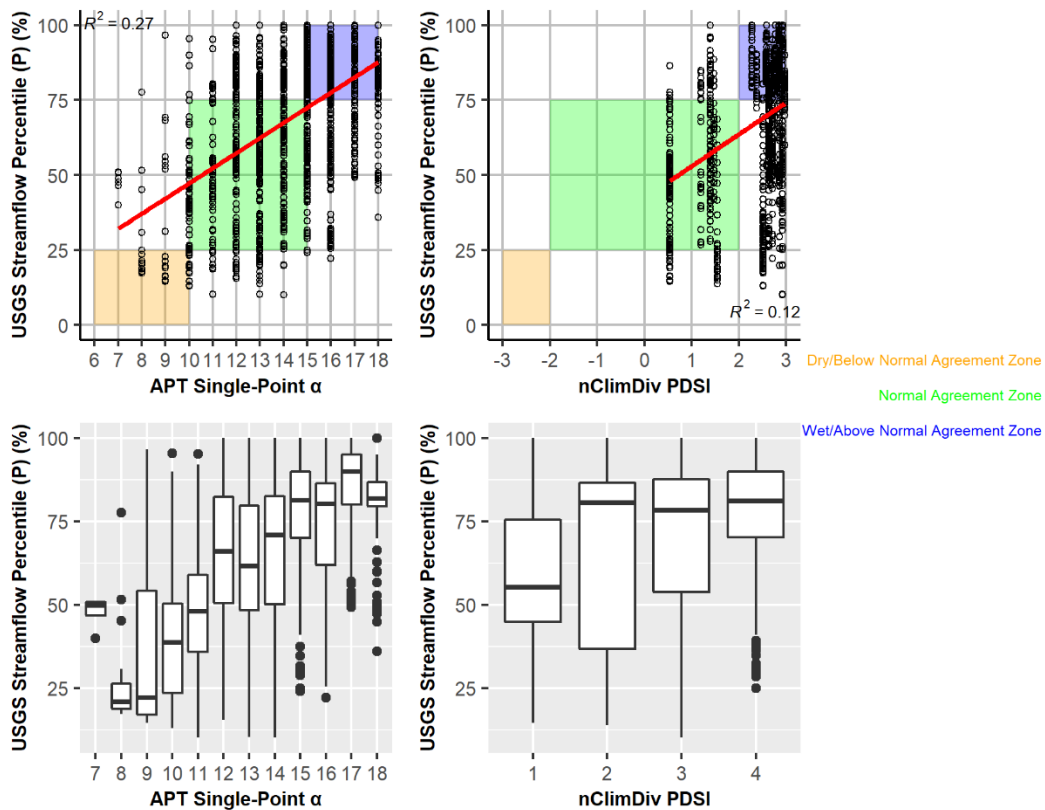


Figure 31. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 04.



4.3.5 HUC 05–Ohio

Figure 32. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 05 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 6 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 3 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

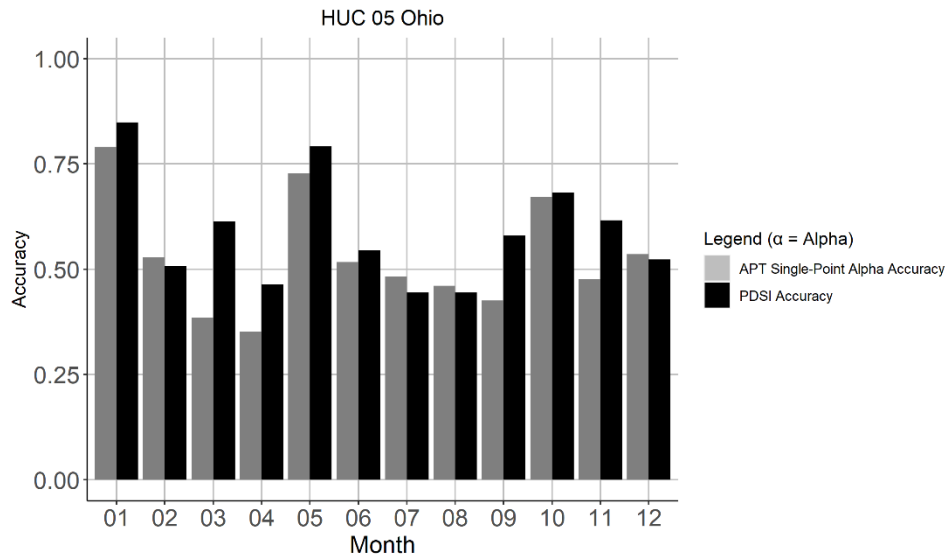


Figure 33. Comparison of APT single-point and custom-watershed APT α accuracy for HUC 05 at USGS Gage 03017500 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 05 Single Point and Custom Watershed Comparison at USGS 03017500

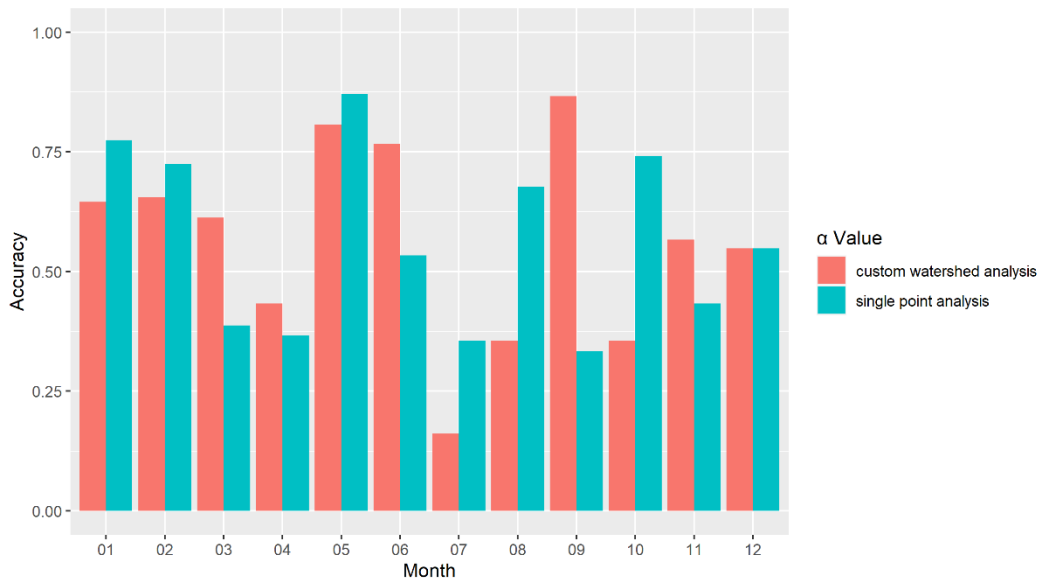
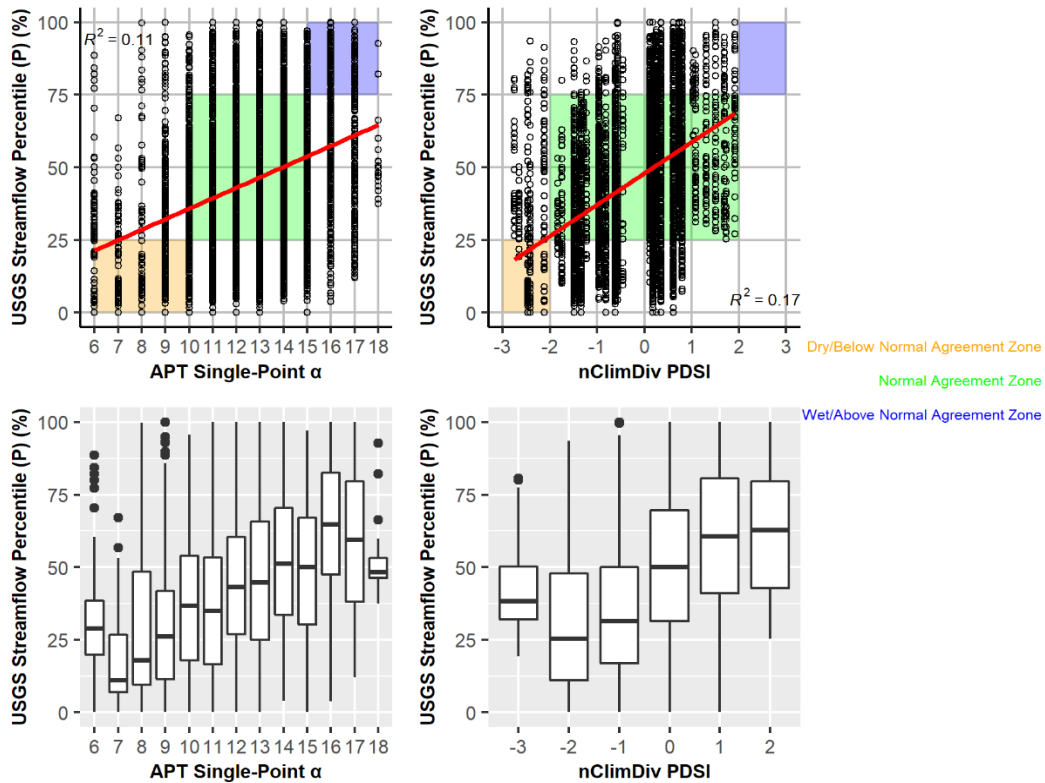


Figure 34. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 05.



4.3.6 HUC 06–Tennessee

Figure 35. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 06 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 2 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

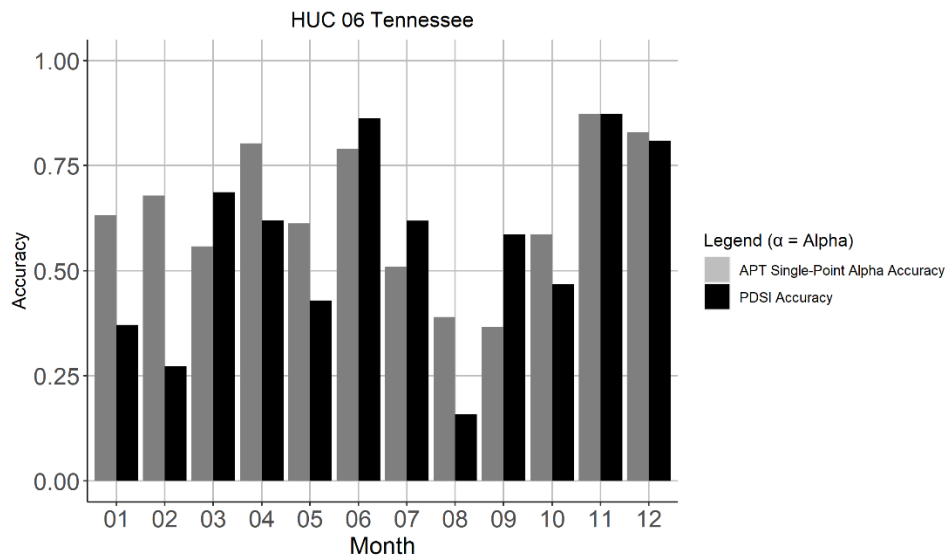


Figure 36. Comparison of APT single-point and custom-watershed α accuracy for HUC 06 at USGS Gage 0345100 from October 2015 to September 2016. The APT custom-watershed accuracy is nearly identical to the APT single-point accuracy for every month of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 06 Single Point and Custom Watershed Comparison at USGS 03451000

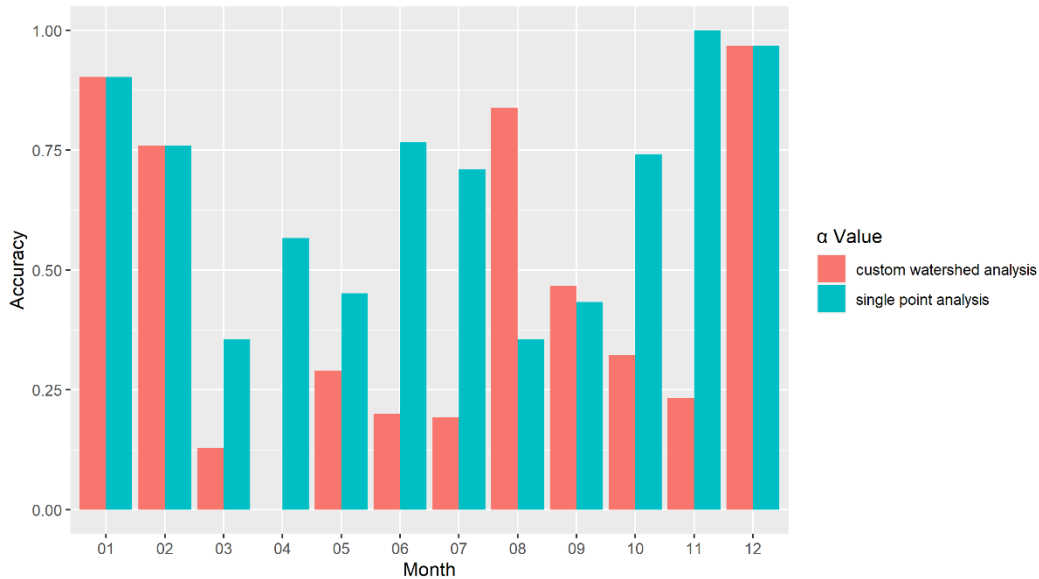
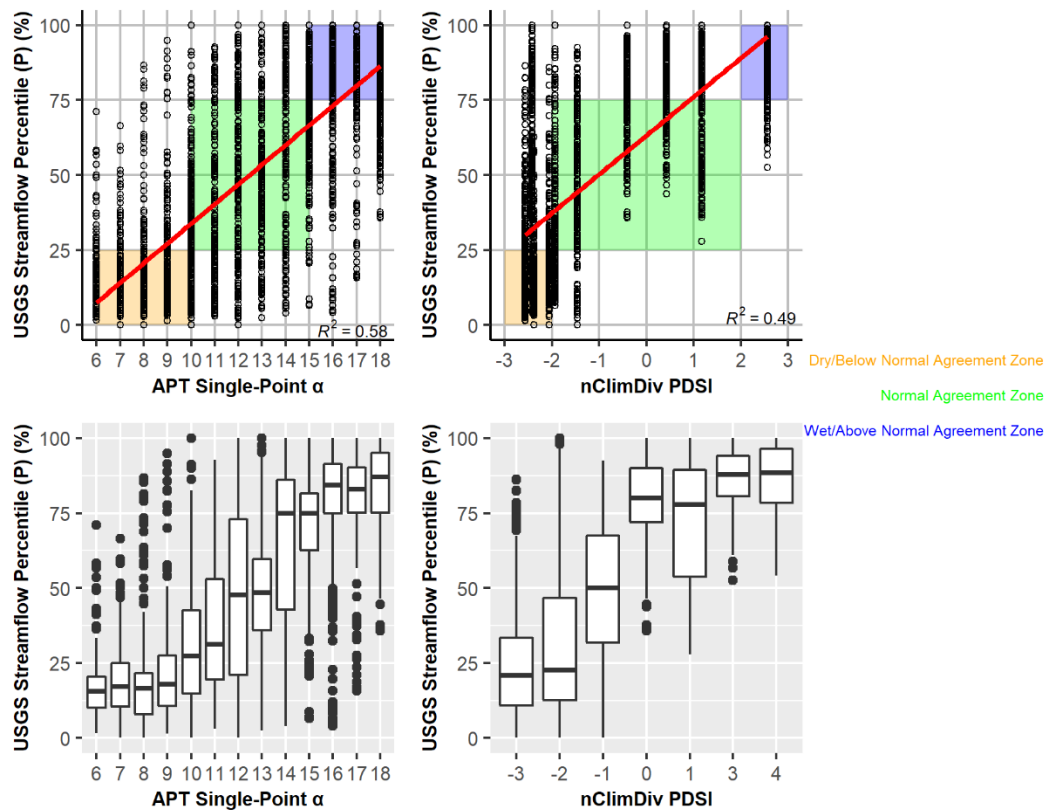


Figure 37. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 06.



4.3.7 HUC 07–Upper Mississippi

Figure 38. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 07 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 3 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 3 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

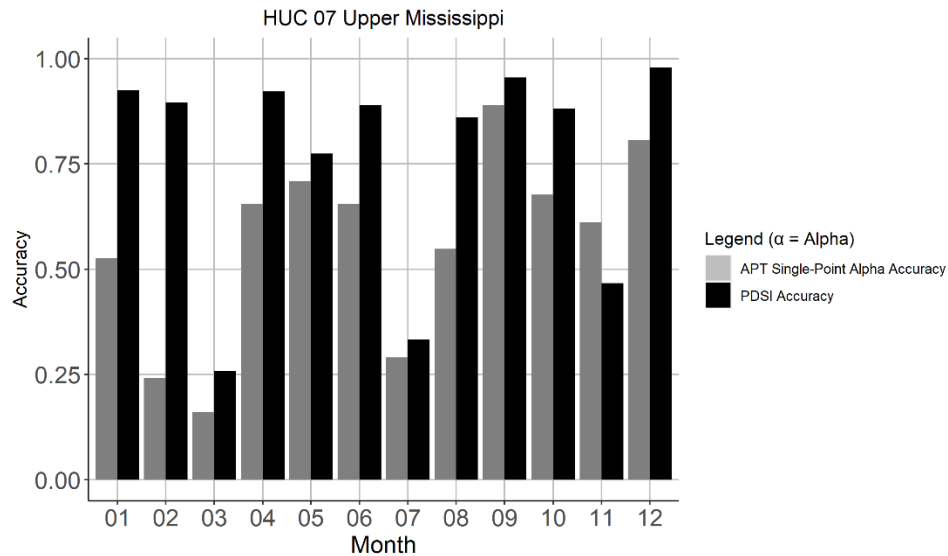


Figure 39. Comparison of APT single-point and custom-watershed α accuracy for HUC 07 at USGS Gage 05270500 from October 2015 to September 2016. The APT custom watershed-accuracy is greater than the APT single-point accuracy for 3 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 07 Single Point and Custom Watershed Comparison at USGS 05270500

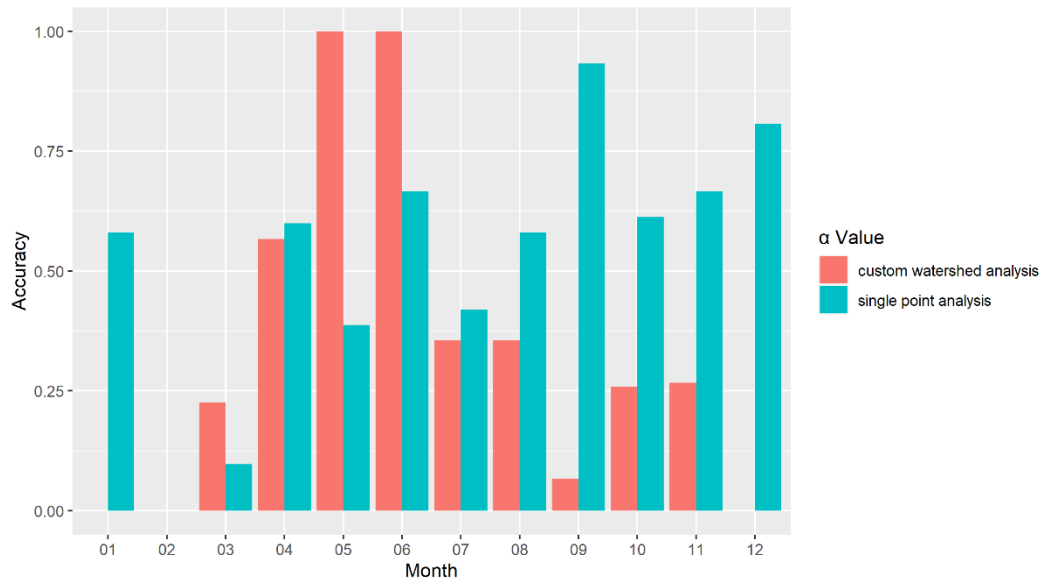
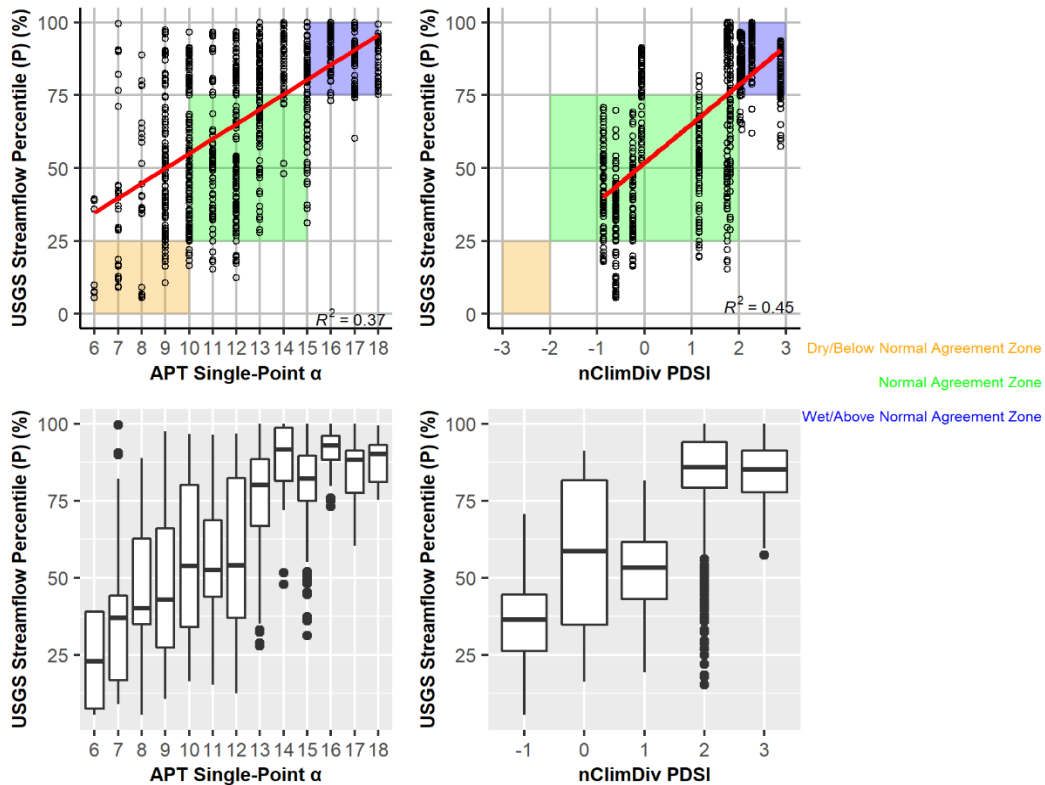


Figure 40. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 07.



