A global evaluation of streamflow drought characteristics

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I. Introduction and Objectives

A river or stream is considered to be in a drought situation, when its discharge is abnormally low. This relative way of defining streamflow droughts means that they can occur in any hydroclimatological region and at any time of the year. The characteristics of streamflow drought differ however, from region to region, and a large number of methods to describe streamflow drought have been developed. Not every method is applicable to every type of stream or gives comparable results for different types of streams.

The main objective of this study is to test and evaluate different methods to describe streamflow drought, in particular their:

a) applicability for perennial, intermittent and ephemeral streams;
b) general applicability for comparison of different types of streams;
c) data requirements and limitations using a daily time step.

Both low flow characteristics and deficit characteristics are included. In addition, a program for a frequency analysis of deficit characteristics is evaluated.

Low flow characteristics

Low flow characteristics describe the average low flow conditions of a stream. Two methods are evaluated:

- Percentiles (Qx) of the flow duration curve (FDC)
- Mean annual minimum *n*-day discharge (MAM(*n*-day))

Deficit characteristics

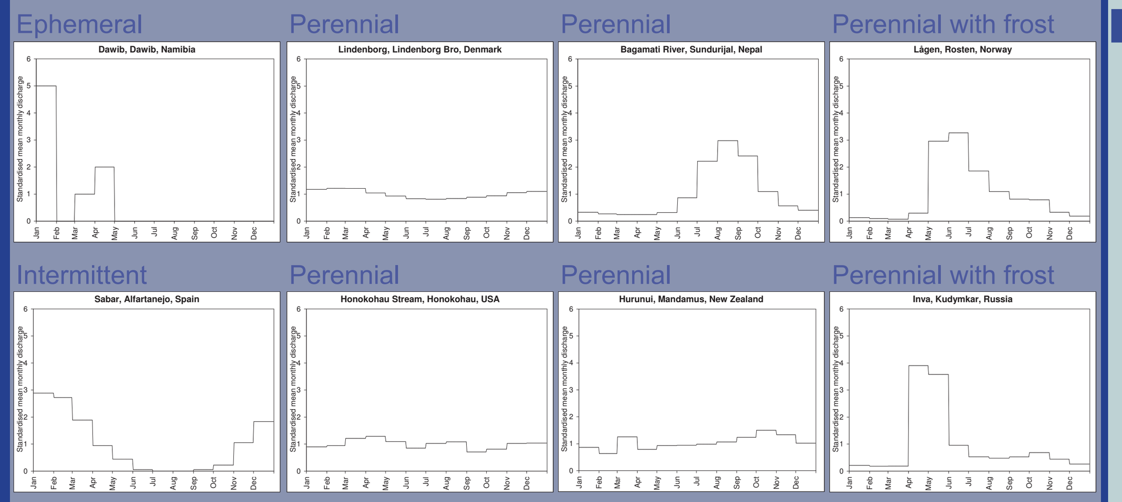
Deficit characteristics describe single drought events, which are derived by the threshold level method. For a daily time resolution an additional pooling procedure is necessary. Three pooling procedures are evaluated:

- Inter event criterion (IT-method)
- Moving-average filter of *n* days (MA(*n*-day)-procedure)
- Sequent peak algorithm (SPA)

The methods are evaluated on the discharge series of the Global Data Set of the ASTHyDA[5] project. Here only the results for deficit characteristics are presented.

II. The Global Data Set of the ASTHyDA[5] project

The Global Data Set consists of 16 daily discharge from different climate zones and hydrological regimes (Tallaksen et al. 2005). Regimes of eight of the streams are shown below.



