Weltdatenzentrum Abfluss
Bundesanstalt für Gewässerkunde
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GIS-related monthly Balance of Water Availability and Water Demand In Large River Basins

Case study for the River Danube

Irina Dornblut

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P.O.Box 20 02 53
D-56002 Koblenz

Am Mainzer Tor 1
D-56068 Koblenz

Phone: (49 261) 1306-5224; Fax: (49 261) 1306-5280; E-Mail:
grdc@bafg.de;http://www.bafg.de/grdc.htm

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Summary

The Global Runoff Data Centre (GRDC) at the German Federal Institute of Hydrology (*BfG*) combined available methodological tools and generally accessible data and information to establish methodological principles for short-range modelling of water availability/demand balances in large international river basins in the light of growing water demands. The core of such a balance is the location- and time-related comparison of available resources with water demands in the river basin, while the underlying methodology is an in-depth balancing by means of a long-term water management model on the basis of the Monte-Carlo technique.

The Pilot Study GRM Danube has proven at the example of the River Danube the applicability of the program system ArcGRM to the modelling of a water-management balance of available resources and water demands in large international river basins. The advantages of the system consist in the location- and time-related balance of resources and demands under consideration of the operation of storage reservoirs. It allows to take into account diverse water uses and demands in their temporal and spatial variability. Integrating of FORTRAN instructions allows to vary and supplement the standard algorithms of the program system in form of "dynamic elements". Thus, demand functions may be adapted individually, and qualitative or economic parameters, interactions with groundwater or flow-times in the river system may be considered.

The monthly balancing step makes it possible to evaluate the satisfaction of demands both in the annual averages and in the variations during the year. The outputs of the balancing procedure may be exceedance probabilities of events at any point along the river course, durations of events, mean values and mean minima and maxima of monthly streamflow.

The River Danube is used here to demonstrate the applicability of the program system *ArcGRM* for a availability/demand balance in large basins. This balance examines the satisfaction of present and future water demands in the Danube basin, assuming constant resources, against the background of changed water uses after 1990. The summative decrease of water consumption in countries in the Danube basin after 1990 results in improvements of the potential safety of supplies, which is illustrated here with the required minimum streamflow for navigation (Q_{RNW})[1].

The program system is flexible and readily applicable provided the necessary input data are available. Hydrological inputs are externally generated time series of monthly streamflow obtained by statistical analyses of time-coordinated observations. The main problem is the acquisition of plausible and reliable data describing the anthropogenic impacts on the hydrological system. If the quantification of the effects of storage reservoirs, water transfers, uses and demands relies on generally available data sources, it is necessary to transfer the given data from country scale to basin scale by means of Geographic

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[1] QRNW from German „Regulierungsniedrigwasser“

Information Systems (GIS).

Balancing of water availability and water demand at selected points in the basin, under consideration of storage reservoir operation, allows to identify cases of surplus and deficit in the satisfaction of the diverse water demands as well as potential risks regarding the potential safety of supplies. Proceeding from the basic version, additional variant computations can examine the impacts of future developments in water uses or large-scale changes of resources availability on the satisfaction of demands and may analyse predicted trends in water demands.

The presented methodological steps allow to set-up a basic model for the selected basin and to use it for short-range computations of varying management scenarios. Such model outputs may be used for global and regional monitoring of areas of (potential) water crises, and the summarized information may help to establish general principles for the management of large international river basins that are affected by permanent water scarcity, high population growth, and increasing water consumption. For applications in "rapid assessments" at regional levels in the context of international programmes, the presented methodology needs formalization by defining separate work steps and simultaneously detailed adjustments to the regional conditions.

1 Introduction

This report is a contribution to the growing efforts of international organizations, programmes, and projects to support the assessment of global and regional water availability against the background of steadily rising water demands. The presented methodology and a program system, that has been successfully employed in Germany in long-term management of complex river basins, make it possible to model the balance of water availability, uses, and demands within a river basin in their temporal and spatial distributions and to examine the quantitative basin behaviour under varying boundary conditions such as changing water resources, uses, or demands also in space and time.

The application range is primarily the rapid assessment of critical water availability on a basin scale and the computation of management scenarios for other large, shared river basins in the context of international programmes.

2 Background

About 6,000 million people live on earth and need water as fundamental resource of their lives. Besides the growth of population, the development of water needs depends on social and economic variables like urbanization and industrialization. Households, industries, agriculture, and power generation need more and more water. Useable water resources are limited and due to climatic and geographic conditions unevenly distributed in time and space. In many regions of the world useable resources have been depleted already. Against the backdrop of global climate change and population growth with a annual increment of about 2 %, extensive uses of the water resources entail in many parts of the world scarcity and impaired quality of water. Economic growth and rising standards of living especially in the agglomerations in developing countries accelerate this trend. Dwindling per capita availability of freshwater for wide sections of the population and rising demand raise up the costs of water treatment and supply. Thus, water becomes a limiting factor of economic and social developments.

However, these negative tendencies may be opposed, since water is a renewable resource. Economical use, rational and consistent regulation of its allocation, multiple use and recycling are possibilities to ensure future water supplies. Such an efficient management of water resources presupposes the analyses of the available resources in terms of quantity and quality, of the system of water management, and of the demands to be met.

Alcamo et al. (1997) and Meigh et al. (1999) used different model approaches for the assessment of the impacts of water demand on water availability on a global scale. Alcamo et al. computed on a 0.5°-grid basis a “Criticality Ratio” i. e. the rate of water use against availability, and based on this figure a “Criticality Index” from 1 to 4 for more than one thousand river basins or countries. Meigh et al. calculated a “Water Availability Index” to describe water surplus and deficit for eastern and southern

Africa regions. For the comparison of water resources between water demands surface flows, groundwater availability and water demands are estimated also on a 0.5°-grid basis. The model uses a rainfall-runoff model for generating river flows and links model approaches to estimate groundwater availability and impacts of lakes, wetlands and reservoirs.

The calculation of available water resources by means of rainfall-runoff models simulates land-use affected runoff, but the continuous anthropogenic impacts on the hydrological system by reservoirs, diversions and water uses are insufficiently reflected or ignored. Grid-based approaches describe the spatial variability of water resources and water demands on a regional scale, but do not differentiate within the river basin. The annual variability is mostly not taken into account. Such model approaches do not allow to differentiate surplus and deficit within the river system and to identify the effects of changing management rules of water allocation on a basin scale.

3 Objectives

The Global Runoff Data Centre (GRDC) at the German Federal Institute of Hydrology (*BfG*) combined available methodological tools and generally accessible data and information to establish methodological principles for short-range modelling of water-management balances in large international river basins in the light of growing water demands.

The analysis of water surplus or deficit in the river basin allows also to identify possibilities of temporal and spatial re-distribution of water resources, modifications in the system of water management or of demand management. Scenario computations are used to examine the implementation of management strategies and their (economic) impacts on the availability of water and the demands for it.

The core of such a balance is the location- and time-related comparison of available resources with water demands in the river basin, while the underlying methodology is detailed balancing by means of a long-term water management model on the basis of the Monte-Carlo technique taking into account the stochastic character of the hydrological inputs (KOZERSKI 1981). The analysis of the system allows to derive conclusions about the availability of water and the satisfaction of water demands along the longitudinal profile of the river for different time horizons. The standard computation interval is one month. The program system and its predecessor have been successfully used in Germany in planning for complex river systems (SCHRAMM 1995, BFG 1995, BFG 2000). On the one hand, it gives an adequate representation of the hydrological system and the water-management structures, including anthropogenic impacts like storage reservoirs, water transfers and uses of all kinds, and on the other hand, it identifies and depicts in detail the varying demands on this system. The current streamflow data from the GRDC database are model inputs, supplemented in cases of data gaps from other sources.

Following these methodological steps, a basic model of the considered river basin can be developed that allows rapid computations of management scenarios. The model outputs may be beneficial for global and regional monitoring of areas of (potential) water crises and for assessing the criticality of river basins affected by permanent water scarcity, high population growth, and increasing water consumption.

The present pilot study takes the example of the river Danube to demonstrate the applicability of the program system ArcGRM for striking a balance between water availability and demands in large basins. ArcGRM presupposes long time series of hydrological input data, knowledge of the reservoir management rules, and annual and monthly values of the water uses. The latter are usually not available on a river-basin scale, so that approaches to the determination of these inputs in large international river basins are also presented.

4 Challenges of balancing water availability versus demand in large river basins

The size of the basins considered here ranges between 50,000 km² and several million km². These vast territories are usually shared by several states, often with different economic structures. Moreover, the hydrological conditions in the basins vary with climatic and geographic factors, which also have essential influences on the demands for water uses. Large systems of storage reservoirs often serve different or multiple purposes. Flow times in the river system may exceed one month and are thus longer than the given balancing interval.

The modelling of the water availability/demand balance of large, international basins focuses on the main river and the major tributaries, the major consumptive water uses, and those water diversions and reservoir operations which become effective beyond the monthly computation interval.

The essence of modelling is the adequate depiction of the hydrological system on the basis of possibly long series of hydrological input data. The database maintained at the GRDC is a good starting point. The focus of the GRDC's data policy for meteorological and hydrological research on a global basis is on the collection of streamflow data from gauging stations located close to the river mouths. The water-management balance presented here, however, requires a much denser network of gauging stations in the basin and possibly long, overlapping time series. Consequently, filling of data gaps from sources outside the GRDC, such as hydrological yearbooks, is indispensable. Because of temporal disharmony of observation intervals of the stations, often only rather short series can be compiled for model inputs. In order to achieve greater variability of input data and thus reliable model outputs, the generation of long time series on the basis of available observation series may be advisable.

Observation series are always a reflection of streamflow conditions affected by human activities. Lack of suitable collateral information for the correction of time series for use impacts forces to work with uncorrected series. This means that all anthropogenic impacts during the observation series, like water releases from reservoirs, water diversions, and major impacts of water uses are also taken into account. Thus, a initial state of the managed water resources is simulated which then can be superimposed by real and potential changes and developments.

Besides hydrological and meteorological data, information and data describing and quantifying the anthropogenic influences like storage reservoir operation, diversions and uses of water in relation to requirements placed on the resources-management system are needed. On a global scale such information is available only to a limited extent, so that it must be derived from generally available data. The main problem, besides lacking data, is the establishment and preservation of the river-basin reference. Employment of geographic information systems (GIS) allows to identify water uses on a basin scale from a combination of basin-related information and national statistics.

5 Basic features of the program system ArcGRM

The program system ArcGRM (WASY GMBH 1999) is an ArcView application of a detailed water-management balance. It uses the functions of GIS ArcView for model set-up and processing. The underlying long-term management model GRM operates by the Monte-Carlo technique. It rests on a stochastic runoff simulation model and depicts anthropogenic impacts with a deterministic approach. The programme system is able to model steady as well as dynamic processes. Proceeding from an analysis of hydrological conditions and the situation of water management in the basin, the response of the water system is examined under varying boundary conditions.

Hydrological input is the mean monthly streamflow through a river profile (e.g. at a gauging station) or of an inter-basin between two or more such profiles, and it may be supplemented by meteorological data about the study area. The model presupposes the existence of long time series of these input data, which are usually generated externally by means of a stochastic simulation model under consideration of time-dependent conditions of the runoff process.

The stochastic simulation of the available resources is then confronted with the deterministic description of water uses and demands. It begins with a break up of the river basin into simulated sub-basins, to which the simulated available resources are assigned in area-weighted form as their inherent water resource at defined balancing points. Summing-up these partial flows in the flow direction gives the initial streamflow values in the river run prior to balancing and storage computation. Reservoirs, diversions, and water uses in the river system are assigned - just like the demands - in location and dimension to the balancing points. A ranking number reflects their significance in the whole system. The spatial structure of the model is shown in an abstract scheme of the hydrological system.

The balancing of available resources and demands along the river is oriented at the actual demand and considers the storage reservoirs in the basin and a predefined ranking. The underlying assumption is that only the amount of water is released from a reservoir that is really necessary for full satisfaction of the users'demand. With view to the availability of the storage reservoir and the ranking, first the required water volume is released and then the volume that is not needed is "returned" to the storage reservoir (arithmetically) within the current month under consideration of other water demands further downstream (Figure 1). The computation interval is one month. ArcGRM assumes that all streamflow-relevant processes are completed during the considered month. Flow times in the river are not considered by its standard algorithms.

A special feature of the ArcGRM program system are the so-called dynamic elements, which change and supplement the standard algorithms with individual algorithms defined by the operator in a sequence of FORTRAN instructions. Thus, constants or outputs from other models may be imported, non-model parameters and units may be converted, or individual model parameters may be adjusted. Such examples are the setting of initial values, consideration of quality parameters along the river, computation of evaporation losses from reservoirs, consideration of interactions with groundwater resources, inclusion of economic parameters, or the consideration of variable control rules.

The results of the balancing effort are probability distributions of state parameters like reservoir filling, deficits in satisfaction of demands of selected users, or the guarantee of the required minimum flow, as well as frequency distributions of events of certain durations, mean values and extremes of computed streamflow at selected balancing points. Variant computations allow the identify positive or negative impacts of different management strategies on the available water resources.

The management model presupposes the analysis of the river basin and the system of water-resources management practiced there, the statistical analysis of selected time series, the generation of long time series by a stochastic simulation model, the determination of monthly values of the storage effects and anthropogenic impacts, as well as the derivation of water demands for various initial and predicted conditions and time horizons.

The main components of the program system ArcGRM are:

- the modelling of the water resources in simulated sub-basins;
- the area-weighted allocation of the simulated resources among balancing points by relative shares;
- the description of anthropogenic impacts by definitions of storage reservoirs and their management rules;
- the description of water uses in their annual course with a pre-defined ranking;
- the definition and programming of the "dynamic elements" to supplement the standard algorithms; and

- the definition of recordable events, durations, and state parameters.

The model set-up follows a system scheme, which defines the geographic relations between the spatial model elements (watercourses, simulated sub-basins, balancing points, storage reservoirs, water users).

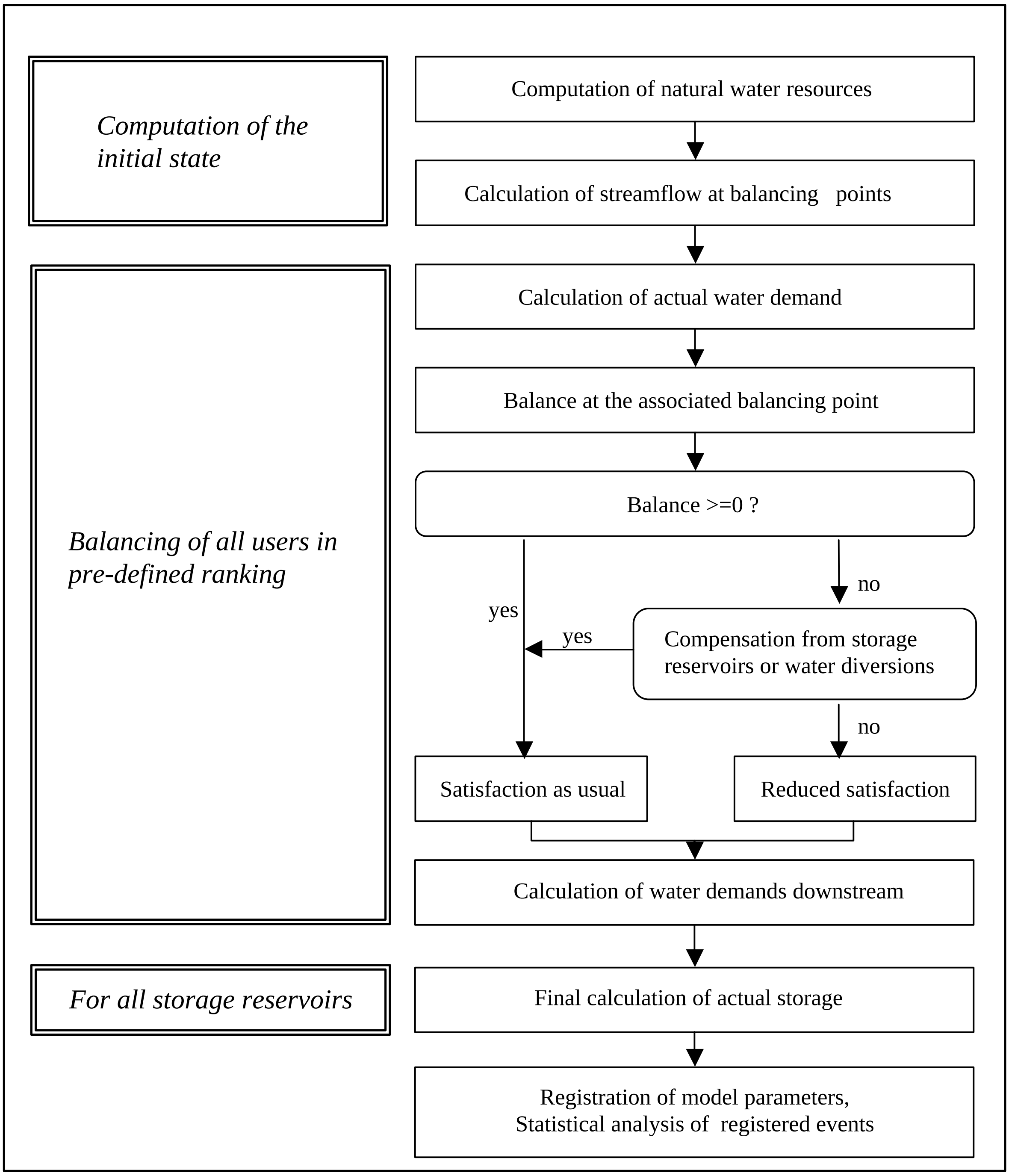

Figure 1: Flow-chart of the water management balance with the program system ArcGRM (WASY 1999)

6 Pilot study: Water-management balance of the River Danube

This pilot study demonstrates at the example of the River Danube the applicability of the program system ArcGRM for balancing water availability and water demand in large, international river basins. In a global perspective, the Danube and its basin are not counted among the areas of water scarcity. With the exception of Hungary, all countries in the Danube basin withdraw less than the renewable supply from groundwater and surface waters each year (WRI 1999b). Nevertheless, the uneven distribution of precipitation causes on the middle and lower Danube reaches occasionally water shortages in autumn and winter. The Danube basin was selected for the pilot study because of the relatively good data basis. This includes both the data kept at the GRDC and the possibility to supplement these from other data sources.

