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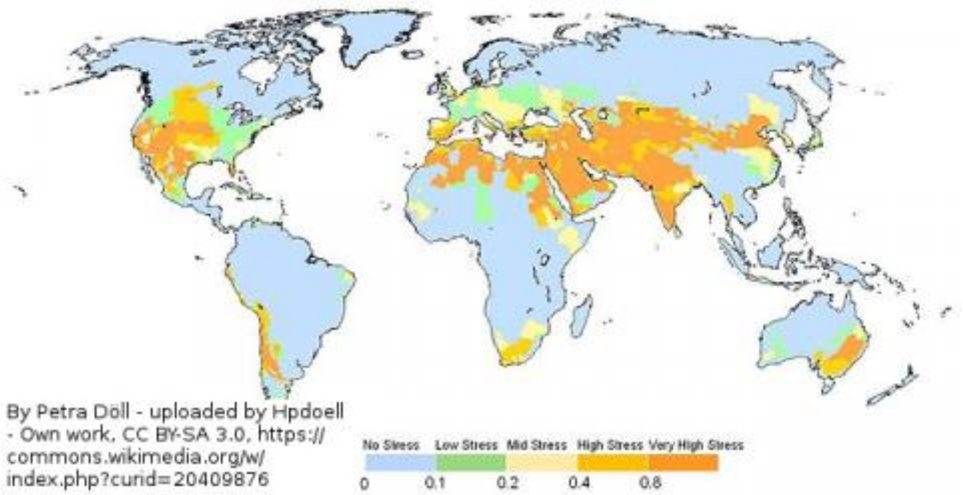
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Workshop Study Smarter Not Harder

Assessing water resources availability - Inductive methods



Estimation of water resources availability is an essential step for devising efficient water resources management strategies. In particular, design and management of water resource systems necessarily needs a preliminary assessment of water demands and water availability. Assessment of water resources is not an easy task, for many reasons including the complexity and the difficult monitoring of groundwater dynamics and the limited availability of observations. Assessment of surface water resources is less complicated with respect to groundwater, for the observability of surface water bodies. Nevertheless, the rigorous quantification of river discharge and storage for natural basins is one of the most relevant challenges for water resources management. The task is more complicated in conditions of water scarcity, as the analysis needs to be more rigorous.

The most relevant challenge when assessing water resources is lack of data. This is a widespread problem in hydrology, as observations of climate and hydrology started relatively recently. Moreover, even when data are available it is not always easy to have access at them, for the institutional fragmentation that usually affects water resources management, especially in Europe.

1. Brief history of water resources systems

Urban hydraulic systems started to develop in the Bronze Age and particularly in the mid-third millennium BC in an area extending from India to Egypt. About the same time advanced urban water technologies were developed in Greece and particularly in the island of Crete where the Minoan civilization was flourishing. These included construction and use of aqueducts, cisterns, wells, fountains, bathrooms and other sanitary facilities, which suggest life style standards close to those of present day. More details are provided by Mays L.W., Koutsoyiannis D. and Angelakis A.N., A brief history of urban water supply in antiquity (2007). The first sources of water were surface bodies like rivers and lakes. These were preferred for the possibility of a direct and inexpensive access to water.

When water is taken at a higher altitude with respect to the users, it is possible to deliver it by gravity therefore saving energy and human resources. However, surface water are less protected against human impact and pollution and therefore already in ancient times people used to dig wells in order to exploit groundwater resources. Water use is increased along time. Today, agriculture accounts for about 70 percent of all the fresh water uses globally. Industries around the world use 20 percent of the fresh water, and only 10 percent is used for domestic activities, including drinking. A comprehensive set of statistics for water uses is given by FAO. An interesting picture of the distribution of percentage freshwater uses for agriculture is again given by FAO.

2. Assessment of water resources availability

Assessing the availability of surface water resources needs to be based on the analysis of the features of the related water bodies. If water is taken from a lake with enough recharge, the estimation of water resources availability reduces to estimation of the water volume in the reservoir. If water is taken from a flowing water body, either superficial or sub-superficial, we need to estimate water fluxes. This is usually done by deciphering the dynamics of the water body itself, with a deductive (i.e. with a model) or inductive (i.e., by using observations). The latter class of methods is also called "indirect methods" while the latter is called "direct methods", as the direct analysis of data is the core of this category of approaches. With surface water bodies the problem is relatively easy as the dynamical features that we need to investigate are largely observable. Here below we will refer to direct methods, while the ungauged (or poorly gauged) problem will be discussed later.