4.3.8 HUC 08–Lower Mississippi

Figure 41. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 08 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 6 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 3 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

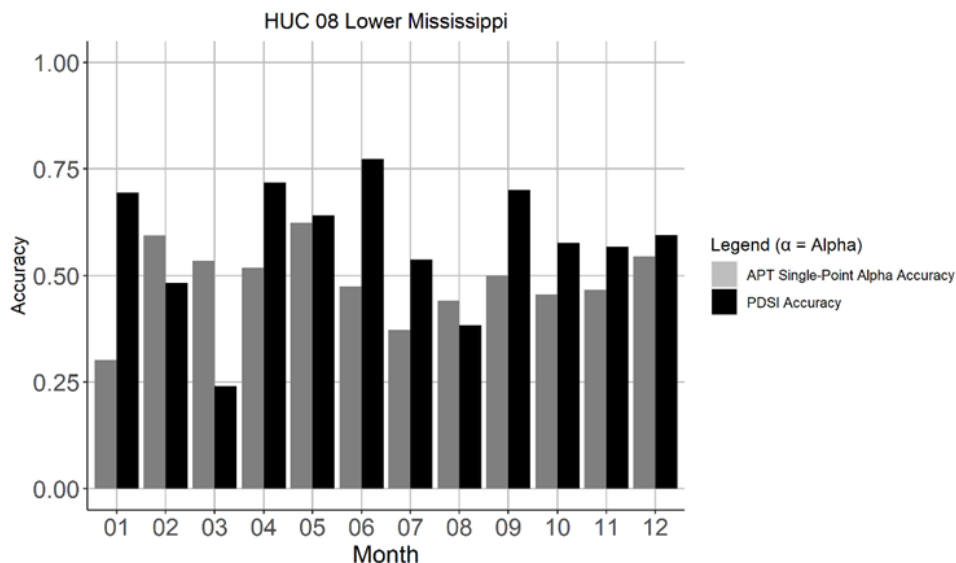


Figure 42. Comparison of APT single-point and custom-watershed α accuracy for HUC 08 at USGS Gage 07024200 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 7 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 08 Single Point and Custom Watershed Comparison at USGS 07024200

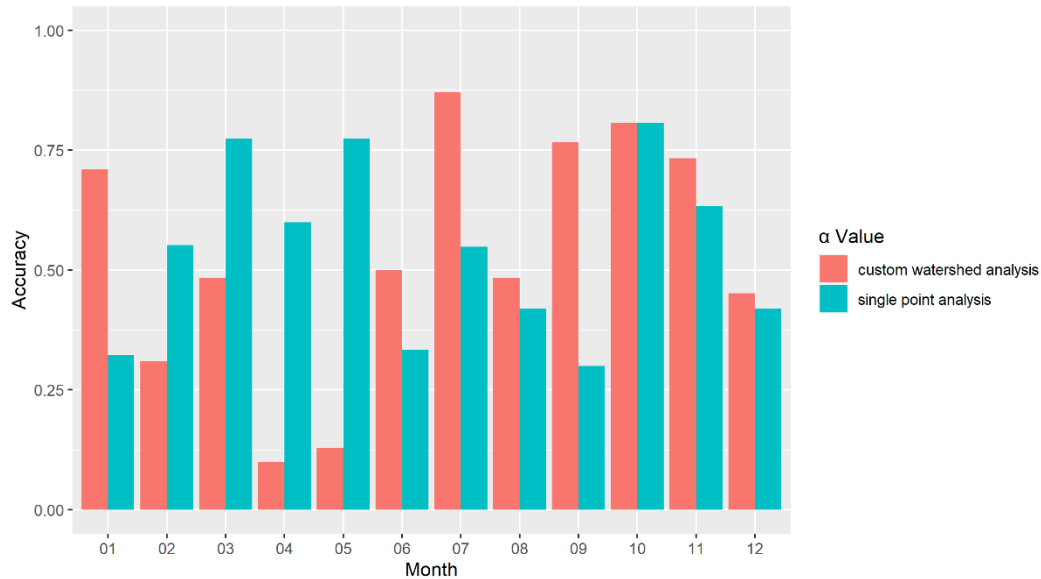
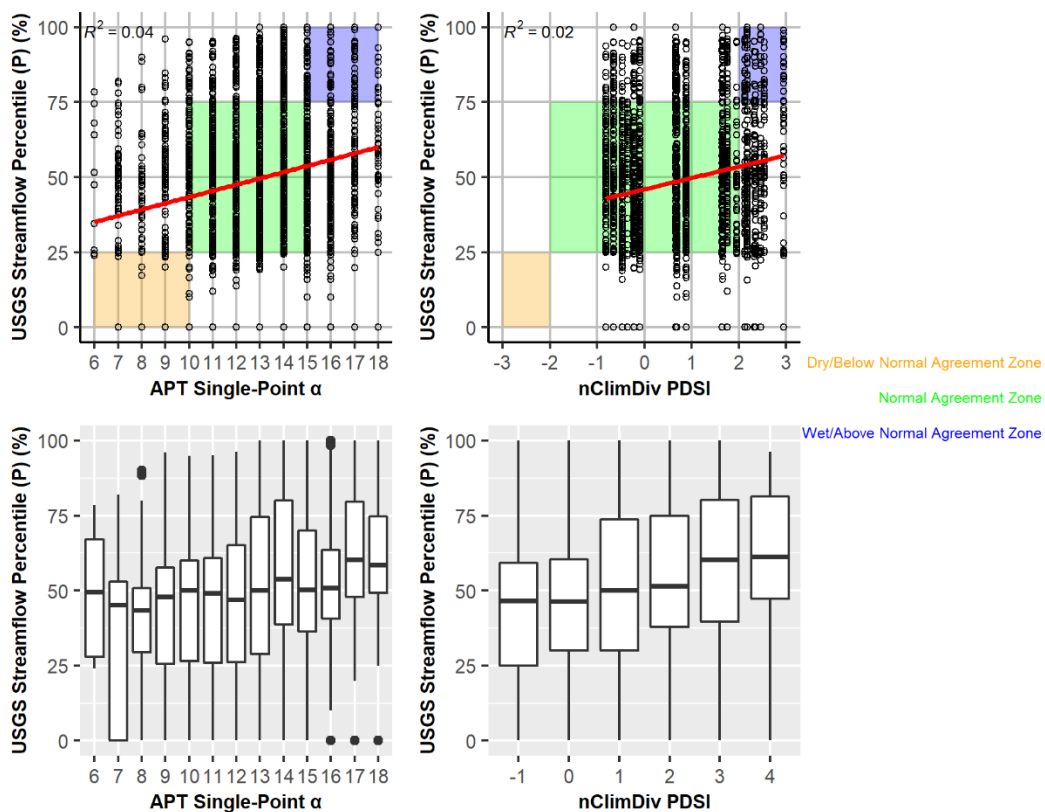


Figure 43. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 08.



4.3.9 HUC 09–Souris-Red-Rainy

Figure 44. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 09 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 6 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

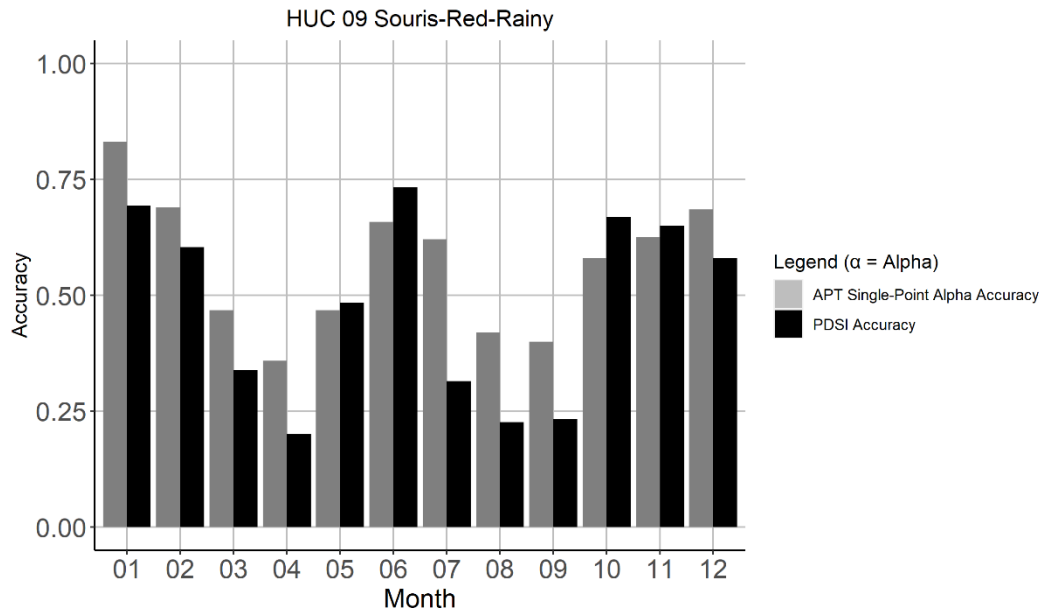


Figure 45. Comparison of APT single-point and custom-watershed α accuracy for HUC 09 at USGS Gage 05050000 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 3 of the 12 months of the year and has an accuracy of zero for 1 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

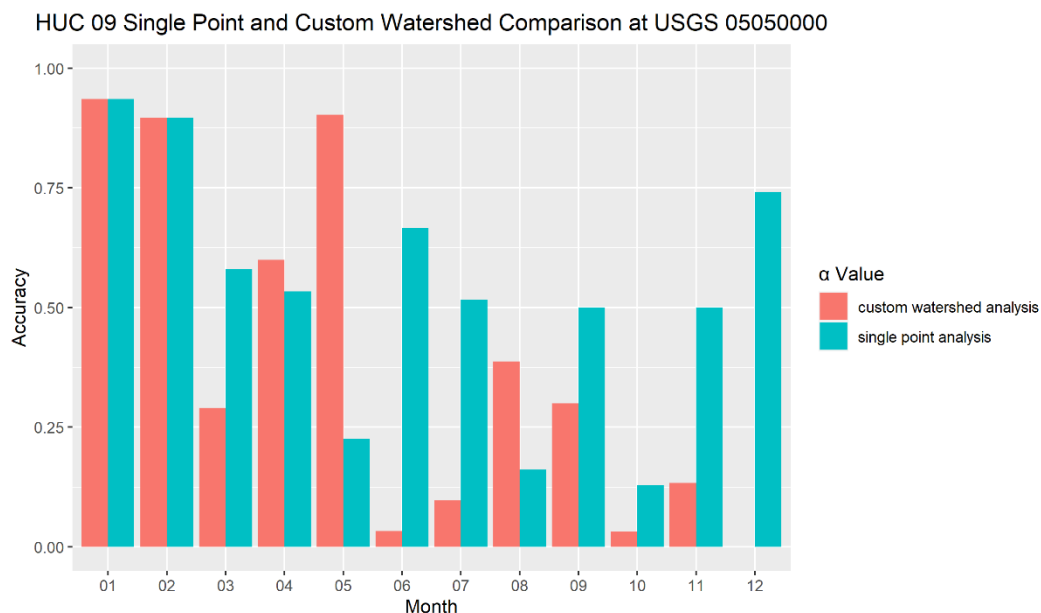
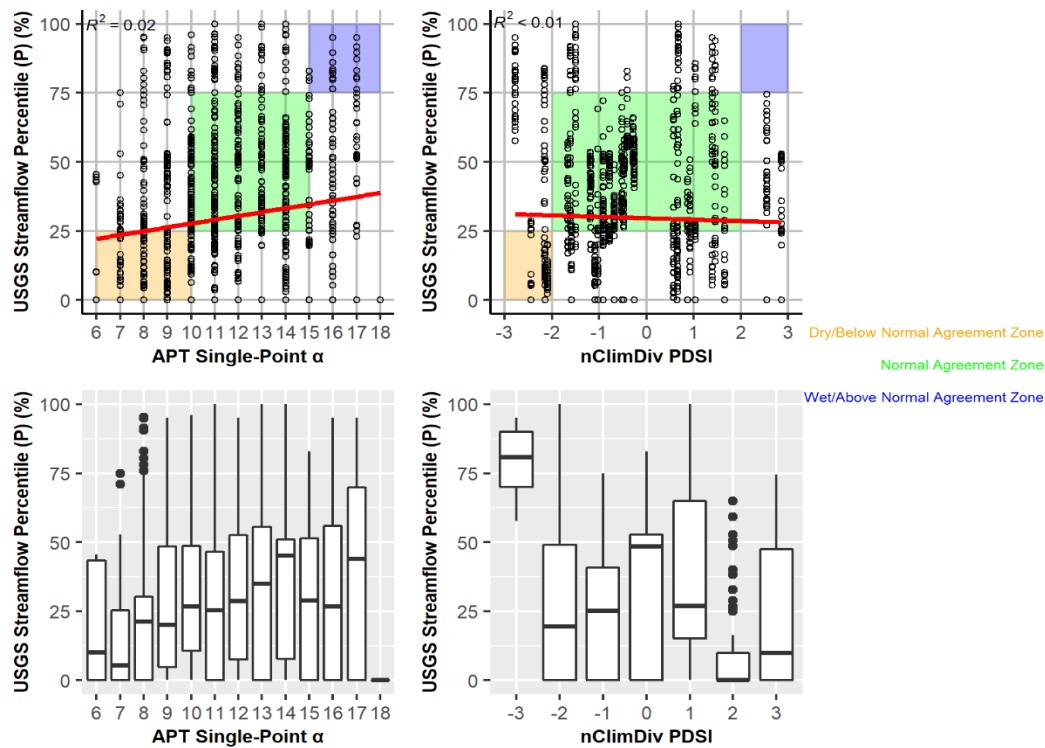


Figure 46. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 09.



4.3.10 HUC 10–Missouri

Figure 47. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 10 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 10 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 6 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

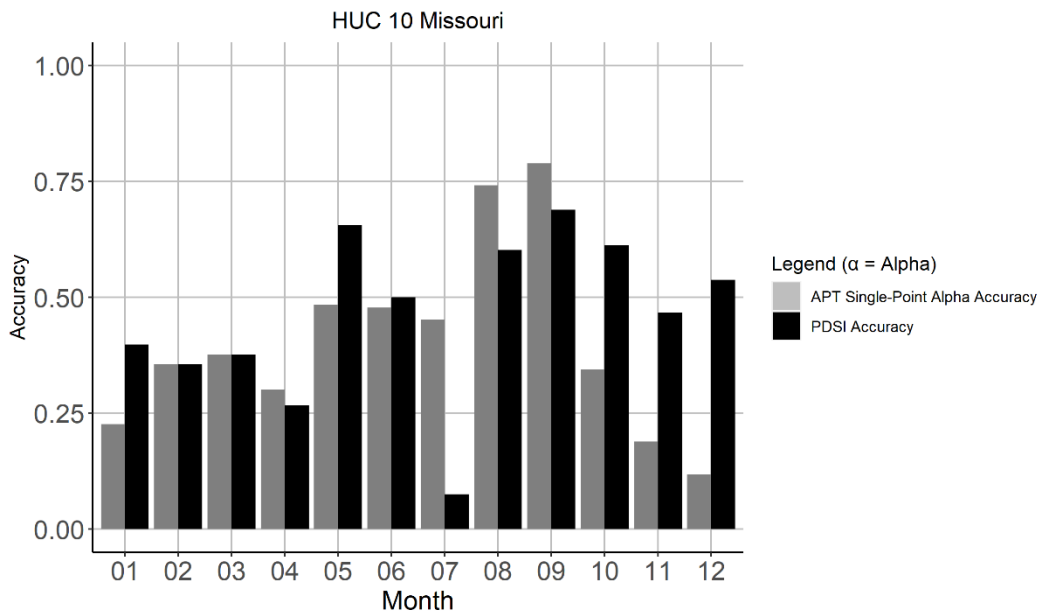


Figure 48. Comparison of APT single-point and custom-watershed α accuracy for HUC 10 at USGS Gage 06019500 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 10 Single Point and Custom Watershed Comparison at USGS 06019500

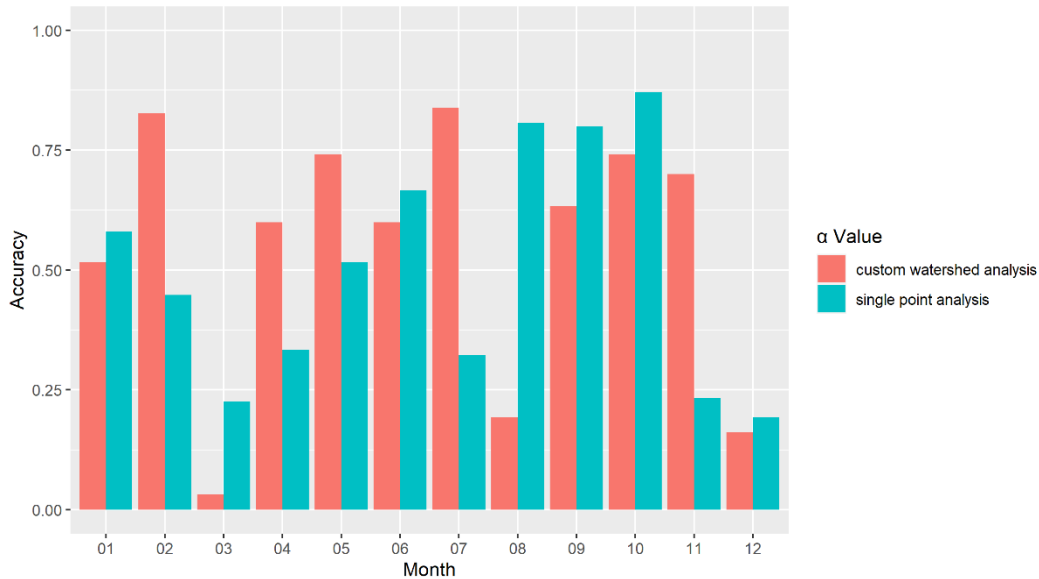
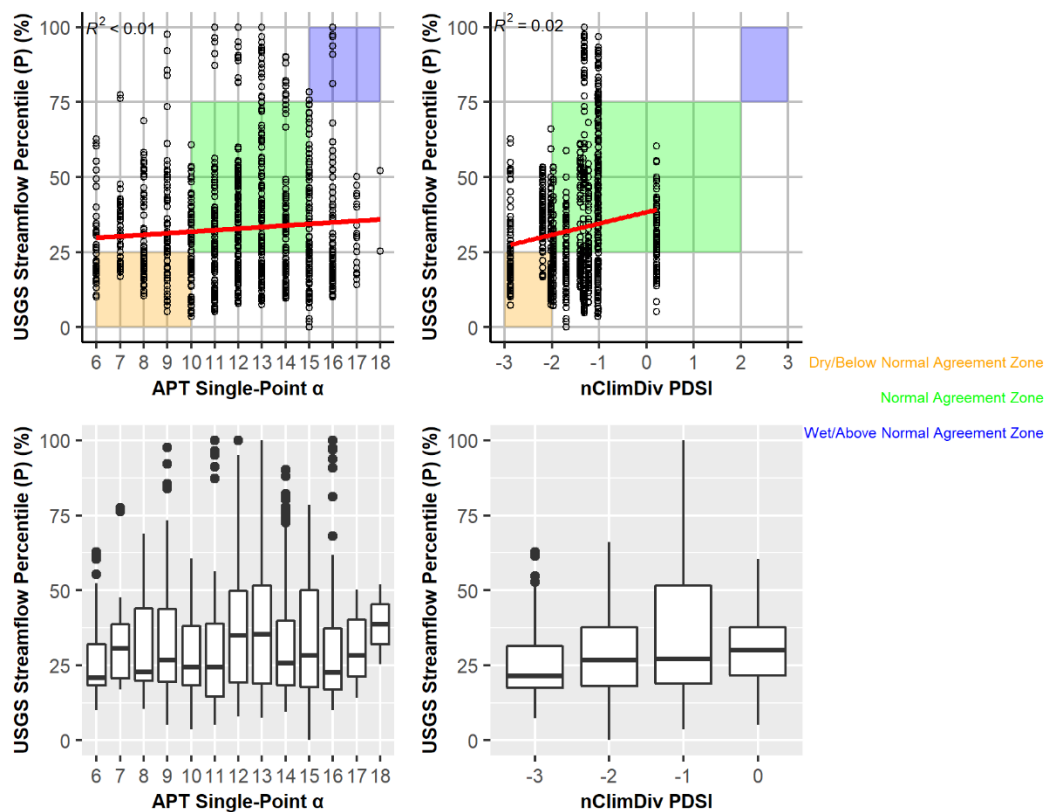


Figure 49. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 10.