With a length of 2,800 km, the Danube is the second river in Europe. Its catchment of 800,000 km² reaches from Central Europe to Eastern Europe. Just before its inflow into the Black Sea, at the gauge of Ceatal Izmail in Rumania the Danube has a mean streamflow of 6,500 m^3/s (Figures 2 and 3). The major tributaries are Inn, Drava (Drau), Sava (Save), Tisza (Theiß), and Velika Morava (Figure 4). The upper Danube basin has high runoff rates per unit area due to the alpine tributaries, above all the River Inn, while the precipitation-deficient regions of the middle and lower Danube have only small values despite the inflows of Drava, Tisza, and Save (Figure 5, Table 1).

The Danube connects Germany, Austria, the Slovak Republic, Hungary, Croatia, Yugoslavia, Rumania, Bulgaria, and the Ukraine; its catchment is shared between 17 states in different portions (Figure 6, Table 2). Hungary's territory lies completely in the catchment, while this applies to 90 % and more of the area of Austria, Rumania, and the Slovak Republic. Poland, Albania, Italy, Switzerland and Macedonia have only very small shares and are not considered as "Danube countries" in the following.

The Danube basin is a region of intensive economic activities. More than 85 million people live there. The Danube flows through ten cities of more than 100,000 inhabitants, and more than 60 cities of this size are located in the river basin, including the capitals Vienna, Bratislava, Budapest, Belgrade, Sofia, and Bucharest. About 70 % of the basin is agricultural land; primary water users are industries and power generation (YATSYK ET AL. 1994). There are numerous storage reservoirs in the basin dedicated to various purposes. Besides hydropower generation, they serve for water supplies, irrigation, and flood protection. Apart from impoundments in the regulated German/Austrian reach with river power plants, there are only few storage facilities in the Danube itself. In the Rumanian-Yugoslavian reach the power stations Djerdap I and Djerdap II have existed since 1971 and 1984, with a total storage capacity of 3,900 million m³. The storage reservoir Aktimova (11 million m³) downstream of the city of Ruse on the Rumanian-Bulgarian reach has been used for irrigation since 1987. In 1993 began the operation of a storage reservoir of 196 million m³ in the impoundment Hrusova in the Slovak Republic and in the associated power station Gabcikovo. Here, about 90 % of the mean streamflow is diverted through a canal (SEAGRANT 1999). For the "old bed" of the Danube downstream of the weir Cunovo, a minimum flow of 300 or 400 m_3/s was reserved (BWK 1998). At Turnu Magurele on the Rumanian-Bulgarian reach, another storage reservoir with more than 4,000 million m^3 capacity is planned (ICOLD 1999). Via the Main-Danube Canal, water is transferred from the Danube basin to the Rhine basin, except in periods of low flow. The river Danube is navigable nearly on its whole length. With the streamflows defined by the Danube Commission for regulated low-flow levels at the main gauges (last update 1995), minimum streamflow values for navigation exist now along the river from Regensburg to the Black Sea. Figure 7 shows the required minimum streamflow and the long-term average of monthly streamflow. In the upper and middle Danube the minimum streamflow cannot be reliably guaranteed from October until January, in the lower Danube from August until November.

6.1 Hydrological input data

From the GRDC database 17 stations in the study area were selected for the simulation of the available water resources (Figure 8). Selection criteria were length and plausibility of the time series. Besides twelve gauging stations on the main river, for each of the five major tributaries one gauge was chosen. The available time series were supplemented by means of the Hydrological Yearbooks of the Danube Commission (COMMISSION DU DANUBE 1953ff). Remaining gaps were closed by regressions to neighbouring gauges or those on tributaries (Figure 9). The time series were not corrected for impacts of water uses because of insufficient data.

The observation series of the selected gauges were checked for plausibility. Causes for trends and discontinuities are usually man-made interventions in the hydrological system like impoundments or storage reservoirs, e.g. Djerdap I and Djerdap II in 1977 and 1984. As the focus of this study was on methodological aspects, a detailed investigation of causes for trends and jumps was omitted just like the correction of the series, except downstream of Djerdap I/II. The impacts of these storage reservoirs on streamflow at the downstream gauges was derived from a comparison of time series before and after these dams were taken into operation.

Series of mean monthly streamflow were compiled from the available data material for the period 1931/90 for twelve gauging stations on the Danube and the tributaries Inn, Drava, Tisza, Sava, and Velika Morava (Table 3). These supplemented observation series were the basis for the stochastic generation of long time series of streamflow at the inflow gauges and the sub-basins between the gauges as model inputs. According to the stochastic character of the hydrological and meteorological elements, the water resources are simulated - proceeding from the statistical analysis of the observation series - as a periodic, unsteady Markov process by the model of the conditioned distribution. The fitting of the distribution functions, the estimates of auto- and cross-correlations and the set-up of the simulation model was performed by the program SIKO (WASY GMBH 1993), the generation of time series by the program SIMO (WASY 1993). The simulation model consists of a multi-dimensional regression model, which rests on the time-variant auto- and cross-correlations and a back-transformation model based on the distribution functions.

A good fit of the distribution functions was achieved for the time series of the inflow gauges (N?^{2} test, described in DYCK 1976). As expected, the fit of the series of inter-basin flows was poorer, but it still meets - with a few exceptions - the required quality criterion. The same applies to the (anyway weak) auto- and cross-correlations of uncorrected streamflows, above all those of the large inter-basins on the middle and lower Danube. All three proposals yielded satisfactory results. The best output came from the simulation proposal that considered the "optimum" correlations of the sub-basin streamflows that were derived from the observation series. The assessment of the simulation is based on the monthly means, the standard deviations of the simulated processes and the preservation of the auto- and cross-correlations, as well as the visual comparison of the generated series with the observed ones (Figure 10).

6.2 Anthropogenic impacts on the hydrological system

In the perspective of the quantitative management of water resources, anthropogenic impacts are understood as those forms of water use which entail a redistribution or consumption of water, such as water releases from reservoirs, water diversion, withdrawal, and return flow.

Proceeding from the simulation of the managed water resources on the basis of the uncorrected streamflow series 1931/90, all man-made influences on the hydrological system are integrated into the simulated water resources in the study area. Balance-relevant are consequently changes against this time horizon. The sources of data on streamflow-relevant water uses in the Danube basin were general statistical data, national data, data from the World Resources Institute (WRI), UN's Food and Agricultural Organization (FAO), the International Commission on Large Dams (ICOLD), as well as basin-related information from publications of the “Danube countries” in the context of cooperation under IHP/OHP.

The greatest influences on the hydrological system of a river basin are exerted by water transfers and storage reservoirs. According to the World Register of Large Dams (ICOLD 1999), there are in the whole Danube basin about 60 storage reservoirs with capacities >100 million m^3, including four >1,000 m^3, either in operation or under construction (Figure 11). Most reservoirs serve multiple purposes. With view to their main function, 41 % serve power generation, 22 % water supplies, 17 % irrigation, and 16 % flood protection (Figure 12). In the water balance of the main river the storage reservoirs Hrusova downstream of Bratislava and Djerdap I and II upstream of Drobeta-Turnu Severin were considered. Following the assumption that for hydropower generation nearly the whole streamflow is available, the mean monthly inflow into the reservoirs was set equal with the reservoir release to the power station. Since the capacity of the reservoir Hrusova corresponds roughly to the daily inflow into the power station - and that of Djerdap I and II to the six-fold thereof - and moreover the mean monthly inflows to the reservoirs are greater than their working capacities even at low-flow conditions, variations of the storage volume are not effective in the balance during the monthly time step.

Water transfer from the Danube to the Rhine basin via the Main-Danube Canal was quoted in RZDD (1998) at 300 million m^3/a on average. WEBER UND FREI (1993) mention 125 million m^3/a as the average transfer volume, and according to EMMERT (1999) 228 million m^3/a were taken into account in the balance as "export" to the Rhine basin. The limit for diversion from the Danube at low flow is set by the mean low flow of 140 m^3/s at the withdrawal site (WEBER 1993). The Danube seepage losses at Immendingen and Möhringen in the German reach were assumed to be constant over all balancing horizons.

Variations in water withdrawals for industries, households, and irrigation in the countries in the Danube basin between the 1980s (up to the year 1990) and the 1990s (after the year 1990) were considered as water uses in the study area. Although for some states in the Danube basin (e.g. Germany, Hungary) detailed, but sometimes contradictory data on water abstractions in the years are available, for the benefit of a unified data basis for all Danube states, generally available data sources, like WRI and FAO were preferred for evaluation. Proceeding from an annual per capita withdrawal (including groundwater pumping) in the 1980s and 1990s and the sectorial percentages in industrial, domestic, and agricultural uses (WRI 1999a,b) the population figures were used to calculate for each country the industrial and domestic per capita use. The water use of large cities was determined from the per-capita figures and the number of inhabitants. Although not all withdrawn quantities are necessarily consumed, these water uses are balanced as consumption in this study. The annual total withdrawals in the Danube changed only slightly from the 1980s to the 1990s (Figure 13). However, changes were noted in some countries in the allocation to the different sectors. For instance, by the data of the WRI, water withdrawals for industries and agriculture decreased in most countries, while in the withdrawals for households both increases and decreases were observed (Figure 14). Water consumption for irrigation comprises the volume of water applied during the growth season without consideration of drainage and water returned into the river system. The irrigation volumes were calculated from the irrigated area in the countries in the basin (FAO 1999) via the areal percentages and an irrigation factor (RZDD 1986, WEBER 1993) as annual withdrawal volumes and related to the growth season. The irrigation period was defined for the European Danube basin from May to October (UNITED STATES DEPARTMENT OF AGRICULTURE 1994). The area under irrigation changed only little from the 1980s to the 1990s, also after the political changes in Eastern Europe. How the reduction of irrigation areas beginning in 1990 will affect the still continuing upward trend since the 1970s remains to be seen. Except in Hungary, Rumania, and the Slovak Republic, the water consumption determined by means of the irrigated area (Figure 15) decreased from the 1980s to the 1990s (Figure 16).

6.3 Definition of water demands

Water demands are in this study - besides withdrawals and transfers of water - also non-consumptive uses, such as the required minimum streamflow for navigation and power generation or the minimum flow requirements for ecological reasons. Here, the minimum streamflow demanded by the Danube Commission for the major Danube gauges was defined for the purposes of this study as the minimum water demands of navigation (Q_{RNW}) (Table 4). This value coincides with streamflow exceedance with 94% probability ($Q_{94\%}$) of a 40-year series, excluding ice periods (RZDD 1997). For the water transfers from the Danube to the Rhine basin via the Main-Danube Canal and for the reach downstream of the storage reservoir Hrusova, the required, seasonally varying minimum flows are considered in the balance (BWK 1999).

6.4 ArcGRM model set-up

For the determination of the available water resources, the Danube basin was divided into 17 simulated sub-basins of the selected gauging stations. The externally generated series of monthly mean streamflow were taken for each sub-basin in the balancing model as the available water resources. The allocation of the streamflows of the simulated sub-basins (Figure 17) to selected balancing points (Figure 18, Table 5) was performed within the model by means of the relative shares in the respective sub-basins, derived from the sub-basin area related to the respective balancing point (Figure 19). The area of the sub-basins were computed with ArcView on the basis of the Hydro1k-data set of the EROS Data Centre at the U.S. Geological Survey (USGS). Summing-up of the sub-basin streamflows in flow direction yields the initial streamflow values along the river course prior to balancing and storage computation.

For the storage reservoirs Djerdap I and Djerdap II, the storage effects were estimated and the water-resources value downstream was corrected for these effects by means of the "dynamic element". The correction values were computed from the difference of the interbasin flows with and without storage effects as monthly correction constants. This correction smoothes the monthly minima and maxima and thus improves the representation of the water resources in the upper and lower streamflow ranges. As the reservoir operation does not affect the balance in the monthly computation step and as the effect of storage is assumed to be unchanged and an implied component of the simulated streamflow, no correction for storage effects was made in the variant computations.

It was not necessary to take flow times into account for the study area, because the flow times from model entry at Regensburg to model exit did not exceed the monthly balancing time step. Although the flow times go beyond the computation time step needed for the storage computation, they may be ignored in the study area, because during the balancing time-step reservoir operations do not become effective. Average flow times were estimated by the visual comparison of streamflow hydrographs and correlations of daily streamflow values of neighbouring gauges (Figure 21). The flow time is obtained from time shifting with the best correlation.

All storages, transfers, uses, and demands were assigned to the respective balancing points in their locations and quantities. The availability of water for the various uses was defined by a ranking (Figure 20, Table 6). The highest priority of all uses have processes that correct the simulated water resources. For all other uses, the position along the river course defines the ranking: upstream uses before downstream uses. Several "dynamic elements" correct the initial streamflow values and serve for testing and verification of the model. The recorded results are monthly probabilities of exceedance and the duration of deficits (relative frequency) of streamflow and of demanded streamflows, the monthly means and extreme values of the computed monthly streamflows, and finally the percentage of satisfaction of demands at certain balancing profiles.

6.5 Results of scenario computations

The basic scenario is the managed initial state of available water resources until 1990. The reference horizon results from the length of the time series underlying the resources simulation, i.e. 1931/90. A comparison of the mean values computed by ArcGRM with the mean values of the observation series 1931/90 shows in the long-term average a deviation of 1 %, with minima deviating on average by 5 % and maxima by 3 % from the observations (Figure 22).

The basic scenario provides the reference horizon for all further scenario computations. A second version strikes a balance of the constant available water resources assumed and the demand for water under consideration of withdrawals for supplies of industrial, domestic and irrigation uses changed against the reference horizon as well as the diversion to the Rhine basin by the Main-Donau Canal. The influence of the changed water use on the availability of resources and thus on the relative reliability of supplies is shown in a comparison of variants at the balancing points Bratislava, Mohacs, and Svistov, which stand here as examples for the upper, middle, and lower Danube, respectively.

A scenario comparison of exceedance probabilities of the mean annual streamflows along the river (Figure 23) and of mean monthly streamflows at the selected balancing points (Figure 24a-c) allows to assume higher reliability of supplies because of the summative decrease of water withdrawals after 1990.

A comparison of the exceedance probabilities of the minimum streamflow required for navigation (Q_{RNW}) in both scenarios shows in the annual average an improved satisfaction of demands downstream the balancing point Achleiten. This corresponds to a reduction of streamflow deficits below Q_{RNW} between two and seven days per year. The aggravation in the German reach is a consequence of water transfers to the Rhine basin via the Main-Danube Canal (Figure 25a). In October, the required minimum streamflow Q_{RNW} is met only at three balancing points despite the improved satisfaction in the annual average (Figure 25b). Q_{RNW} coincides with the 94 % exceedance of mean streamflow at the respective balancing points. Against this threshold value surplus and deficit in the satisfaction of demands become obvious. For the three selected balancing points, the surpluses calculated for the balancing horizon of the 1990s are always greater than the deficit (Figure 26).

Although the required exceedance probability is guaranteed in the annual average, there are differences in the satisfaction of demands in the individual months. Figure 27a-c shows again for the examples of

Bratislava, Mohacs, and Svistov, the satisfaction of demands in the course of the year and the increased reliability of supplies in low-flow periods due to the decreasing water consumption.

