FLOW REGIME OF RIVER DANUBE AND ITS CATCHMENT – ABOUT UPDATING CHAPTER II OF THE DANUBE MONOGRAPH

Jörg Uwe Belz[1], Dr. László Goda[2]

[1]*Department M1 / Water Quantities, Water-Levels, Runoff-Models, Bundesanstalt für Gewässerkunde / Federal Institute of Hydrology (bfg), Dep. M 1 / "Water Quantities, Water-Levels, Runoff-Models", Koblenz, Germany, e-mail:* ***belz@bafg.de***
[2]*Water Management Department, Lower-Danube Water Authority (ADU-VÍZIG), Baja, Hungary, e-mail goda.laszlo@adukovizig.hu*

Abstract: In addition to the 1986 release of the publication "The Danube and its basin – A hydrological monograph" a German-Hungarian working-group worked out an update which concentrates on the discharge characteristics of the catchment with enlarged data-base: series from 1931 up to 1990. The work took place within the scope of the International Hydrological Programme (IHP) of UNESCO.
Keywords: Data validation, flow regime, hydrological primary values, statistical data-analysis, transboundary co-operation,

DAS ABFLUSSREGIME DER DONAU UND IHRES EINZUGSGEBIETES – ZUR AKTUALISIERUNG DES KAPITELS II DER DONAUMONOGRAPHIE

Zusammenfassung: Als Fortschreibung der im Jahre 1986 erschienenen Publikation "Die Donau und ihr Einzugsgebiet – Eine hydrologische Monographie" erarbeitete eine deutsch-ungarische Arbeitsgruppe eine Aktualisierung, welche sich unter Verwendung einer auf den Zeitraum 1931-1990 erweiterten Datengrundlage auf die Analyse des Abflußregimes konzentriert. Die Arbeit erfolgte im Rahmen des Internationalen Hydrologischen Programmes (IHP) der UNESCO.
Schlüsselworte: Abflußregime, Datenprüfung, gewässerkundliche Hauptwerte, grenz-überschreitende Kooperation, statistische Datenanalysen.

1. Introduction

Cooperation of the riparian nations of the Danube in hydrology began as part of the International Hydrological Decade (1965-1974) and has continued since 1975 as part of the International Hydrological Programme (IHP) of UNESCO. The aim of this cooperation is an optimal joint utilization of the available water by developing the fundamentals of hydrological water management and endeavouring to find co-ordinated solutions. For this, comparable data records have to be obtained and evaluation processes worked out. Main subject here is quantitative hydrology.

This work is supported by two pillars: on the one hand the development of basic hydrological water management projects with regard to the catchment area and, on the other hand, the biennial conferences of the Danube countries on hydrological forecasting and hydrological fundamentals of water management, the proceedings of which include the work results and lectures presented.

One of the first results of this extensive work was the publication in 1986 of "The Danube and its Basin – A Hydrological Monograph". This monograph is based on the data series of 1931 – 1970. As this data material was becoming obsolete, the need of a revision was growing. It was decided to update the Danube monograph by adding the time series up to 1990. It would have been preferred to extend the new reference period 1931-1990 to the year 2000, but this was not possible, because such recent data were available only from a small number of the selected gauging stations.

A German/Hungarian working group was assembled for that updating under project-coordination of the German Federal Institute of Hydrology (BfG), Koblenz, as a contribution to the IHP of the UNESCO and to the OHP of the WMO. Participating experts come from the Bavarian State Agency for Water Management (LfW), Munich, the Hungarian Ministry of Transport, Communication and Water-Management, the VITUKI AG, Budapest and the Lower-Danube Water Authority, Baja (Hungary).

The concept of the new project with the title "Flow regime of River Danube and its Catchment – An Update of Chapter II of the Danube Monograph" intends only in part to be a continuation of the comprehensive publication of 1986, but rather concentrates on the subject of discharge. The important topics river engineering and hydrological balance, that are not covered here, will be treated in separate projects.