4.3.11 HUC 11–Arkansas-White-Red

Figure 50. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 11 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 7 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 9 of the 12 months of the year, including 1 month, October, with an accuracy of zero. Months are presented according to the Julian calendar (e.g., January = 01).

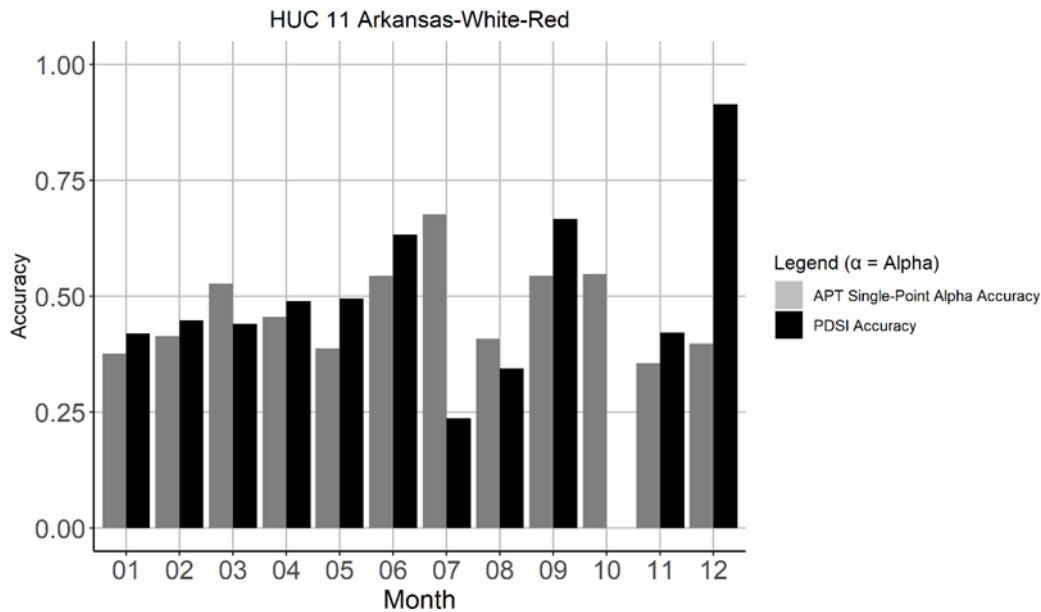


Figure 51. Comparison of APT single-point and custom-watershed α accuracy for HUC 11 at USGS Gage 07052152 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 6 of the 12 months of the year and has an accuracy of zero for 2 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 11 Single Point and Custom Watershed Comparison at USGS 07052152

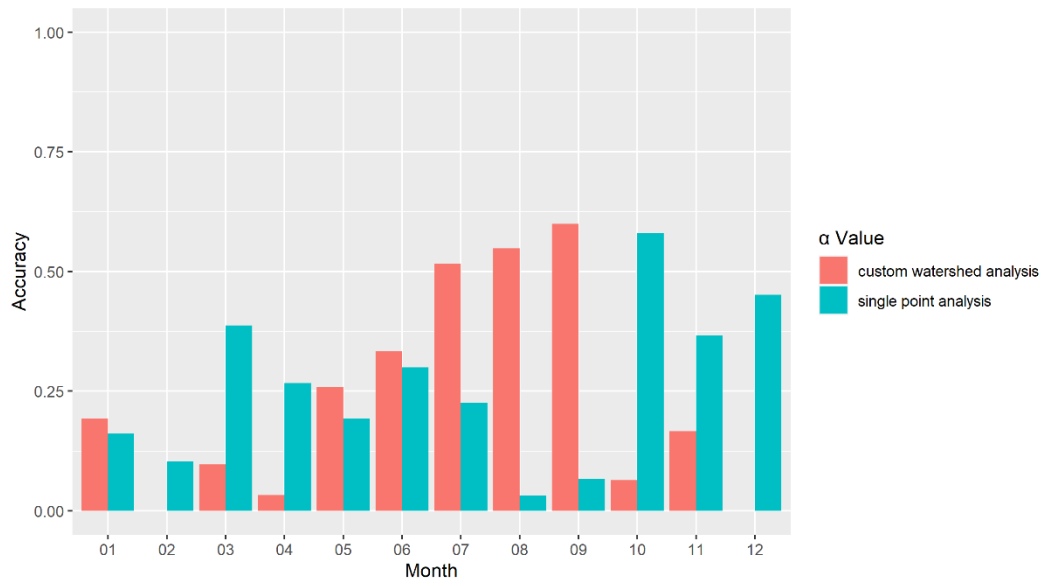
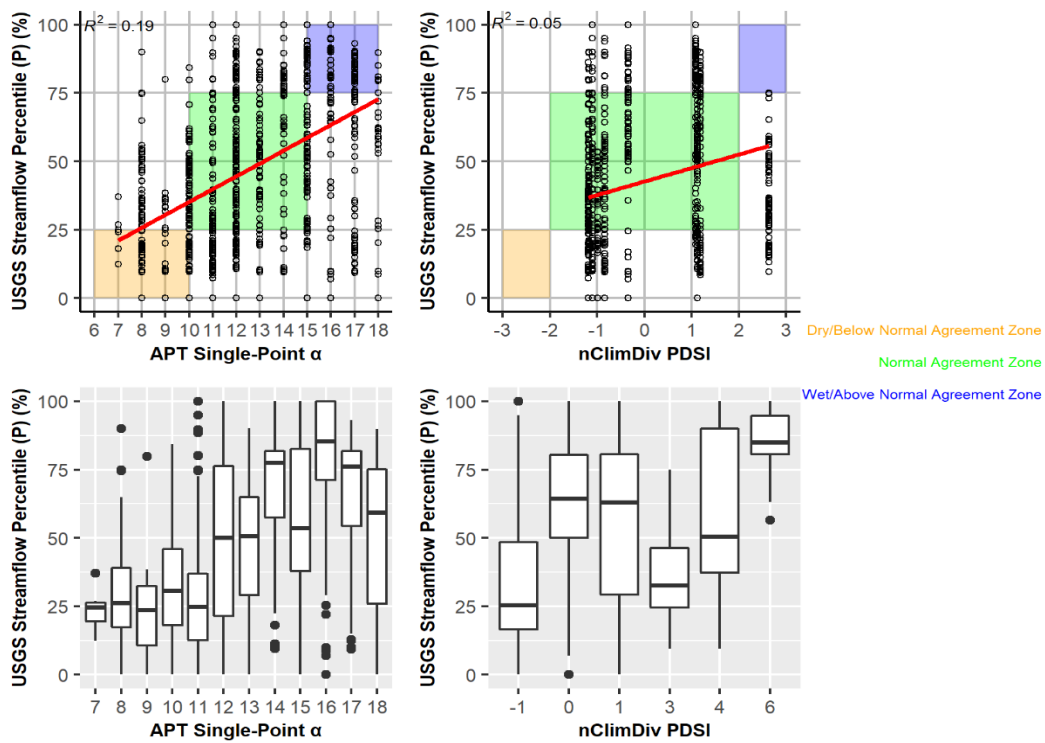


Figure 52. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 11.



4.3.12 HUC 12-Texas-Gulf

Figure 53. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 12 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 3 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 4 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

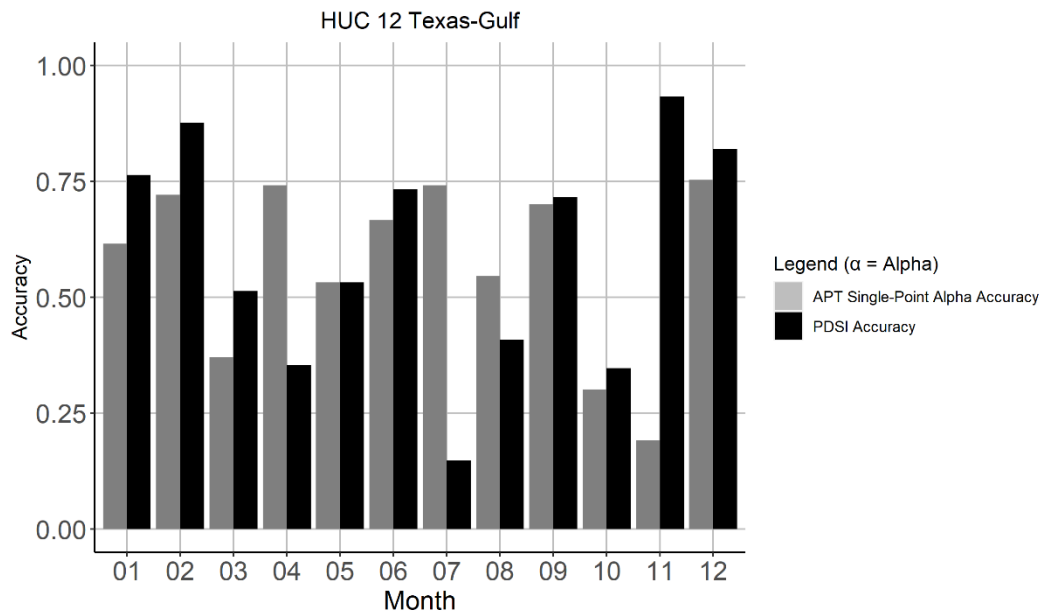


Figure 54. Comparison of APT single-point and custom-watershed α accuracy for HUC 12 at USGS Gage 08017410 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 3 of the 12 months of the year and has an accuracy of zero for 4 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

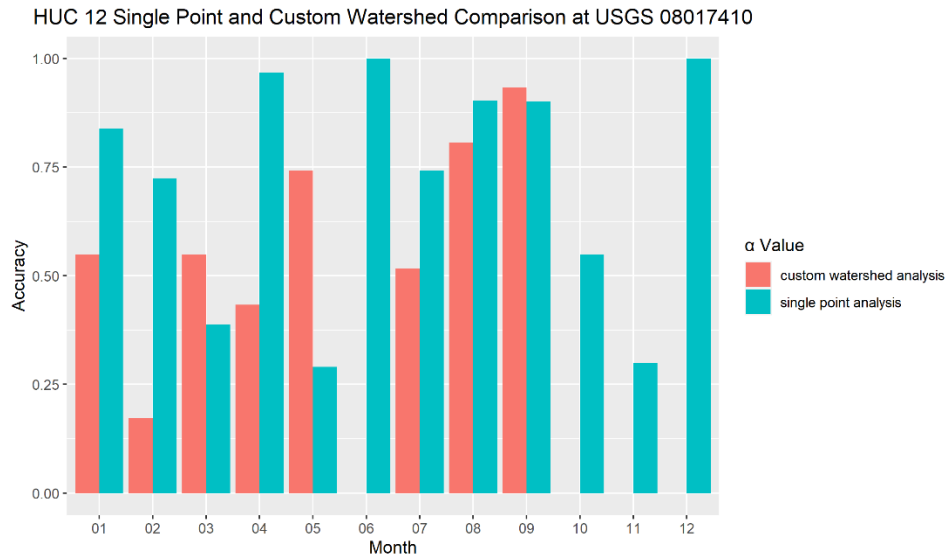
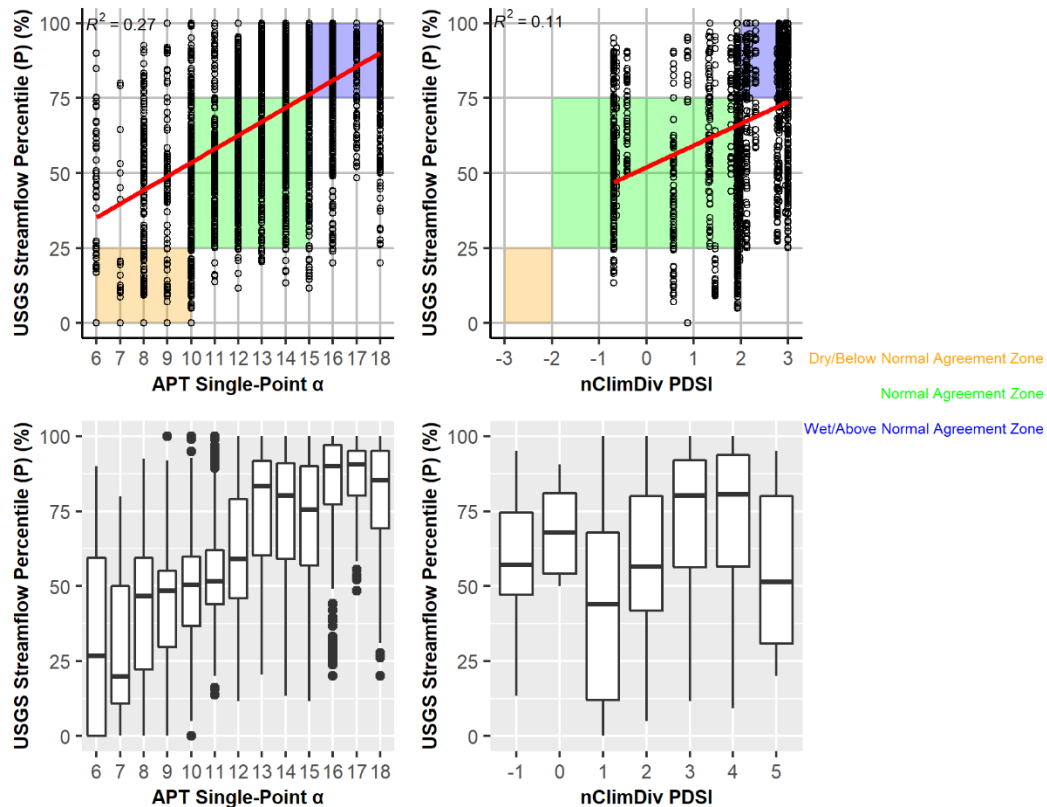


Figure 55. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 12.



4.3.13 HUC 13–Rio Grande

Figure 56. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 13 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 4 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 2 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

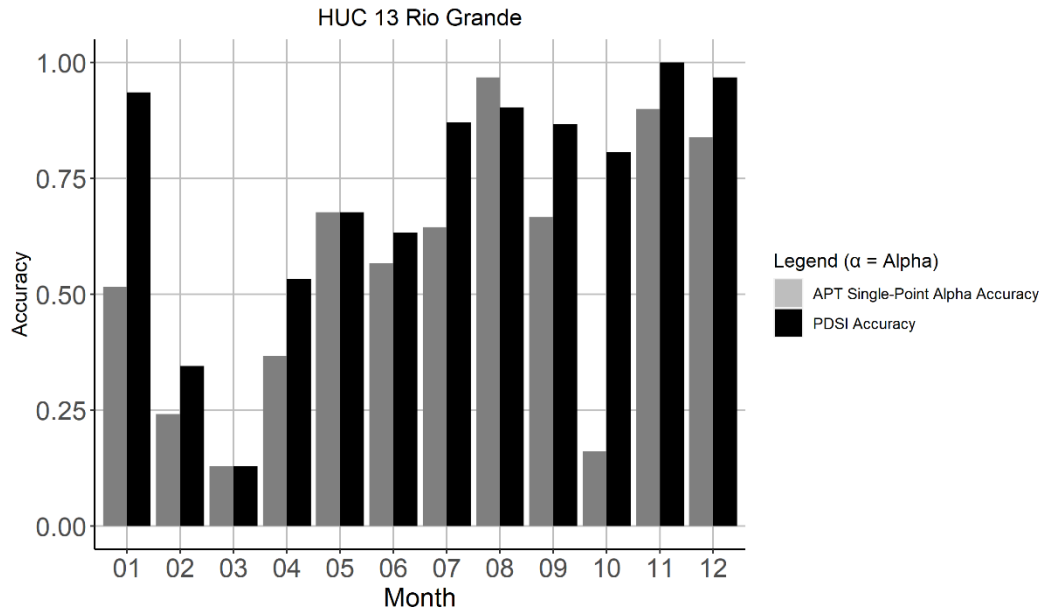


Figure 57. Comparison of APT single-point and custom-watershed α accuracy for HUC 13 at USGS Gage 08220000 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 5 of the 12 months of the year and has an accuracy of zero for 2 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 13 Single Point and Custom Watershed Comparison at USGS 08220000

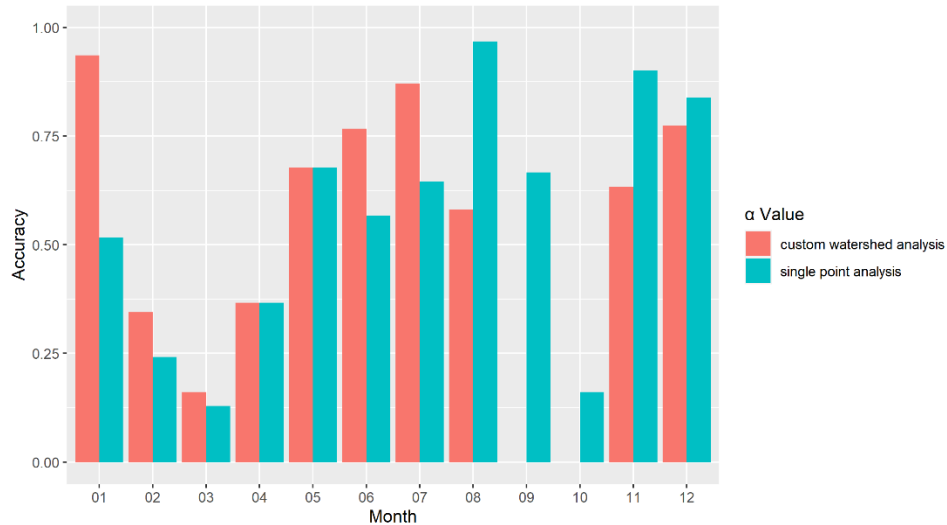
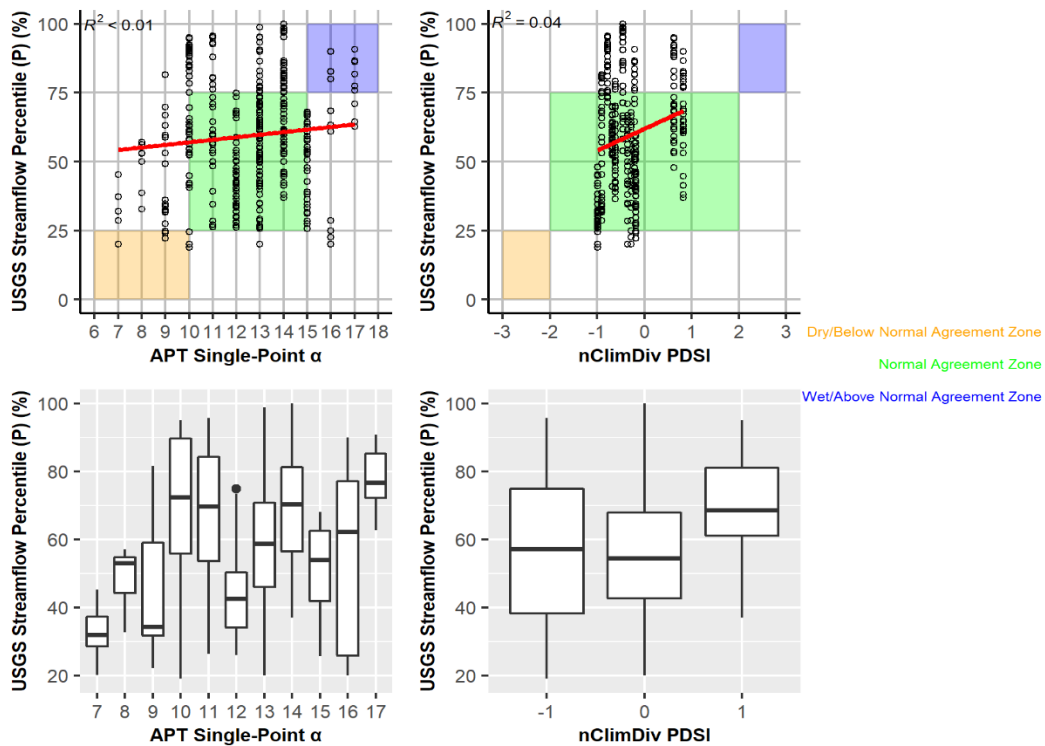


Figure 58. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 13.



