



From Hydrological Drought Indicators to Local Threshold Limits [†]

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Abstract

Local threshold limits translate abstract information on hydrological drought into concrete operational guidance for individual water resources. For reservoirs, surface water intakes, and groundwater sources that are important to a region, key monitored quantities and failure conditions are identified, critical levels corresponding to loss of function or unacceptable quality are derived, and an advance time to reach them is set. From these, threshold values analogous to flood stages are calculated, possibly varying over the year with the hydrological regime and demand. Implemented through regional drought plans and displayed in the HAMR (Hydrology–Agronomy–Meteorology–Retention drought monitoring and prediction system, hamr.chmi.cz), local threshold limits complement nationwide warnings by capturing the specific behaviour of each resource and enabling timely, proportionate and locally accepted drought management actions.

Keywords: drought; surface water; groundwater; warning; prediction

1. Introduction

Hydrological drought is a slow-onset extreme event whose impacts accumulate through reduced streamflow, declining groundwater levels, and reservoir depletion, often with strong spatial heterogeneity. While drought indicators and regional warning products are essential for situational awareness, operational decisions—such as staged restrictions, interconnection use, or emergency supply activation—typically hinge on source-specific constraints, including intake elevations, minimum abstraction flows, or drawdown and water-quality limits. To bridge this gap between generalized drought information and operational management, the Czech drought monitoring and prediction system HAMR (Hydrology–Agronomy–Meteorology–Retention drought monitoring and prediction system, hamr.chmi.cz) integrates warning information with resource-specific local threshold limits (LTL) for selected water sources [1,2].



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2. Methods: Deriving Local Threshold Limits for Individual Resources

2.1. Hydrological Drought Indicators and Their Interpretation

Drought indicators convert time series of climate and hydrology into comparable measures of anomaly and risk across time scales. Commonly used indices include the Standardized Precipitation Index (SPI) for precipitation anomalies [3,4], the Standardized Precipitation Evapotranspiration Index (SPEI) to account for atmospheric demand [5], the Standardized Runoff Index (SRI) for streamflow/runoff [6], and standardized groundwater indices such as the Standardized Groundwater Level Index (SGI) [7]. These indices support consistent regional communication, but they do not directly encode infrastructure or water-quality constraints that determine when a specific source fails to meet demand or regulatory requirements.

2.2. HAMR as an Operational Drought Information System

HAMR is an online system for drought and water content assessment with prediction products extending up to several weeks. It is designed as an operational decision-support service that integrates multiple components (hydrological, agronomic, meteorological, and retention) and provides both monitoring and forecasting outputs [8,9]. In addition to nationwide and municipality-level warning information, HAMR provides an application layer for displaying and evaluating local threshold limits for specific water resources based on regional drought plans [2]. The sequence of the HAMR system is shown in Figure 1.

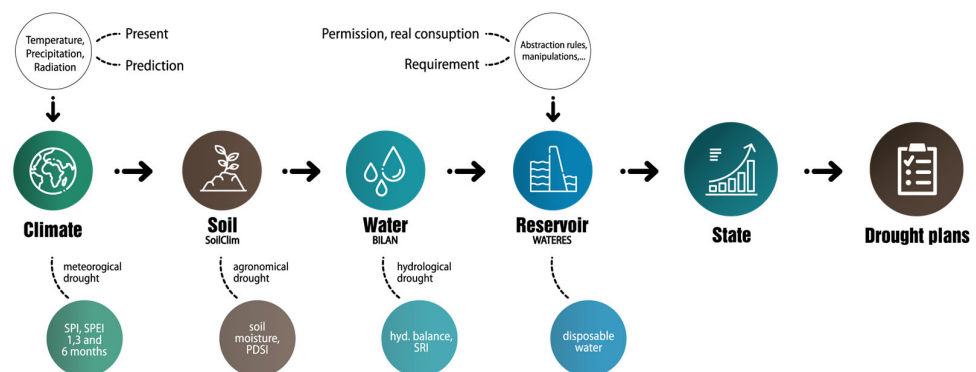


Figure 1. System HAMR scheme.

2.3. Why Local Threshold Limits Are Needed

Local threshold limits are intended to complement generalized warning information by capturing the specific behaviour and failure modes of each water resource. According to the HAMR description, an LTL is reached when there is a high probability of insufficient yield or unacceptable quality associated with drought and when a sufficiently long period remains before the source can no longer cover users' needs. LTLs are described as an analogy to flood stages and may take multiple values throughout the year to reflect the hydrological cycle and variable demand [1]. Within the HAMR system, local threshold limits are displayed for surface water sources, groundwater sources, and reservoirs and may include associated time series where available [2].

Local threshold limits are operationalized through drought management planning and staged measures. In Czech legislation, regional authorities prepare and update drought management plans for their territory in cooperation with basin managers and the Czech Hydrometeorological Institute [10]. These plans provide the institutional framework within which thresholds can trigger proportionate measures, helping to align early warning information with practical response actions [2].