Publication's release is summer 2004.

2. Working progress and methods

For the 60-year period 1931-1990 data series from all over the Danube basin had to be collected and analysed (both daily mean and annual peak maximum values). This was necessary for the whole time-interval, because the former collected database with series 1931-1970 of the first monograph-issue could not be retrieved any more. Finally, 46 different gauges on the Danube and its tributaries (see Fig. 1) were chosen. These gauges had been selected not only for their position in the river system, but above all for their data availability and reliability. Most of them were analysed in the 1986 edition, too, but of several reasons (e.g. abandonment of the station, no data-deliverance by the responsible authorities or in-acceptable data-quality) there were a few changes to be made and some stations had to be substituted.

Fig. Interval číslování Fig.: Considered gauges in the Danube basin

Experiences from former transboundary co-operation projects show, that usually some typical obstacles appear, especially during the data-collecting phase. So, particularly in a cooperative effort like this with at least 14 different countries participating competenceconflicts, changes in staff and contact-persons, the common habit of giving priority to internal issues instead to the international obligations, heterogeneous quality of the delivered data etc. were quite foreseeable. Sometimes the engaged and highly motivated efforts of many can be frustrated by negligence of a few. In order to avoid major delays in our project, in the beginning a time-schedule with large-scale buffer periods was drawn up.

This proved to be favourable, nevertheless unforeseeable complications in the Balkan-region, on one hand the consequences of the recent breakdown of the former socialist administrative structures, on the other hand the political conflicts in Yugoslavia, culminating in the war in Kosovo, finally led to unplanned delay.

Besides the data-collection itself, questions of data-quality are very important. For that purpose the data-files were checked in three steps: As plausibility-check, the completeness of the series was reviewed and smaller gaps were filled. Secondly, a trend analysis was carried out for the annual minima, the annual means, and the annual maxima of every station. Furthermore, the third and very important instrument for quality assessment of the collected data was the homogeneity test of the data-series (again for the station minima, means and maxima, for details see below).

