EDO - European Drought Observatory

Emergency Management Service

EDO INDICATOR FACTSHEET

Low-Flow Index (LFI)

This Factsheet provides a detailed technical description of the Low-Flow Index (LFI) indicator, which is implemented within the Copernicus European Drought Observatory (EDO), and which is used for monitoring the timing (i.e. starting date and duration) and spatial evolution of major hydrological (streamflow) drought events in Europe. The variable of the hydrological cycle upon which the LFI indicator is based, as well as the indicator's temporal and spatial scales and geographic coverage, are summarized below. An example of the LFI indicator implemented within EDO, is shown in Figure 1.

Variable	Temporal scale	Spatial scale	Coverage
Daily river water discharge	10 days (= 1 dekad)	5 km	Europe

Figure 1: *Example of the continuously updated LFI indicator, implemented within the Copernicus European Drought Observatory (EDO), showing the hydrological (or streamflow) drought status computed for the 10-day period 21-30 June 2017.*

1. Brief overview of the indicator

The Low-Flow Index (LFI) indicator, which is implemented within the Copernicus European Drought Observatory (EDO), is used for the operational, near real-time monitoring of hydrological (i.e. streamflow) drought. The LFI indicator, which was developed by Cammalleri et al. (2017), exploits the simulated daily river water discharge outputs of the JRC's in-house LISFLOOD hydrological model (de Roo et al. 2000), in order to capture unbroken consecutive periods of unusually low streamflow, and compares the consequent water deficit during those periods with the historical climatological conditions, in order to derive the severity of the events. A key advantage of the LFI indicator, compared for instance with the widely used Standardized Runoff Index (SRI), developed by Shukla and Wood (2008), is that the LFI indicator directly exploits daily streamflow values, allowing a near real-time update of the index at regular time steps (i.e. 10 days, or 1 dekad). EDO's LFI indicator has been shown to capture effectively the timing (i.e. starting date and duration) and the spatial evolution of major historical hydrological drought events in Europe.

2. What the indicator shows

Hydrological (or streamflow) drought is one of the three main types of drought, which are defined according to the variables of the hydrological cycle (i.e. precipitation; soil moisture; groundwater; streamflow) that are most affected. **Meteorological drought** is a prolonged period of less than average rainfall in a given region, which generally precedes **agricultural drought**, when there is reduced crop production due to insufficient soil moisture, and **hydrological drought**, when there is below-normal water availability in rivers, streams, reservoirs, lakes, or the groundwater table. Hydrological droughts are usually out of phase with the occurrence of meteorological and agricultural droughts, as it takes longer for precipitation deficiencies to show up in components of the hydrological system such as streamflow, and groundwater and reservoir levels.

3. How the indicator is calculated

The Low-Flow Index (LFI) hydrological drought indicator that is implemented within EDO, is computed from daily water discharge (streamflow) values produced by the LISFLOOD hydrological model, which has been developed by the Joint Research Centre (JRC) of the European Commission in order to reproduce the hydrology of large and trans-national European river catchments (de Roo et al., 2000), and which currently runs operationally within the Copernicus European Flood Awareness System (EFAS, http://www.efas.eu/). LISFLOOD simulates the main hydrological processes occurring in the land–atmosphere system through conceptual approaches, including infiltration of effective precipitation, soil evaporation and plant transpiration, deep percolation and groundwater recharge, whereas surface runoff routing in the river network is simulated using a four-point implicit finite-difference solution of the kinematic wave (Chow et al., 1988).

At the European scale, the LISFLOOD model that is used operationally for EFAS adopts a number of static inputs developed for spatially consistent applications, including: soil hydraulic properties mapped according to the European Soil Database[1] and the HYPRES (Hydraulic Properties of European Soils) database (Wösten et al. 1999); land-surface coverage and vegetation classes information derived from the CORINE land-use database (Batista e Silva et al., 2013); a climatological Leaf Area Index (LAI) dataset derived from Moderate-Resolution Imaging Spectroradiometer

---

[1] https://esdac.jrc.ec.europa.eu/content/european-soil-database

(MODIS) satellite observations (Myneni et al., 2002). The hierarchically structured river network and drainage areas are derived from a consistent digital elevation model with 100x100 metre grid cells, as part of the JRC's Catchment Characterisation and Modelling (CCM) project (Vogt et al. 2007). For more details on the main LISFLOOD inputs and parameterization, see van der Knijff et al. (2008).