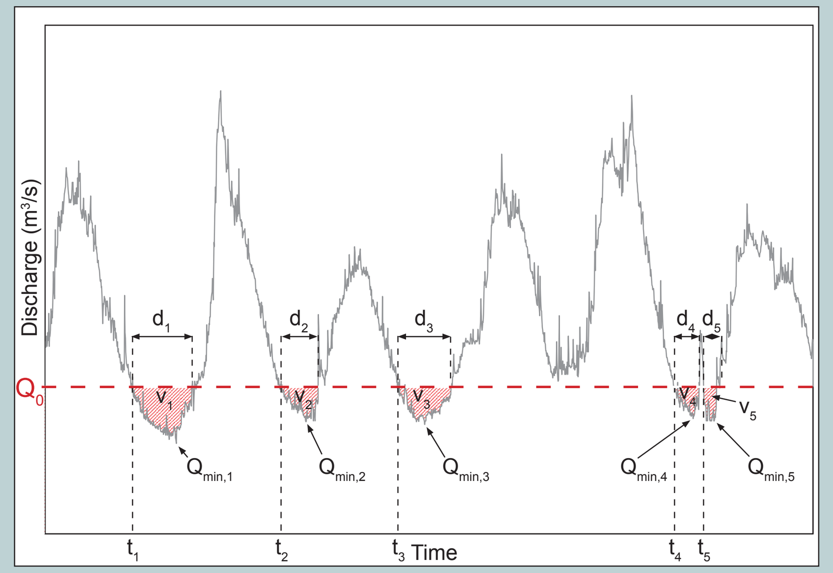
III. Deficit characteristics

III.1 Threshold level method

The Threshold level method defines drought events as periods during which the discharge $Q(t)$ is below a certain threshold level Q_0: $Q(t) < Q_0$.

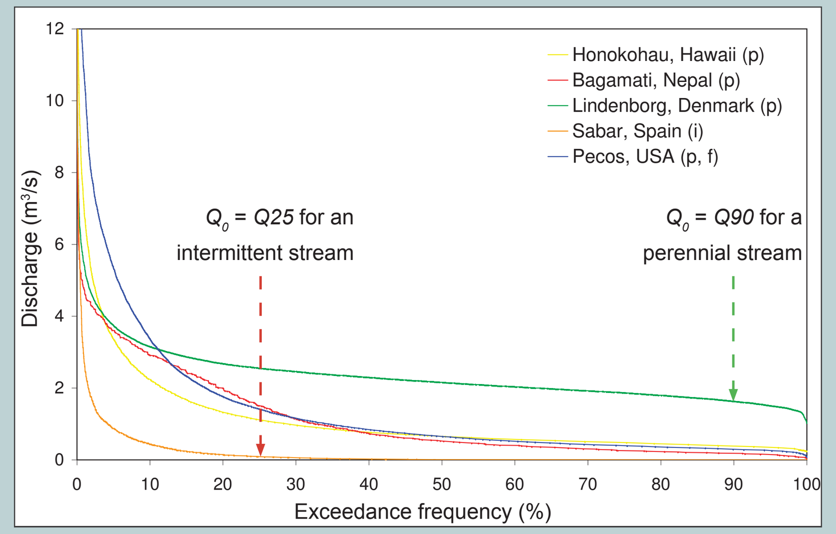
This allows to derive series of single drought events and the characteristics of each event. Important deficit characteristics of a drought event are:

- Deficit volume or severity v_i
- Duration d_i
- Time of occurrence t_i
- Minimum discharge $Q_{min,i}$



Threshold level selection

The threshold level can either represent a certain demand, e.g. water supply or ecological minimum discharge, or it can represent a normal low flow condition of the stream. In the latter case a percentile of the daily FDC can be applied as threshold level. The FDC allows to select suitable threshold levels both for perennial (p) streams without and with a frost season (p, f) as well as for intermittent streams (i). For perennial streams e.g. the 95, 90 or 70 percentile (*Q95, Q90* or *Q70*) can be applied, whereas for intermittent streams lower percentiles have to be chosen, depending on their percentage of zero flow.