The changes in the demands for diverse water uses from the 1980s to the 1990s find also expression in changed durations for deficits below Q_{RNW} in relative frequencies given in percent. Figure 28a-c shows the frequency of Q_{RNW} deficits in the 1980s and the 1990s. For instance, Q_{RNW} at Bratislava is not reached in the long-term average for January with a probability of 18 % or 11,9 %, respectively. The higher reliability of supplies is here to be seen in the reduced frequencies. Figure 29a-c reflects the probabilities of ensuring a water-demand percentage, here in form of the required minimum streamflow Q_{RNW} at the selected balancing profiles. The 100-% curve corresponds to the exceedance probability of the required minimum streamflows. In the low-flow period from September to December the 80 percentage of the required minimum streamflow is supplied at Bratislava and Mohacs with a safety of more than 95 % and at Svistov of more than 90 %. The above-mentioned higher reliability of supplies becomes apparent in a comparison of the scenarios.

7 Discussion

The presented water-management balance on the Danube examines the safety of satisfaction of water demands under the assumption of constant water resources against the background of changing water uses after 1990. The general decrease in water consumption since 1990 has resulted in improved potential reliability of supplies, shown here at the example of the minimum streamflow required for navigation (Q_{RNW}). The data on the satisfaction of water demands in percentages allow to derive actions and measures aiming at demand management in a river basin. The slight improvement in the reliability of supplies did not allow to develop for the study area a modified management strategy. Compared with Q_{RNW} as threshold value, the surplus calculated for the balancing horizon of the 1990s is at all three selected balancing points larger than the respective deficits.

Building on the basic scenario, additional scenario computations allow to examine the impacts of future developments in water uses or large-scale changes of water resources availability on the satisfaction of demands and permit to predict developments in water demands themselves.

The Pilot Study GRM Danube has proven at the example of the River Danube the applicability of the program system ArcGRM to the modelling of a water-management balance of available resources and water demands in large international river basins. The advantages of the system consist in the location- and time-related balance of resources and demands under consideration of the operation of storage reservoirs. It allows to take into account diverse water uses and demands in their temporal and spatial variability. Integrating of FORTRAN instructions allows to vary and supplement the standard algorithms of the program system in form of "dynamic elements". Thus, demand functions may be adapted individually, and qualitative or economic parameters, interactions with groundwater or flow-times in the river system may be considered.

The monthly balancing step makes it possible to evaluate the satisfaction of demands both in the annual averages and in the variations during the year. The outputs of the balancing procedure may be exceedance probabilities of events at any point along the river course, durations of events in form of relative frequencies, mean values and mean minima and maxima of monthly streamflow.

The program system is flexible and readily applicable provided the necessary input data are available. Hydrological inputs are externally generated time series of monthly streamflow obtained by statistical analyses of time-coordinated observations. The programs employed for statistical analysis and time-series generation achieved good results for non-intermittent flow processes. Provided intermittent flow processes do not occur in the main river of large basins or in its major tributaries, the programs used in this study are well applicable to the generation of streamflow time series in other climatic regions.

The main problem is the provision of plausible and reliable data describing the anthropogenic impacts on the hydrological system. If the quantification of the effects of storage reservoirs, water transfers, uses and demands relies on generally available data sources, it is necessary to transfer the given data from country scale to basin scale by means of Geographic Information Systems (GIS).

8 Outlook

Balancing water availability and water demands under consideration of storage-reservoir operation at selected points in a river system allows to identify surplus and deficit of water resources in this basin, regarding the potential reliability of supplies and makes it possible to assess potential risks with view to the satisfaction of the demands of diverse water uses.

Provided the time series of hydrological input parameters in form of monthly means were generated and the water uses and demands in the river basin were identified and quantified, the presented methodology of balancing water availability, uses, and demands is applicable in its set-up to other large international river basins as well. Adaptations and specifications as to regional features can be considered already in model development, but may also be integrated as supplements in later scenario computations.

The application range is in particular the risk assessment of water availability at river-basin level and the possibility of scenario computations. For an application in the sense of a "rapid assessment" at regional level within the scope of international programmes, the presented methodology has to be formalized by pre-defining separate working steps and, in parallel, adapted in detail to specific regional features, such as a basin-related quantification of water consumption or the defining of characteristic quantities for the consideration of water quality parameters.

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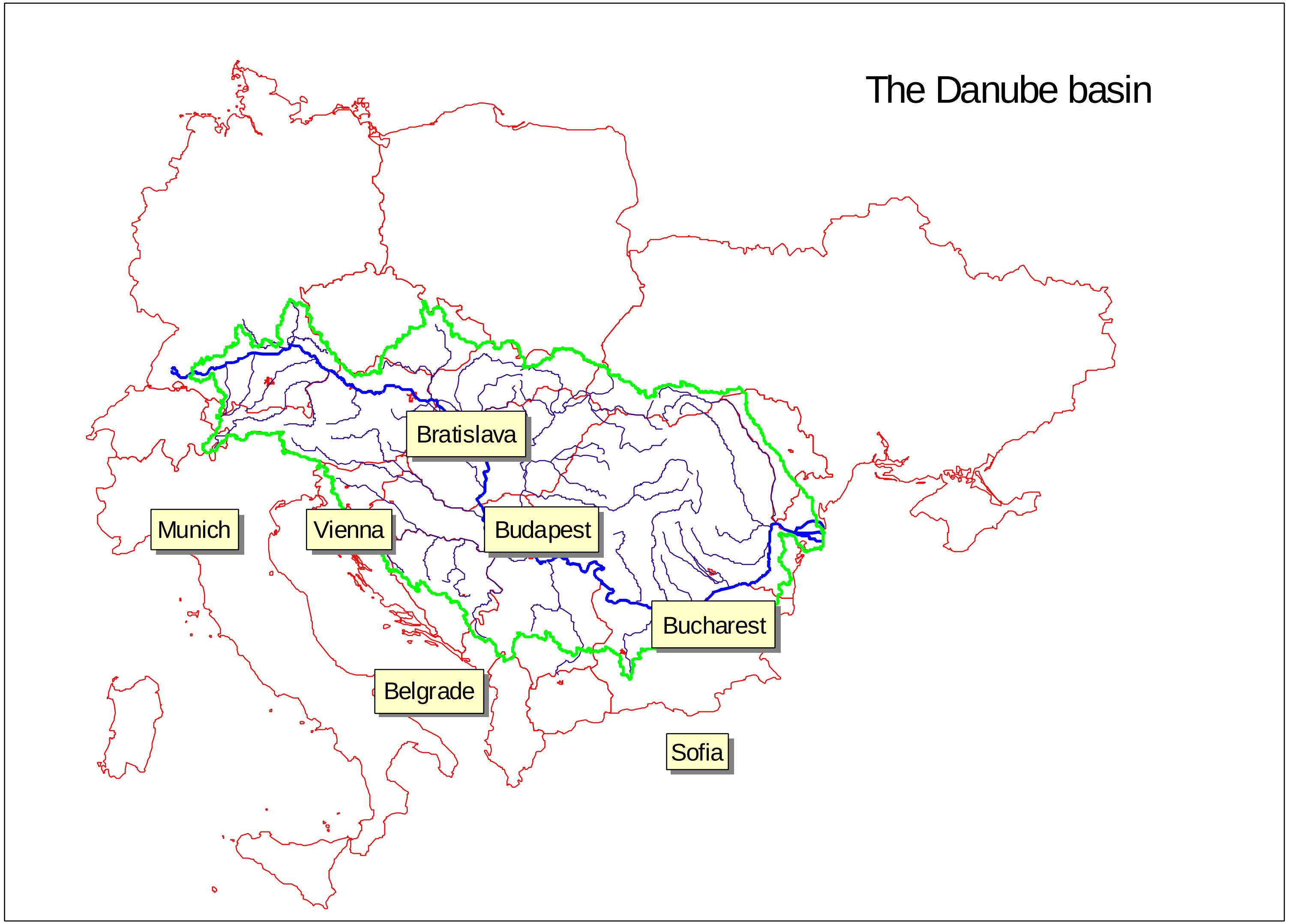