The Low-Flow Index (LFI) is computed from the daily streamflow values produced by the LISFLOOD hydrological model, in two main steps, as described below.

1. Definition of low-flow threshold values:

The threshold value of water discharge or flow rate (Q) that characterizes a river's natural low-flow regime, and accounts for possible seasonality in the streamflow values, have been computed for each calendar day, based on the "Flow Duration Curve" (FDC) – which plots a river's flow rate (Q) against percentage exceedence (0-100%) – and using a 31-day moving window of streamflow values for a 21-year baseline period (i.e. 1995-2015) of LISFLOOD output values. The daily low-flow threshold values were defined as the streamflow values (Q) corresponding to the 95th percentile of the FDC ("Q95"), meaning those flow rates that are equalled or exceeded for 95% of the time.

2. Calculation of the Low-Flow Index:

Based on the previously defined threshold, a hydrological drought is defined as a period of consecutive days with Qt < Q95,t (see Figure 2), and the total deficit of the i-th event, Di, is computed as:

$$D_i = \sum_{t=t_{s,i}}^{t_{e,i}} Q_{95,t} - Q_t$$

where ts,i and te,i are the initial and final time steps of the run, respectively. The corresponding drought duration, di, is computed as te,i – ts,i + 1. In order to consider the mutual dependency of close events, these are merged if the inter-event time (ts,i+1 – te,i) < tc (Zelenhasić and Salvai, 1987). Here a value of 10 days for tc is used. Additionally, the minor events are ignored in the analysis, as the ones that last less than d¬c (assumed equal to 5 days) according to the procedure suggested by Jakubowski and Radczuk (2004).

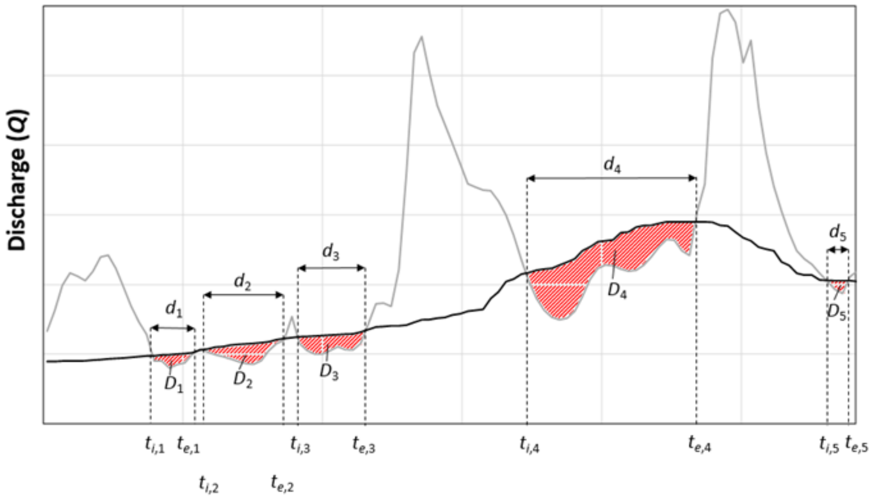

Figure 2: Schematic representation of a sequence of runs with examples of total deficit, duration, mutual dependent events and minor events. Discharge (Q) is shown as a grey line and the low-flow threshold (Q95) as a black line.

The partial duration series of D can be analyzed as constituted by continuous non-negative random variables generated by a time-dependent Poisson process, whose frequency can be fitted using an exponential distribution:

$$F(D_i; \lambda) = 1 - e^{-\lambda D_i} \quad \text{with} \quad D_i \geq 0$$

where $\lambda > 0$ is the inverse scale parameter, which is equal to the inverse of the sample mean according to the maximum likelihood method. The fitting of λ was performed for each cell using the events observed in the baseline period (1995-2015) only if more than five events were observed in the historical dataset.

The frequency of the event (FD) is used as a proxy of the severity, and represents the low-flow index, which is finally classified in four classes. The procedure is summarised in Figure 3 below.