2.1. Inductive assessment of water resources availability in rivers

When estimating river water resources availability we need to make reference to a location along the river where water is to be withdrawn. Usually such location is placed at a higher altitude with respect to the place of use. In such a location we need to refer to a river cross section, where we need to estimate the regime of the river discharge.

The river cross section is the geometric figure that is obtained by cutting the river with a plane that is perpendicular to the average velocity vector for a given fluid particle within the river flow (within a river flow water particle follow approximately the same direction). Cross sections represent the geometric boundary of the stream. The theory of fluidmechanics provides the tools for estimating the average velocity vector in a river cross section under given assumptions. We will not get into these details here.

Given that the velocity vector crosses the river section, it follows that a certain amount of water flows through it. In a given river cross section, the river discharge (or river flow) is the volume of water that flows through the cross section per unit time. It is usually measured in m^3/s. Measuring the river discharge along a sufficiently long observation period allows one to assess water resources availability. This is a direct method to assess water resources, based on the identification of the river regime. There is an underlying implicit assumption that past observations are representative of current and future conditions.

In gauged rivers with a relatively long record of observations, inductive estimation of water resources availability is a classical technical problem, which is usually resolved by estimating the flow duration curve (FDC). The FDC is a graphical representation, for which an analytical approximation can be provided. The use of a graphical representation presents the advantage of providing a more immediate communication to stakeholders, therefore enhancing transparency.

The FDC depicts the percentage of time (duration) over a given observation period during which a given streamflow is equalled or exceeded (see Figure 1).

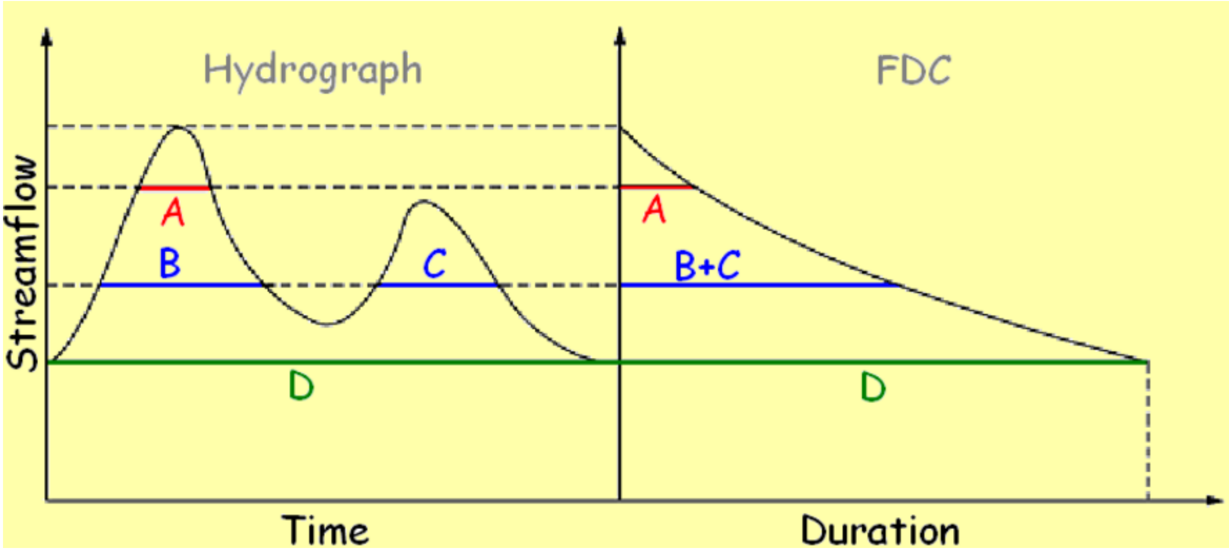


Figure 1. Construction of flow duration curve from an observed hydrograph (courtesy by Attilio Castellarin)

The FDC is a key signature of the hydrologic behaviour of a given basin, as it results from the interplay of climatic regime, size, morphology, and permeability of the basin. From a statistical viewpoint, the FDC is the cumulative probability distribution of the random variable streamflow. In fact, being the FDC an indication of the frequency with which a given flow is equalled or exceeded, if the observation period is sufficiently long the FDC itself is an approximation of the probability of equalling or exceeding a given river flow. Note that for a real random variable the probability of "equalling or exceeding" is technically coincident with the probability of "exceeding". Remember that the frequency of an event is an approximation of its probability. We will discuss about probability theory and its implications later on.