The Danube basin
Munich
Vienna
Bratislava
Budapest
Belgrade
Bucharest
Sofia

Figure 2: Long-term mean streamflow along the River Danube

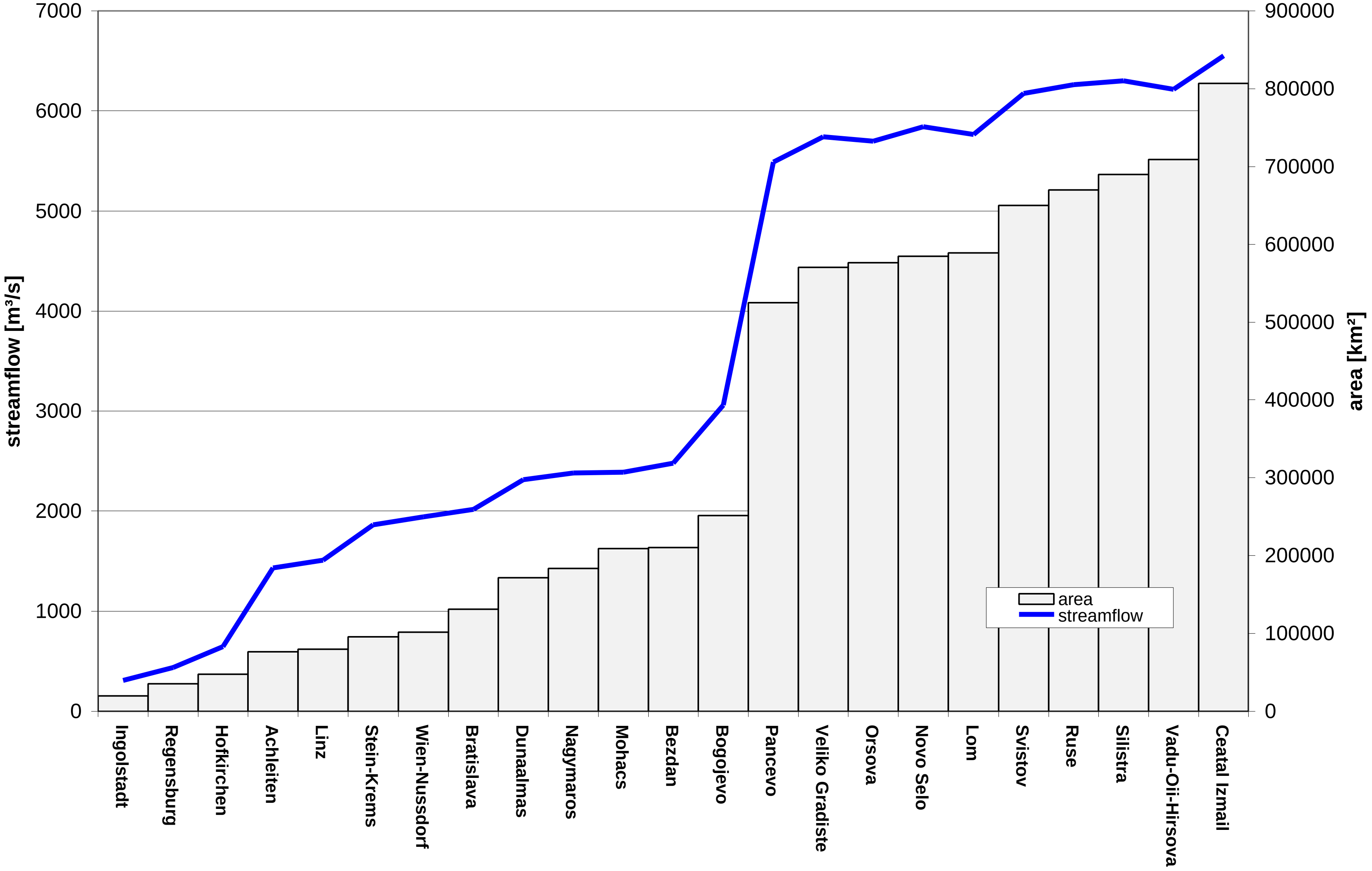


Figure 3: **Mean streamflow at major gauges on the River Danube**

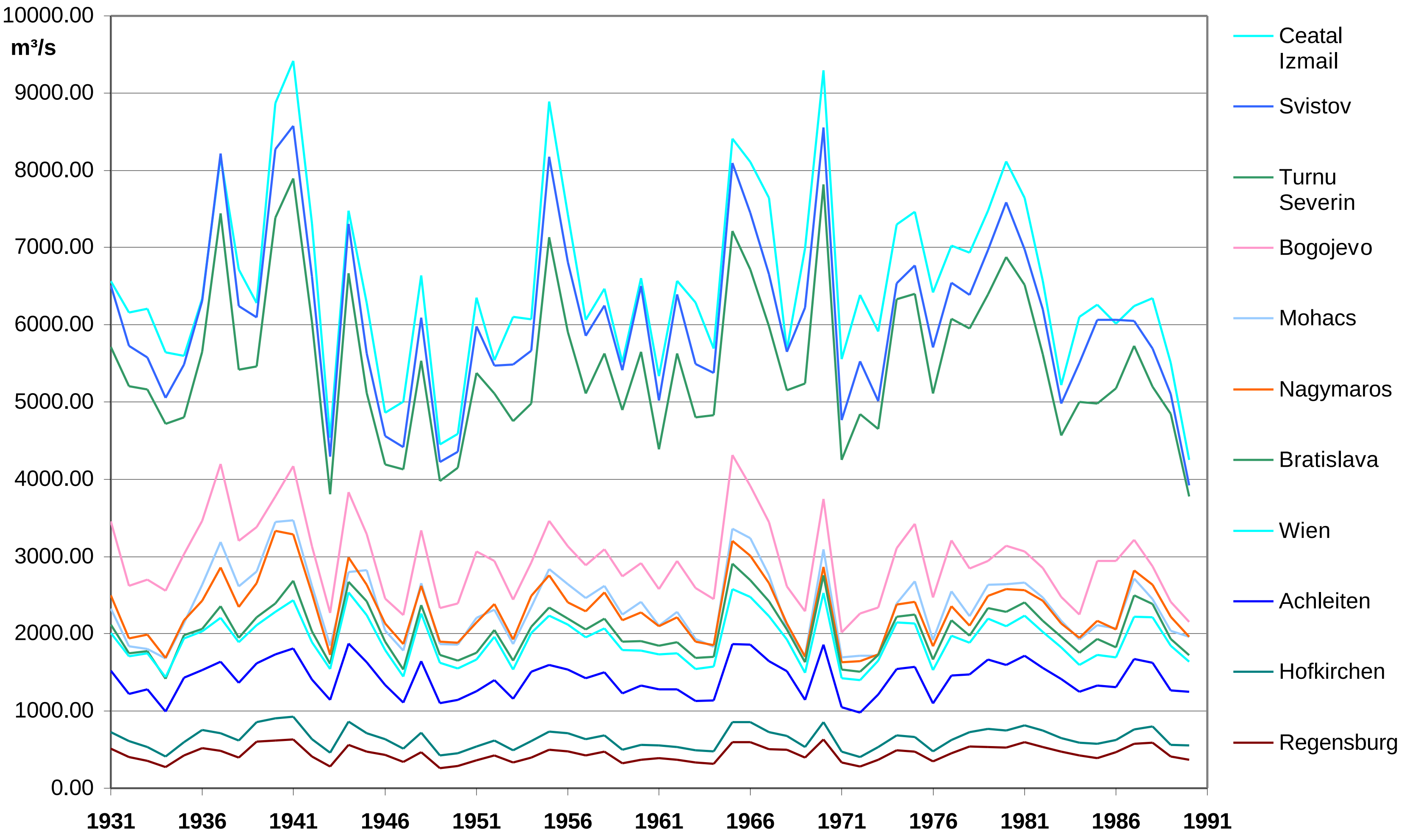


Figure 4: **The main tributaries to the River Danube**

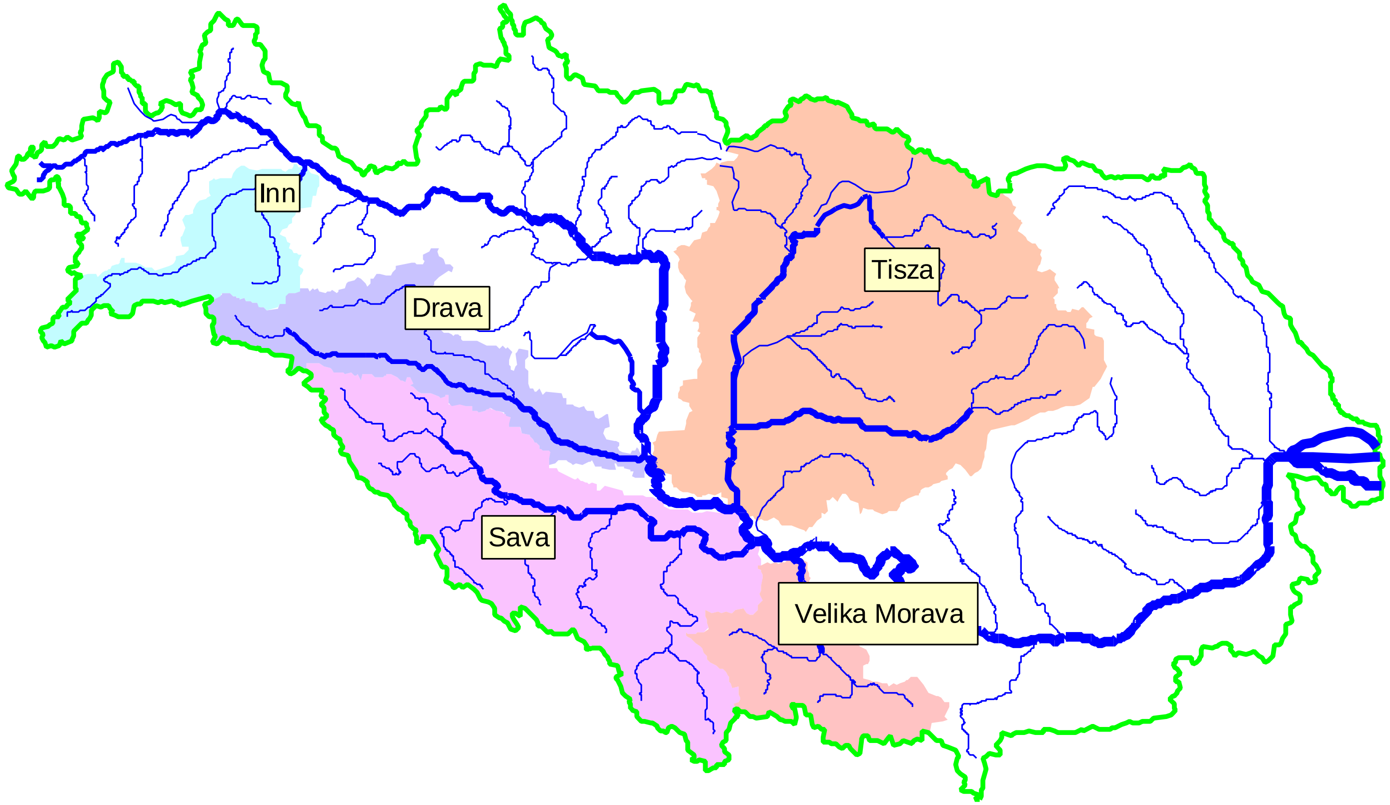


Figure 5a: Mean streamflow 1931-1990

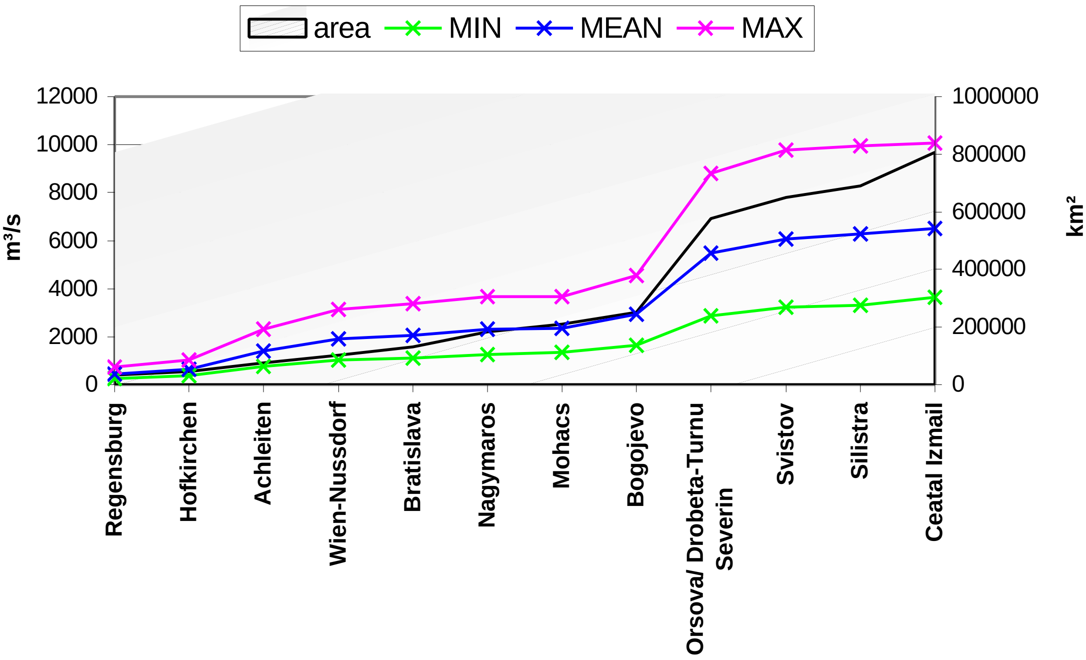


Figure 5b: Mean discharge per unit area 1931-1990

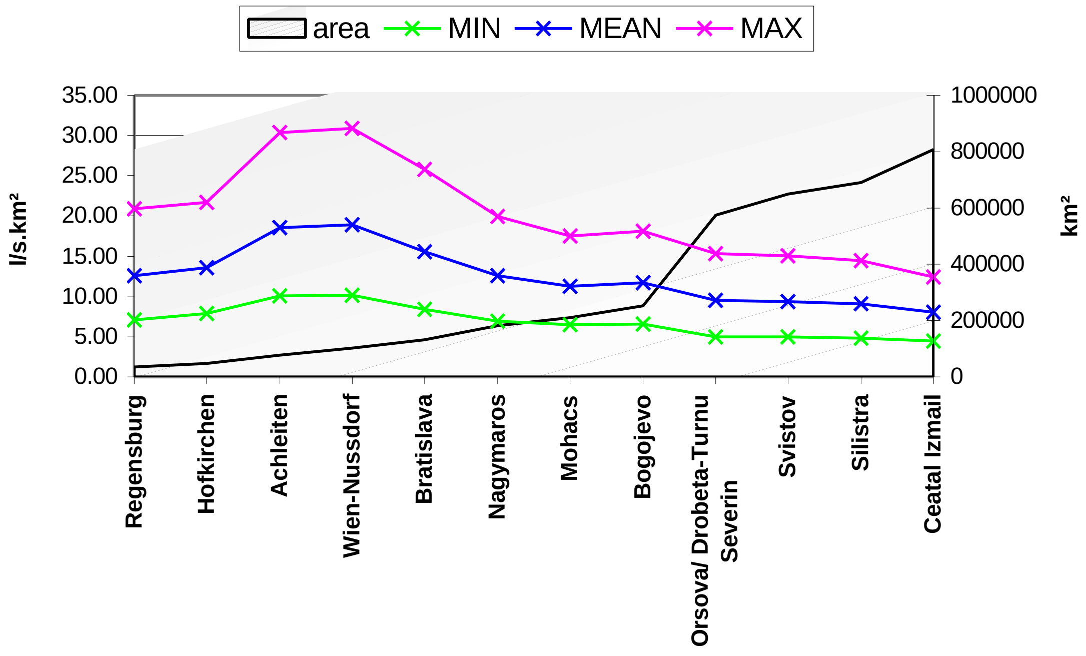


Figure 6: States sharing the Danube basin

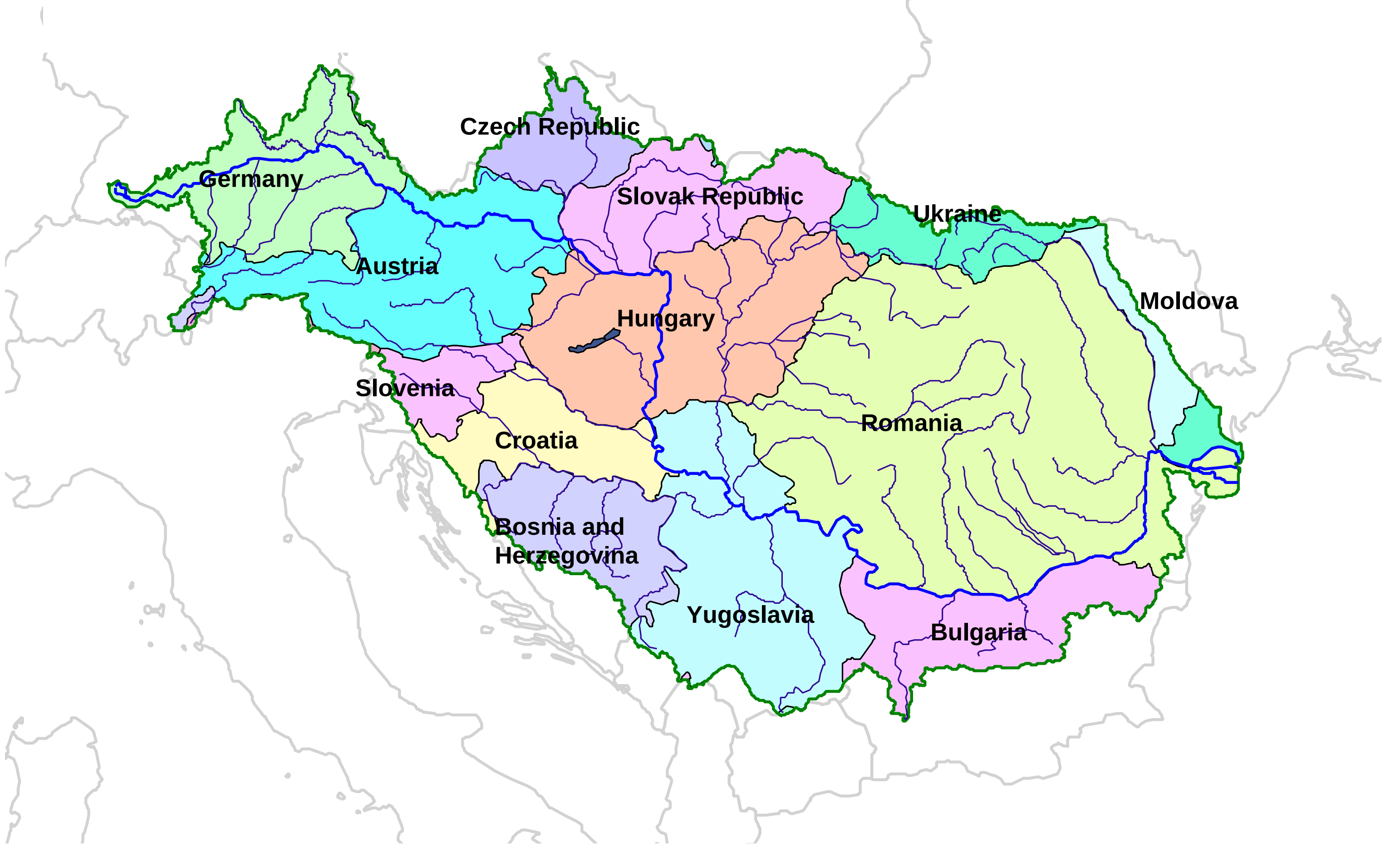
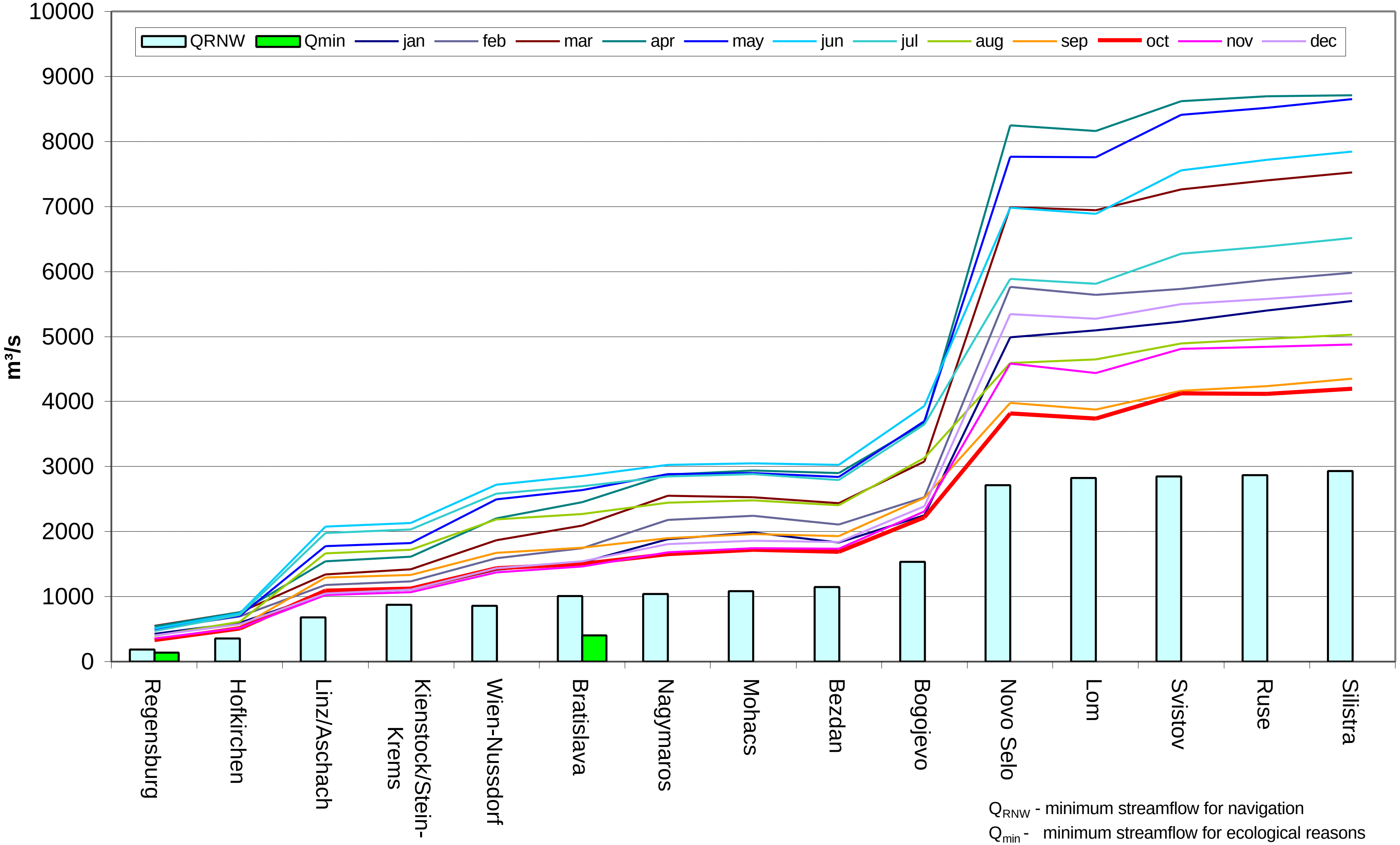


Figure 7:
Observed mean monthly streamflow versus required minimum streamflow along the River Danube



Q_{RNW} - minimum streamflow for navigation
Q_{min} - minimum streamflow for ecological reasons

Figure 8: Danube basin with selected gauging stations

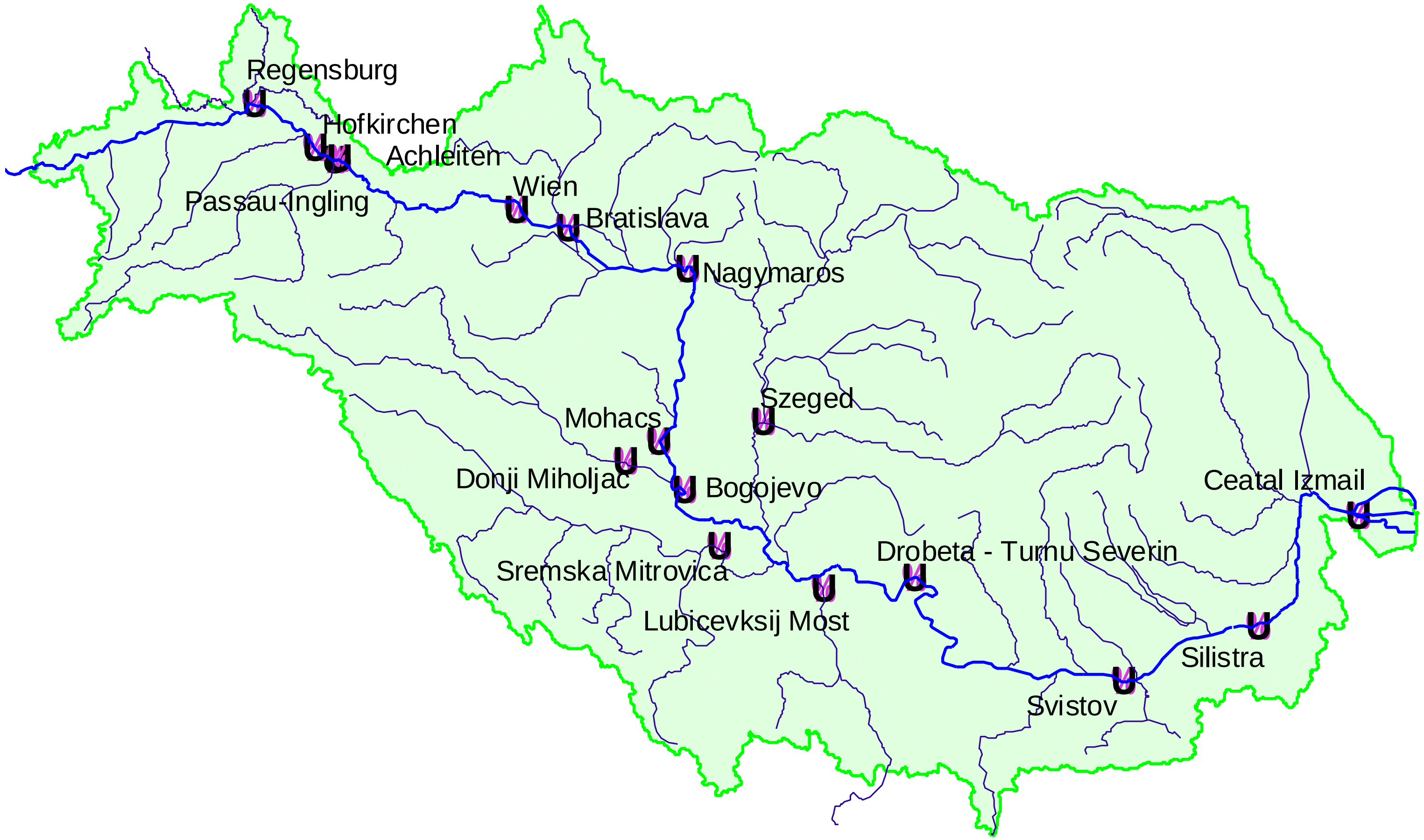


Figure 9a:
Length of time series of mean monthly streamflow data of the River Danube available at GRDC

