USING PRECIPITATION EFFECTIVENESS MORE BROADLY TO CAPTURE RAINFALL VARIABILITY

Shifting precipitation patterns due to climate change can be quantified in a number of different ways. In addition to trends in monthly or annual precipitation totals, trends in the intensity, duration, frequency, or extent of precipitation events can be evaluated. An example of this challenge for drought assessment is when monthly precipitation totals are near or above normal, but that precipitation falls in only a few short events. In cases like this, much of the precipitation typically runs off, with little infiltration into the soil.

Most common drought indices are ineffective at capturing the variable nature of precipitation (e.g., extreme events), which can influence the availability of water at a daily timescale. For example, the SPI and the SPEI metrics consolidate daily precipitation measurements into longer-periods (e.g., 30-days, 60-days), making the user unaware if the precipitation came in several small events or one large one.

The term *effective precipitation* was introduced by Byun and Wilhite (1999) to describe a daily sum of precipitation with a time-dependent reduction function to represent the daily depletion of water resources. Effective precipitation is meant to represent the water that remains in the landscape after accounting for runoff and evaporation. Scheff et al. (2022) points to the concept of a runoff ratio and indicates that rainfall events that might be ineffective at soil infiltration might be highly effective at increasing streamflow and reservoir storage. Key components to assess effective precipitation, whether for runoff or infiltration, include runoff, evapotranspiration, and soil moisture and groundwater. While this concept could prove quite useful in evaluating changes in soil-water availability, it has its shortcomings and challenges. These include the lack of agreement on a definition, difficulty accurately calculating the depletion of water resources in nature by runoff and evapotranspiration, and the inability to apply a general methodology on a large geographic scope. Further exploration follows.

Definition Challenge: The AMS Glossary of Meteorology defines *effective precipitation* both as the part of precipitation that reaches stream channels as direct runoff and, in irrigation, the portion of precipitation that *does not* run off and remains in the soil (AMS, 2022). To complicate the matter, there is also a definition for *precipitation effectiveness* which focuses on the portion of total precipitation used to satisfy vegetation needs (AMS, 2019b). While muddled definitions is an obvious overall problem, a secondary problem lies in the difficulty of applying this concept beyond vegetation. The concept of effective precipitation could be very beneficial in drought assessment if it considers ways to measure the water that is not getting to certain locations or industries that would usually expect it, including hydropower, fisheries, groundwater aquifers, or sector-specific water usages such as the outdoor recreation economy. Therefore, this concept needs a definition that can be applied within different contexts.

Despite the AMS definitions, for clarity and consistency within this section, the two terms are used in the following ways: *effective precipitation* describes the calculation proposed by Byun and Wilhite (1999); and *precipitation effectiveness* generally describes the concept of measuring the usefulness of precipitation within various systems.

Depletion Calculations Challenge: The choice of the effective precipitation reduction function remains unresolved due to the complexity of interacting parameters such as soil characteristics, topography, air temperature, humidity, and wind speed (Rončák et al., 2021). In order to accurately calculate effective precipitation for soils and working lands, runoff and evapotranspiration require precise calculations (Akhtari et al., 2008; Kalamaras et al., 2010; Kim & Byun, 2009; Kim et al., 2009; Morid et al., 2006; Roudier & Mahe, 2009).

Geographic Scope Challenge: Studies on calculating effective precipitation are not widespread and have been limited in their geographic scope and scale. Within the research community there is a clear need to identify a robust methodology to calculate effective precipitation at both the local and regional scale, especially considering the dynamic nature of precipitation variability on sub-monthly timescales, and the premise of a non-stationary climate. Adopting a drought metric that incorporates effective precipitation—or runoff-ratio or some other means of quantifying precipitation effectiveness—in its calculation would both allow for a more accurate assessment of water availability and assessments of drought in a non-stationary climate. A few geographic considerations and nuances are as follows:

- **In the Western United States,** establishing or revising a regional precipitation metric for mountainous and snow fed areas as a ratio of snow water equivalent (SWE)/precipitation (P), would account for the natural storage in snowpack. SWE vs. streamflow later in the year could provide insight into runoff and evaporation conditions. Tracking this over time would be an insightful measure of a changing climate. However, this will be challenging in Alaska, where thawing permafrost contributes to streamflow along with snowmelt.
- **In the Midwestern and Eastern United States,** a new or revised precipitation effectiveness metric could be soil moisture vs. precipitation to answer the question, “How much water made it into the ground as opposed to runoff?”

Priority Actions:

1. Consider a broader view of effective precipitation in drought assessment, beyond agriculture, as a way to quantify water scarcity for certain locations and industries.
2. Design a research-to-action framework to define and estimate precipitation effectiveness for different regions, times, sectors. Incorporate the evaluation of current infrastructure for precipitation effectiveness measurement/monitoring capacity.
3. Undertake a proof-of-concept study of precipitation effectiveness using a network of soil moisture sensors to quantify precipitation infiltration versus runoff.

4. Calculate effective precipitation at local and regional scales (e.g., gridded product) and incorporate effective precipitation—or some other means of quantifying precipitation effectiveness—into drought assessment.
5. Improve national soil moisture observations and data accessibility to inform drought assessment and disseminate related products to inform decision-making. This could include expansion of the efforts of the National Coordinated Soil Moisture Monitoring Network.
6. Develop a better understanding of how drought characteristics (e.g., duration, rate of intensification) might change in the future due to changes in meteorological drivers and vegetation properties. This includes a better understanding of hydrologic cycle intensification (e.g., fewer but larger magnitude precipitation events and more rapid transition between high and low precipitation extremes).

Research Questions:

1. How could the growing *in situ* soil moisture monitoring infrastructure be leveraged to improve soil moisture modeling?
2. What is the value of increased observations in heavily forested areas to remotely sensed products and models?
3. How can measurements and indicators of the hydrologic impacts of precipitation (or lack thereof) including soil moisture, shallow groundwater, and runoff, be increased and improved? How are management decisions accounted for?
4. Could soil moisture data be used to infer both available soil moisture and precipitation runoff information, and could this information be used in place of precipitation effectiveness?
5. How do changes to soil properties due to climate change, disturbance, and management practices impact infiltration, runoff, and soil moisture levels?
6. How can products addressing precipitation intensity normalize for spatial variability in soil infiltration capacity, based on soil type?
7. How can effective precipitation be quantified in real-time with current observation networks? How can changes in precipitation effectiveness over time be used to inform intensity-duration-frequency curves to support built infrastructure and account for precipitation changes at a location?
8. Once precipitation effectiveness is defined and quantified, how has precipitation effectiveness changed over time? How will it change in the future?
9. How does changing variability (especially intensity, but also other factors) impact precipitation effectiveness (e.g., precipitation returns to soil moisture, groundwater, reservoirs)? (See Scheff et al., 2022 for discussion on this topic as framed by the runoff-ratio).
10. Does groundwater infiltration fit into the concept of precipitation effectiveness (e.g., unconfined aquifers versus confined, pace of groundwater recharges)? How are aquifer recharge rates affected by changes in precipitation total and precipitation rates?

11. How does the gap between events (e.g., wetter but fewer events, longer dry spells) change characteristics and condition of soils to include more drying, and what are the ecological ramifications of these changes?
12. How can irrigation models inform our need to calculate precipitation effectiveness?
13. Can specific changes to precipitation duration and intensity translate to changes in effects, impacts, and usefulness of precipitation in a drought situation?
14. What time after the precipitation event should be examined (e.g., immediate, hours, integrated over some time period) to inform precipitation effectiveness?
15. Can thresholds be set for various sectors including water supply by comparing drought assessments with impacts as it pertains to precipitation events?