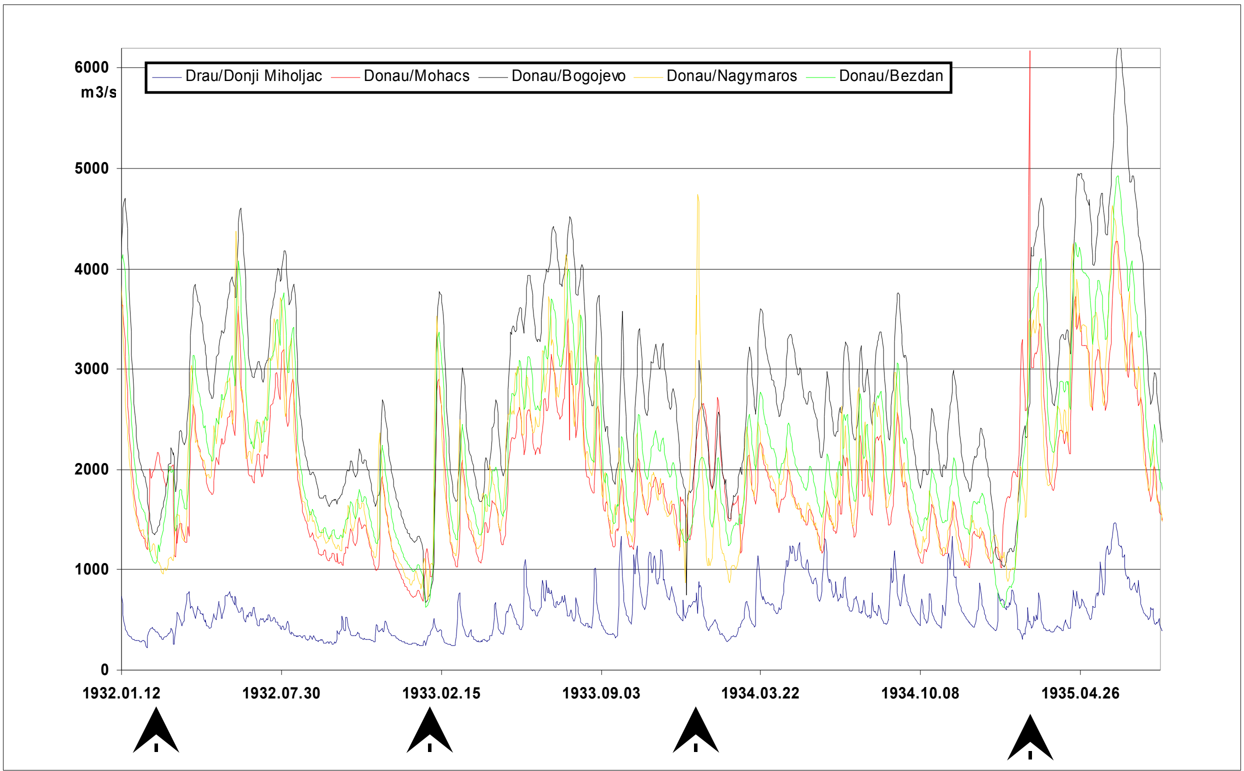

Fig. Interval číslování Fig.: Checking homogeneity – comparison of daily mean-discharge series of five stations in the central Danube basin (excerpt)

In cases when the result of the investigations revealed irregularities, the respective station series were reviewed again in detail, whenever possible together with neighbouring gauges (which was unfortunately rather rare by the case for Danube's tributaries, because at the smaller rivers there were not much reference-data in hand of the project-team). Explanations for inhomogeneities could not be found very often from the responsible authorities because of coordination-problems and lack of time. Figure 2 shows such an examination for some stations on the rivers Danube and Drava in Hungary and Yugoslavia, which partially did not pass the homogeneity test (Critical points are marked with black arrows).

Whenever possible obvious mistakes and irregularities were corrected. Sometimes a station was replaced by a better one, in other cases the statistical data-analyses had to be omitted in case of certain discharge-series (then always combined with an textual explanation).

3. 3. Statistical analysis

The most important working tool for that purpose is the Hungarian software TH (Technical Hydrology), which has been tested and found suitable for such tasks. TH was developed to ensure correct solutions for the hydrological problems arising in water management and hydraulic engineering. The methods applied in the software are based mainly on mathematical statistics and other techniques of the probability theory.

The main lines of the methodology of TH are as follows:

- high-water analysis to determine the parameters of floods and high-water periods for flood control and design;
- water resources estimation, based on low-water analysis, to provide data for water-resources management;
- reservoir hydrology, serving the hydrological design and operation of reservoirs.

In the project in question, the two first branches are used, applying the following functions of the TH software.

3.1 3.1 Homogeneity and trend analysis

As mentioned above, for statistical analyses the quality of the data material is essential. The statistical methods can be applied only when the samples are homogenous and without a significant trend. The homogeneity is investigated with the advanced form of the two-sample Kolmogorov-Smirnov test. As this method is not very common yet, some remarks to its practical application (Goda-Zsuffa, 1994):

The basic idea of the test is that the empirical distribution functions of two statistical samples, chosen arbitrarily from a homogenous population, must be close to each other (Fig. 3). The random deviation of the two functions is measured with the maximum difference, D_{max}, that is

$$D_{\max} = \max_{x} \left| F_{emp}^{(m)}(x) - F_{emp}^{(n)}(x) \right| , \qquad (1)$$

where

$F_{emp}^{(m)}(x)$

and

$F_{emp}^{(n)}(x)$

are the empirical distribution functions of the two samples with the number of elements m and n. Using these values, a further variable, z is composed, as