2.4. Deriving Local Threshold Limits for Individual Resources

2.4.1. Definitions

A strategic water resource is characterized by a monitored key quantity $X(t)$, such as reservoir level $h(t)$ or storage $S(t)$, streamflow $Q(t)$, or groundwater level $H(t)$ at a control borehole. A failure condition is deemed to occur when the source can no longer provide the required yield or acceptable quality; the associated critical level is denoted X_{crit} . A local threshold limit X_{LTL} is established so that, when it is reached, an agreed lead time τ remains before X_{crit} would be reached under plausible drought evolution, thereby allowing predefined measures to be implemented [1,2].

2.4.2. Four-Step Procedure

Local threshold limits are derived through a procedure informed by the operator and the relevant authority:

1. Key monitored quantities describing the functioning of the resource during long-term drought are selected.
2. Critical levels corresponding to loss of function or unacceptable quality are defined.
3. An advance time (lead time) τ between the critical condition and the threshold limit that triggers action is proposed.
4. The threshold value X_{LTL} is derived so that it precedes the critical condition by the chosen lead time under plausible drought evolution.

2.4.3. Translating Lead Time into a Numeric Threshold

Two complementary approaches may be applied.

(A) Trajectory-based derivation. An estimated depletion or decline rate r (units of X per day) is used to set a threshold:

$$X_{LTL} = X_{crit} + r \cdot \tau \quad (1)$$

For reservoirs, a storage-balance formulation may be applied, after which conversion back to level is performed via stage-storage relations.

(B) Forecast-conditioned derivation. Probabilistic forecasts are used to define a threshold at which the probability of reaching the critical condition within τ exceeds a decision-relevant probability p^* . The two approaches may be combined, and thresholds may be updated as monitoring and forecast skill evolve.

2.4.4. Seasonal Thresholds

Because hydrological regimes and demands vary during the year, local threshold limits may be specified as seasonal sets $X_{LTL}(m)$ (e.g., by month or operational season). This allows earlier triggers during high-demand periods or predictable low-inflow seasons, consistent with the HAMR concept of multiple LTL values within a year [1].

3. Results

Comparison of the site-specific exceedance of local threshold limits (LTL) with standardized drought indicators for surface waters, reservoirs, and groundwater sources during 2023–2026 is shown in Figures 2–4. Red markers indicate days when the monitored variable at a given profile fell below the seasonally varying LTL. Blue and green markers denote hydrological and meteorological drought conditions based on weekly indices mapped to daily records (last available value), i.e., SRI and SPEI; orange markers show groundwater drought based on SGI (applicable to the groundwater panel only).

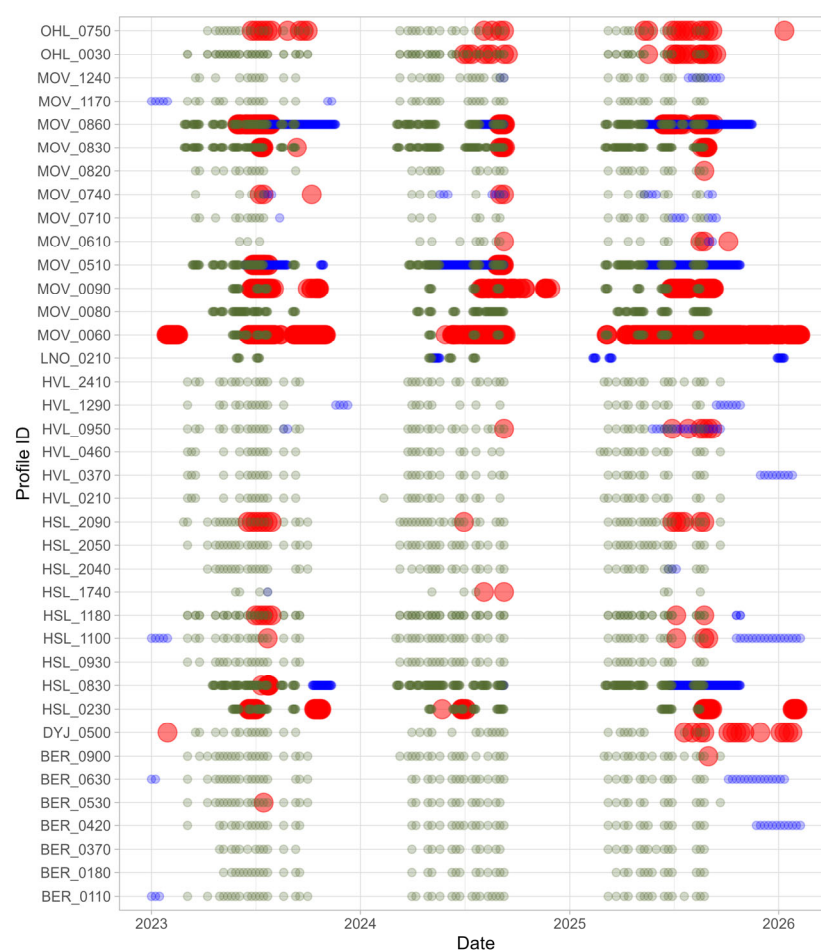


Figure 2. Timing of LTL exceedance (red) in streams compared with weekly drought indicators mapped to days (SRI blue, SPEI green). Negative indicators often coincide with LTL breaches, but mismatches occur because LTL reflects intake-specific operational requirements and buffering.