Problems when using daily discharge series

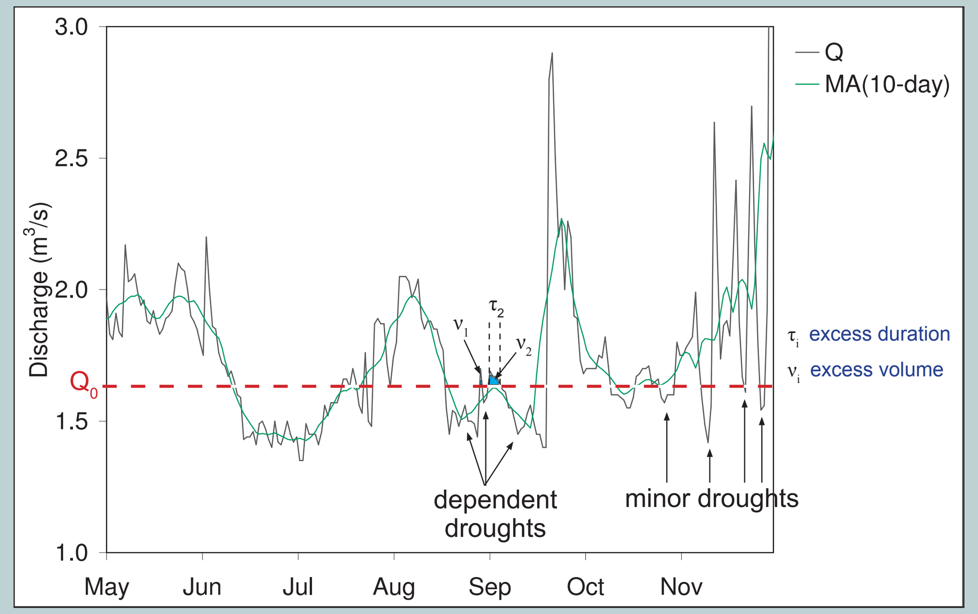
Deriving drought events from a daily discharge series involves two problems (displayed in the next figure):

1. Mutually dependent drought events
2. Minor drought events

1. During a prolonged period of low discharge, excess periods with $Q(t) > Q_0$ of short duration τ_i and small excess volume v_i can occur. These excess periods divide the period of low discharge into several drought events, which one would generally consider to be one long event. These drought events are called mutually dependent droughts. They can be combined into larger events by so called pooling procedures.

2. Minor droughts of short duration and small deficit volume are included in the sample of drought events. A high number of minor drought events might disturb a frequency analysis of extreme events. In this case the number of minor droughts should be reduced.

III.2 Pooling procedures



IT-method

The inter event method (IT-method) is a simplified version of the inter event criterion (IC-method). The IC-method pools drought events based on an inter event time as well as an inter event volume criterion. The IT-method only considers an inter event time criterion t_c. Minor droughts can be excluded in an additional step.

Two mutually dependent droughts are pooled when they occur no more than a predefined number of days t_c apart from each other ($\tau_i \leq t_c$).

Recommendable criterion: t_c = 5 or 6 days

Minor droughts are excluded when their deficit volume is smaller than a certain percentage α of the maximum observed deficit volume ($v_i \leq \alpha * v_{max}$), or when they are of short duration ($d_i \leq d_{min}$).

Recommendable criteria: α = 0.5 %

d_{min} = 3 days

MA-procedure

A moving-average filter (MA) smoothens the discharge series and as a result short excess periods are filtered out and mutually dependent droughts are pooled.

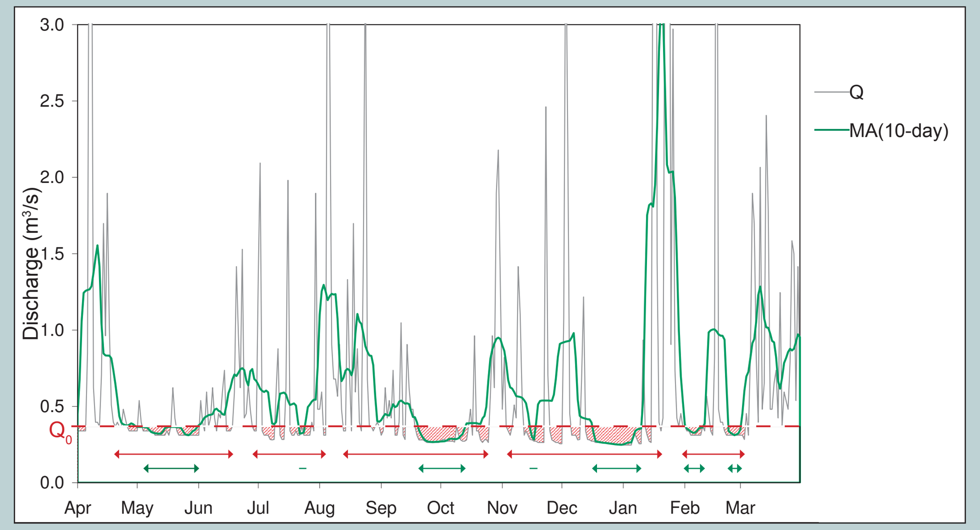
Recommendable averaging interval: n = 10 days

In the same way minor droughts are automatically filtered out in the MA-procedure.