$$z = \sqrt{\frac{n \cdot m}{n+m}} \cdot D_{\max} \qquad (2)$$

According to a theorem of Smirnov, z follows the Kolmogorov distribution, that is

$$L(z) = p\left(\sqrt{\frac{n \cdot m}{n+m}} \cdot D_{\max} < z\right) , \qquad (3)$$

where, with knowledge of z, the $L(z)$ probability value comes from the Kolmogorov distribution given by its equation or from a table. Consequently $L(z)$ is the probability that the random maximum deviation between the empirical distribution functions of any two samples from a homogenous population should be less than D_{max}. In practice the 1-*L(z)* complementary value is usually used. Based on practical experiences, two significance levels are applied to account the results: when

$$1 - L(z) > 0.7 \tag{4}$$

then the whole sample can be considered as homogenous. In the case

$$1 - L(z) < 0.3 \tag{5}$$

then it is qualified not to be homogenous. If 1-*L(z)* gets in the range of 0.3-0.7 then further considerations are necessary. For instance, omitting a part of the total sample (usually the first section of the record) the test can be repeated for the rest.

Manually the test is carried out by splitting the record at the half, or at the point where some event influencing the homogeneity is supposed.

With the improved version of the method offered by TH the test is repeated for all possible splitting points of the record. So, if the length of the record is *N* and the minimal length of the partial samples is fixed as N_0, then N-2N_0+1 elementary tests can be done.

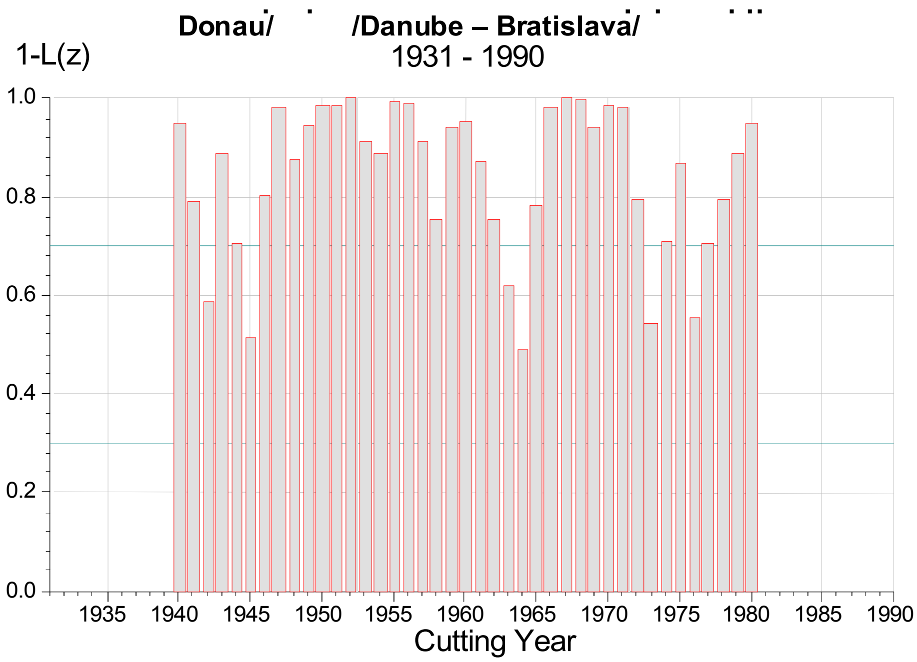

Figure 3: The detailed homogeneity-analysis, applied to annual MQ-series 1931-1990 of station Bratislava (Danube)

The results of this detailed analysis are presented in figure 3, where the histogram of the 1-*L(z)* results is plotted as the function of the splitting point (year). The whole record can be qualified to be homogenous, if the 1-*L(z)* results exceed the significance level of 0.7 for the major part of the elementary tests.

The possible trends of all samples are also checked, as mentioned above. Figure 4 shows the result of these analyses.