Figure 3. Timing of LTL exceedance (red) in reservoirs compared with SRI (blue) and SPEI (green). Long red clusters indicate sustained operational stress during storage depletion; negative indices can precede breaches or occur without them due to regulation and storage effects.

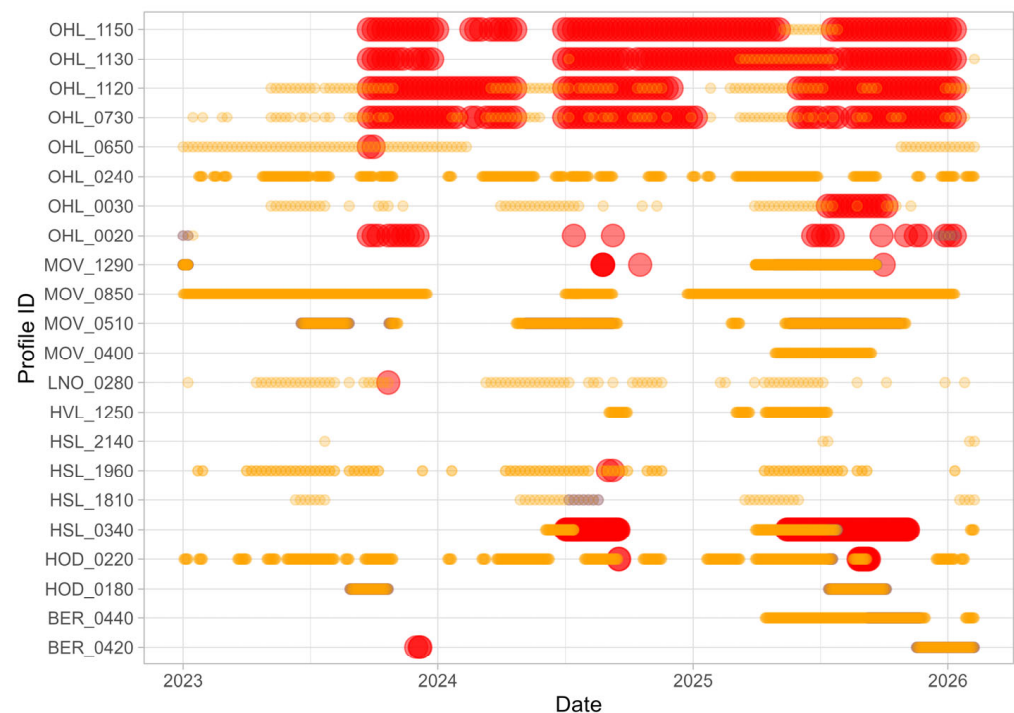


Figure 4. Timing of LTL exceedance (red) in groundwater contrasted with drought indicators, especially SGI (orange). Agreement is common during prolonged deficits, while discrepancies highlight that LTL is set by source-specific constraints and low indices may still coincide with sufficient local groundwater head.

Across resource types, extended clusters of LTL exceedances often overlap with persistently negative indicator values, confirming that regional drought indicators frequently capture the broader hydroclimatic context in which local operational limits are breached. At the same time, the figures show that LTLs are defined primarily by source-specific requirements (e.g., intake functionality, usable storage volume, abstraction constraints, or water-quality limits) and therefore do not necessarily align with standardized indices.

Conversely, there are periods with markedly negative SRI/SPEI/SGI values without any red markers—i.e., a regional-scale drought signal while the specific source remains above its operational threshold. In the opposite sense, short episodes of LTL exceedance can occur even with only weak index anomalies, indicating locally driven stress (e.g., operational drawdown, intake-specific constraints, or transient low-flow conditions) that is not fully expressed in standardized indices.

Importantly, these results imply that a low indicator value (SPEI, SRI, SGI) does not automatically mean insufficient water at a given source, and conversely that local threshold exceedance may arise even when the indices are not extreme. Taken together, the figures highlight the complementarity of both information layers: indices provide comparable regional early warning, while LTLs translate source-specific requirements into practically usable operational situations/triggers and capture deviations driven by local conditions and management.

4. Conclusions and Discussion

Local threshold limits (LTLs) provide a practical bridge between drought indicators and source management by translating generalized drought information into source-specific, actionable triggers. The main conclusion of this study is that drought indicators describe the regional context, whereas LTLs operationalize this information for individual

strategic water sources through explicit failure conditions and decision-relevant lead times. Thus, both tools are complementary rather than interchangeable [1,2].

The main innovation of this study is the derivation of LTLs from monitored variables, failure conditions, and response lead times, including the possibility of seasonal adjustment. Their implementation in regional drought management plans and the HAMR system strengthens their practical value by enabling timely, proportionate, and locally accepted response measures [1,2]. At the same time, their application is affected by data limitations, forecast uncertainty, climate change, and changing demand; therefore, periodic review and scenario testing are recommended [11].

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