Example and Evaluation

Honokohau Stream, Hawaii

Honokohau Stream lies in a tropical climate region. Its hydrograph shows a large daily variability and the discharge falls frequently below the threshold level Q_0 = *Q90*. Pooling by the 5-day IT-method (upper arrows) and the MA(10-day)-procedure (lower arrows) gives quite different results. With the MA(10-day)-procedure fewer and shorter events are recorded than with the 5-day IT-method. For example from mid August 1945 to mid September 1945 the IT-method pools a series of minor drought events with a larger event, extending the drought for a whole month. This is due to the use of only an inter event time criterion. In this case the IC-method would perform better.



Results for the pooling procedures

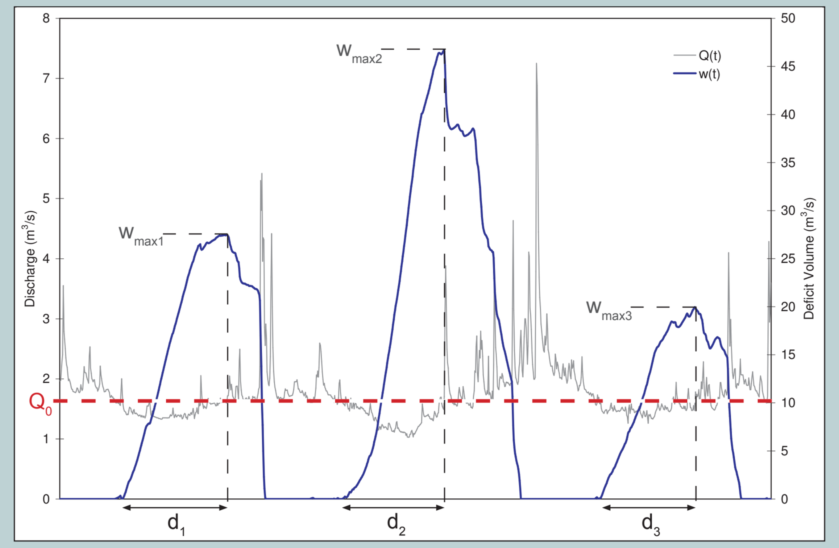
- The IT-method and MA-procedure can both be applied to perennial and intermittent streams.
- For fast responding catchments with a flashy hydrograph the MA-procedure performs better: with the IT-method many droughts are pooled, in spite of a large excess volume.

III.3 Sequent Peak Algorithm

The Sequent Peak Algorithm (SPA) has been developed for the design of water reservoirs and derives the largest deficit volume of a discharge series with respect to a certain threshold level. Here it is used as a pooling procedure.

SPA as pooling procedure

A time series of the deficit volume $w(t)$ is derived by summing up the deficits between the discharge and the threshold level and subtracting the excess volumes, until the total excess volume is so large that $w(t)$ equals zero again. The largest deficit volume w_{max} is then selected from the period with $w(t)$ > 0.