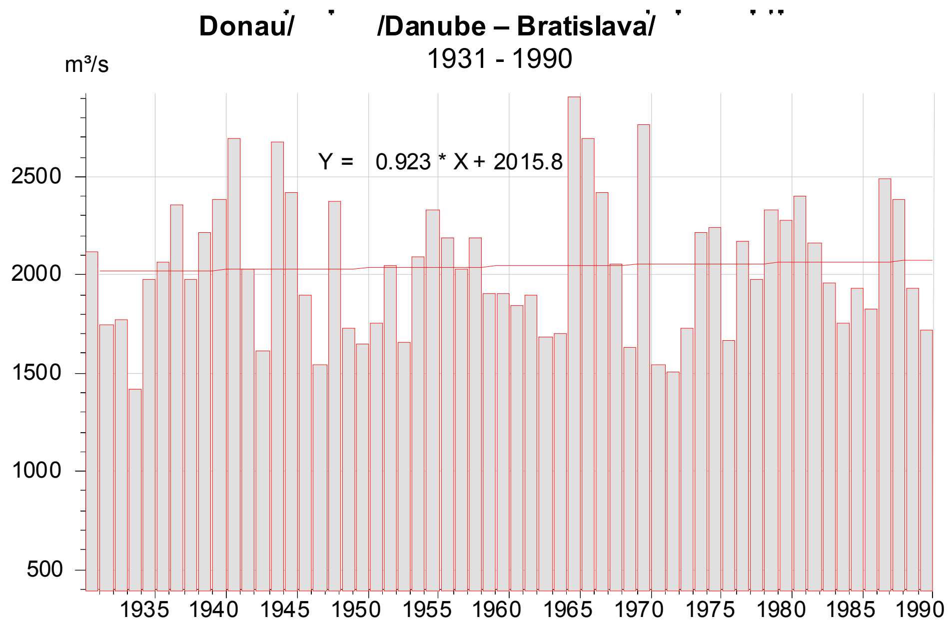

Fig ... ava (Danube)

3.2 3.2 Analysis of the water regime

The characterization of the discharge regime of the Danube and its tributaries used the common classification method by Pardé (1964) in a simplified form. This classification is based on the long-term mean annual variation of discharge at a gauging station, presented in the so-called Pardé-diagrams. Their data basis is provided by computing the relation of each single of the twelve long-term monthly MQ values to the respective long-term annual MQ (Pardé-coefficient). The computation of Pardé-coefficients has always a normalizing effect, what facilitates the direct comparison of different annual hydrographs.

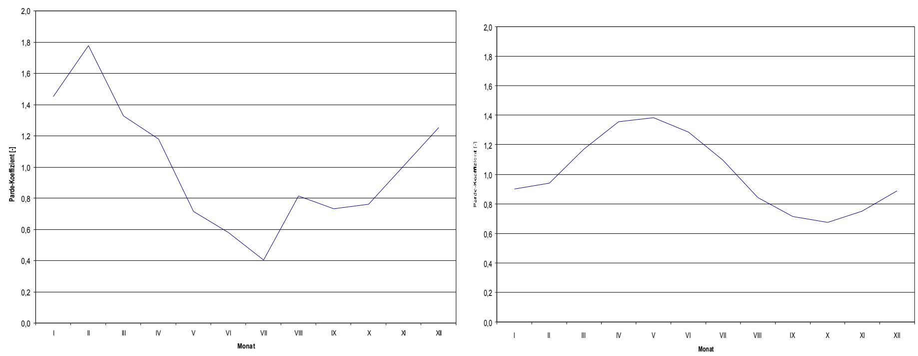

Figure 5: Stations Berg (Upper Danube) - left side - and - right side - Ceatal Izmadľ (Lower Danube): Monthly discharge coefficients acc.to Pardé 1931 - 1990

Investigation of high and low water characteristics are largely based on the same or similar statistical tools, therefore they are describen here jointly (Goda, 1995).