4.3.14 HUC 14–Upper Colorado

Figure 59. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 14 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 5 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 1 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

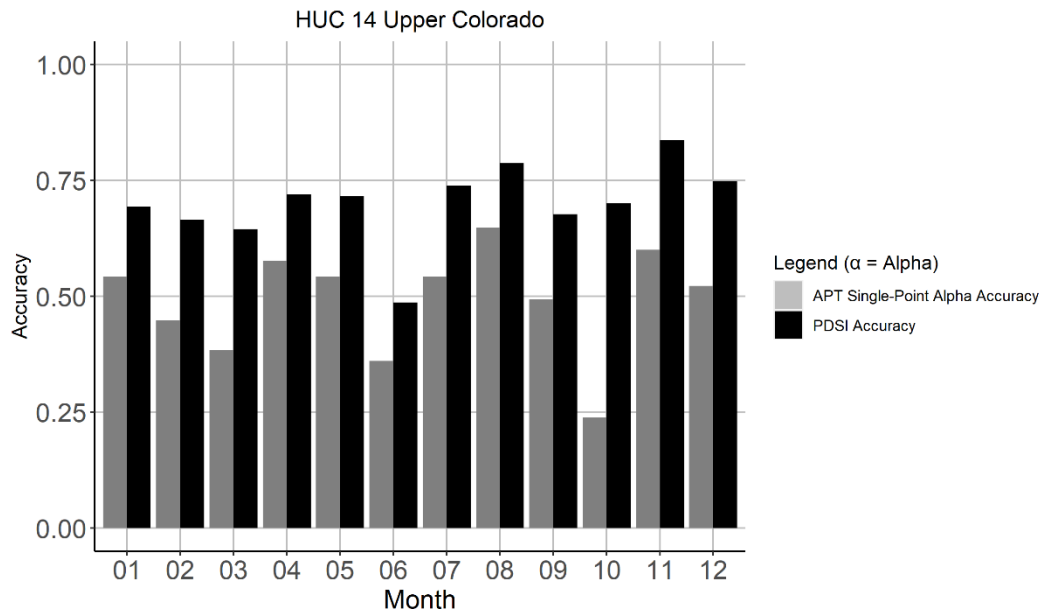


Figure 60. Comparison of APT single-point and custom-watershed α accuracy for HUC 14 at USGS Gage 09022000 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 5 of the 12 months of the year, and the accuracy is zero for 1 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

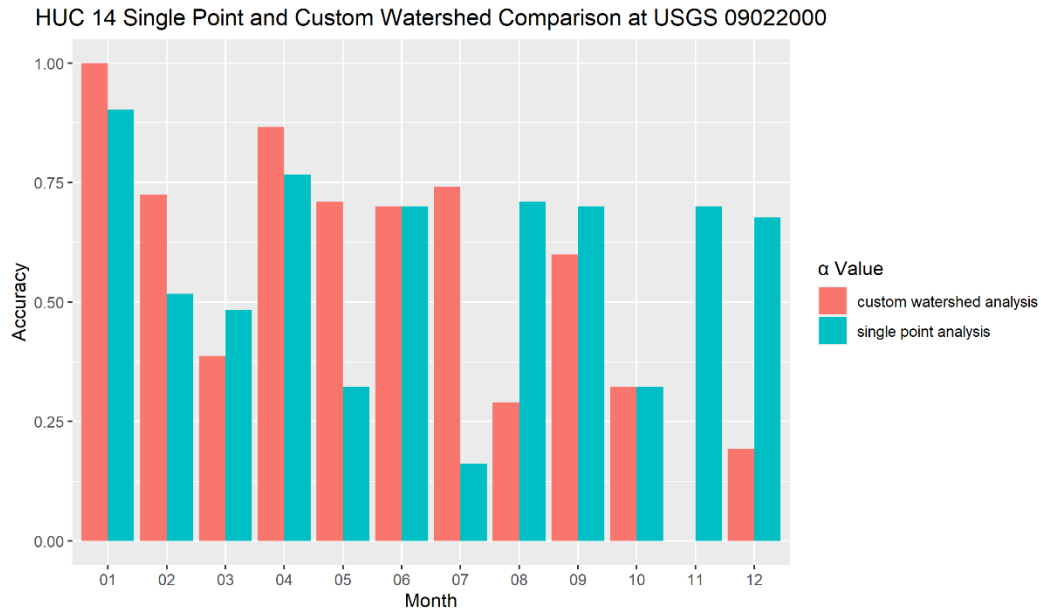
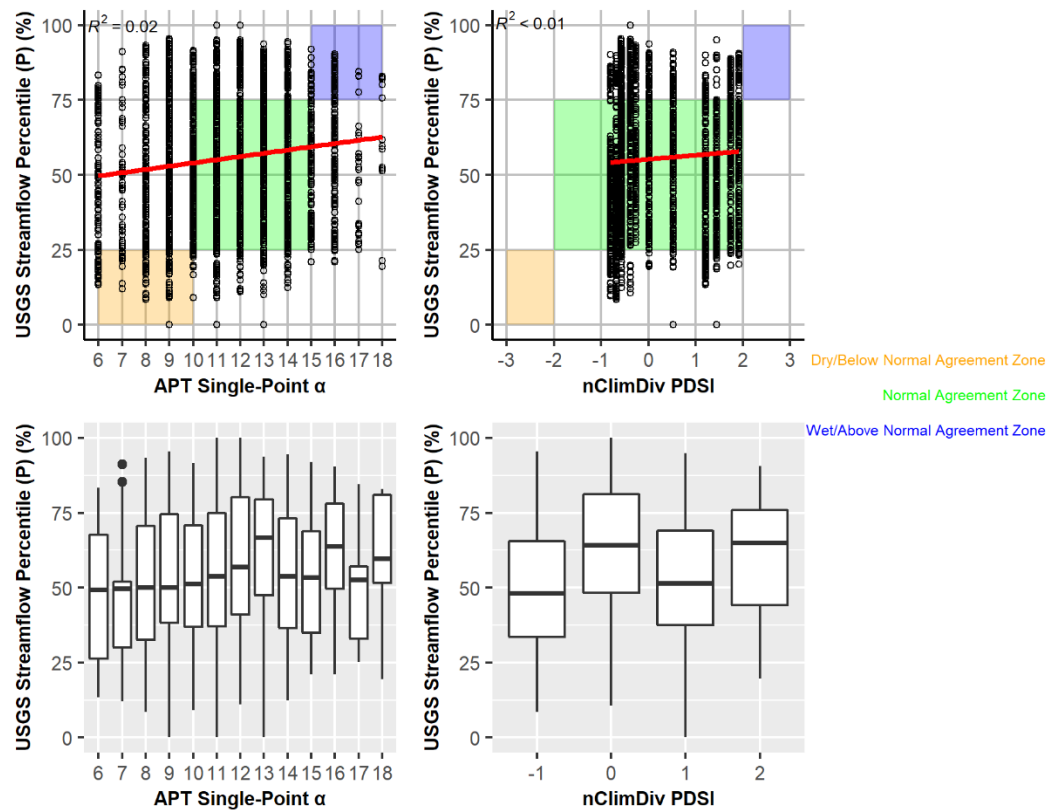


Figure 61. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 14.



4.3.15 HUC 15–Lower Colorado

Figure 62. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 15 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 7 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 9 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

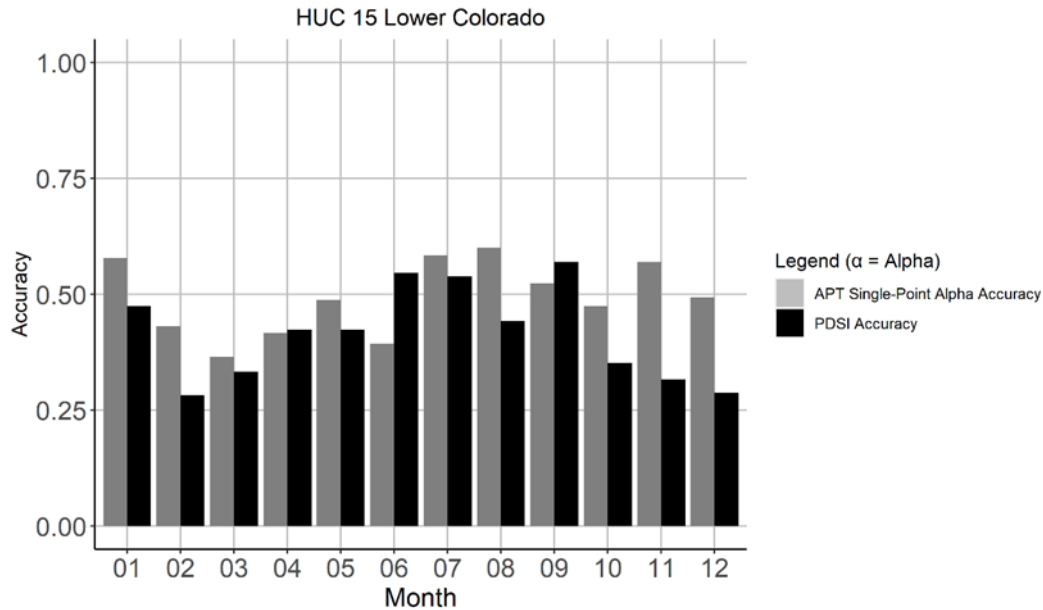


Figure 63. Comparison of APT single-point and custom-watershed α accuracy for HUC 15 at USGS Gage 09385700 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 3 of the 12 months of the year and is equal to zero for 6 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 15 Single Point and Custom Watershed Comparison at USGS 09385700

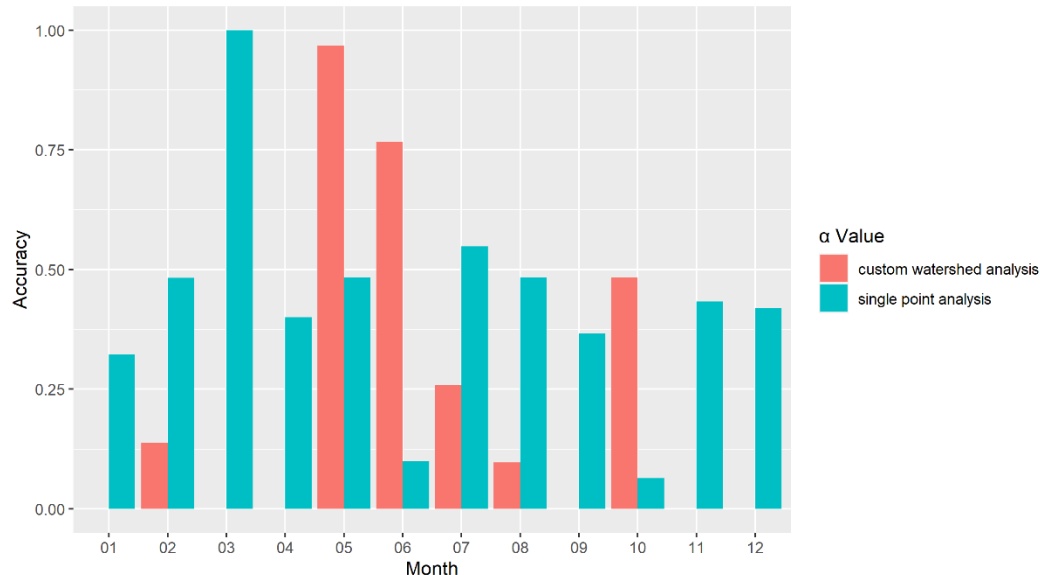
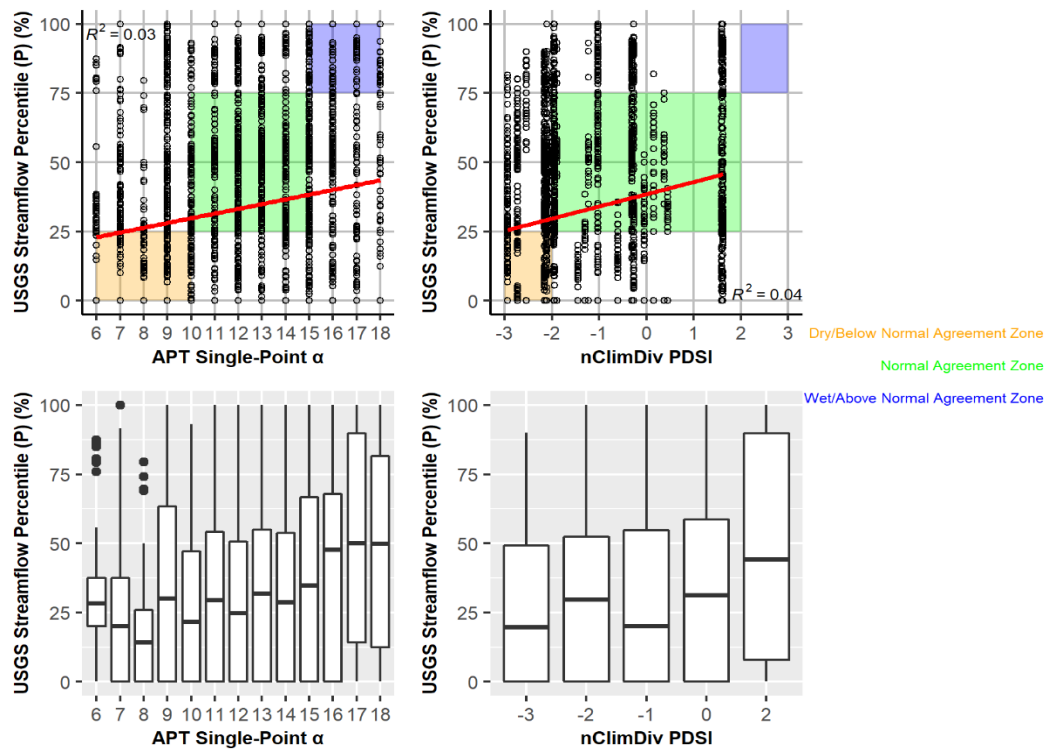


Figure 64. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 15.



4.3.16 HUC 16–Great Basin

Figure 65. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 16 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 10 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

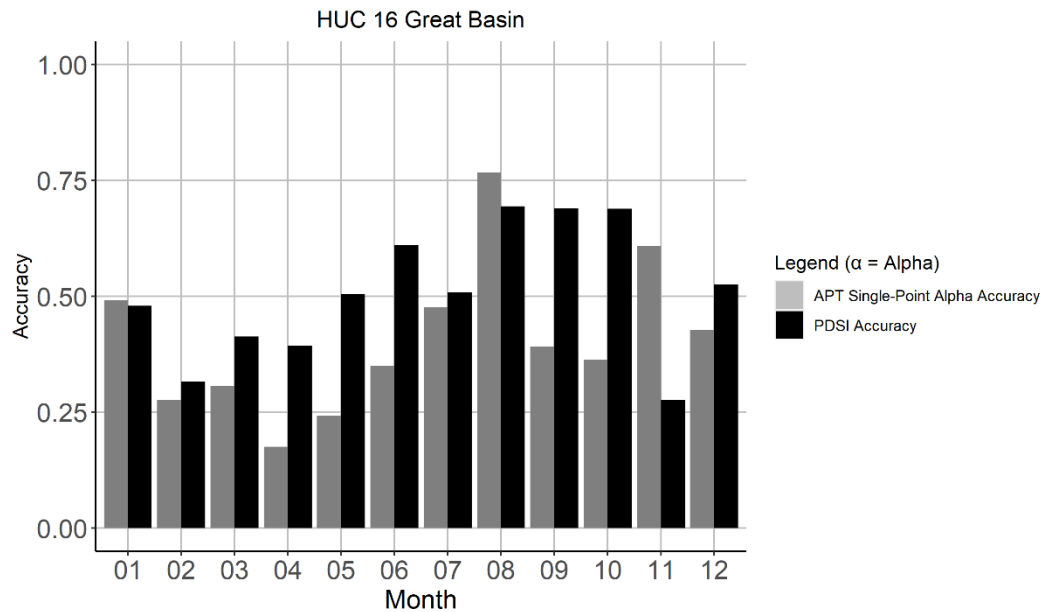


Figure 66. Comparison of APT single-point and custom-watershed α accuracy for HUC 16 at USGS Gage 10016900 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 7 of the 12 months of the year and is zero for 3 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

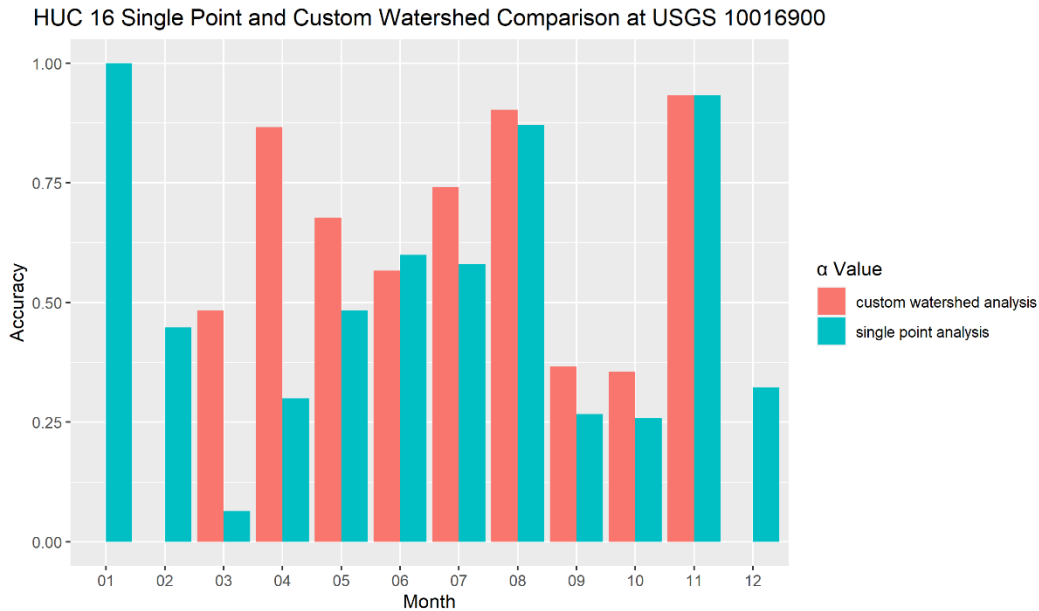
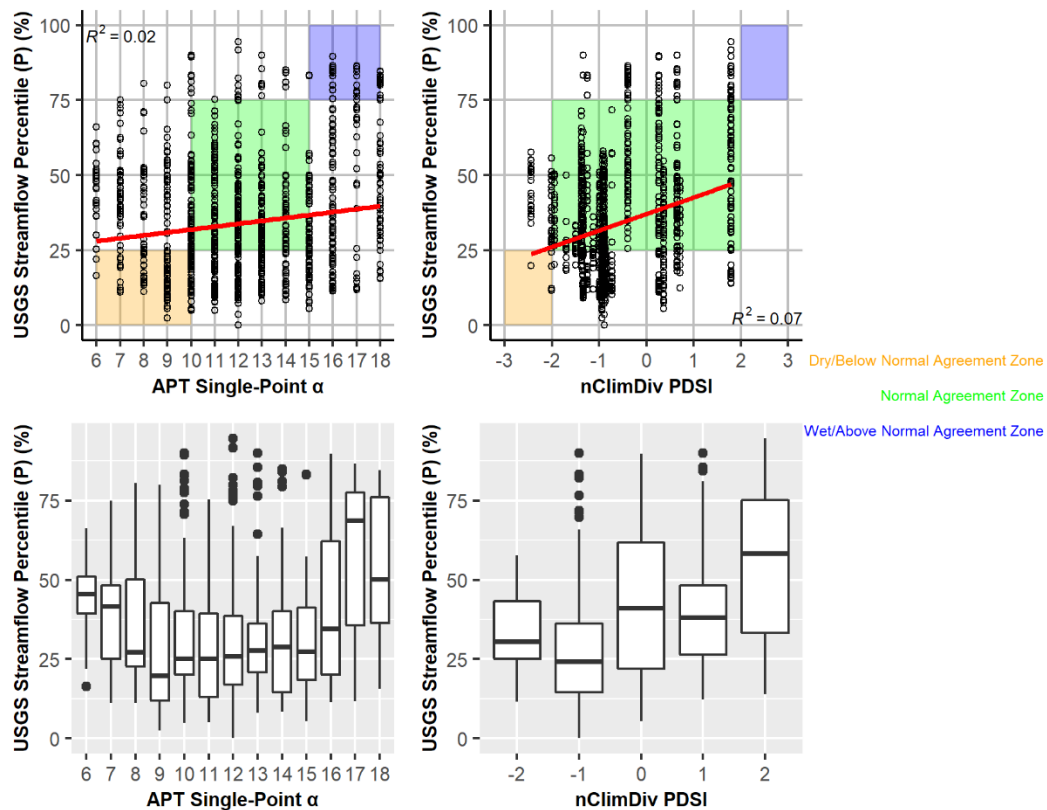


Figure 67. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 16.