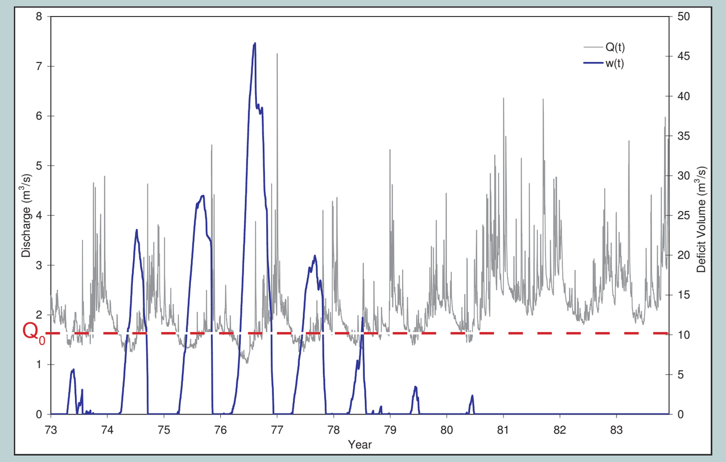
Drought events are pooled until $w(t)$ returns to zero. The deficit volume of one event is $w_{max,i}$, its duration goes from the first day with $w(t)$ > 0 until $w_{max,i}$.

In the time following $w_{max,i}$ the stream is not considered to be in a drought situation, even though $w(t)$ > 0. In this period the discharge exceeds the threshold level on average, but still there can be periods during which the discharge is below the threshold level. When large drought events occur this implies that subsequent droughts might not be recognized, which happens easily when higher threshold levels are used, e.g. *Q80* or *Q70*.

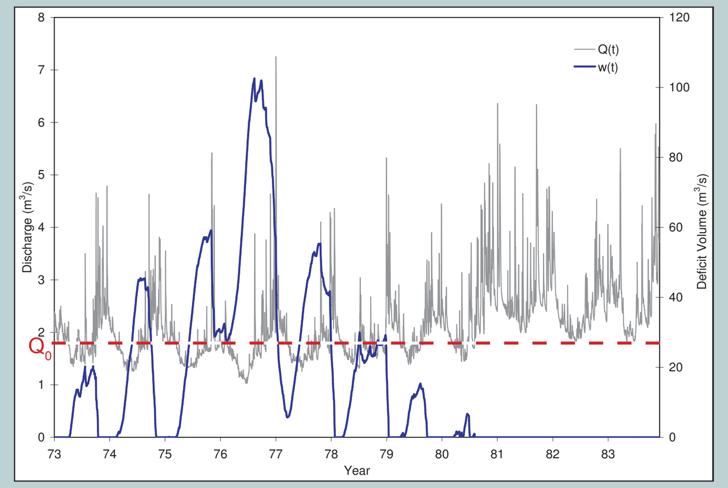
Example and Evaluation

River Lindenborg, Denmark

- Within a 35 year long data record the five severest drought events occurred between 1974 and 1978 for a threshold level of Q_0 = *Q90*.
- In 1977 the fourth severest drought occurred.



- With Q_0 = *Q80* the drought events from 1975, 76 and 77 are pooled into a multi-year drought and the maximal deficit volume is reached in October 1976. Thus the drought is considered to end in 1976.
- The year 1977 is considered to be drought-free.



Results for the SPA

- When the SPA is used as pooling procedure only very low threshold levels can be applied in order to avoid that too many drought events are pooled.

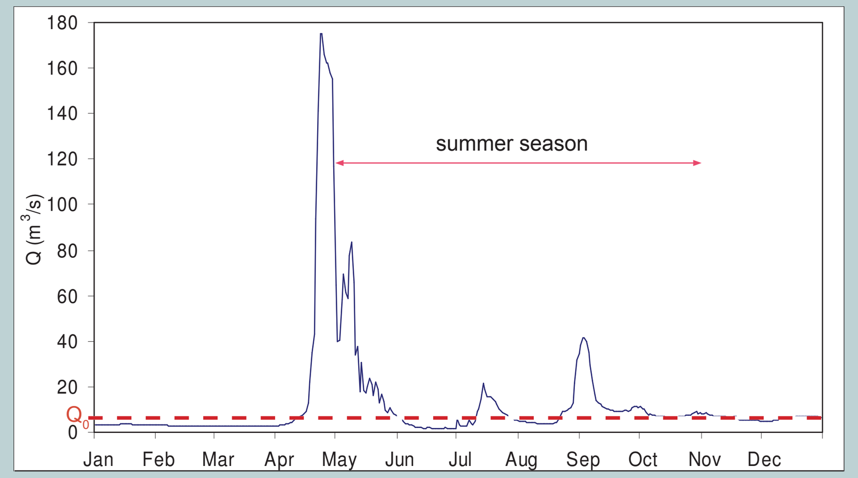
III.4 Seasonal calculations

For a frequency analysis it is necessary to obtain a series of drought events which are caused by the same underlying processes. Seasonal calculations are therefore necessary for catchments, where different types of drought can occur, e.g. in catchments with frost influence:

Summer droughts caused by
- Low precipitation
- High temperature

Winter droughts caused by
- Low temperature (frost)
- Low precipitation

In this study focus is on summer droughts.