Conventional distribution analysis is done for the annual primary values, applying several distribution types. The fitting is checked with the Kolmogorov-Smirnov test (similar to that used for testing the homogeneity), with the chi-square test, and also with a graphical method. The last one is presented on figure 6, where the values of the empirical probabilities are plotted in the net of the Gumbel distribution. (Hofkirchen/ Danube, Germany).

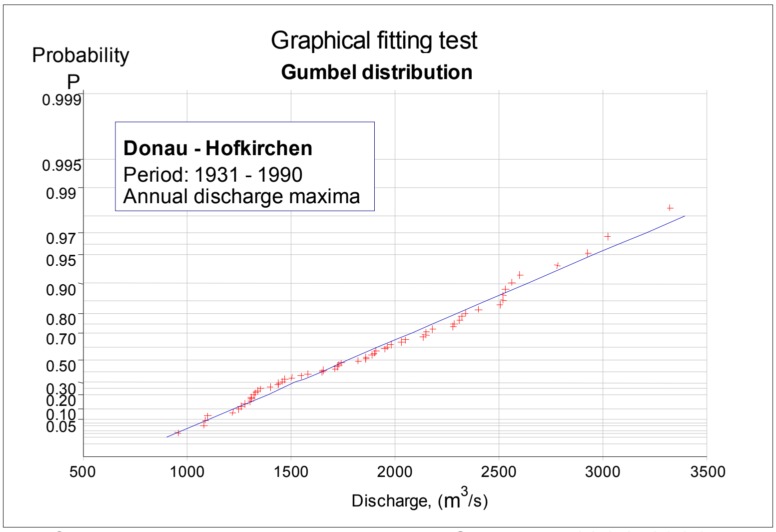

Figure 6: Graphical fitting test, applied to annual HQ-series 1931-1990, station Hofkirchen (Danube)

The same data are shown in figure 7, with linear probability scale, completed with the 70- and 95 % confidence limits.

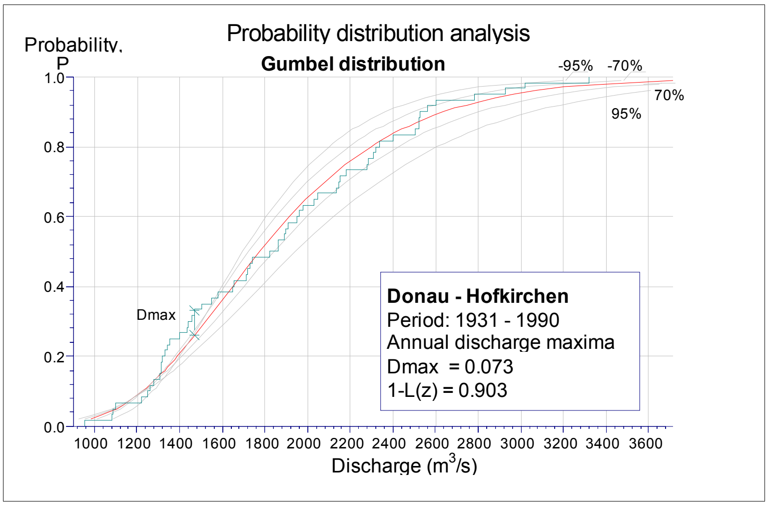

Figure 7: Distribution analysis for flood computation, applied to annual HQ-series 1931-1990, station Hofkirchen (Danube)

Besides the graphical preparations generated by the TH-software, many results of the analysis are presented in tables. That concerns hydrologically significant values ("primary values") as well as probabilities of discharge-thresholds, being exceeded respectively non-exceeded, or duration-statements. Table 1 shows some examples (excerpt).