4.3.17 HUC 17–Pacific Northwest

Figure 68. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 17 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 3 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 6 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

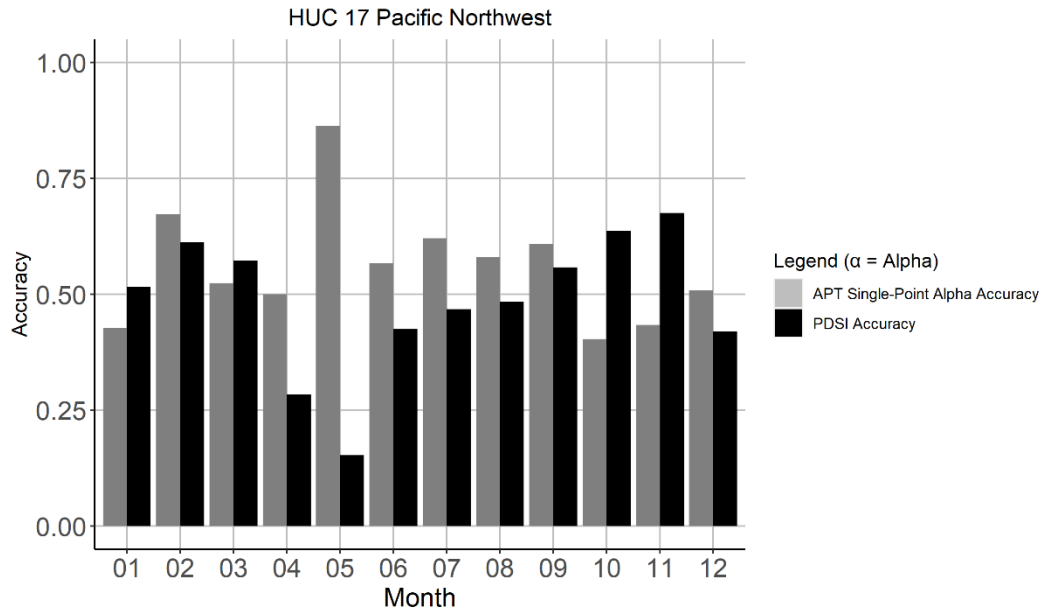


Figure 69. Comparison of APT single-point and custom-watershed α accuracy for HUC 17 at USGS Gage 12013500 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 1 of the 12 months of the year and is zero for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 17 Single Point and Custom Watershed Comparison at USGS 12013500

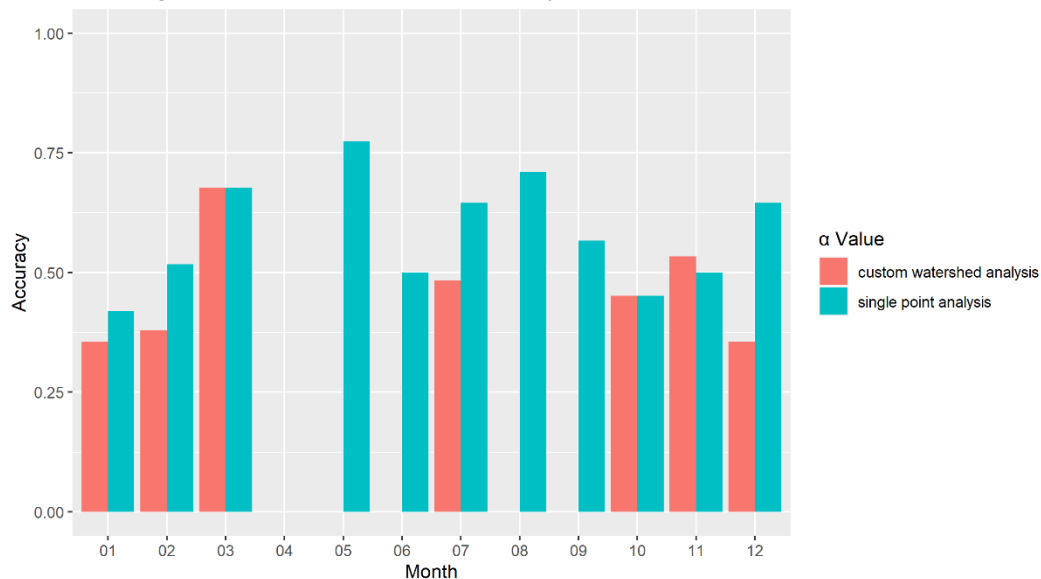
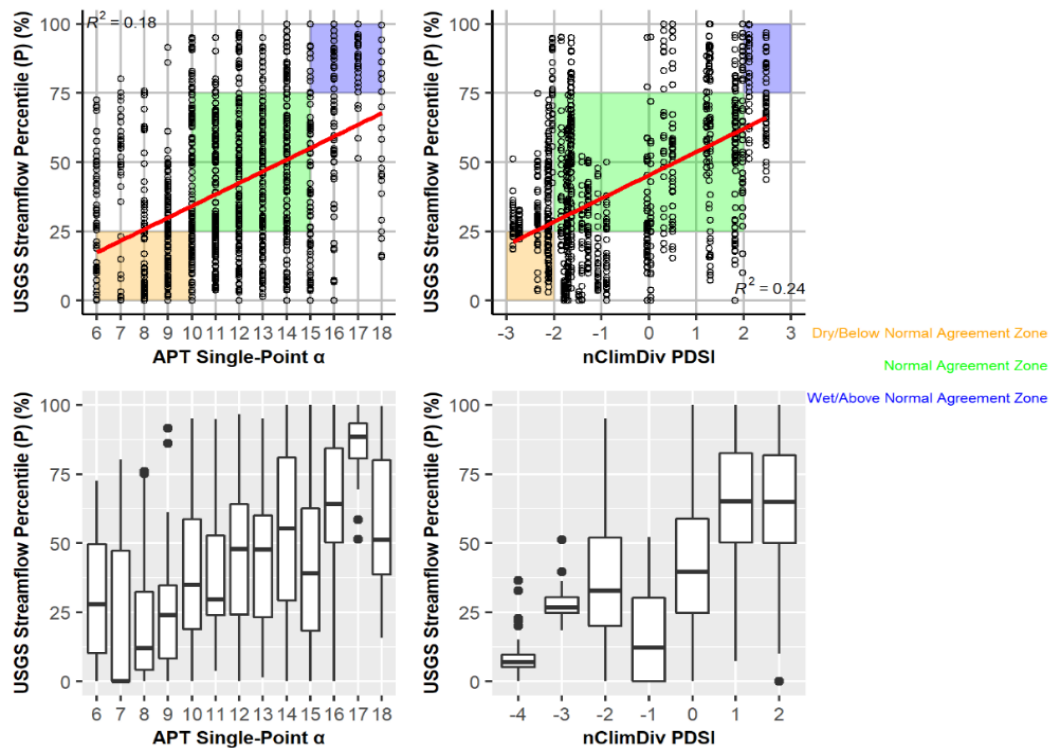


Figure 70. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 17.



4.3.18 HUC 18–California

Figure 71. Monthly assessment of APT single-point α and nClimDiv PDSI accuracy for HUC 18 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 7 of the 12 months of the year. The monthly nClimDiv PDSI single-point accuracy is below 0.5 for 11 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

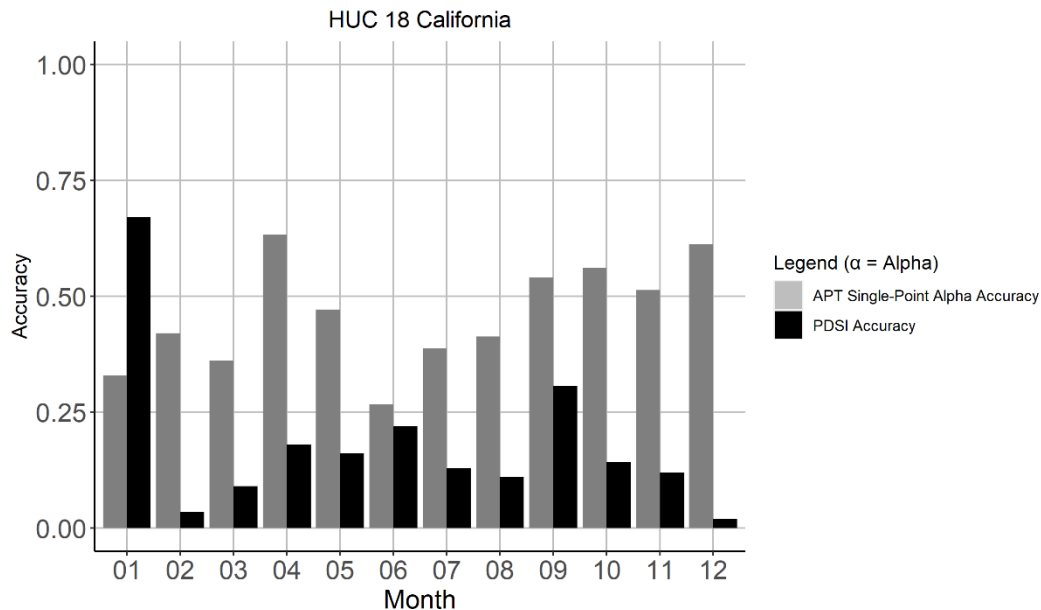


Figure 72. Comparison of APT single-point and custom-watershed α accuracy for HUC 18 at USGS Gage 10251290 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 5 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

HUC 18 Single Point and Custom Watershed Comparison at USGS 10251290

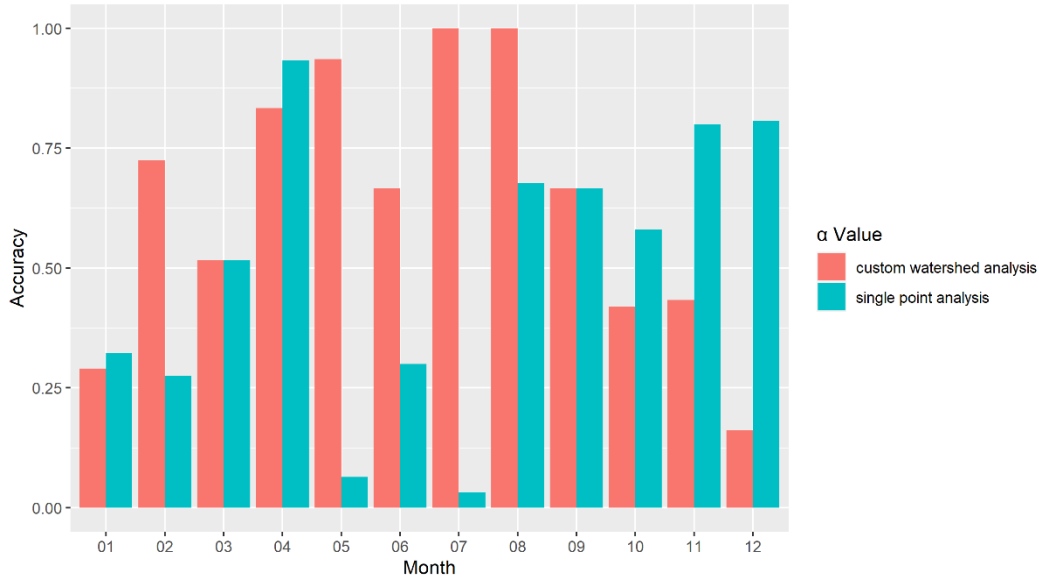
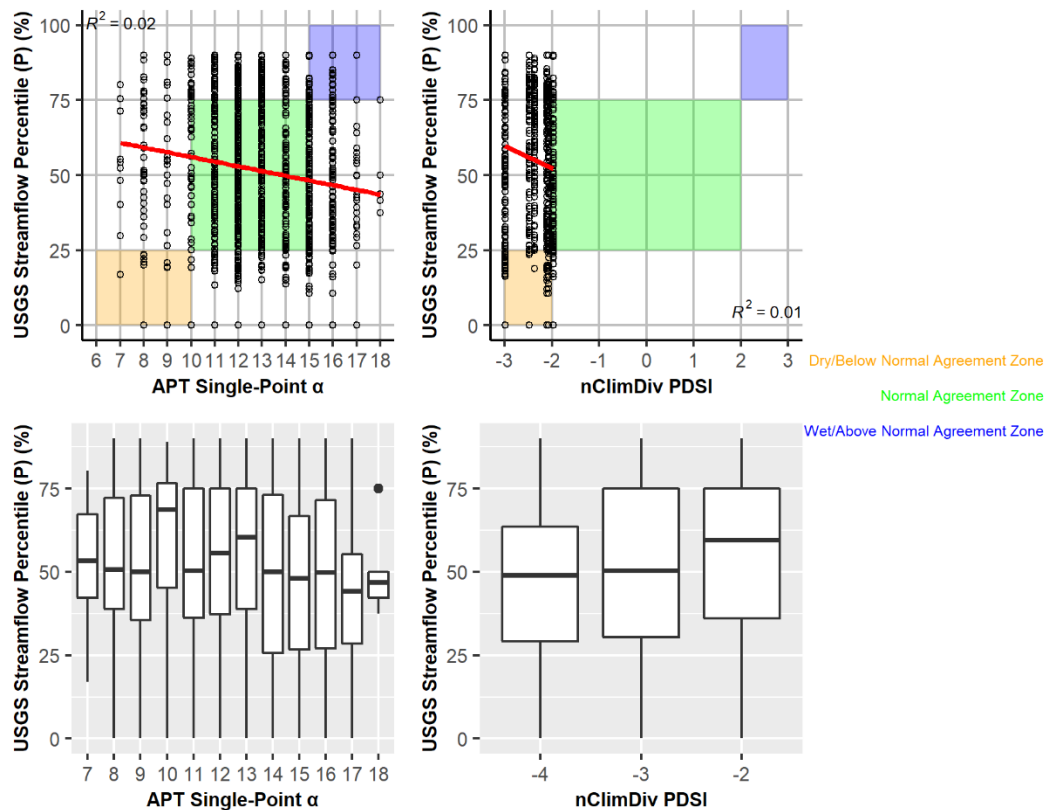


Figure 73. Comparison of APT single-point α and nClimDiv PDSI to P for the USGS gages in HUC 18.



4.3.19 HUC 19–Alaska

Figure 74. Monthly assessment of APT single-point α accuracy for HUC 19 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 6 of the 12 months of the year. The nClimDiv PDSI is unavailable for HUC 19. Months are presented according to the Julian calendar (e.g., January = 01).

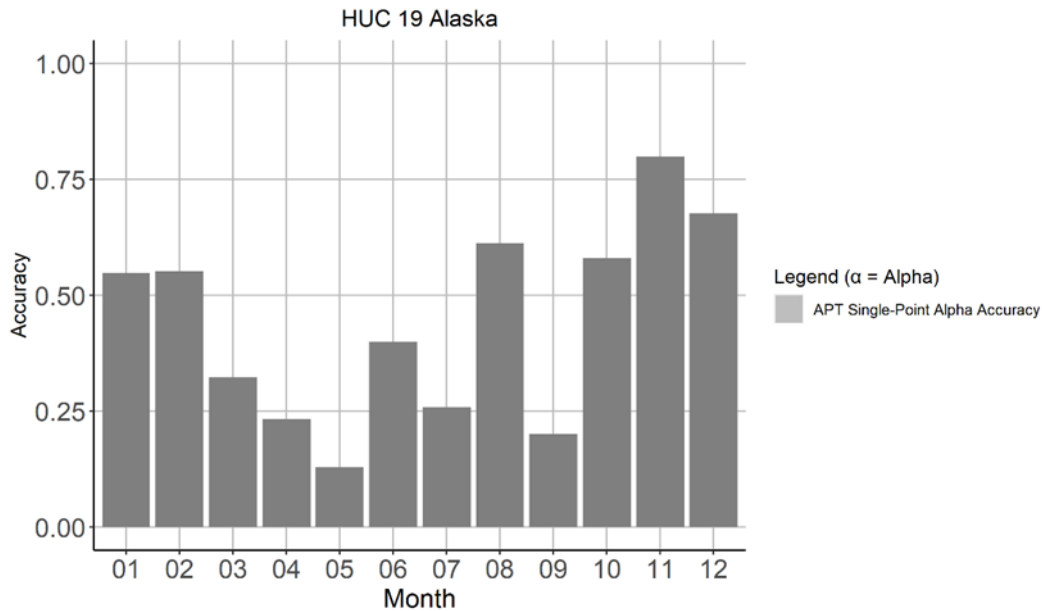
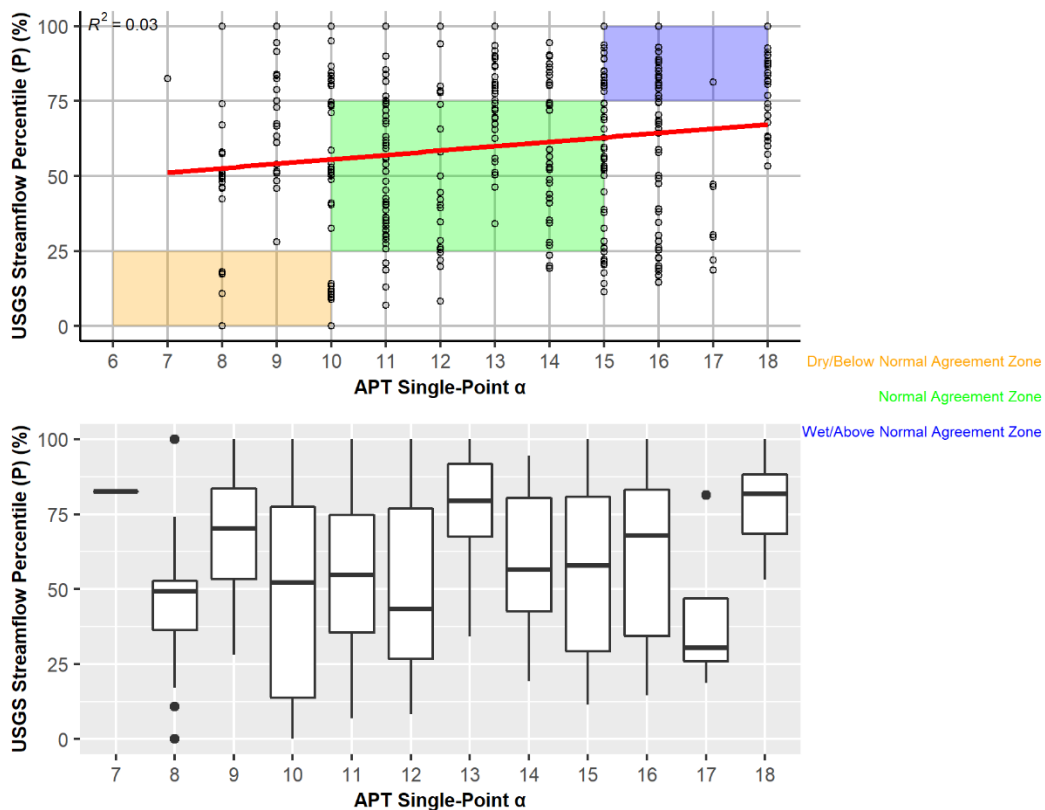


Figure 75. Comparison of APT single-point α to P for the USGS gages in HUC 19.