Recommended procedure

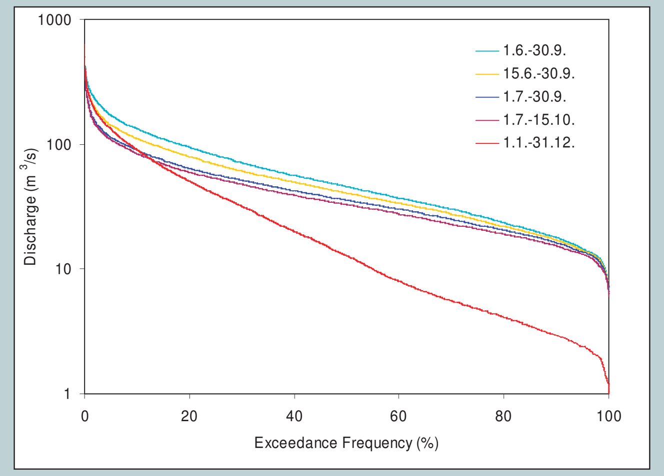
1. specification of the summer season according to the hydrological regime;
2. derivation of a series of deficit periods for the whole year;
3. classification of each deficit period according to which season the longest part of the deficit period belongs to;
4. pooling of summer deficit periods into summer droughts.

Remaining problems

- Treatment of severe summer droughts that continue as a long winter drought;
- Catchments that are only in some parts influenced by frost.

Threshold level selection

The daily FDC can vary considerably with the chosen season and the threshold level has to be selected according to the specified summer season (Example: River Lågen, Norway).



III.5 Conclusions and Recommendations

The threshold level method is well suited for perennial as well as intermittent streams. For ephemeral streams interest lies more in the duration of zero flow periods and in the volume of flow events and the use of the threshold level method is not recommended.

- Pooling procedures can be used for perennial and intermittent streams.

  Limitations:
  - The IT-method is not advisable for very flashy streams.
  - The MA(*n*-day)-procedure modifies the discharge series and thus deficit volume and duration.
  - As pooling procedure the SPA is only advisable for low threshold levels.

- For the comparison of different types of streams the MA(*n*-day)-procedure is the most flexible and therefore recommended approach.

- For seasonal calculations of summer droughts it has to be decided how to treat mixed summer and winter droughts.

IV.1 Frequency Analysis on Deficit Characteristics

Deficit characteristics: Deficit volume *v* and duration *d* using the threshold level method

Threshold levels: *Q90* and *Q70*

Pooling: IT-method with t_c = 5 days, α = 0.5 %, d_{min} = 3 days

Frequency analysis: From a partial duration series (PDS) of drought events the distribution function for the largest event within one year is derived by combining:

1. the distribution function of the magnitude (*v* or *d*) of all events: $H(x)$
   → theoretical solution: Generalised Pareto distribution (GP);
2. the probability that *k* events occur during one year: Pr(Z=k)
   → theoretical solution: Poisson distribution.

The combined model describes the annual maximum series (AMS).

Question: Can the model with the GP distribution for $H(x)$ (GP model) in general be recommended for different types of streams?

