# Ecologically relevant flow metrics for intermittent rivers and ephemeral streams

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# Ecologically relevant flow metrics for intermittent rivers and ephemeral streams


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## Background

The COST-Action SMIRES brings together scientists from various disciplines to foster a common understanding of hydrology, hydrochemistry and ecology of intermittent rivers and ephemeral streams. Such rivers (IRES) are characterized by episodes of stagnant waters or drying-off, occurring either annually during the drought season or exceptionally during extreme drought years. Since IRES can be seen as a special, ultimate, case of low-flow regimes when discharge reaches zero-values, relevant low-flow characteristics exist but need to be adapted to characterise ecologically relevant features of the particular flow regime.

## Objectives

We present a set of metrics and methods for characterizing flow intermittency in an ecologically relevant way, stemming from interdisciplinary discussions among SMIRES experts of various disciplines. The indices are compatible with standard low-flow indices of the WMO manual on low-flow estimation and prediction (Gustard and Demuth, 2008) and the handbook Hydrological Drought (Tallaksen and Van Lanen, 2004), extending these indices to no-flow conditions.

## 1. General definitions

- All indices derived from daily discharge hydrographs Q
- No-flow spell: period of time when discharge is less or equal some no-flow threshold (= detection limit): $Q \leq Q_0$ (default 1 l/s)
- No-flow event: a contiguous period of days with no-flow occurrence, terminated by rewetting period. Some pooling is usually applied to successive, dependent events in order to define an independent sequence of events.
- All annual characteristic may be calculated based on calendar years or hydrological years (e.g. for European climates usually staring with 1 April)
- All annual characteristics can be calculated from the whole time series (all-season characteristics) or stratified by seasons (seasonal characteristics)


## 2. No-flow characteristics

### 2.1 Proportion of no-flow years

| Name | Acronym | Function | Description |
|---|---|---|---|
| Proportion of no-flow years | $f_0$ | `no_flow_years(x)` | Number of years with no-flow occurrence (when flow is at least for one day below the no-flow threshold) divided by the study period in years |

### 2.2 Number of no-flow days

| Name | Measure | Acronym | Function | Description |
|---|---|---|---|---|
| Mean annual number of no-flow days | Location | $MAN$ | `MAN(x)` | Mean annual number of days with no-flow occurrence (when flow is below the no-flow threshold) |
| CV of the annual number of no-flow days | Variability | $CVAN$ | `CVAN(x)` | Coefficient of variation of the annual number of days with no-flow occurrence (when flow is below the no-flow threshold) |
| Distribution of the annual number of no-flow days | Distribution | $FAN$ | `FAN(x)` | Statistical distribution (cdf) of the annual number of days with no-flow occurrence (when flow is below the no-flow threshold) |

### 2.3 Duration

| Name | Measure | Acronym | Function | Description |
|---|---|---|---|---|
| Mean annual maximum duration | Location | $MAMD$ | `MAMD(x)` | Mean duration of the longest annual no-flow event (during which flow remains below the no-flow threshold) |
| CV of annual maximum duration | Variability | $CVAMD$ | `CVAMD(x)` | Coefficient of variation of the duration of the longest annual no-flow event (during which flow remains below the no-flow threshold) |
| Distribution of annual maximum duration | Distribution | $FAMD$ | `FAMD(x)` | Statistical distribution (cdf) of the duration of the longest annual no-flow event (during which flow remains below the no-flow threshold) |

### 2.4 Timing and seasonality

| Name | Measure | Acronym | Function | Description |
|---|---|---|---|---|
| Mean onset | Location | $\tau_0$ | `tau0(x)` | Mean Julian date (day-of-year) of the first annual no-flow day (using circular statistics) |
| Variability of onset | Variability | $\tau_{0r}$ | `tau0r(x)` | Circular variability index r (between 0 and 1) of the onset |
| Mean termination | Location | $\tau_E$ | `tauE(x)` | Mean Julian date (day-of-year) of the end of the first no-flow spell (using circular statistics) |
| Variability of termination | Variability | $\tau_{Er}$ | `tauEr(x)` | Circular variability index r (between 0 and 1) of the termination |
| Mean seasonality | Location | $\tau$ | `tau(x)` | Mean Julian date of all no-flow days (using circular statistics) |
| Strength of seasonality | Variability | $\tau_r$ | `taur(x)` | Circular variability index r (between 0 and 1) of all no-flow days |

## 3. Rate of change before/after no-flow event

| Name | Measure | Acronym | Function | Description |
|---|---|---|---|---|
| Mean recession rate | Location | $k$ | `k(x)` | Mean rate of decay of the hydrograph during flow recession periods |
| Standard deviation of recession rate | Variability | $k_{sd}$ | `ksd(x)` | Standard deviation of rate of decay of the hydrograph during flow recession periods |
| Mean annual number of reversals in flow magnitude | Location | $n_{rv}$ | `nrv(x)` | Mean annual number of reversals in flow magnitude |

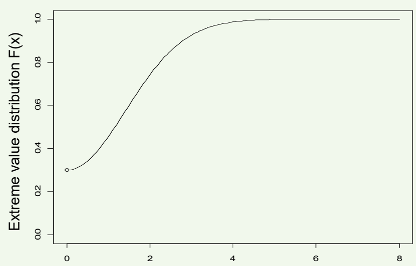
Similar indices for recovery rates are needed, but would require a clear definition of the termination of the recovery period from drought. We here suggest to define the recovery period consistently with process-based pooling criteria (e.g. used in Laaha et al. 2017): events are pooled unless the day when the catchment has completely recovered from a negative water balance, marking the end of recovery period.

## 4. Low-flow frequency analysis

Annual minima series of IRES contain zero values, hence a conditional probability model is required. First, a distribution model $G(x)$ is fitted to the censored series (i.e., the annual minima for all years except for no-flow years). In a second step, the distribution $F(x)$ of the entire annual minima series containing no-flow years is obtain by

$$F(x) = f_0 + (1 - f_0)G(x)\,,$$

using $f_0$ (section 2.1) as an estimator of the annual probability that the river falls dry. The figure shows an example of a river with 30% no-flow years.




## Conclusions

**R-Software package *smires* (Gauster et al. 2017) has been compiled to foster the use of statistically sound no-flow indices that are consistent with earlier definitions in low-flow hydrology. In addition, more qualitative characteristics about flow states are needed, which are subject of ongoing SMIRES research.**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**Cited papers:**
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