4.3.20 HUC 20–Hawaii

Figure 76. Monthly assessment of APT single-point α accuracy for HUC 20 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 8 of the 12 months of the year. The nClimDiv PSDI is unavailable for HUC 20. Months are presented according to the Julian calendar (e.g., January = 01).

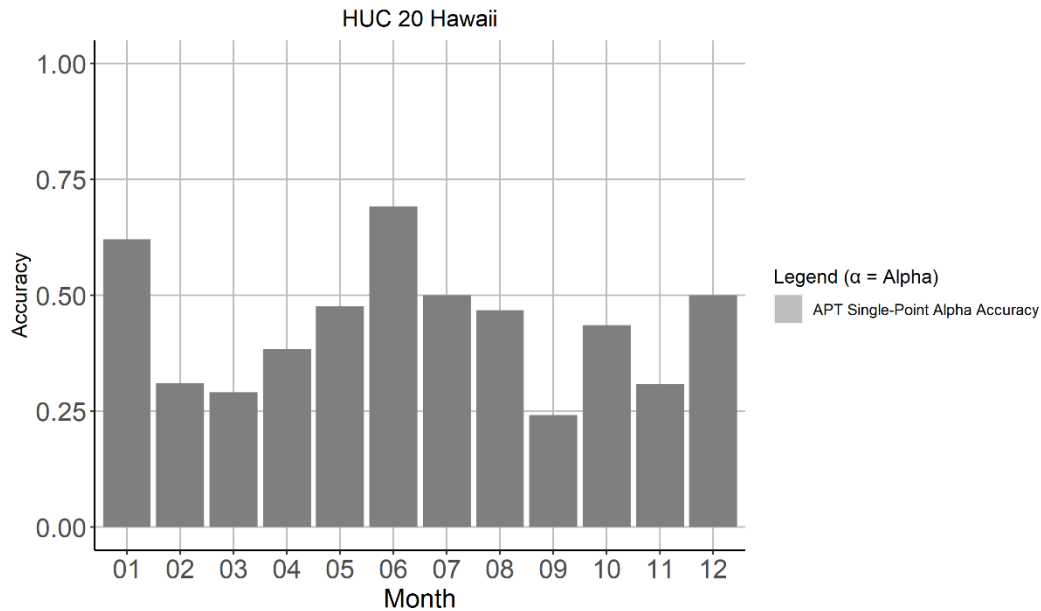


Figure 77. Comparison of APT single-point and custom-watershed α accuracy for HUC 20 at USGS Gage 16036000 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 4 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

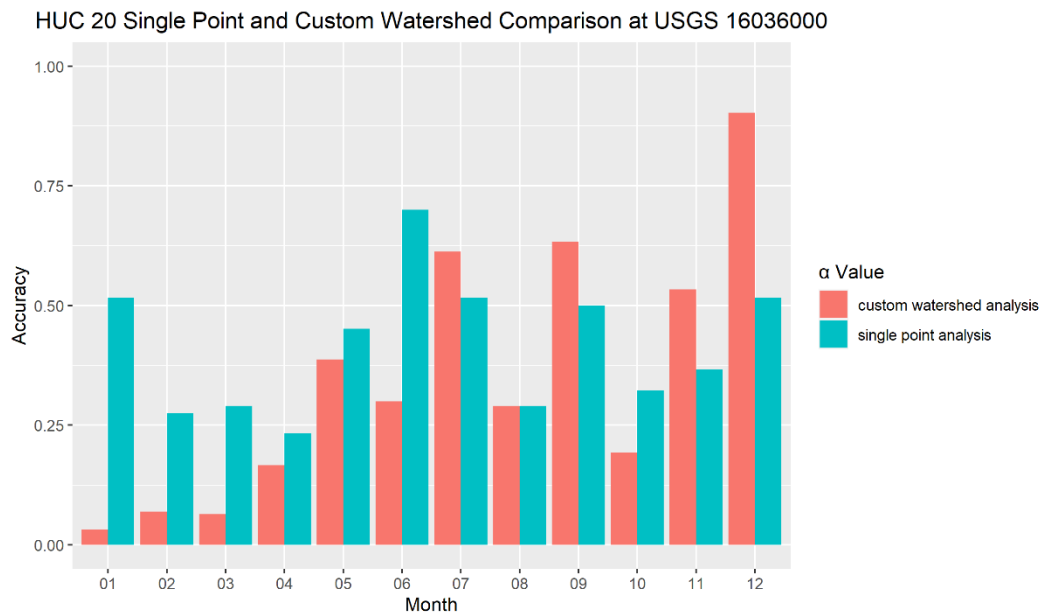
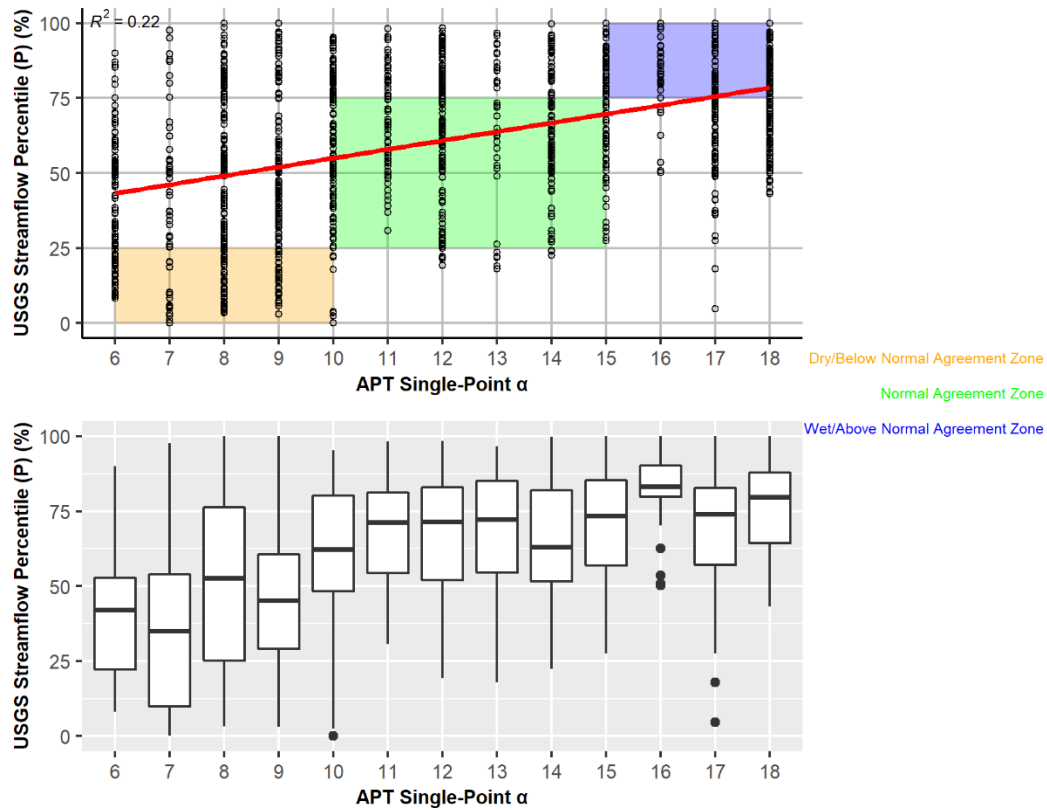


Figure 78. Comparison of APT single-point α to P for the USGS gages in HUC 20.

4.3.21 HUC 21–Caribbean

Figure 79. Monthly assessment of APT single-point α accuracy for HUC 21 from October 2015 to September 2016. The monthly APT single-point α accuracy is below 0.5 for 7 of the 12 months of the year. The nClimDiv PDSI is unavailable for HUC 21. Months are presented according to the Julian calendar (e.g., January = 01).

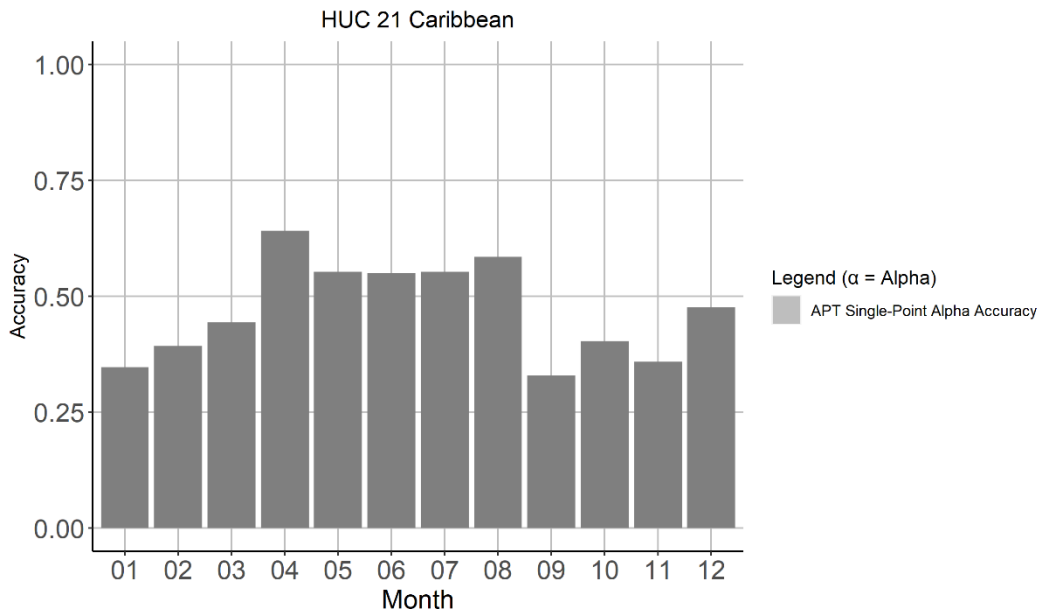


Figure 80. Comparison of APT single-point and custom-watershed α accuracy for HUC 21 at USGS Gage 50021700 from October 2015 to September 2016. The APT custom-watershed accuracy is greater than the APT single-point accuracy for 8 of the 12 months of the year. Months are presented according to the Julian calendar (e.g., January = 01).

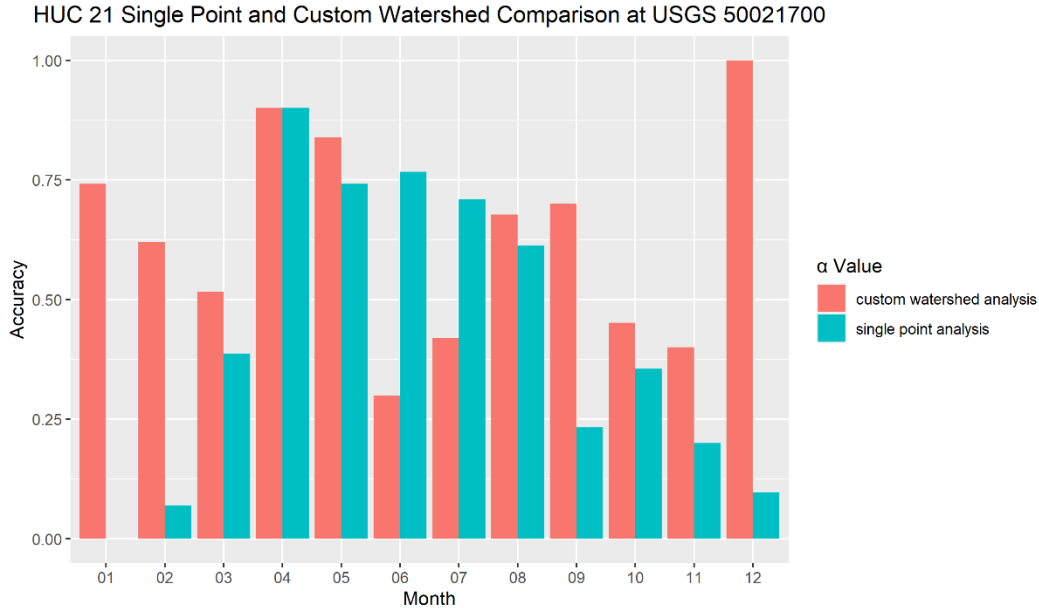
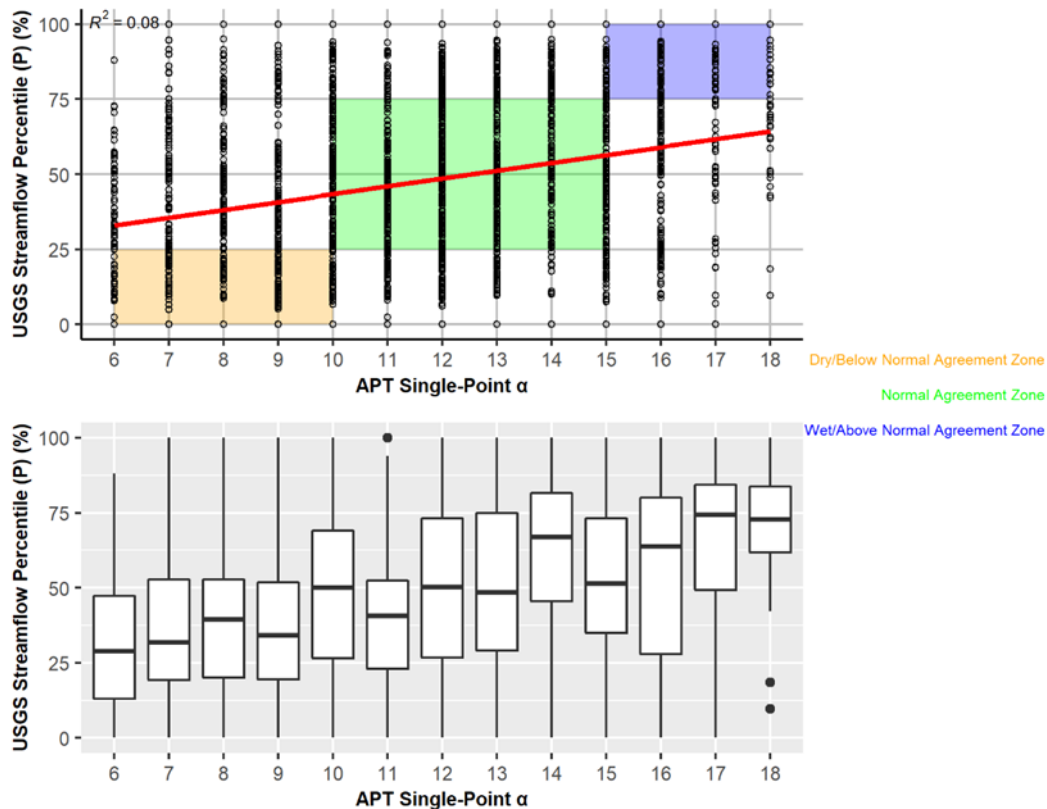


Figure 81. Comparison of APT single-point α to P for the USGS gages in HUC 21.



5 Summary

This report documented the tools available to practitioners for evaluating climatic and hydroclimatic conditions for regulatory purposes. The report also highlighted specific weather phenomena to consider during climatic and hydrologic analysis of a site. The research also investigated the capabilities of the methodology underlying the APT for typical year determinations for rivers and streams.

This report identified eight data sets that are currently available to practitioners for evaluating climatic and hydroclimatic conditions. These data sets were chosen because of their ability to provide climatic and hydroclimatic context for an aquatic resource. Table 1 identified the data sets, where to access them, and some of their key limitations. The data sets have varying levels of availability and fidelity.

The USGS WaterWatch, NWM Streamflow Anomaly, and NOAA climate data sets (e.g., CPC data suite and PDSI) each characterize various hydroclimatic variables, such as streamflow and soil moisture. These hydroclimatic data sets are preferred for assessing the hydroclimatic normalcy of aquatic resources given that they are either direct observations of the aquatic resource (e.g., USGS WaterWatch) or account for multiple hydrologic components. However, some of the data sets have a coarse spatial and temporal resolution or have a limited window of archived data available for public consumption.

The APT, PRISM, and NOAA Stage IV data sets can each characterize precipitation climatology but do not explicitly account for other hydrologic processes. These tools can supplement the evaluation of an aquatic resource and potentially fill spatial or temporal gaps. The USDM may provide a ready indication of extreme dryness, but it does not offer an analysis of extreme wetness. If drought conditions are present at an observation point, the USDM data provide more context for evaluating normal hydroclimatic conditions than other hydroclimatic and climatic data sets, except USGS WaterWatch. The USDM accounts for hydroclimatic and climatic data sets, such as the CPC data suite. However, the USDM cannot be used to determine normal, above normal, or wet conditions.

SNODAS can alert practitioners to above or below average snowpack prior to a melt season, which will have a significant effect on snow dominated

watersheds, such as those in the Intermountain West. Practitioners should make use of all data sets listed, to the greatest extent possible, to fully assess the climatologic and hydroclimatologic conditions of an aquatic resource.

This report identified several weather phenomena to consider when assessing the climatology and hydroclimatology of a region. The weather conditions that were highlighted could potentially lead to inaccurate assessments of streamflow normalcy when using only weather station data for an APT analysis. The events discussed either lead to isolated and convective rainfall, sharp precipitation gradients over short distances, or rapid snowmelt.

The North American Monsoon was noted as one of the primary weather patterns that affects the accuracy of APT analyses, particularly in the southwestern US. This atmospheric circulation develops over the southwestern US and advects moisture into the region, where isolated thunderstorms and flash flooding can occur. Significant changes in streamflow often occur well downstream of the precipitation. If weather station data used by the APT do not reflect the isolated precipitation that occurred upstream, inaccurate assessments of streamflow normalcy could be made.

Nor'easters and lake effect snow were also identified as events that can lead to inaccurate APT analyses due to sharp gradients in precipitation. If the weather stations used by the APT fall along these gradients, the results might not accurately depict streamflow conditions.

Snowmelt was highlighted as another event that might need further analysis beyond using the APT alone. Snowmelt can sometimes occur rapidly due to temperature fluctuations, particularly in mountainous regions. There can be streamflow effects well downstream, which can have large time lags between the precipitation occurring and the increase in streamflow. Inaccurate assessments of streamflow normalcy could be seen if weather stations that are used by the APT do not reflect the amount of precipitation that fell in the vicinity of snowpack. There might also be low accuracy if the APT does not account for the time lag between the precipitation occurring and the change in streamflow conditions. During this event and the previously mentioned events, a direct estimate or measurement of streamflow conditions (e.g., NWM or USGS stream gages)

would be a better indicator of streamflow normalcy than analyzing nearby rain gages.

The events that were described herein are not necessarily unusual or anomalous unless they lead to extreme precipitation or flooding that exceeds a certain climatologic threshold. We recommend using the tools and data sets discussed for assessing streamflow normalcy rather than relying solely on the APT for any of the highlighted weather patterns.

This research also evaluated the use of the APT for characterizing streamflow normalcy. USACE originally developed the predecessor of the APT to streamline and automate the evaluation of precipitation normalcy and other climatic variables to complete wetland delineations, but its capacity for evaluating streamflow was not well understood. The APT provides an α and queries a NOAA PDSI archive. Both variables were considered and compared to recorded USGS daily streamflow percentiles throughout CONUS, Hawaii, Alaska, and Puerto Rico. The use of streamflow percentiles allowed the research team to consistently evaluate the correlation between APT precipitation categories, PDSI indices, and streamflow conditions (based on exceedance and nonexceedance probabilities) throughout the United States.

The comparison between the APT α and PDSI showed that they were unreliable in predicting streamflow normalcy. For a large amount of the APT analysis, the monthly accuracy of the APT single-point α was below 0.50 when used to represent an analysis of normal, above normal, or below normal streamflow conditions. This indicated that the APT was accurate in predicting streamflow normalcy less than half the time. This score was calculated by examining individual gages within the various watersheds. While the PDSI occasionally provided a more accurate representation of current streamflow conditions than the APT single-point α , such as in HUC 02–Mid-Atlantic, this improvement in accuracy was sporadic throughout our sample USGS gages, as shown in HUC 18–California, and was completely unavailable in HUC 19–Alaska.

Additional analyses were conducted to compare the APT single-point accuracy to the custom-watershed analysis. Due to the longer computation times necessary for the APT custom-watershed analysis, the average monthly accuracy in this analysis only applied to one USGS gage in each two-digit HUC. This does not apply to HUC 19–Alaska due to the inability

to generate a custom watershed. The APT custom-watershed analysis provided little to no improvement in the accuracy of the APT above that of the APT single-point analysis. For example, at HUC 12 and USGS Gage 08017410, the average monthly APT custom-watershed accuracy was better than the APT single-point accuracy for only three months of the year (Figure 54). Additionally, the custom-watershed analysis had an accuracy of zero for four months of the year. Counterintuitively, inclusion of the hydroclimatic characteristics throughout the entire upstream drainage area within the APT analysis offered little to no increase in the accuracy of the hydroclimatology of the stream when compared to using the APT single-point analysis.