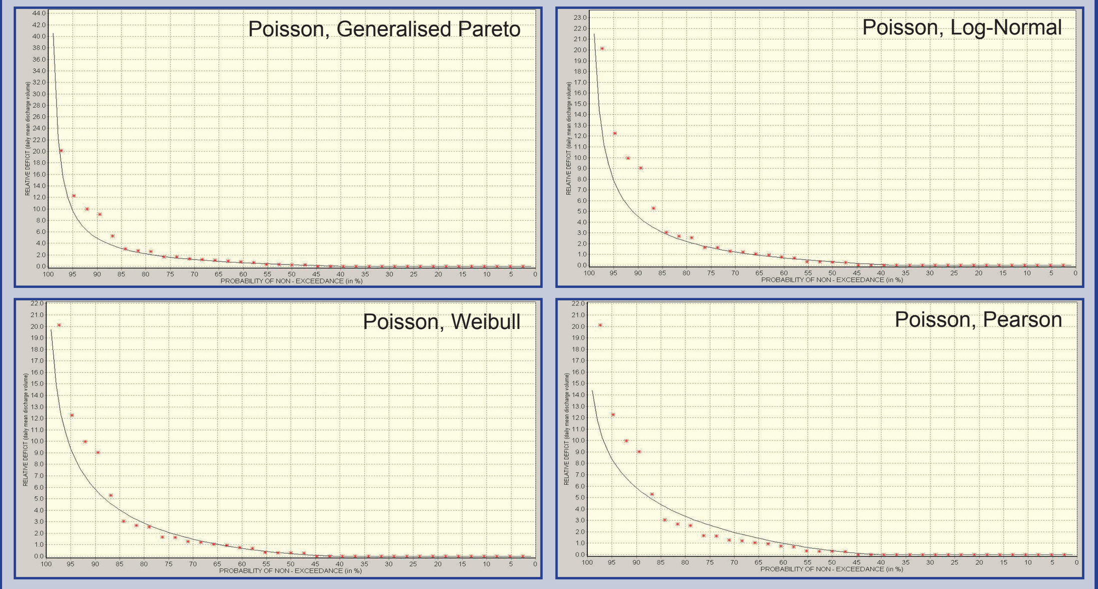
Procedure:

1. derivation of a PDS of drought events;
2. fitting of distribution functions to $H(x)$ (GP, Double Exponential, Johnson, Log-Normal, Weibull, Pearson) and Pr(Z=k) (Poisson);
3. judging the functions by a chi-squared goodness-of-fit test
4. visual comparison of the estimates using the different models with the observed AMS of drought events.

Program: NIZOWKA2003[6], based on Zelenhasić & Salvai (1987)

Example: River Lindenborg, Denmark

Four models could be accepted on a significance level of 0.05. The highest attained significance level is obtained by the Log-Normal model. There are different scales on the figures, but it still can be seen that the GP model best describes the extreme range.



IV.2 Results for the frequency analysis

Estimations for deficit volume *v* and duration *d* were performed for 12 perennial and two intermittent streams. Two different threshold levels were applied and in total 50 estimations could be done successfully. The performance of the GP model is compared to other models:

Estimation	Number of stations	Number of stations for which: GP shows best overall fit	GP fits best for largest events	GP fits equally well as others	Other models fit better
v: Q_0 = *Q90*	12	5	4	3	0
d: Q_0 = *Q90*	12	1	8	3	0
v: Q_0 = *Q70*	12	6	1	3	2
d: Q_0 = *Q70*	14	3	5	2	4
Total	50	15	18	11	6

Results: 1. GP model

- can be recommended for perennial and intermittent streams, since it is the theoretically most correct model and did not perform worse than other models.

Results: 2. Program NIZOWKA2003

- good tool for perennial streams;
- for intermittent streams only applicable for a frequency analysis of deficit duration, since for deficit volumes zero-flow periods should be treated as censored data;
- not applicable for multi-year droughts;
- the way of selecting summer droughts has to be modified since severe summer droughts may not be considered when they develop into a long winter drought.

Footnotes and References

Footnotes

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[5] ASTHyDA: "Analysis, Synthesis and Transfer of Knowledge and Tools on Hydrological Drought Assessment through a European Network". <http://drought.uio.no>
[6] NIZOWKA2003: Wojciech Jakubowski, Agricultural University of Wroclaw, pl. Grunwaldzki 24, 50-363 Wroclaw, Poland. E-mail: wj@ozi.ar.wroc.pl

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Zelenhasić, E. & Salvai, A. (1987) A Method of Streamflow Drought Analysis. *Water Resources Research*, **23**(1), 156-168.

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