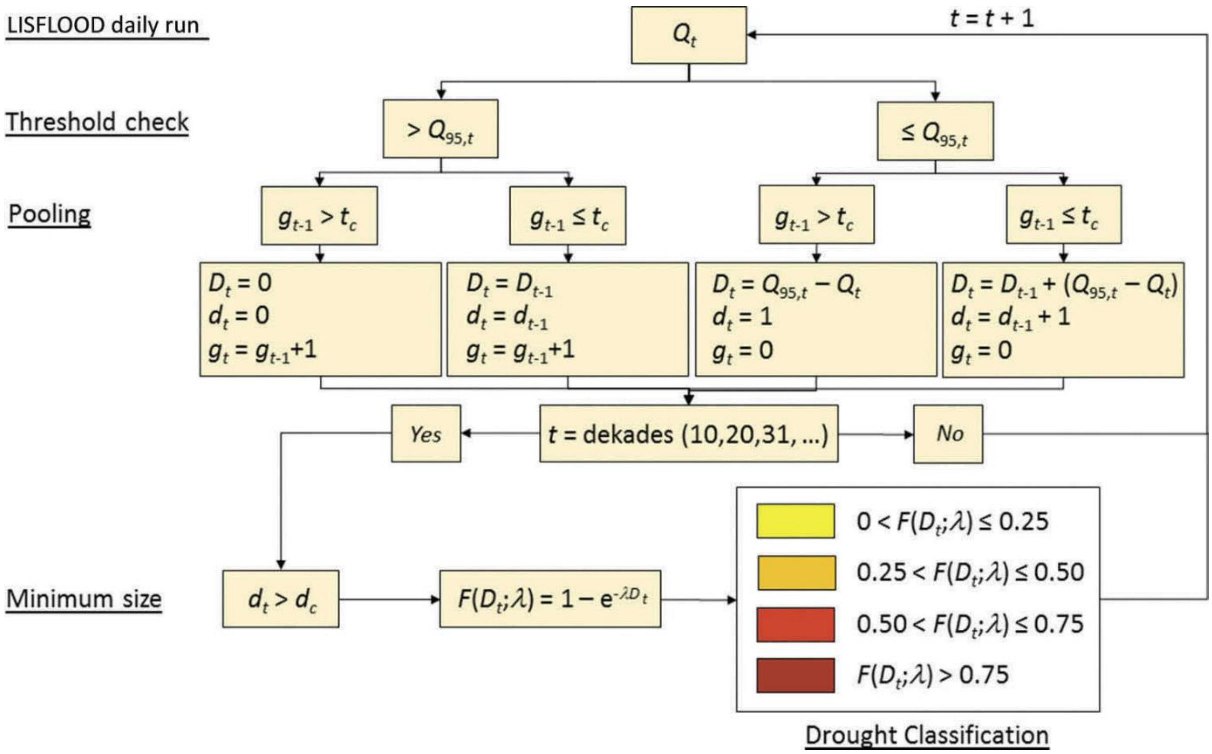

Figure 3: Flowchart describing the computational scheme for the implementation of the Low-Flow Index (LFI) within the Copernicus European Drought Observatory (EDO).

4. How to use the indicator

The Low-Flow Index (LFI) can be used for near real-time monitoring of hydrological droughts, and may be visualized as both maps and graphs, providing information on the spatial distribution of the drought events and on the temporal persistence of the drought over a specific location.

The EDO Mapserver MapViewer displays the LFI indicator for an averaged value of ten days. Usually data are available with a delay of two days after the completion of a ten-day period – i.e. on the 2nd, 12th and 22nd days of each month. The data are displayed over a matched river network from the LISFLOOD 5x5 km network and a high-detail 100x100 metres CCM2 network. When the user zooms in, the affected 5x5 km pixels are coloured. Previous low-flow events are easily selected by a right-click in the menu. The affected rivers, found based on the CCM2 5x5 km grid-matching, are listed in the Table of Contents (TOC), allowing for a quick zooming to the river if selected.

The LFI indicator is dimensionless, ranging from 0 to 1 in terms of real values, and from yellow to red on the map, where 1 corresponds to a maximum drought severity. Four classes are considered, varying from Low Hazard to Very High Hazard (if the index is above 0.75).

For correct interpretation, it is important to bear in mind that LFI is based on modelled river flow-rates, and does not consider specific water regulations in actual river conditions over certain areas.