Tab. 1: Comparison of computed mathematical (theoretical) extreme values (HQ) of different probabilities with the recorded discharge-maximum [mł/s], period 1931-1990. Station: Hofkirchen/Danube (Germany)

RIVER: **DANUBE**
STATION: **HOFKIRCHEN**
CATCHMENT AREA: **47496 KM˛**
PERIOD: **1931-1990**

MAXIMUM 1931-1990	**MAXIMA: PROBABILITIES OF NON-EXCEEDANCE GUMBEL-DISTRIBUTION (RECURRENCE / P)**			
	HQ_2 / 0,50	**HQ_{10} / 0,90**	**HQ_{20} / 0,95**	**HQ_{100} /0,99**
(13.07.1954) 3320	1775	2638	2968	3715

The annual maximum, characterized by a probability value, is usually the most important result of the flood computation. Besides other parameters of the high-water phenomena can also be very useful for the optimal design, dimensioning and operation. For instance, in the complex regulation of floodplains one needs to know the recurrance, how many times in a year, how much water inundates the basin, etc. To answer the question, the length, the mass and the occurrence of flood waves should be examined. To analyse these parameters the Crossing Method is applied.

The interpretation of the problem is shown by figure 8: the continuous record of the discharges is compared with the horizontal level of the Q_0 base flow. The sections of the record below the base flow are called low-water periods or "downhill passages" while the sections above the base flow can be called high-water periods or "uphill passages". The latter ones are considered as flood waves. These flood waves can be characterized by their peak value, length (duration) and mass.

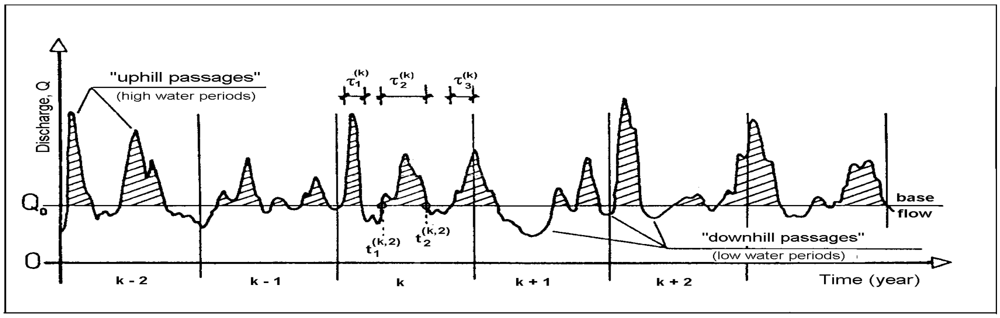

Figure 8: Illustration of the crossing method

These values are individual probability variables and may be characterized accordingly. If the annual period is chosen for base time, then the parameters to be investigated are:

- the annual longest flood duration,
- the annual maximum flood mass,
- the total flood duration in a year,
- the number of occurrences in a year.

The result of the computation depends also on the Q_0 threshold level. It can also be considered as a further variable of the analysis. In this case, conditional distribution functions can be composed with the condition of the Q_0 level. An example for the annual maximal flood periods can be seen on Figure 9.