The final analysis compared the APT single-point α to the observed USGS WaterWatch streamflow percentile at the same location. Each point in the scatterplot represented one day during the study period at each USGS location (e.g., Figure 23). The APT single-point α typically had a positive correlation with USGS streamflow percentiles. This was shown by the upward slope of the line of best fit. HUC 18 was the only region that had a downward sloping trend indicative of a negative correlation between the APT single-point α and the USGS WaterWatch streamflow percentile (Figure 73). Even though the APT single-point α typically trended with the USGS streamflow percentiles, the R^2 were not strong, ranging between <0.01 to 0.58 (and commonly <0.25). This indicated that the APT single-point α was not a precise indicator of USGS streamflow percentiles. The general lack of precision indicates that the APT's skill in predicting streamflow normalcy is unlikely to improve without reformulation.

Because of the consistent lack of accuracy and precision, the APT analysis conducted as part of this research provided only a high-level overview of the APT α and PDSI accuracy and precision in measuring streamflow conditions. The analysis only considered one water year, did not assure that the sample of USGS gages was representative of each two-digit HUC, did not further analyze the influence of specific meteorological conditions, such as those found in Section 3, and did not offer specific analysis of isolated seasonality (e.g., HUC 04–Great Lakes) or improved performance (e.g., HUC 06–Tennessee). The composite results of the APT analysis suggest there is room for improvement in assessing streamflow normalcy conditions. One potential improvement would be to alter the analysis of the rolling period for precipitation totals within the APT. The rolling periods

can be modified by changing of the number of rolling periods or changing the rolling period window used to calculate the APT α .

Due to their limitations, no single existing data set can currently address the climatic and hydroclimatic needs of the USACE Regulatory program. Until further tools and data sets are developed, a composite of these tools (i.e., multiple lines of evidence) can be used to assess an observation site's climatology and hydroclimatology, in conjunction with field indicators, aerial photos, and other tools that have been used for decades.

6 Recommendations

A robust and accurate alternative to the APT is needed. This alternative should improve streamflow normalcy assessments for ungaged locations by (1) using hydrologic modeling and (2) accounting for additional hydrologic processes, such as snow melting or rain on snow events. In many ways, practitioners encounter remote assessment challenges that are similar to the ungaged basin problem within the hydrologic community (Sivapalan 2003). Ungaged basins are those locations within a watershed where streamflow observations are not collected. Both situations require the practitioner to assess an aquatic resource without the use of in situ data to validate their approach. In response to the challenge of the ungaged basin, the hydrologic forecasting community developed large spatial extent hydrologic forecasting frameworks, such as the NWM and SPT (Snow et al. 2016; Wahl et al. 2016). The NWM and SPT systemically use meteorological input to approximate streamflow at locations where observed streamflow is unavailable. Though the NWM and SPT focus on streamflow forecasting, accurate historical conditions are important for providing subseasonal forecast initialization (Li et al. 2009) and context for the magnitude of those forecasts (Snow et al. 2016). It is possible that large spatial extent hydrologic models may offer a better alternative to understanding the normalcy of aquatic resources, particularly streams and rivers. It is important to note that, unlike direct gage measurements, the use of model estimates of streamflow requires considering the uncertainty in those estimates.

There are impediments that preclude the use of existing large spatial extent hydrologic models. The NWC currently only maintains a five-day archive of previous NWM anomaly graphics, meaning that this product has limited utility in evaluating normal hydroclimatic conditions beyond five days from the present. Further, the SPT could provide an assessment of streamflow normalcy at ungaged locations, but the SPT's current visualizations only support flood forecasting

Additional accuracy in determining normal climatologic and hydroclimatic conditions may be achieved by actively collaborating with the hydrologic forecasting community to develop tools that approximate hydrologic processes and also achieve common goals across federal agencies. One possible avenue for collaboration is in assessing the capacity of large spatial

extent hydrologic models, such as the SPT and NWM, to predict stream-flow normalcy. If proven effective, USACE Regulatory can work with ERDC and the NWC to archive and make usable forms of the data readily accessible to practitioners. Additionally, the Interagency Council for Advancing Meteorological Services, Committee for Services, Subcommittee on Water Information and Services (SC-Water), and Working Group for Inland Water Services support the delivery of water information services. Though the working group does not explicitly support the CWA, the products and services the group supports indirectly benefit CWA applications. Additionally, USGS gages, field indicators, aerial photos, and other tools that we have used for decades have been beneficial and will continue to be effective.

Furthermore, several interagency teams and working groups are working to address the meteorologic and hydrologic data needs of the field. An interagency team composed of representatives from the Department of the Army, USGS, EPA, and US Fish and Wildlife Service formed to provide recommendations on improving the mapping and modeling of aquatic resources. This interagency team hopes to leverage existing geospatial data sets, such as the NHD and National Wetlands Inventory, to create an aquatic resource decision support system (DSS) that informs the user about waters regulated under the CWA. The interagency group has identified several test basins for the DSS that span a range of environmental conditions. Data produced by modeling within the DSS may help to support the determination of streamflow normalcy.

A plausible next step for USACE Regulatory is to align the work of ERDC, the NWC, aquatic resource DSS, and the SC-Water working group to develop a comprehensive hydrologic approach to remotely determining typical year. A collaboration with the aquatic resource DSS team could be beneficial for investigating the use of the large spatial extent hydrologic models for correctly identifying streamflow normalcy within the test basins determined by the aquatic resources DSS team. These watersheds include

- Upper Donner Blitzen in Eastern Oregon (HUC 10 1712000301),
- Roaring Fork in Colorado (HUC 08 14010004),
- Cedar Creek in Northern Indiana (HUC 10 0410000307), and
- Upper Choptank in Maryland and Delaware (HUC 10 0206000502).

The results of this analysis could then be tied into the work of the aquatic resource DSS team and communicated to the SC-Water working group. This action could enhance USACE Regulatory's capacity to determine the normalcy of hydroclimatic conditions and lay the foundation for future advancement by taking advantage of activities across the federal government.

References

- Abatzoglou, J. T. 2013. "Development of Gridded Surface Meteorological Data for Ecological Applications and Modelling." *International Journal of Climatology* 33 (1): 121–131. <https://doi.org/10.1002/joc.3413>.
- Adams, D. K., and A. C. Comrie. 1997. "The North American Monsoon." *Bulletin of the American Meteorological Society* 78 (10): 2197–2213. [https://doi.org/10.1175/1520-0477\(1997\)078<2197:TNAM>2.0.CO;2](https://doi.org/10.1175/1520-0477(1997)078<2197:TNAM>2.0.CO;2).
- Anderson, B., and A. Rea. 2020. *National Hydrography Datasets*. Reston, VA: USGS. https://icwp.org/wp-content/uploads/2020/04/USGS-Hydrography_202001231.pdf.
- Balsamo, G., C. Albergel, A. Beljaars, S. Boussetta, E. Brun, H. Cloke, D. Dee, et al. 2015. "ERA-Interim/Land: A Global Land Surface Reanalysis Data Set." *Hydrology and Earth System Sciences* 19 (1): 389–407. <https://doi.org/10.5194/hess-19-389-2015>.
- Balsamo, G., A. Beljaars, K. Scipal, P. Viterbo, B. van den Hurk, M. Hirschi, and A. K. Betts. 2009. "A Revised Hydrology for the ECMWF Model: Verification from Field Site to Terrestrial Water Storage and Impact in the Integrated Forecast System." *Journal of Hydrometeorology* 10 (3): 623–643. <https://doi.org/10.1175/2008JHM1068.1>.
- Barrett, A. P. 2003. *National Operational Hydrologic Remote Sensing Center Snow Data Assimilation System (SNODAS) Products at NSIDC*. Special Report No. 11. Boulder, CO: National Snow and Ice Data Center, Cooperative Institute for Research in Environmental Sciences, University of Colorado. https://nsidc.org/sites/nsidc.org/files/technical-references/nsidc_special_report_11.pdf.
- Beardsley, R. C., C. Chen, and Q. Xu. 2013. "Coastal Flooding in Scituate (MA): A FVCOM Study of the 27 December 2010 Nor'easter." *Journal of Geophysical Research* 118 (11): 6030–6045. <https://doi.org/10.1002/2013JC008862>.
- CPC (Climate Prediction Center). n.d.a. "NLDAS2 Soil Moisture Percentile." Accessed 13 November 2021. <https://www.cpc.ncep.noaa.gov/products/Drought/Monitoring/smp.shtml>.
- CPC (Climate Prediction Center). n.d.b. "Soil Moisture." Accessed October 2021. <https://www.cpc.ncep.noaa.gov/soilmst/w.shtml>.
- CPC (Climate Prediction Center). 2004. *The North American Monsoon*. College Park, MD: Climate Prediction Center. https://www.cpc.ncep.noaa.gov/products/outreach/Report-to-the-Nation-Monsoon_aug04.pdf.
- Daly, C. n.d. "PRISM High-Resolution Spatial Climate Data for the United States: Max/Min Temp, Dewpoint, Precipitation." Last updated 12 May 2022. <https://climatedataguide.ucar.edu/climate-data/prism-high-resolution-spatial-climate-data-united-states-maxmin-temp-dewpoint>.

- Daly, C., W. P. Gibson, G. H. Taylor, G. L. Johnson, and P. Pasteris. 2002. "A Knowledge-Based Approach to the Statistical Mapping of Climate." *Climate Research* 22 (2): 99–113. <https://doi.org/10.3354/cr022099>.
- Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. P. Pasteris. 2008. "Physiographically Sensitive Mapping of Climatological Temperature and Precipitation across the Conterminous United States." *International Journal of Climatology* 28 (15): 2031–2064. <https://doi.org/10.1002/joc.1688>.
- Davis, R. E., and R. Dolan. 1993. "Nor'easters." *American Scientist* 81 (5): 428–439. <http://www.jstor.org/stable/29775010>.
- Eberts, S. M., M. D. Woodside, M. N. Landers, and C. R. Wagner. 2019. *Monitoring the Pulse of Our Nation's Rivers and Streams: The U.S. Geological Survey Streamgaging Network*. US Geological Survey Fact Sheet 2018–3081. Reston, VA: US Geological Survey. <https://doi.org/10.3133/fs20183081>.
- ECMWF (European Centre for Medium-Range Weather Forecasts). 2020. "Fact sheet: Reanalysis." <https://www.ecmwf.int/en/about/media-centre/focus/2020/fact-sheet-reanalysis>.
- EPA (US Environmental Protection Agency). 2020. *Clean Water Act Programs Utilizing the Definition of WOTUS*. EPA. <https://www.epa.gov/nwpr/clean-water-act-programs-utilizing-definition-wotus>.
- EPA (US Environmental Protection Agency). 2021a. "About Waters of the United States." EPA. <https://www.epa.gov/wotus/about-waters-united-states>.
- EPA (US Environmental Protection Agency). 2021b. "WATERS (Watershed Assessment, Tracking & Environmental Results System)." EPA. <https://www.epa.gov/waterdata/waters-watershed-assessment-tracking-environmental-results-system>.
- Falcone, J. A. 2011. *GAGES-II: Geospatial Attributes of Gages for Evaluating Streamflow*. Reston, VA: US Geological Survey. <https://doi.org/10.3133/70046617>.
- Federal Register. 2021. "Notice of Public Meetings Regarding 'Waters of the United States'; Establishment of a Public Docket; Request for Recommendations." Document Number 2021-16643. *Federal Register* 86 (147): 41911–41914. <https://www.govinfo.gov/content/pkg/FR-2021-08-04/pdf/2021-16643.pdf>.
- Fritz, K. M., T.-L. Nadeau, J. E. Kelso, W. S. Beck, R. D. Mazor, R. A. Harrington, and B. J. Topping. 2020. "Classifying Streamflow Duration: The Scientific Basis and an Operational Framework for Method Development." *Water* 12 (9): 2545. <https://doi.org/10.3390/w12092545>.
- Github. 2021. "ulmo-dev/ulmo." Github.v0.8.8. <https://github.com/ulmo-dev/ulmo>.

- Gutenson, J. L., and J. C. Deters. 2022. *Antecedent Precipitation Tool (APT) Version 1.0: Technical and User Guide*. ERDC/TN WRAP-22-1. Vicksburg, MS: US Army Engineer Research and Development Center.
<http://dx.doi.org/10.21079/11681/43160>.
- Hamill, D., and G. C. L. David. 2021. *Hydrologic Analysis of Field Delineated Ordinary High Water Marks for Rivers and Streams*. ERDC/CRREL TR-21-9. Hanover, NH: Cold Regions Research and Engineering Laboratory.
<https://hdl.handle.net/11681/41681>.
- Huang, J., H. van den Dool, and K. P. Georgakakos. 1996. "Analysis of Model-Calculated Soil Moisture over the United States (1931–1993) and Applications to Long-Range Temperature Forecasts." *Journal of Climate* 9 (6): 1350–1362.
[https://doi.org/10.1175/1520-0442\(1996\)009<1350:AOMCSM>2.0.CO;2](https://doi.org/10.1175/1520-0442(1996)009<1350:AOMCSM>2.0.CO;2).
- Jian, X., D. M. Wolock, H. F. Lins, and S. J. Brady. 2017. *Streamflow of 2016–Water Year Summary*. Fact Sheet 2017–3063. Reston, VA: US Geological Survey.
<https://pubs.usgs.gov/fs/2017/3063/fs20173063.pdf>.
- Kent, K. M. 1972. "Travel Time, Time of Concentration and Lag," In *National Engineering Handbook*, Section 4: Hydrology, edited by D. E. Woodward et al., 15-1–15-5. Washington, DC: USDA.
<https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=18389.wba>.
- Li, H., L. Luo, E. F. Wood, and J. Schaake. 2009. "The Role of Initial Conditions and Forcing Uncertainties in Seasonal Hydrologic Forecasting." *Journal of Geophysical Research Atmospheres* 114 (4): 1–10.
<https://doi.org/10.1029/2008JD010969>.
- Li, Z., and S. M. Quiring. 2021. "Identifying the Dominant Drivers of Hydrological Change in the Contiguous United States." *Water Resources Research* 57 (5): e2021WR029738. <https://doi.org/10.1029/2021WR029738>.
- Lin, Y., and K. E. Mitchell. 2005. "The NCEP Stage II/IV Hourly Precipitation Analyses: Development and Applications." In *Proceedings, 19th Conference on Hydrology, American Meteorological Society*, January 2005. San Diego, CA: American Meteorological Society. <https://ams.confex.com/ams/pdfpapers/83847.pdf>.
- McKay, L., T. Bondelid, T. Dewald, C. Johnston, R. Moore, and A. Rea. 2012. *NHD Plus Version 2: User Guide*. Herndon, VA: Horizon Systems Corporation.
http://www.horizon-systems.com/NHDPlusData/NHDPlusV21/Documentation/NHDPlusV2_User_Guide.pdf.
- National Weather Service. n.d.a. "North American Monsoon Highlights." National Weather Service. <https://www.weather.gov/abq/northamericanmonsoon-intro>.
- National Weather Service. n.d.b. "What is a Nor'easter?" National Weather Service. <https://www.weather.gov/safety/winter-noreaster>.
- National Weather Service. n.d.c. "What is Lake Effect Snow?" National Weather Service. <https://www.weather.gov/safety/winter-lake-effect-snow#>.

- National Weather Service. 2019. "River Forecast Centers." Last modified 1 March 2019. <https://water.weather.gov/ahps/rfc/rfc.php>.
- NCAR (National Center for Atmospheric Research). 2020. "Palmer Drought Severity Index (PDSI)." <https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi>.
- Nelson, B. R., O. P. Prat, D.-J. Seo, and E. Habib. 2016. "Assessment and Implications of NCEP Stage IV Quantitative Precipitation Estimates for Product Intercomparisons." *Weather and Forecasting* 31 (2): 371–394. <https://doi.org/10.1175/WAF-D-14-00112.1>.
- NOAA (National Oceanic and Atmospheric Administration). n.d.a. "National Gridded Snowfall Analysis." Last modified 23 March 2022. https://www.noahrs.noaa.gov/snowfall_v2/.
- NOAA (National Oceanic and Atmospheric Administration). n.d.b "National Snow Analyses." Last modified 31 May 2018. <https://www.noahrs.noaa.gov/nsa/>.
- NOAA (National Oceanic and Atmospheric Administration). n.d.c. *The National Water Model*. Silver Spring, MD: NOAA. <https://water.noaa.gov/about/nwm>.
- NOAA (National Oceanic and Atmospheric Administration). 2014. *nClimDiv: Statewide-Regional-National Drought*. <https://www1.ncdc.noaa.gov/pub/data/cirs/climdiv/drought-readme.txt>.
- NOAA (National Oceanic and Atmospheric Administration). 2022. "Historical Palmer Drought Indices." <https://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers/>.
- Northwest Alliance for Computational Science and Engineering. 2022. "Anomalies: Deviation from Long-Term (30-year) Averages." <https://prism.oregonstate.edu/comparisons/anomalies.php>.
- NRCS (Natural Resources Conversation Service). 1997. "Hydrology Tools for Wetland Determination." In *Part 650 Engineering Field Handbook*, edited by NRCS, 19-1–19-55. Washington, DC: US Department of Agriculture.
- Palmer, W. C. 1965. *Meteorological Drought*. Research Paper 45. Washington, DC: US Department of Commerce, Weather Bureau. <https://erdclibrary.on.worldcat.org/oclc/794781018>.
- Peace, R. L., Jr., and R. B. Sykes, Jr. 1966. "Mesoscale Study of a Lake Effect Snow Storm." *Monthly Weather Review* 94 (8): 495–507. [https://doi.org/10.1175/1520-0493\(1966\)094<0495:msoale>2.3.co;2](https://doi.org/10.1175/1520-0493(1966)094<0495:msoale>2.3.co;2).
- Seaber, P. R., F. P. Kapinos, and G. L. Knapp. 1987. *Hydrologic Unit Maps*. United States Geological Survey Water-Supply Paper 2294. Denver, CO: USGS. https://pubs.usgs.gov/wsp/wsp2294/pdf/wsp_2294.pdf.

- Sivapalan, M. 2003. "Prediction in Ungauged Basins: A Grand Challenge for Theoretical Hydrology." *Hydrological Processes* 17 (15): 3163–3170. <https://doi.org/10.1002/hyp.5155>.
- Snow, A. D., S. D. Christensen, N. R. Swain, E. J. Nelson, D. P. Ames, N. L. Jones, D. Ding, et al. 2016. "A High-Resolution National-Scale Hydrologic Forecast System from a Global Ensemble Land Surface Model." *Journal of the American Water Resources Association (JAWRA)* 52 (4): 950–964. <https://doi.org/10.1111/1752-1688.12434>.
- Sprecher, S. W., and A. G. Warne. 2000. *Accessing and Using Meteorological Data to Evaluate Wetland Hydrology*. ERDC/EL TR-WRAP-00-1. Vicksburg, MS: US Army Engineer Research and Development Center. <http://hdl.handle.net/11681/4362>
- Steenburgh, W. J., and L. S. Campbell. 2017. "The OWLeS IOP2b Lake-Effect Snowstorm: Shoreline Geometry and the Mesoscale Forcing of Precipitation." *Monthly Weather Review* 145 (7): 2421–2436. <https://doi.org/10.1175/MWR-D-16-0460.1>.
- Svoboda, M., D. LeComte, M. Hayes, R. Heim, K. Gleason, J. Angel, B. Rippey, et al. 2002. "The Drought Monitor." *Bulletin of the American Meteorological Society* 83 (8): 1181–1190. <https://doi.org/10.1175/1520-0477-83.8.1181>.
- USACE (US Army Corps of Engineers). 2008. *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Arid West Region* (Version 2.0). Vicksburg, MS: U.S. Army Engineer Research and Development Center.
- USACE (US Army Corps of Engineers). 2020a. *Interim Approved Jurisdictional Determination Form User Manual—Navigable Waters Protection Rule*. Washington, DC: USACE. <https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll11/id/4655>.
- USACE (US Army Corps of Engineers). 2020b. *Regulatory Program Overview*. Washington, DC: USACE. <https://usace.contentdm.oclc.org/utis/getfile/collection/p16021coll6/id/2136>.
- USDM (US Drought Monitor). n.d. "Current Map." Accessed 2 February 2021. <https://droughtmonitor.unl.edu/>.
- USGS (US Geological Survey). 2011. "What is a percentile?" USGS. <https://help.waterdata.usgs.gov/faq/surface-water/what-is-a-percentile>.
- USGS (US Geological Survey). 2017. "National Hydrography Dataset Plus High Resolution (NHDPlus HR)—USGS National Map Downloadable Data Collection." USGS. <https://www.sciencebase.gov/catalog/item/57645ff2e4b07657d19ba8e8>
- USGS (US Geological Survey). 2020a. "About WaterWatch." USGS. https://waterwatch.usgs.gov/?id=ww_about.
- USGS (US Geological Survey). 2020b. "National Hydrography." USGS. <https://www.usgs.gov/core-science-systems/ngp/national-hydrography>.