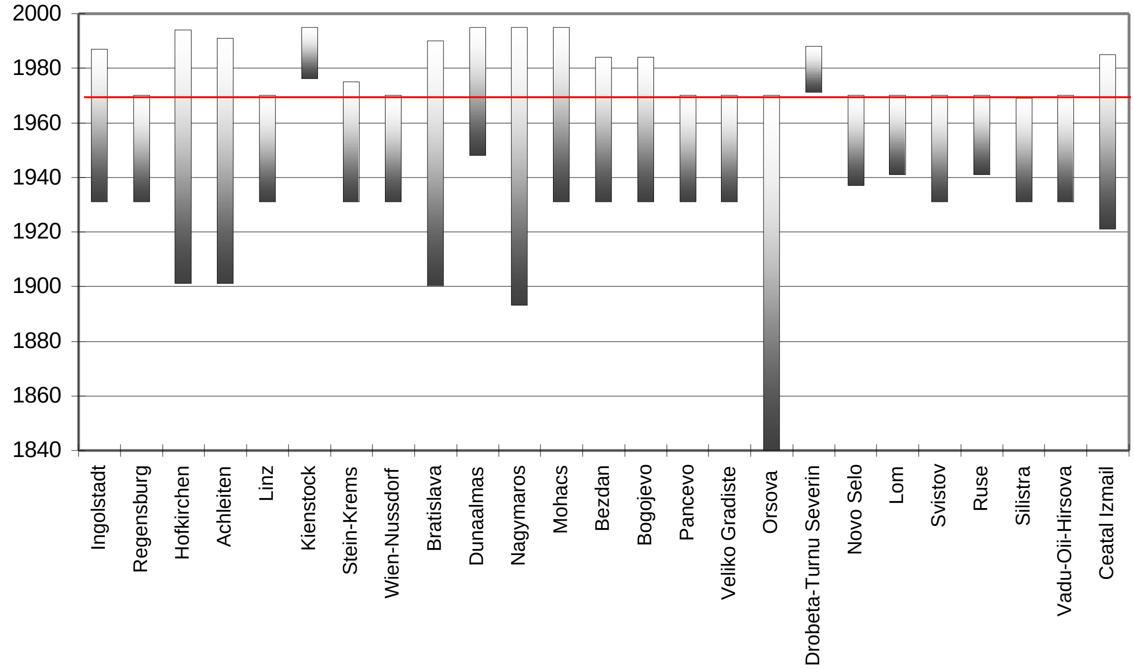


Figure 9b:
Length of completed time series of mean monthly streamflow data of the River Danube

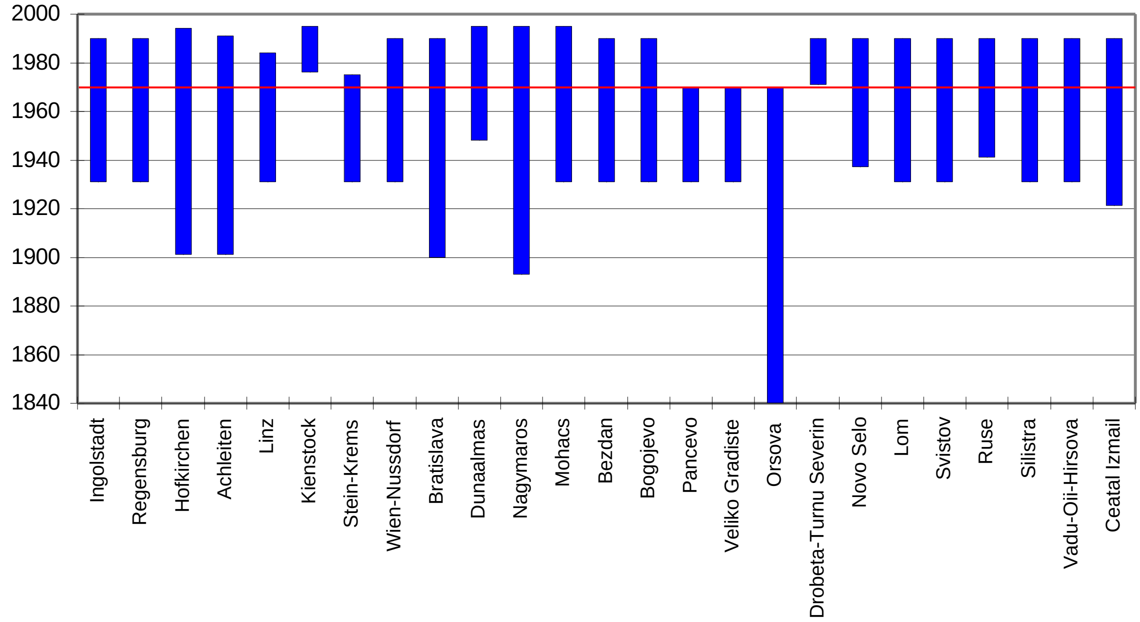
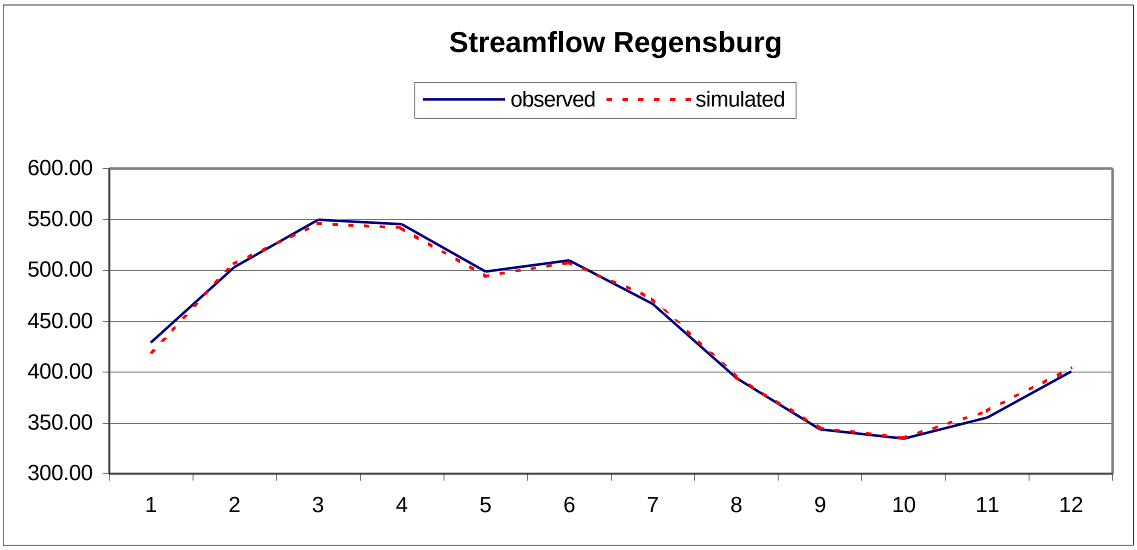
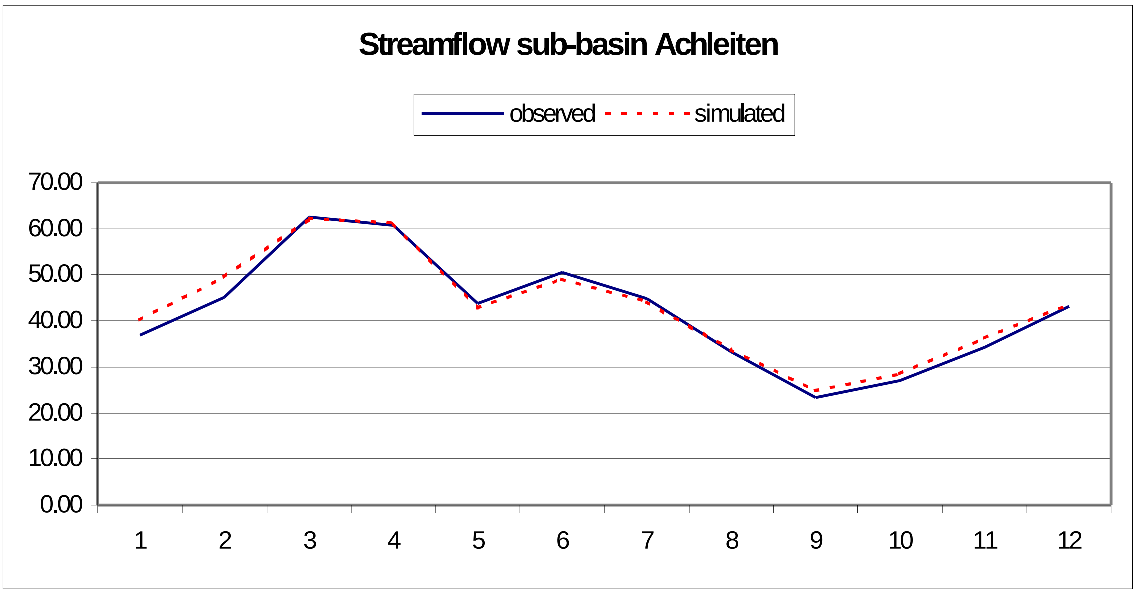


Figure 10 a-c: Comparison of simulated and observed monthly streamflow





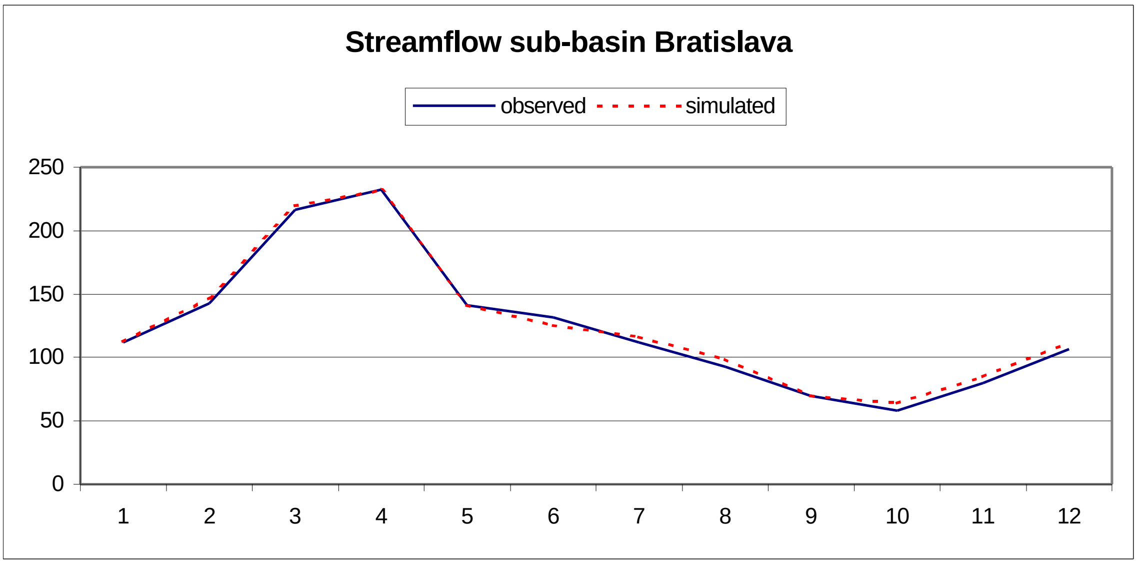
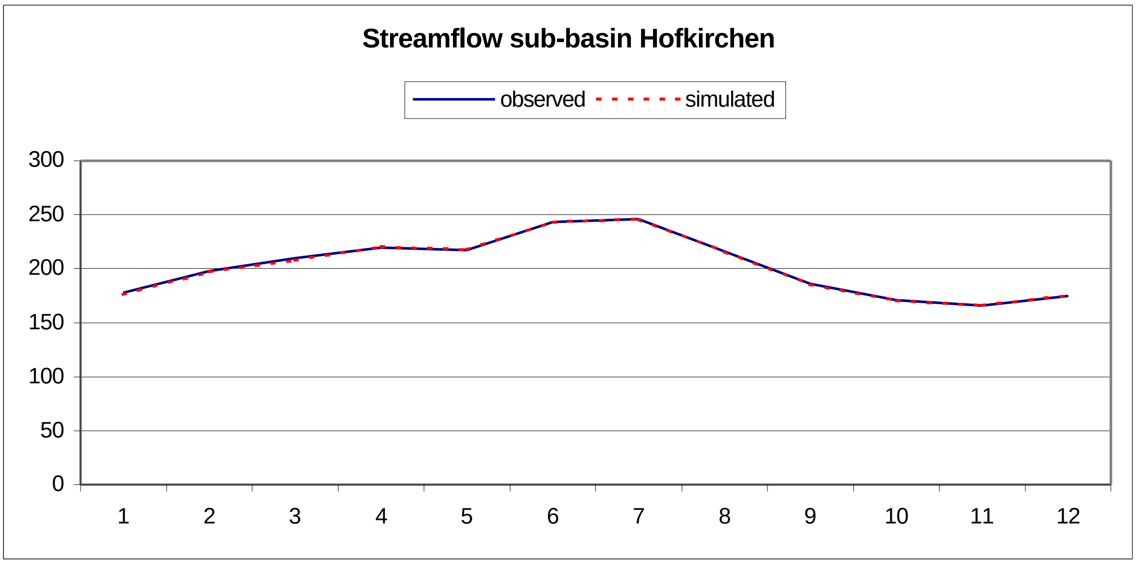
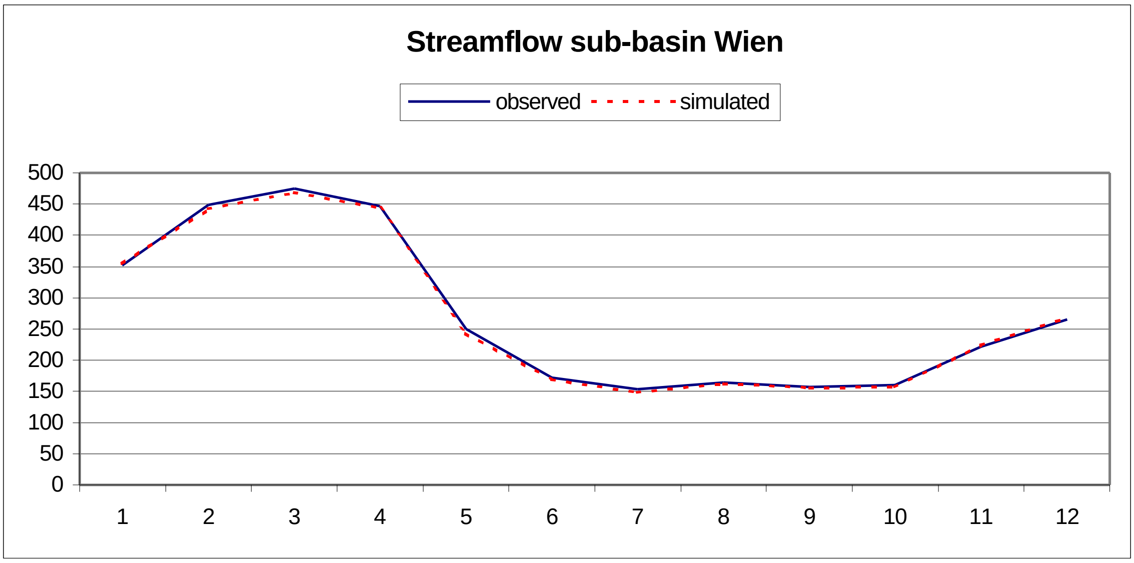