2.2. Estimation of the FDC for a gauged site

The construction of FDC from a time series of river flows observed at a given and fixed time step is straightforward. One should:

- Pool all observed streamflows in one sample.
- Rank the observed streamflows in descending order.
- Identify the position of the i_{th} observation in the ordered sample.
- Plot each ordered observation versus its position duration, in relative or absolute terms (i.e., in percentage terms with respect to the sample size or actual position; for instance, from 1 to 365 for daily values over an observation period of one year in absolute terms).

If F_i is estimated using a Weibull plotting position, the duration D_i is

$$D_i = Pr\{Q > q(i)\} = i/(n + 1)$$

where *n is the length of the daily streamflow series and q(i), i=1, 2, ..., n, are the observed discharges arranged in descending order. The above computed FDC is called the "period-of-record" FDC.*

An alternative method to compute the FDC from an observed time series is to build one FDC for each year of the observation period and then compute, for any within-year duration, the average of the corresponding river flow across all annual curves. Therefore, if the record counts *y* years:

- *y* annual FDC's (AFDC) are constructed from the *y*-year long record of streamflows (for leap years, the streamflow measured on February 29 is discarded).
- From the group of *y* empirical AFDC's one may infer the mean or median AFDC (an hypothetical AFDC that provides a measure of central tendency, describing the annual streamflow regime for a typical hydrological year).
- By using the same methodology adopted for inferring the median AFDC one may also construct the AFDC associated with a given non-exceedance frequency p/100 (which is indicated as "Percentile AFDC" in Figure 2).

An example of the results from the computation of AFDC is provided in Figure 2.

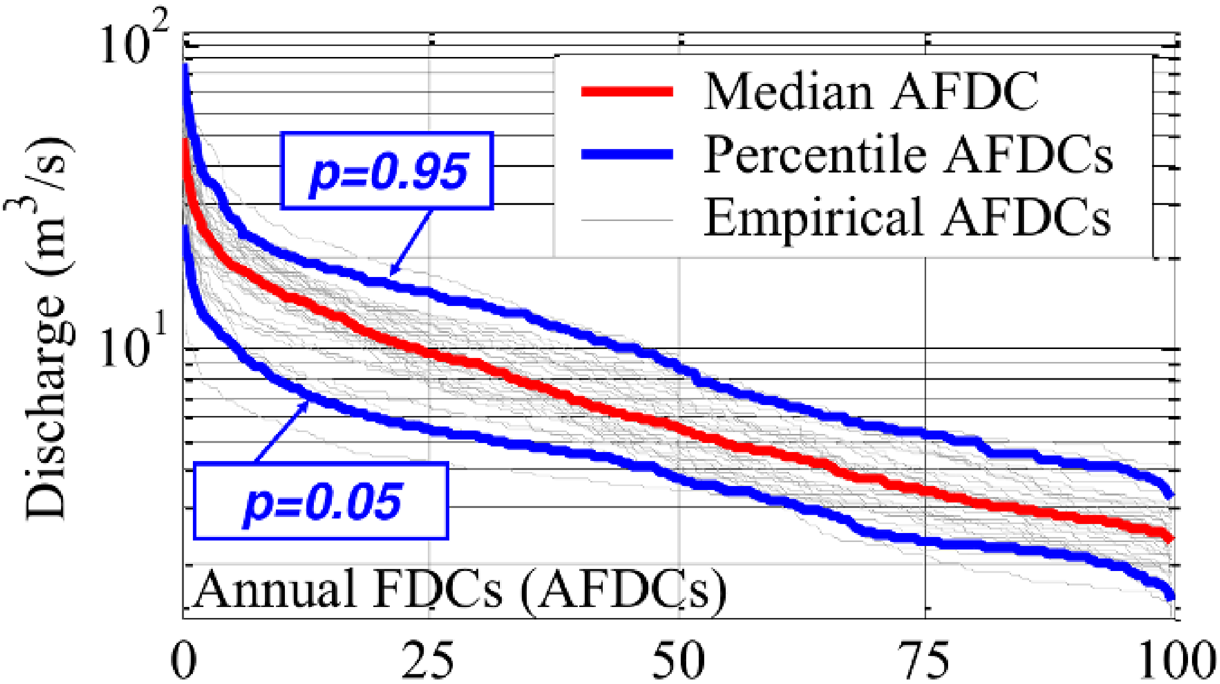


Figure 2. Construction of annual flow duration curve from an observed hydrograph (courtesy by Attilio Castellarin)

FDCs can be displayed according to different graphical representations (Figure 3).