5. Strengths and weaknesses of the indicator

Strengths:

- The Low-Flow Index allows near real-time monitoring of the evolution of hydrological drought, by quantifying the cumulative deficit up to the update time. This dynamic approach accounts for the continuous nature of streamflow data, using the daily LISFLOOD data, in contrast with the widely used Standardized Runoff Index (SRI), for example, which is calculated for predetermined integration periods (e.g. monthly, 3 months).
- Unlike the “anomalies” approach of many drought indicators (e.g. Standardized Precipitation Index, Standardized Runoff Index), the Low-Flow Index better reproduces the conceptual mechanism behind the evolution of drought as a phenomenon that is derived from a continuous hydrological quantity, with daily values that are strongly dependent on the antecedent status.
- The use of daily discharge data from LISFLOOD, which was specifically developed for simulating hydrological processes in large European river basins, ensures consistency with the Copernicus European Flood Awareness System (EFAS), and with other drought indicators within EDO (e.g. Soil Moisture Anomaly) that are based on the same modelling framework.

Weaknesses:

- As the Low-Flow Index is based on modelled values, it may not take into account of some water regulation mechanisms that occur in the real-world rivers.
- The reliability of the Low-Flow Index is dependent on the robustness of the baseline period of LISFLOOD simulations, which is limited in length (only 21 years, 1995-2015).

References

- Batista e Silva, F., C. Lavalle, and E. Koomen. 2013. A procedure to obtain a refined European land use / cover map. Journal Land Use Sciences, Vol. 8 (3): 255–283. https://doi.org/10.1080/1747423X.2012.667450

- Cammalleri, C., J. Vogt and P. Salamon. 2017. Development of an operational low-flow index for hydrological drought monitoring over Europe. Hydrological Sciences Journal, Vol. 62, No. 3, 346-358. http://dx.doi.org/10.1080/02626667.2016.1240869

- Chow, V.T., D. Maidment, and L.W. Mays. 1988. Applied Hydrology. New York: McGraw-Hill. ISBN 0-07-100174-3. 588 pages.

- De Roo, A., C. Wesseling, and W. van Deursen. 2000. Physically based river basin modelling within a GIS: the LISFLOOD model, Hydrological Processes, 14, 1981–1992. Doi: 10.1002/1099-1085(20000815/30)14:11/12<1981::AID-HYP49>3.0.CO;2-F

- Jakubowski, W. and L. Radczuk. 2004. Estimation of hydrological drought characteristics: NIZOWKA 2003 – Software Manual. In: Tallaksen, L.M. and H.A.J. van Lanen (editors). 2004. Hydrological Drought – Processes and estimation methods for streamflow and groundwater. Elsevier, Amsterdam. [CD-ROM].

- Myneni, R.B., S. Hoffman, Y. Knyazikhin, J.L. Privette, J. Glassy, Y. Tian, Y. Wang, X. Song, Y. Zhang, G.R. Smith, A. Lotsch, M. Friedl, J.T. Morisette, P. Votava, R.R. Nemani, and S.W. Running. 2002. Global products of vegetation leaf area and fraction absorbed PAR from year one of MODIS data. Remote Sensing of Environment, 83(1–2): 214–231. https://doi.org/10.1016/S0034-4257(02)00074-3

- Shukla, S. and A.W. Wood. 2008. Use of a standardized runoff index for characterizing hydrologic drought. Geophysics Research Letters, 35, L02405. Doi: 10.1029/2007GL032487

- Smakhtin, V.U., 2001. Low flow hydrology: a review. Journal of Hydrology, 240, 147–186. Doi: 10.1016/S0022-1694(00)00340-1

- van der Knijff, J.M., J. Younis, and A.P.J. de Roo. 2008. LISFLOOD: A GIS-based distributed model for river basin scale water balance and flood simulation. International Journal of Geographical Information Science, Vol. 24(2): 189–212. https://doi.org/10.1080/13658810802549154

- Vogt J., P. Soille, A. De Jager, E. Rimaviciute, W. Mehl, S. Foisneau, K. Bodis, J. Dusart, M.-L. Paracchini, P. Haastrup, and C. Bamps. 2007. A pan-European River and Catchment Database. JRC Reference Report. EUR 22920 EN. European Commission. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC40291/ccm2-report_eur-22920-en_2007_std.pdf

- Wösten, J.H.M., A. Lilly, A. Nemes, and C. Le Bas. 1999. Development and use of a database of hydraulic properties of European soils. Geoderma, Vol. 90: 169-185. https://doi.org/10.1016/S0016-7061(98)00132-3

- Zelenhasić, E. and A. Salvai. 1987. A method of streamflow drought analysis. Water Resources Research, Vol. 23 (1): 156–168. https://doi.org/10.1029/WR023i001p00156