Figure 10 d-f: Comparison of simulated and observed monthly streamflow





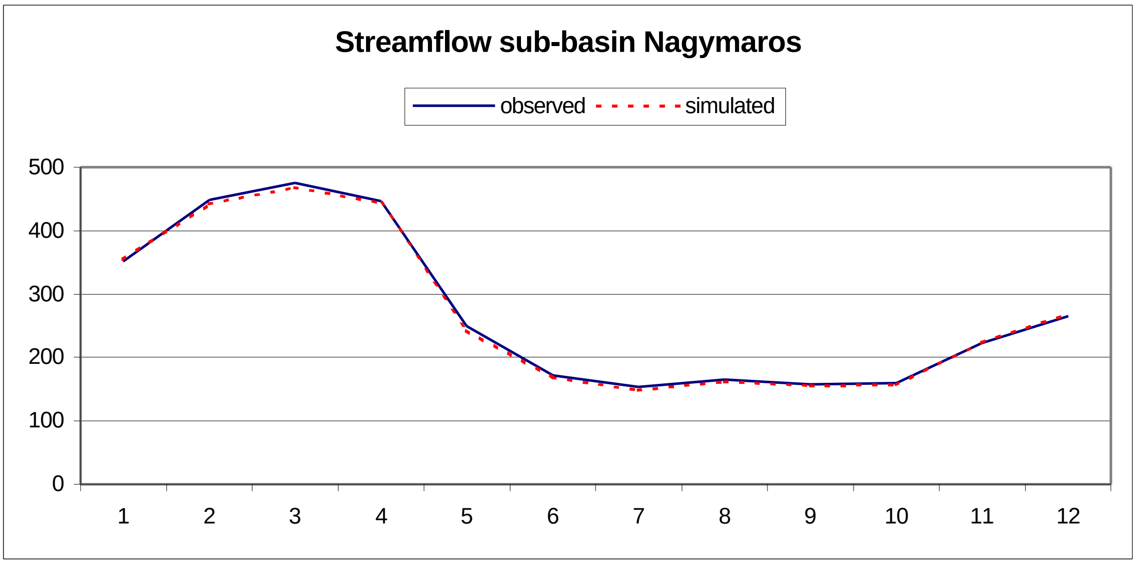
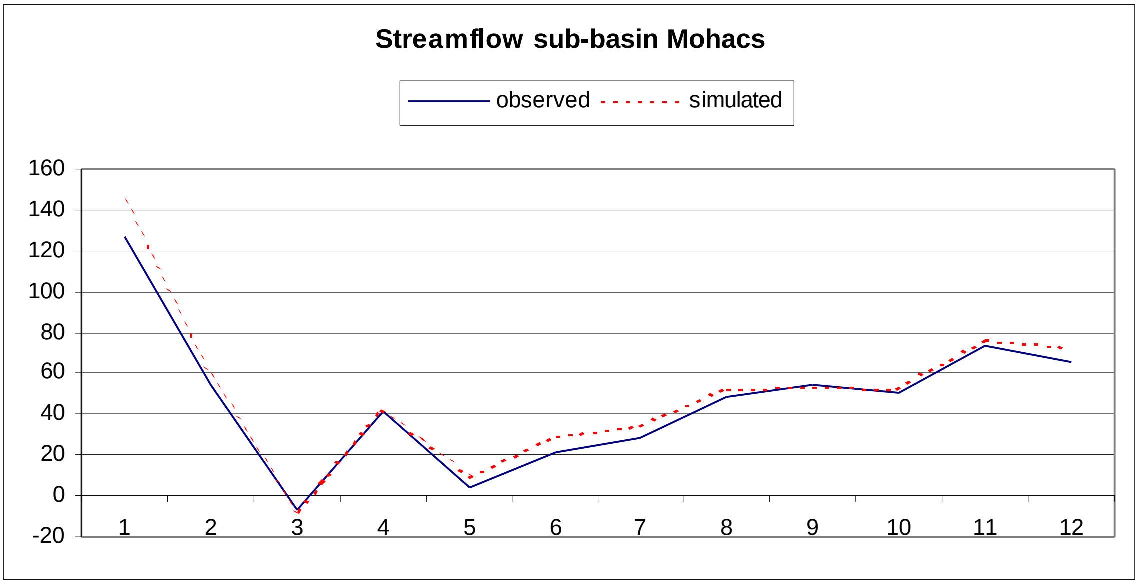
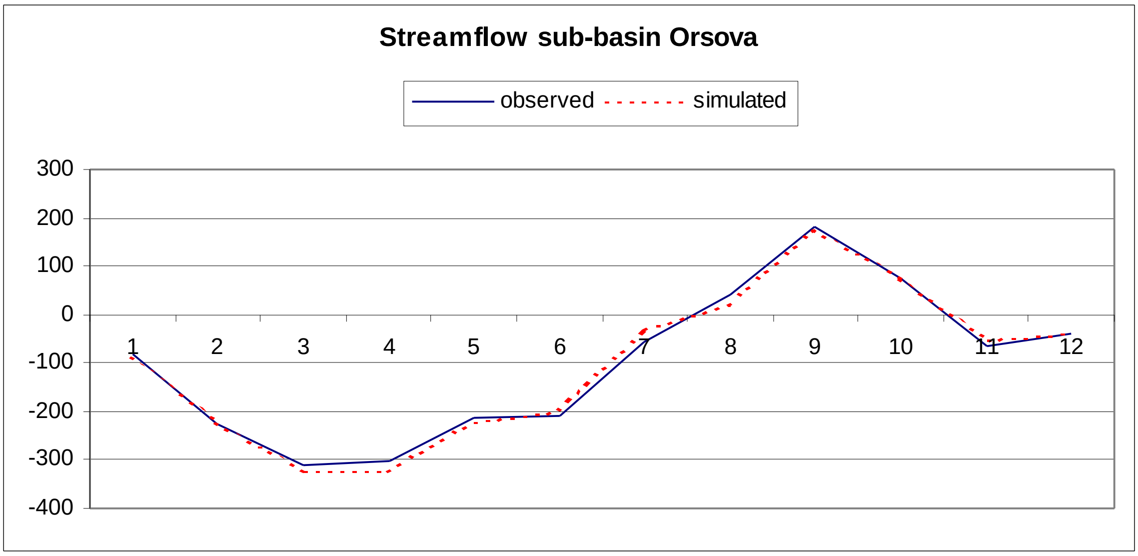


Figure 10 g-i: Comparison of simulated and observed monthly streamflow





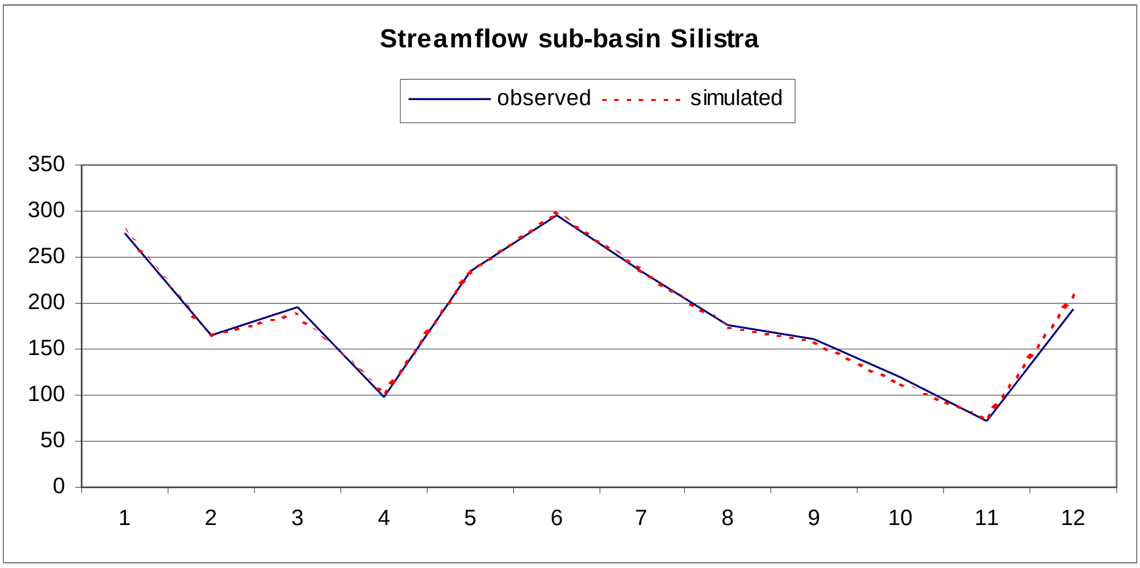
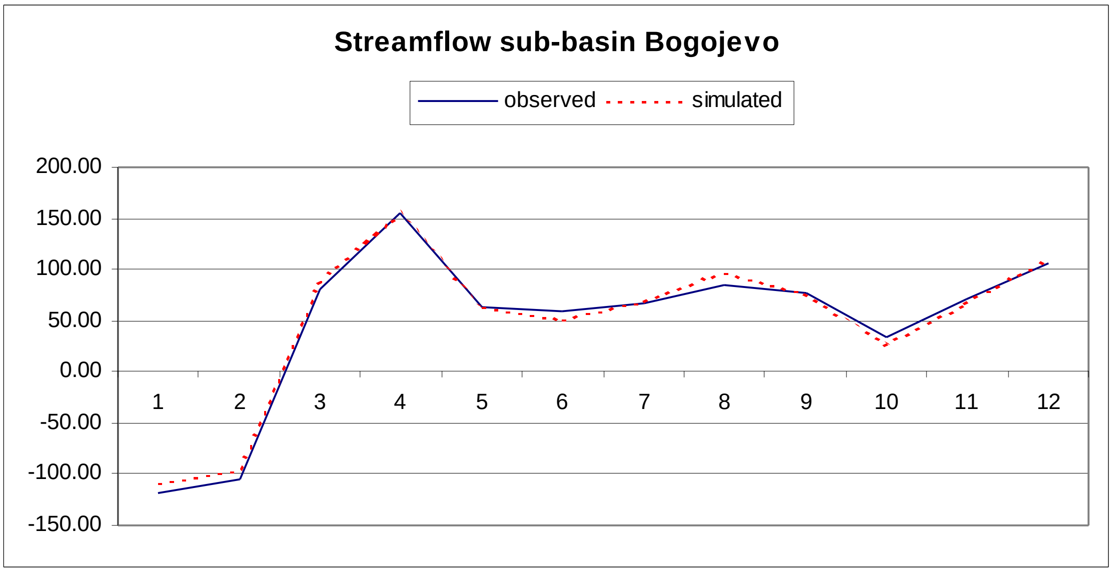
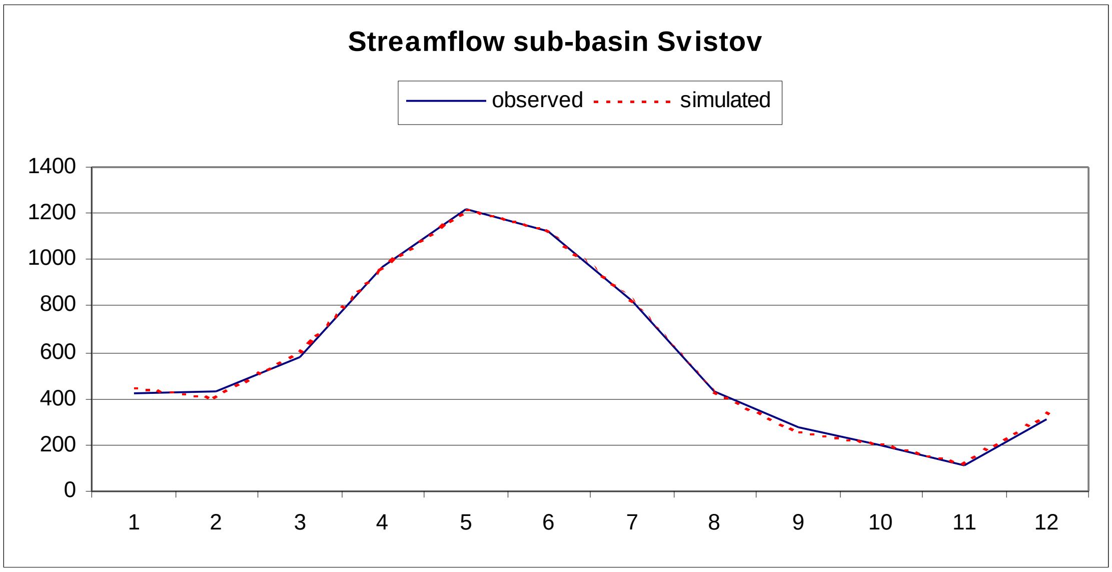


Figure 10 j-l: Comparison of simulated and observed monthly streamflow





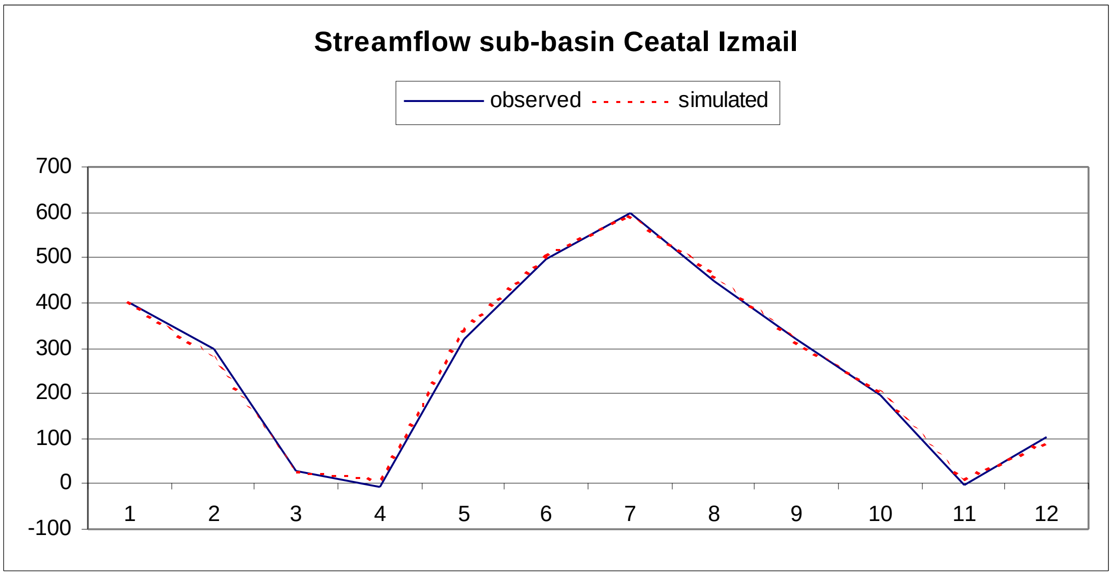
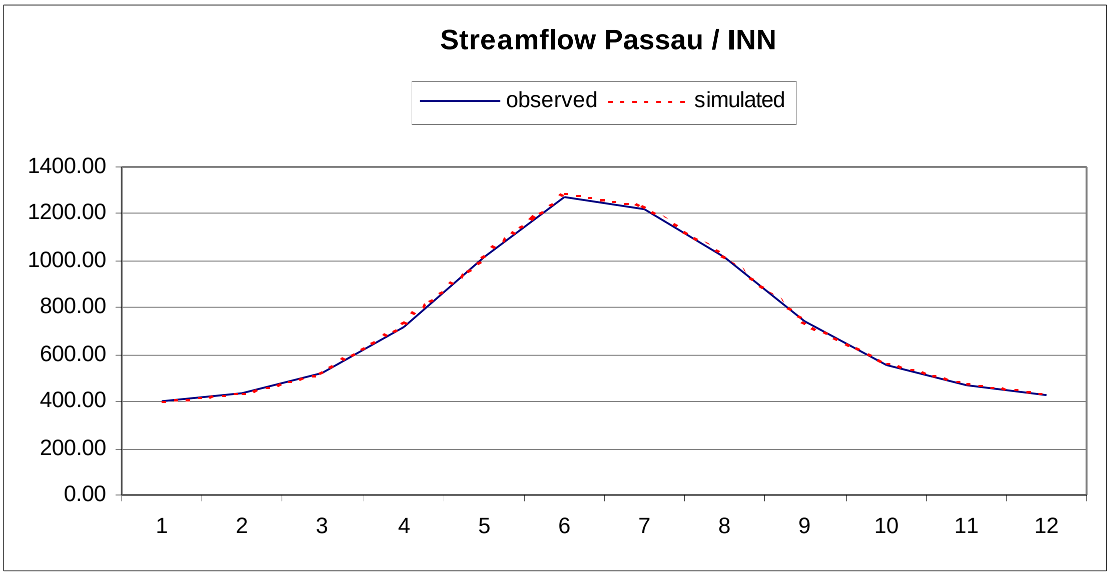
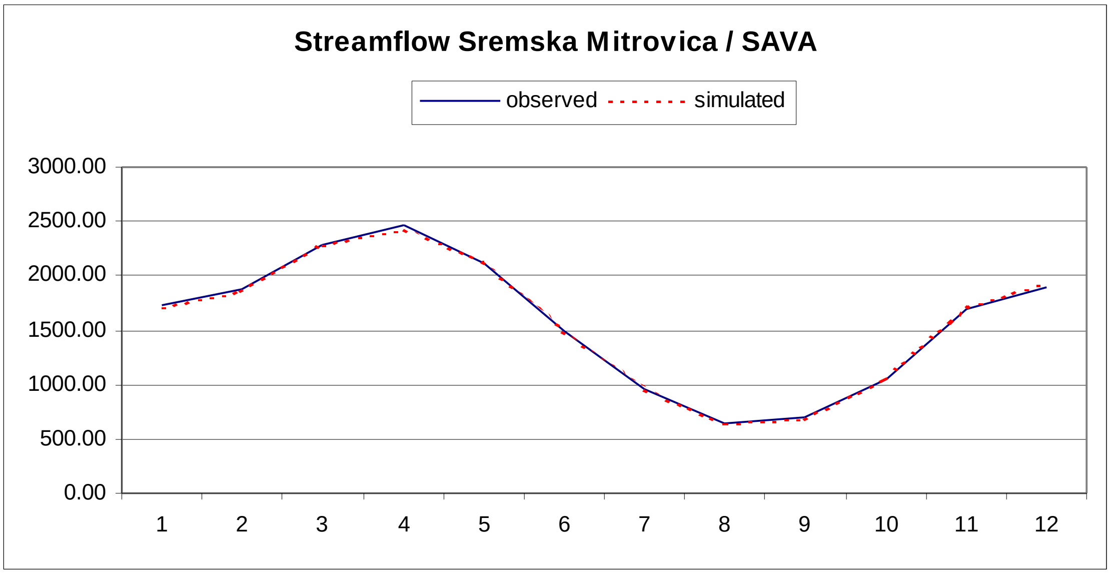