- USGS (US Geological Survey). 2022. "National Water Information System: Web Interface." USGS. <https://waterdata.usgs.gov/nwis>.
- van den Dool, H., J. Huang, and Y. Fan. 2003. "Performance and Analysis of the Constructed Analogue Method Applied to U.S. Soil Moisture over 1981–2001." *Journal of Geophysical Research* 108 (16). <https://doi.org/10.1029/2002JD003114>.
- Vepraskas, M. J., J. F. Berkowitz, and C. Arellano. 2019. "Determining Normal Precipitation Ranges for Hydric Soil Assessments." *Soil Science Society of America Journal* 83 (2): 503–510. <https://doi.org/10.2136/sssaj2018.09.0333>.
- Villani, J. P., M. L. Jurewicz, Sr., and K. Reinhold. 2017. "Forecasting the Inland Extent of Lake Effect Snow Bands Downwind of Lake Ontario." *Journal of Operational Meteorology* 05 (05): 53–70. <https://doi.org/10.15191/nwajom.2017.0505>.
- Vose, R. S., S. Applequist, M. Squires, I. Durre, C. J. Menne, C. N. Williams, C. Fenimore, K. Gleason, and D. Arndt. 2014. "Improved Historical Temperature and Precipitation Time Series for US Climate Divisions." *Journal of Applied Meteorology and Climatology* 53 (5): 1232–1251. <https://doi.org/10.1175/JAMC-D-13-0248.1>.
- Wahl, M., M. Follum, A. Snow, and A. Tavakoly. 2016. "Developing Hydrologic Awareness." *The Military Engineer* 108 (700): 65–66. <https://www.jstor.org/stable/26354594>.
- Water Science School. 2019. "Snowmelt Runoff and the Water Cycle." USGS. <https://www.usgs.gov/special-topics/water-science-school/science/snowmelt-runoff-and-water-cycle>.
- Williams, G. P. 1978. "Bank-Full Discharge of Rivers." *Water Resources Research* 14 (6): 1141–1154. <https://doi.org/10.1029/WR014i006p01141>.
- Wu, S., J. Zhao, H. Wang, and M. Sivapalan. 2021. "Regional Patterns and Physical Controls of Streamflow Generation across the Conterminous United States." *Water Resources Research* 57 (6): e2020WR028086. <https://doi.org/10.1029/2020WR028086>.
- Xia, Y. 2012. "Continental-Scale Water and Energy Flux Analysis and Validation for North American Land Data Assimilation System Project Phase 2 (NLDAS-2): 2. Validation of Model-Simulated Streamflow." *Journal of Geophysical Research* 117: D03110. <https://doi.org/10.1029/2011JD016048>.
- Yang, L., J. Smith, M. L. Baeck, and E. Morin. 2019. "Flash Flooding in Arid/Semiarid Regions: Climatological Analyses of Flood-Producing Storms in Central Arizona during the North American Monsoon." *Journal of Hydrometeorology* 20 (7): 1449–1471. <https://doi.org/10.1175/JHM-D-19-0016.1>.
- Zhang, J., K. Howard, C. Langston, B. Kaney, Y. Qi, L. Tang, H. Grams, et al. 2016. "Multi-Radar Multi-Sensor (MRMS) Quantitative Precipitation Estimation: Initial Operating Capabilities." *Bulletin of the American Meteorological Society* 97 (4): 621–638. <https://doi.org/10.1175/BAMS-D-14-00174.1>.

Appendix: USGS Gages Used in the Analysis

Table A-1. USGS gages used in the analysis.

USGS Gage Number	Site Name	Drainage Area (km ²)	Latitude	Longitude	HUC 2
01011000	Allagash River near Allagash, ME	3,828	47.06972	-69.0794	01
01013500	Fish River near Fort Kent, ME	2,261	47.2375	-68.5828	01
01015800	Aroostook River near Masardis, ME	2,310	46.52306	-68.3717	01
01017000	Aroostook River at Washburn, ME	4,284	46.77722	-68.1572	01
01017060	Hardwood Brook below Glidden Branch near Caribou, ME	15	46.78361	-67.9892	01
01017550	Williams Brook at Phair, ME	10	46.62806	-67.9531	01
01021000	St. Croix River at Baring, ME	3,559	45.13694	-67.3181	01
01021470	Libby Brook near Northfield, ME	20	44.80083	-67.725	01
01021480	Old Stream near Wesley, ME	75	44.93694	-67.7361	01
01022294	East Branch Bear Brook near Beddington, ME	0.11	44.85909	-68.104	01
01302020	Bronx River at NY Botanical Garden at Bronx, NY	99.5	40.86231	-73.8744	02
01303000	Mill Neck Creek at Mill Neck, NY	22.2	40.8875	-73.5636	02
01303500	Cold Spring Brook at Cold Spring Harbor, NY	20.2	40.85722	-73.4633	02
01304000	Nissequogue River near Smithtown, NY	70	40.84944	-73.2242	02
01304500	Peconic River at Riverhead, NY	194	40.91361	-72.6867	02
01305000	Carmans River at Yaphank, NY	189	40.83028	-72.9061	02
01305500	Swan River at East Patchogue, NY	20.9	40.76694	-72.9936	02
01306460	Connetquot Bk nr Central Islip, NY	56.7	40.77194	-73.1586	02
01306500	Connetquot River near Oakdale, NY	63.5	40.7475	-73.1503	02
01308000	Sampawams Creek at Babylon, NY	58.8	40.70417	-73.3139	02
01308500	Carlls River at Babylon, NY	91.7	40.70861	-73.3283	02
01309500	Massapequa Creek at Massapequa, NY	100	40.68889	-73.4547	02
01309950	Bellmore Creek near Bellmore, NY		40.67871	-73.5157	02
02044500	Nottoway River near Rawlings, VA	821	36.98348	-77.7997	03
02045500	Nottoway River near Stony Creek, VA	1,494	36.90015	-77.3997	03
02046000	Stony Creek near Dinwiddie, VA	293	37.06709	-77.6025	03
02047500	Blackwater River near Dendron, VA	751	37.02515	-76.8747	03

Table A-1 (cont.). USGS gages used in the analysis.

USGS Gage Number	Site Name	Drainage Area (km ²)	Latitude	Longitude	HUC 2
02047783	Blackwater River at Route 620 Near Zuni, VA		36.90654	-76.82	03
02049500	Blackwater River near Franklin, VA	1,588	36.76265	-76.8983	03
02053200	Potecasi Creek near Union, NC	583	36.37083	-77.0256	03
02053500	Ahoskie Creek at Ahoskie, NC	164	36.28028	-76.9994	03
04010500	Pigeon River at Middle Falls nr Grand Portage, MN	1,577	48.01211	-89.6162	04
04015330	Knife River near Two Harbors, MN	217	46.94688	-91.7924	04
04015438	St. Louis River near Skibo, MN	262	47.48111	-92.04	04
04021520	Stoney Brook at Pine Drive near Brookston, MN	192	46.78167	-92.6367	04
04024000	St. Louis River at Scanlon, MN	8,884	46.70328	-92.4188	04
03007800	Allegheny River at Port Allegany, PA	642	41.81868	-78.2928	05
03010500	Allegheny River at Eldred, PA	1,424	41.9634	-78.3861	05
03010655	Oswayo Creek at Shinglehouse, PA	256	41.96173	-78.1981	05
03010820	Allegheny River at Olean, NY	3,087	42.07306	-78.4511	05
03011020	Allegheny River at Salamanca, NY	4,165	42.15639	-78.7153	05
03011800	Kinzua Creek near Guffey, PA	100	41.76645	-78.7186	05
03012550	Allegheny River at Kinzua Dam, PA	3,087	41.84145	-79.012	05
03014500	Chadakoin River at Falconer, NY	3,253	42.1125	-79.2039	05
03015000	Conewango Creek at Russell, PA	2,113	41.93811	-79.1331	05
03015310	Allegheny River bl Conewango Creek at Warren, PA	8,109	41.84395	-79.1498	05
03015500	Brokenstraw Creek at Youngsville, PA	3,074	41.85256	-79.3173	05
03016000	Allegheny River at West Hickory, PA	9,479	41.57089	-79.4078	05
03017500	Tionesta Creek at Lynch, PA	603	41.60201	-79.05	05
03020000	Tionesta Creek at Tionesta Creek Dam, PA	1,241	41.47784	-79.4439	05
03020500	Oil Creek at Rouseville, PA	733	41.48173	-79.6953	05
03021350	French Creek near Wattsburg, PA	238	42.01533	-79.7826	05
03021520	French Creek near Union City, PA	572	41.90783	-79.8967	05
03022540	Woodcock Creek at Blooming Valley, PA	81	41.69061	-80.0481	05
03439000	French Broad River at Rosman, NC	176	35.14333	-82.8247	06
03441000	Davidson River near Brevard, NC	105	35.27306	-82.7058	06
03443000	French Broad River at Blantyre, NC	767	35.29917	-82.6239	06
03446000	Mills River near Mills River, NC	173	35.39806	-82.595	06

Table A-1 (cont.). USGS gages used in the analysis.

USGS Gage Number	Site Name	Drainage Area (km ²)	Latitude	Longitude	HUC 2
03447687	French Broad River near Fletcher, NC	1,658	35.42917	-82.5525	06
03448942 05	North Fork Swannanoa River near Walkertown, NC	38	35.68528	-82.3328	06
03450000	Beetree Creek near Swannanoa, NC	14	35.65306	-82.4053	06
03451000	Swannanoa River at Biltmore, NC	337	35.56833	-82.5447	06
03453000	Ivy River near Marshall, NC	409	35.76972	-82.6208	06
03453500	French Broad River at Marshall, NC	3,450	35.78639	-82.6608	06
05270500	Sauk River near St. Cloud, MN	2,668	45.55969	-94.2336	07
05270700	Mississippi River at St. Cloud, MN	34,499	45.54719	-94.1458	07
05275000	Elk River near Big Lake, MN	1,448	45.33385	-93.6669	07
03613000	Humphrey Cr at LaCenter, KY	114	37.07755	-88.9559	08
07024000	Bayou de Chien near Clinton, KY	178	36.62867	-88.964	08
07024200	Crooked Creek near Huntingdon, TN	68.6	36.06451	-88.4048	08
07024500	South Fork Obion River near Greenfield, TN	992	36.11812	-88.8109	08
07025400	North Fork Obion River near Martin, TN	963	36.40531	-88.8548	08
07026040	Obion River at Hwy 51 near Obion, TN	4,856	36.24083	-89.2176	08
07026680	Bayou du Chien nr Walnut Log, TN	66.6	36.49361	-89.3006	08
07027720	South Fork Forked Deer River near Owl City, TN	1,860	35.71877	-89.2123	08
07030050	Hatchie River at Rialto, TN	5,978	35.63733	-89.6095	08
05014500	Swiftcurrent Creek at Many Glacier, MT	80.8	48.79883	-113.657	09
05046475	Otter Tail River Diversion at Breckenridge, MN		46.28246	-96.5826	09
05050000	Bois de Sioux River near White Rock, SD	3,004	45.86246	-96.574	09
05051300	Bois de Sioux River near Doran, MN	4,869	46.15218	-96.5792	09
06018500	Beaverhead River near Twin Bridges, MT	9,371	45.38339	-112.453	10
06019500	Ruby River above reservoir near Alder, MT	1,383	45.19232	-112.143	10
06020600	Ruby River below reservoir near Alder, MT	1,541	45.24187	-112.111	10

Table A-1 (cont.). USGS gages used in the analysis.

USGS Gage Number	Site Name	Drainage Area (km ²)	Latitude	Longitude	HUC 2
07052152	Wilson Creek near Brookline, MO	132	37.14714	-93.3755	11
07052250	James River near Boaz, MO	1,197	37.00658	-93.3647	11
07052345	Finley Creek below Riverdale, MO	676	36.97489	-93.3279	11
08017410	Sabine River near Wills Point, TX	1,958	32.80624	-95.9194	12
08018500	Sabine River near Mineola, TX	3,515	32.61375	-95.4858	12
08019000	Lake Fk Creek near Quitman, TX	1,515	32.76318	-95.463	12
08019200	Sabine River near Hawkins, TX	5,851	32.55986	-95.2066	12
08020000	Sabine River near Gladewater, TX	7,229	32.52709	-94.9602	12
08020700	Rabbit Creek at Kilgore, TX	196	32.38821	-94.9033	12
08022040	Sabine River near Beckville, TX	9,295	32.32738	-94.3535	12
08023080	Bayou Grand Cane near Stanley, LA	188	31.96272	-93.9412	12
08023400	Bayou San Patricio near Benson, LA	208	31.87517	-93.6585	12
08025360	Sabine River at Toledo Bd Res near Burkeville, TX	18,591	31.1738	-93.566	12
08025500	Bayou Toro near Toro, LA	383	31.30713	-93.5157	12
08026000	Sabine River near Burkeville, TX	7,482	31.06408	-93.5196	12
08220000	Rio Grande near Del Norte, CO	3,419	37.68861	-106.46	13
09010500	Colorado River below Baker Gulch nr Grand Lake, CO	165	40.32582	-105.857	14
09014050	Grand Lake Outlet blw Chipmunk Ln at Grand Lk, CO	198	40.24611	-105.829	14
09015000	Colorado River Bl Shadow Mountain Reservoir, CO	492	40.20519	-105.838	14
09022000	Fraser River at Upper Sta, near Winter Park, CO	27.2	39.84582	-105.752	14
09024000	Fraser River at Winter Park, CO	71.5	39.89999	-105.777	14
09025000	Vasquez Creek at Winter Park, CO	72.3	39.92026	-105.785	14
09025300	Elk Creek at Upper Station, near Fraser, CO	4.33	39.88943	-105.833	14
09026500	St. Louis Creek near Fraser, CO	85.2	39.90999	-105.878	14
09027100	Fraser River at Tabernash, CO	298	39.99033	-105.83	14
09032000	Ranch Creek near Fraser, CO	51.8	39.94999	-105.766	14
09383300	Filler Ditch at Greer, AZ		34.01616	-109.458	15
09383400	Little Colorado River at Greer, AZ	75.4	34.01671	-109.457	15

Table A-1 (cont.). USGS gages used in the analysis.

USGS Gage Number	Site Name	Drainage Area (km ²)	Latitude	Longitude	HUC 2
09383409	South Fork Little Colorado River near Greer, AZ		34.0555	-109.401	15
09384000	Little Colorado R abv Lyman Lake nr St. Johns, AZ	1,823	34.31449	-109.362	15
09385700	Little Colorado River below Salado Springs, AZ	2,189	34.45059	-109.362	15
09386030	Little Colorado Rvr abv Zion Res. nr St. Johns, AZ	2,607	34.58365	-109.407	15
09386300	Little Colorado Rvr blw Zion Res. nr St Johns, AZ	3,033	34.60475	-109.489	15
09386900	Rio Nutria near Ramah, NM	185	35.28255	-108.553	15
09386950	Zuni River abv Black Rock Reservoir, NM	2,196	35.10028	-108.752	15
09390500	Show Low Creek near Lakeside, AZ	178	34.17949	-109.988	15
10010020	Gsl Breach at Lakeside, UT		41.22243	-112.85	16
10016900	Bear River at Evanston, WY	1,147	41.26986	-110.964	16
10020100	Bear River above reservoir, near Woodruff, UT	1,955	41.43439	-111.018	16
10020300	Bear River below reservoir, near Woodruff, UT	2,031	41.5055	-111.015	16
10396000	Donner und Blitzen River nr Frenchglen, OR	518	42.79083	-118.868	17
12013500	Willapa River near Willapa, WA	337	46.65093	-123.653	17
12020000	Chehalis River near Doty, WA	293	46.61732	-123.278	17
12021800	Chehalis River near Adna, WA	881	46.62566	-123.102	17
09527594	Coachella Canal near Niland, CA		33.25622	-115.451	18
09527597	Coachella Canal near Desert Beach, CA		33.53808	-115.919	18
09527660	Brock Reservoir Outlet near Calexico, CA		32.70558	-115.034	18
09527700	All-American Canal below Drop 2 Reservoir Outlet		32.70425	-115.048	18
10251290	Borehole Spg Channel nr Tecopa Hot Spgs, CA		35.88569	-116.234	18
15051010	Salmon C nr Juneau, AK	25.1	58.33217	-134.468	19
16010000	Kawaikoi Stream nr Waimea, Kauai, HI	9.89	22.13281	-159.62	20
16019000	Waialae Str at alt 3,820 ft nr Waimea, Kauai, HI	5.41	22.08583	-159.569	20
16036000	Makaweli River nr Waimea, Kauai, HI	67.8	21.97139	-159.646	20

Table A-1 (cont.). USGS gages used in the analysis.

USGS Gage Number	Site Name	Drainage Area (km ²)	Latitude	Longitude	HUC 2
16049000	Hanapepe Riv blw Manuahi Str nr Eleele, Kauai, HI	47.8	21.95492	-159.551	20
50011200	Rio Guajataca blw Lago Guajataca, PR		18.39828	-66.9274	21
50014800	Rio Camuy nr Bayaney, PR		18.39444	-66.8176	21
50021700	Rio Grande de Arecibo abv Utuado, PR	93.2	18.24221	-66.7219	21
50024950	Rio Grande de Arecibo blw Utuado, PR	170	18.3001	-66.7037	21
50025155	Rio Saliente at Coabey nr Jayuya, PR	22.9	18.21083	-66.5628	21
50026025	Rio Caonillas at Paso Palma, PR	98.4	18.22943	-66.6367	21
50027000	Rio Limon abv Lago Dos Bocas, PR	81.6	18.3241	-66.6206	21
50027600	Rio Grande de Arecibo nr San Pedro, PR	450	18.39682	-66.6912	21

Abbreviations

APT	Antecedent Precipitation Tool
CAC	Common access card
ERDC	Engineer Research and Development Center
DSS	Decision Support System
CONUS	Contiguous United States
CPC	Climate Prediction Center
CWA	Clean Water Act
EPA	Environmental Protection Agency
EROM	Enhanced Runoff Method
gridMET	Gridded Surface Meteorological
HUC	Hydrologic Unit Code
NHDPlus	National Hydrography Dataset–Plus
NLDAS	National Land and Data Assimilation System
NOHRSC	National Operational Hydrologic Remote Sensing Center
NSN	National Streamflow Network
NWC	National Water Center
NWIS	National Water Information System
NWM	National Water Model
NWPR	Navigable Waters Protection Rule
OCONUS	Outside CONUS
PDSI	Palmer Drought Severity Index
PRISM	Parameter-elevation Regression on Independent Slopes Model
QPE	Quantitative Precipitation Estimate
RFCs	River Forecast Centers
SC-Water	Subcommittee on Water Information and Services

SNODAS	Snow Data Assimilation System
SPT	Streamflow Prediction Tool
SWE	Snow Water Equivalent
USACE	US Army Corps of Engineers
USDM	United States Drought Monitor
WATERS	Watershed Assessment, Tracking and Environmental Results System
WOTUS	Waters of the United States

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14. ABSTRACT Short-term climatic and hydrologic interactions, or <i>hydroclimatology</i> , are an important consideration when delineating the geographic extent of aquatic resources and assessing whether an aquatic resource is a jurisdictional water of the United States (WOTUS) and is therefore subject to the Clean Water Act (CWA). The now vacated 2020 Navigable Waters Protection Rule (NWPR) required the evaluation of precipitation and other hydroclimatic conditions to assess the jurisdictional status of an aquatic resource based on normal hydroclimatic conditions. Short-term hydroclimatic conditions, such as antecedent precipitation, evapotranspiration, wetland delineation, and streamflow duration assessments, provide information on an aquatic resource's geographic extent, hydrologic characteristics, and hydrologic connectivity with other aquatic resources. Here, researchers from the US Army Corps of Engineers, Engineer Research and Development Center (ERDC) evaluate tools and data available to practitioners for assessing short-term hydroclimatic conditions. The work highlights specific meteorological phenomena that are important to consider when assessing short-term hydroclimatic conditions that affect the geographic extent and hydrologic characteristics of an aquatic resource. The findings suggest that practitioners need access to data and tools that more holistically consider the impact of short-term antecedent hydroclimatology on the entire hydrologic cycle, rather than tools based solely on precipitation.					
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