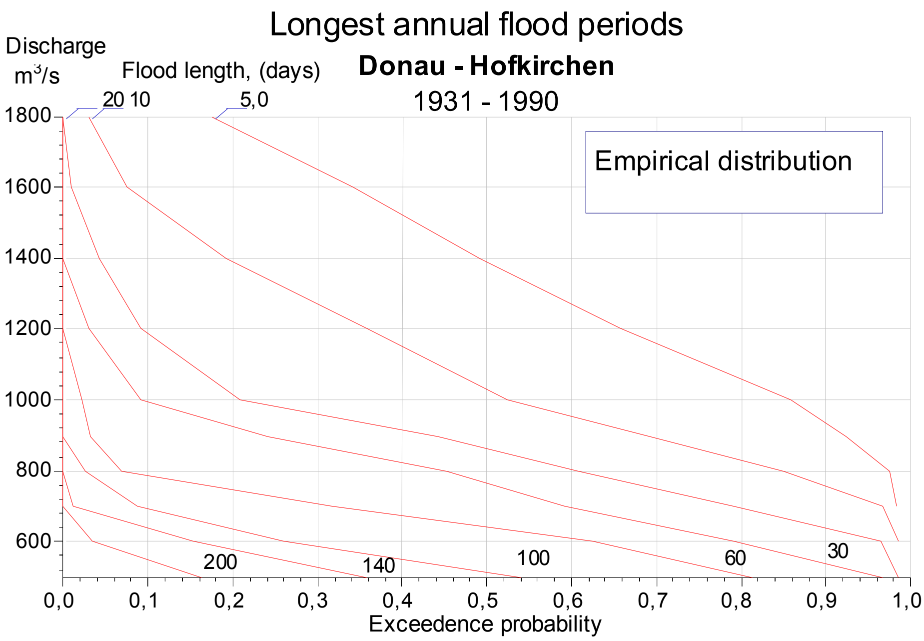

Figure 9: Conditional distributions of the longest annual floods, applied to annual HQ-series 1931-1990, station Hofkirchen (Danube)

4. 4. Utilization

The benefit to be derived from the project is, first of all, the compilation of discharge data from the Danube-basin, which *en bloc* was not available before. It is intended to publish a CD-ROM containing the raw-data files (station-related series of daily mean discharge and of annual maxima) of this compilation together with the report to facilitate the user's individual work with these data. Furthermore, the results of the data-analysis, like primary values and duration numbers, constitute a useful basic material for a wide variety of applications and planning dealing with aspects of quantitative and qualitative hydrology. A few examples to be specified in this context are

- navigation purposes (transport planning of shipping companies etc.),
- ship-constructional tasks (especially concerning the hull design),
- planning aspects of subjects of hydrological engineering, like river-training or flood-prevention,
- risk calculation of insurance companies with direct monetary approach
- sizing in water-resources management for purposes of water abstraction for drinking purposes, industries, and agriculture etc.

Modern water-management not only has to meet quantitative, but also numerous qualitative aspects. Freshwater of good chemical and biological quality is important for a huge number of ecological and economic needs. In the sense of the globally accepted philosophy of "sustainable development" great efforts are made to find possibilities to satisfy both these ecological and the economic demands.

This means, as one example, that many basic research activities take place to determine the mass load of rivers, either resulting from natural background or from anthropogenous sources. On the other side, it is the aim to identify and quantify the needs of environmental quality of waters, which is claimed by the various elements of the natural environment and by human socio-economics. Not only for this kind of basic research, fundamental information about discharge characteristics is essential, these are also very important for the definition of thresholds and orientation values, which are to suit the purpose of prevention of non-tolerable water pollution. Very often these threshold values are not specified in absolute numbers but as a quotient related to mean discharges or to mean low-water discharges.

Against the background of the ecological disaster caused by toxic mining sludge, which occurred during a major flood event in the Tisza-catchment in winter and spring 2000, the newly calculated data concerning the statistical probability of flood-events of different magnitudes gain particular importance. These values, for instance, provide assistance for the risk-assessment concerning the re-mobilisation of polluted sediments, which were deposited downstream and in the foreshore.

Reference values of the water-yield (discharge) in the above exemplified meaning are provided by the publication " Flow regime of River Danube and its Catchment " on the time-basis of a 60-year analytical study not only selectively resp. station-relatedly but also for the whole Danube catchment. This particularly facilitates another aspect of increasing importance for qualitative hydrology: transboundary management, for instance in cases of proportioning the tolerable emissions of pollutants between neighbouring countries upstream and downstream a river.

Altogether, the transboundary, catchment-related handling of hydrological tasks, as they are especially required by the EU Water Framework Directive, which, after the enlargement of the European Union, will be applicable for nearly half of the Danube-catchment, will be alleviated.

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