Figure 10 m-o: Comparison of simulated and observed monthly streamflow





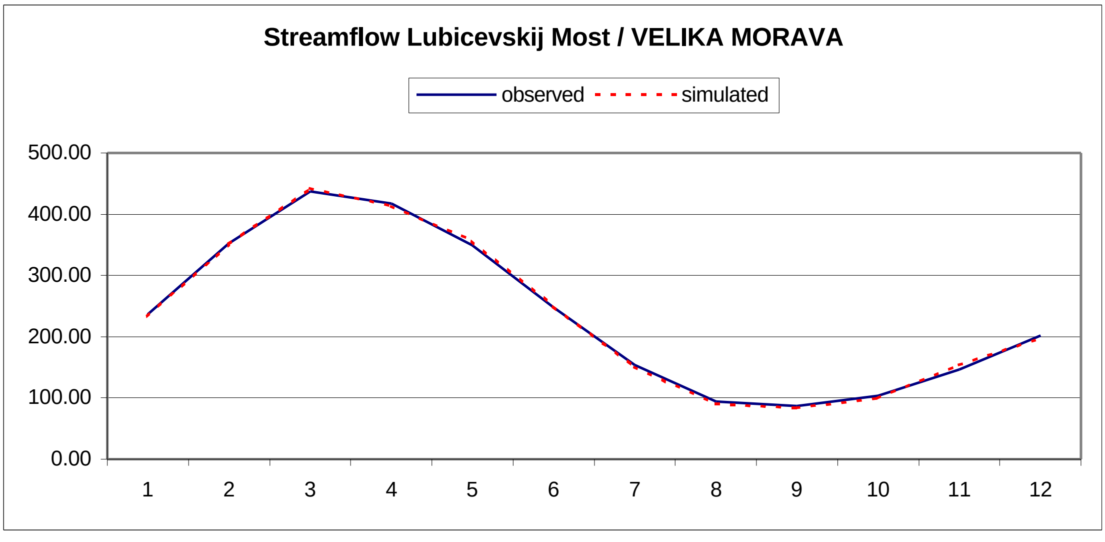
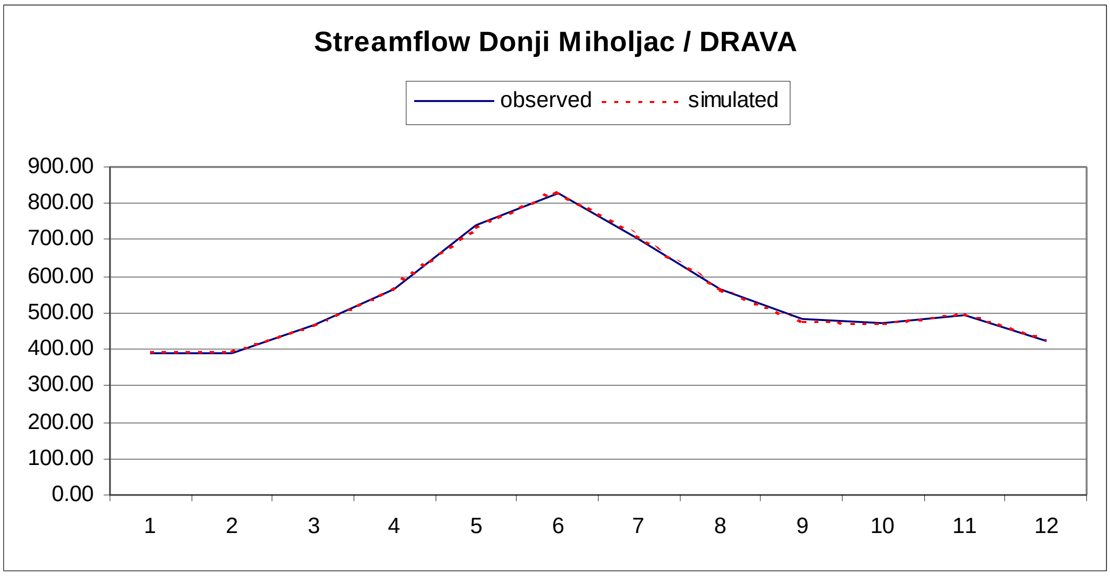


Figure 10 p-q: Comparison of simulated and observed monthly streamflow



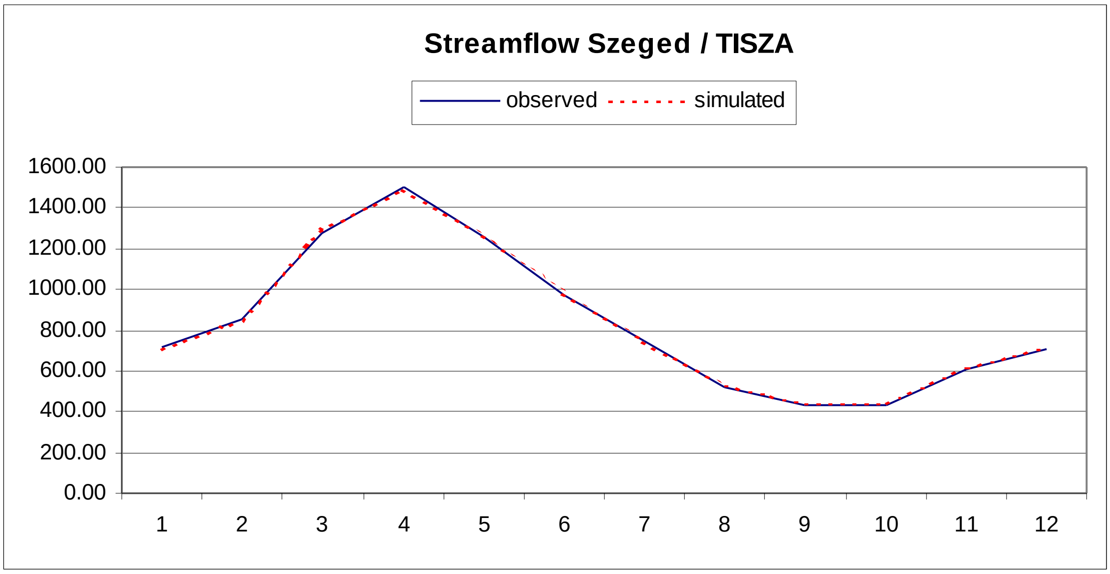


Figure 11: Permanent storage reservoir (without weir impoundments) in the Danube basin*

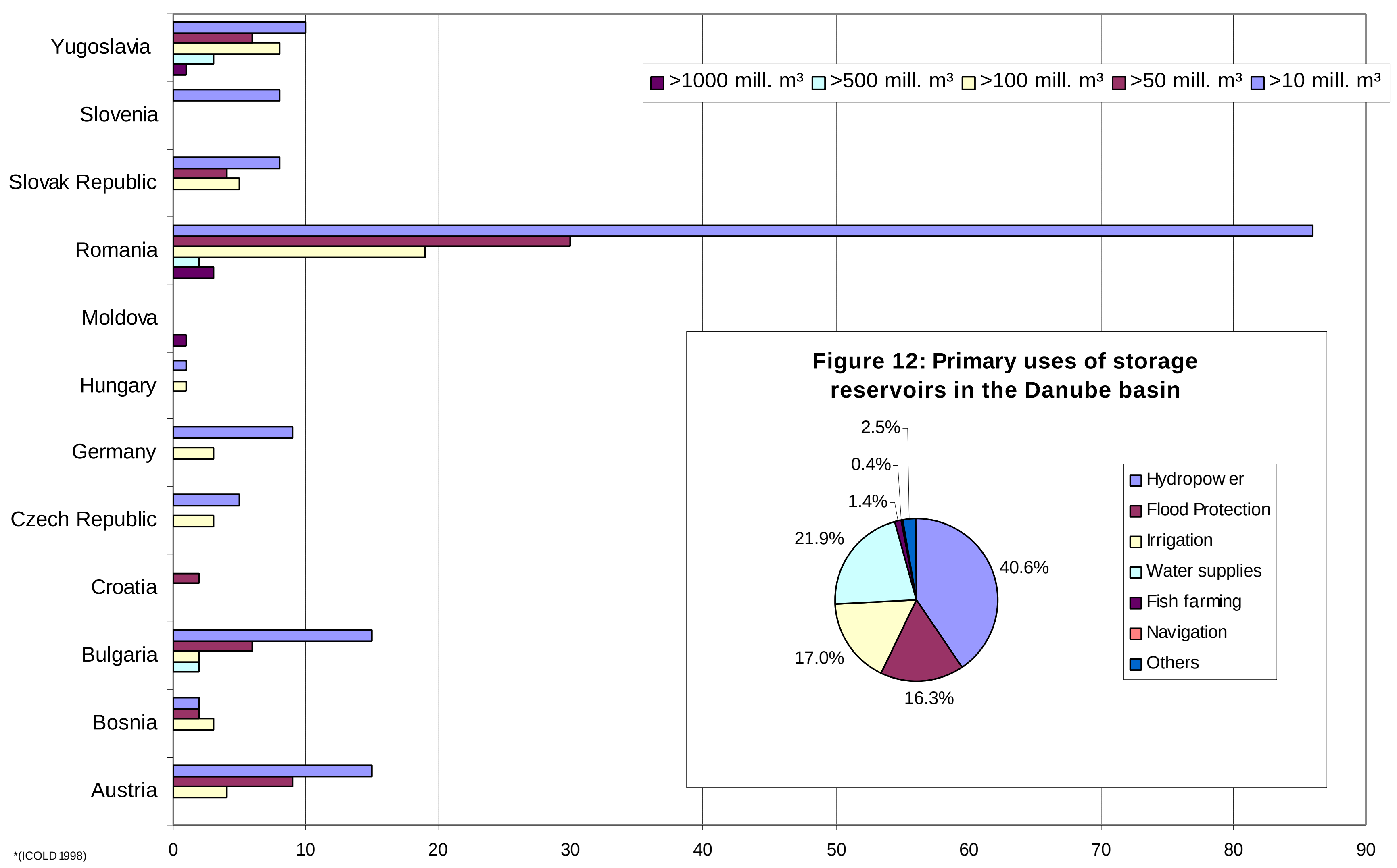
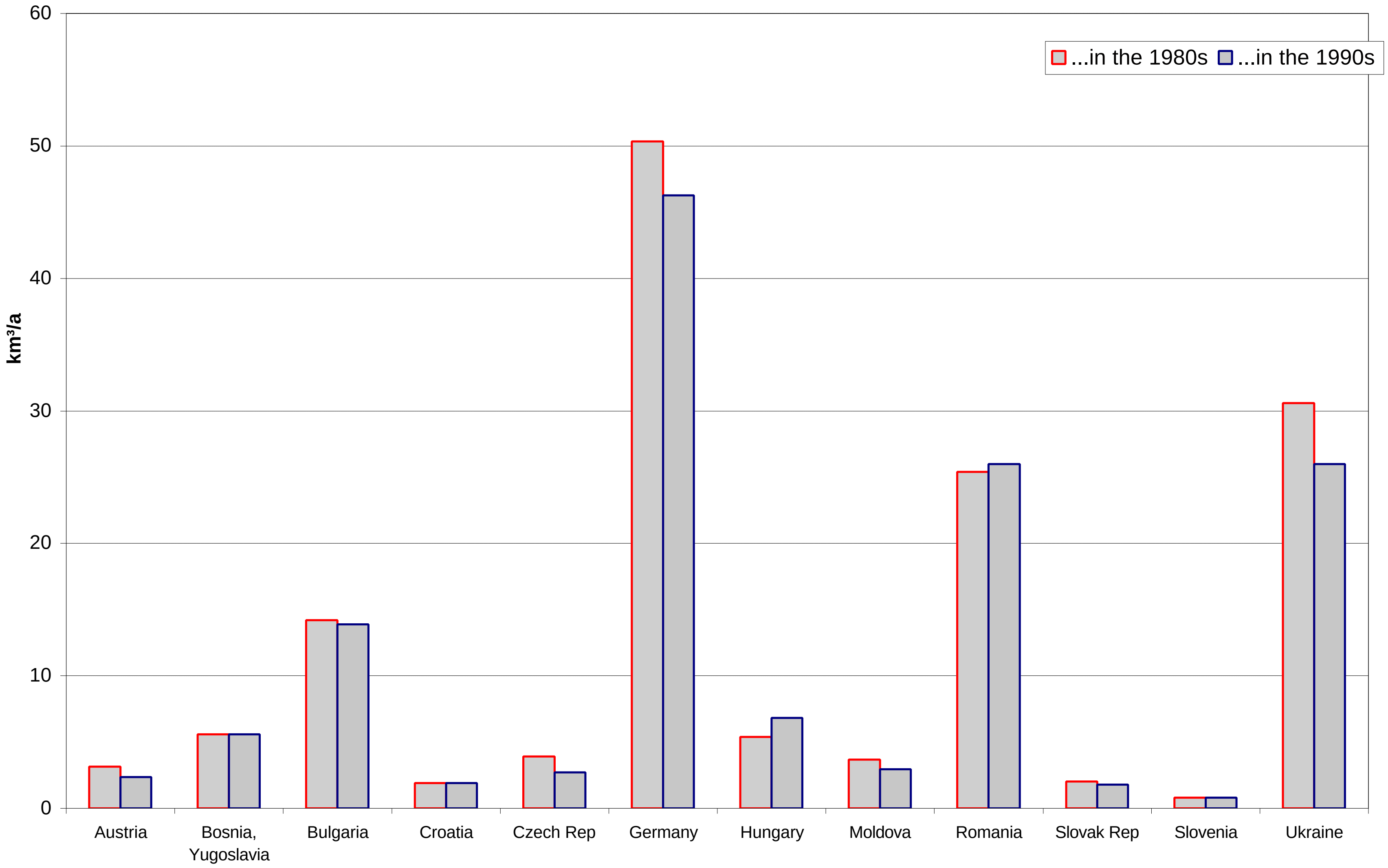


Figure 12: Primary uses of storage reservoirs in the Danube basin

*(ICOLD 1998)

Figure 13: Total annual withdrawal of countries in the Danube basin



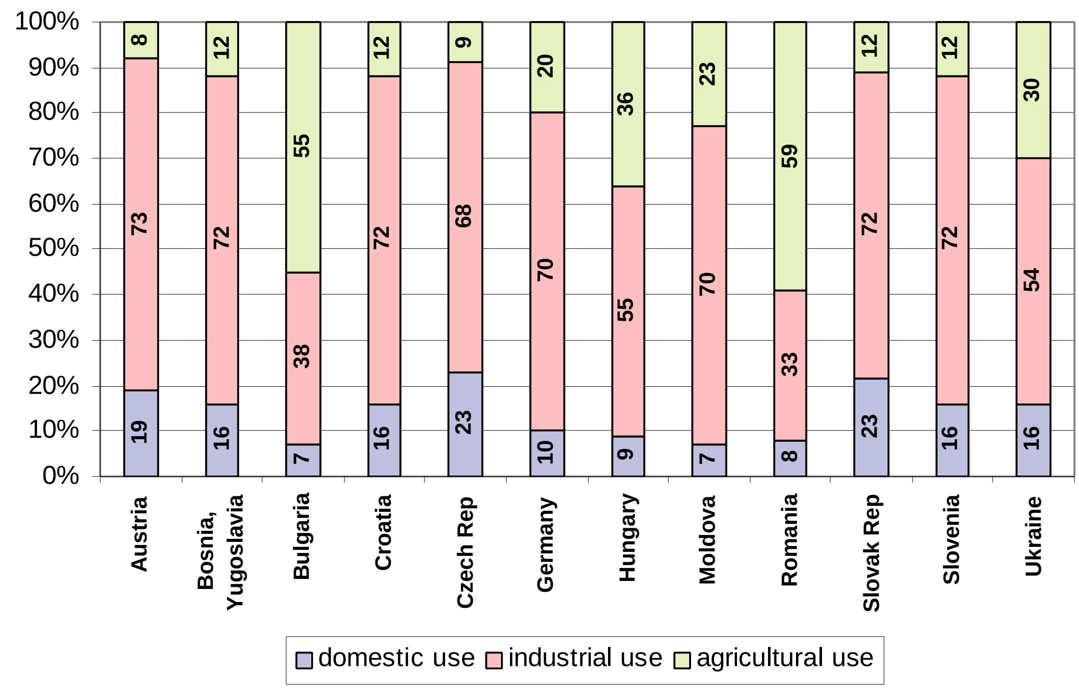


Figure 14a: Percentages in water withdrawal in the 1980s

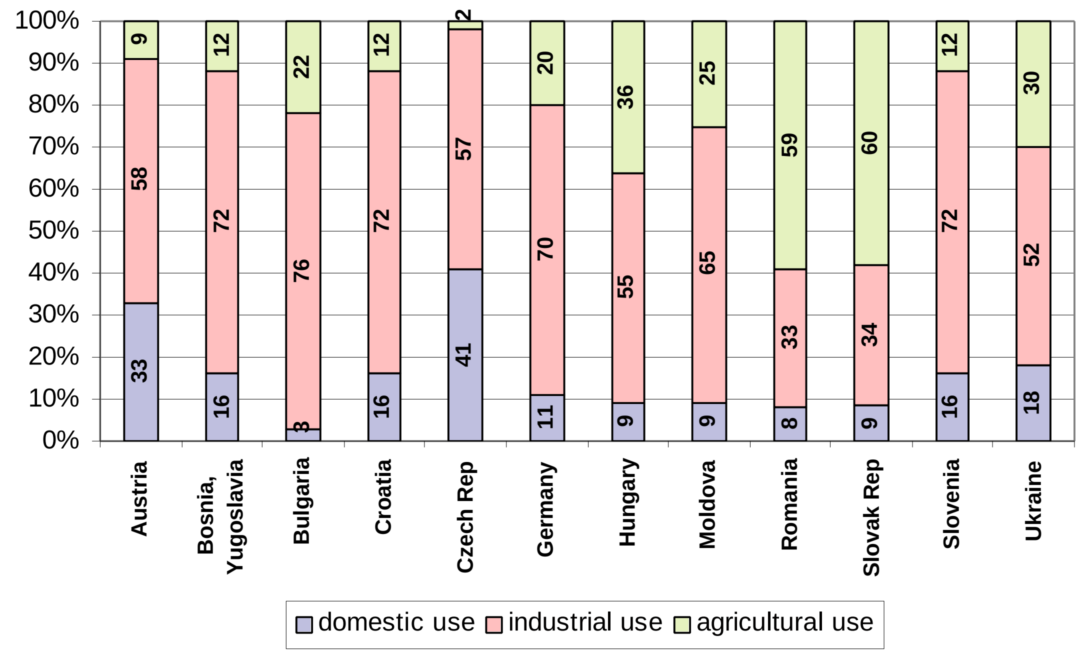
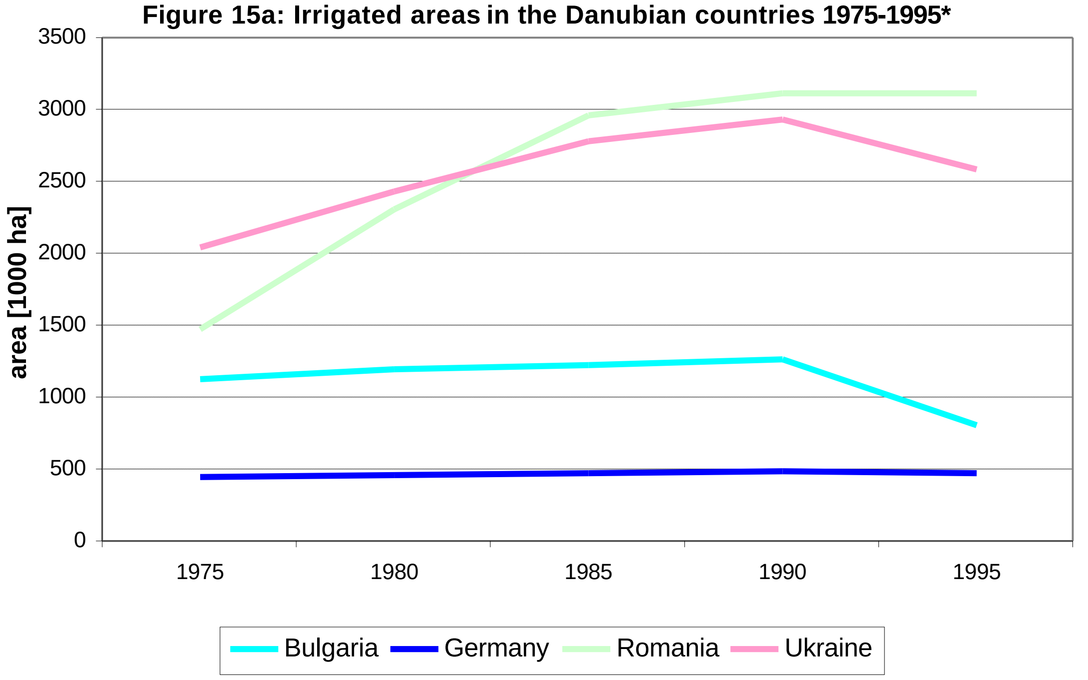


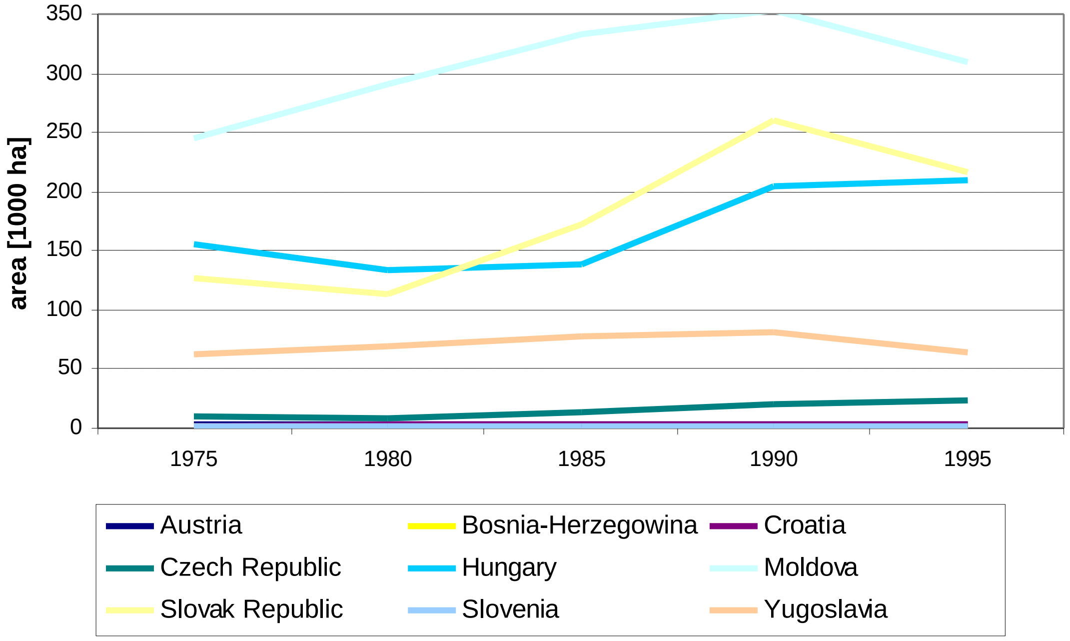
Figure 14b: Percentages in water withdrawal in the 1990s

Figure 15a: Irrigated areas in the Danubian countries 1975-1995*



* FAOstat 1999

Figure 15b: Irrigated areas in the Danubian countries 1975-1995*



* FAOstat 1999

Figure 16: Changes in water consumption for irrigation in the Danube basin between the 1980s and the 1990s

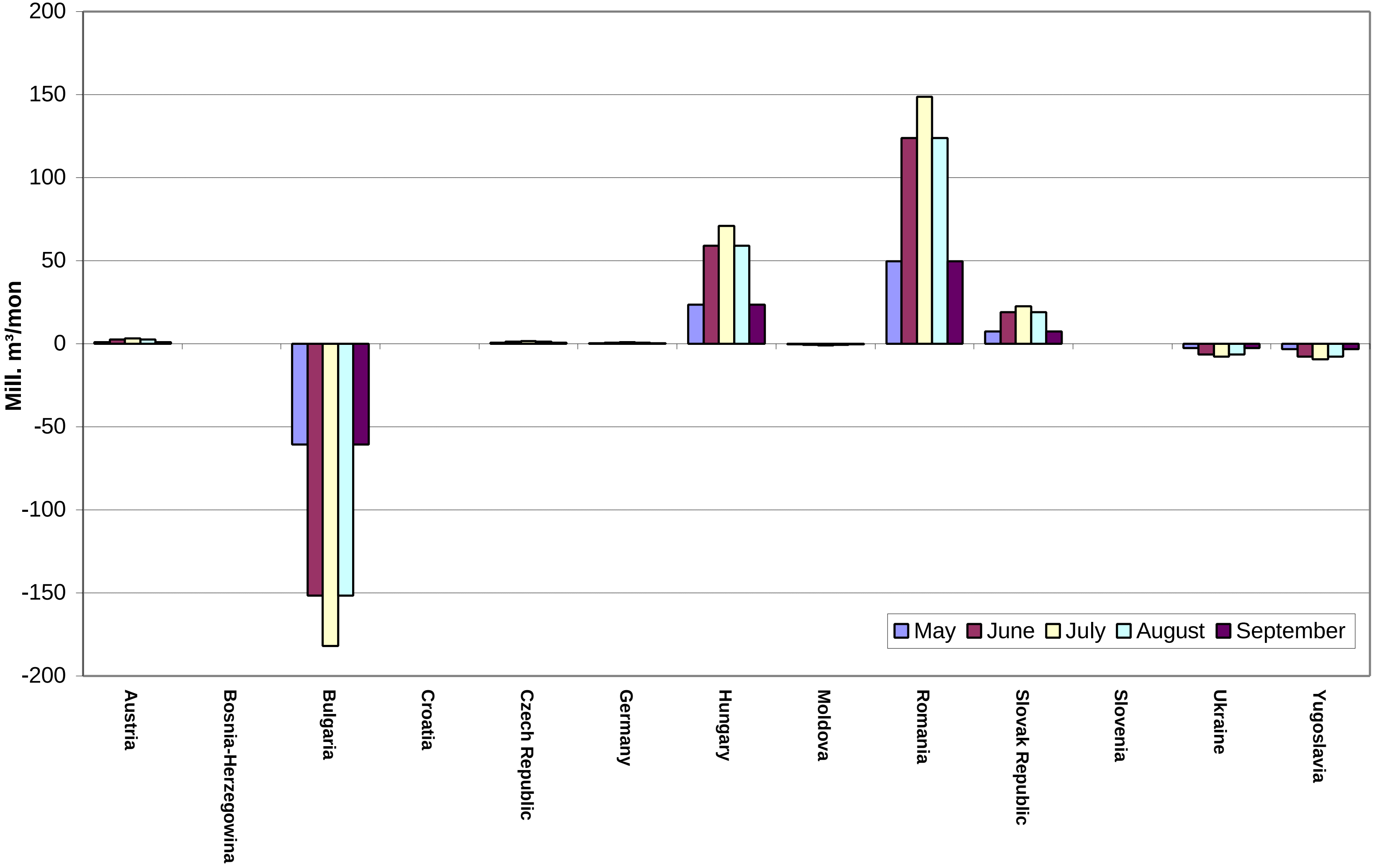


Figure 17: River network with balancing points

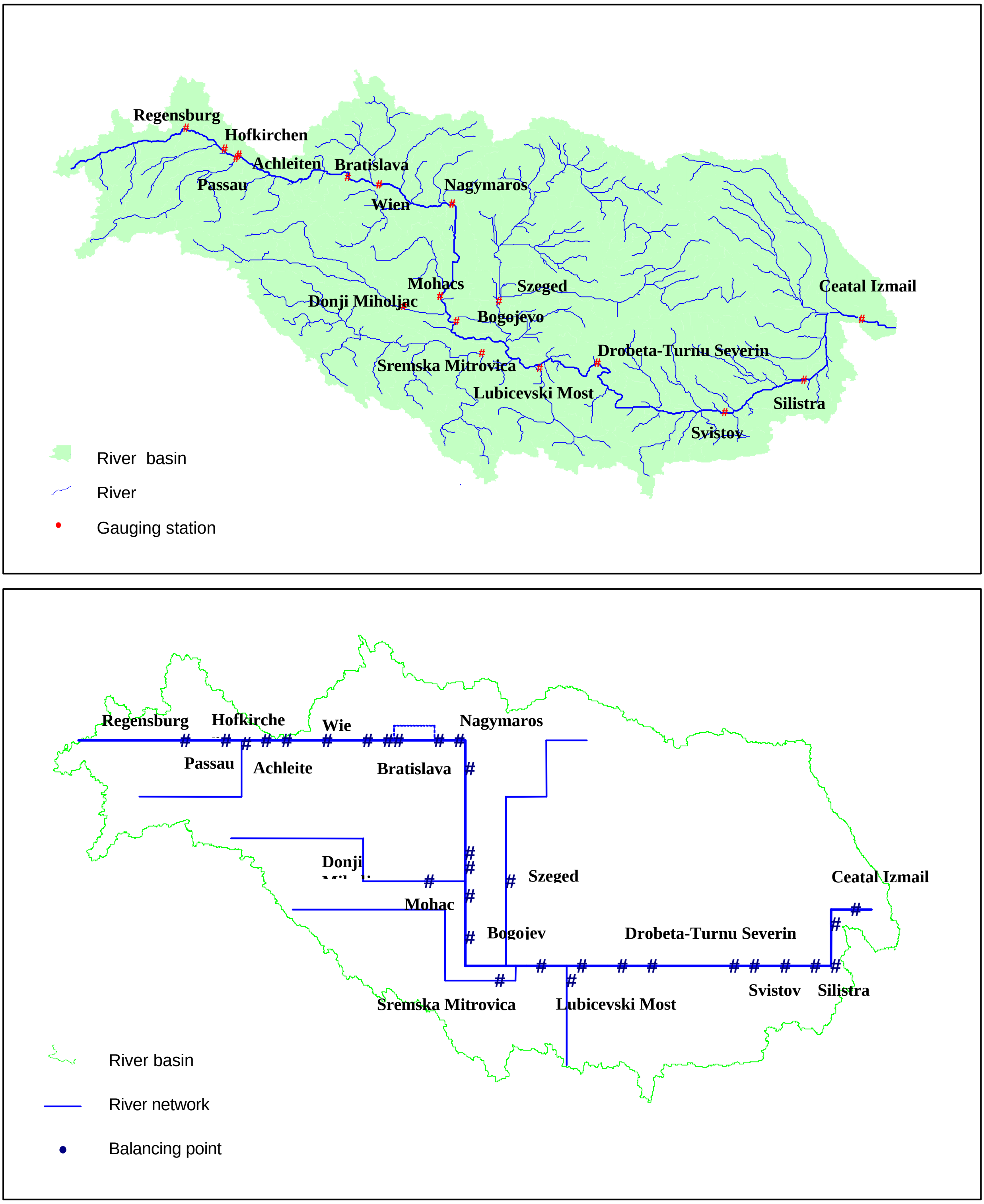


Figure 18: Gauge-related sub-basins

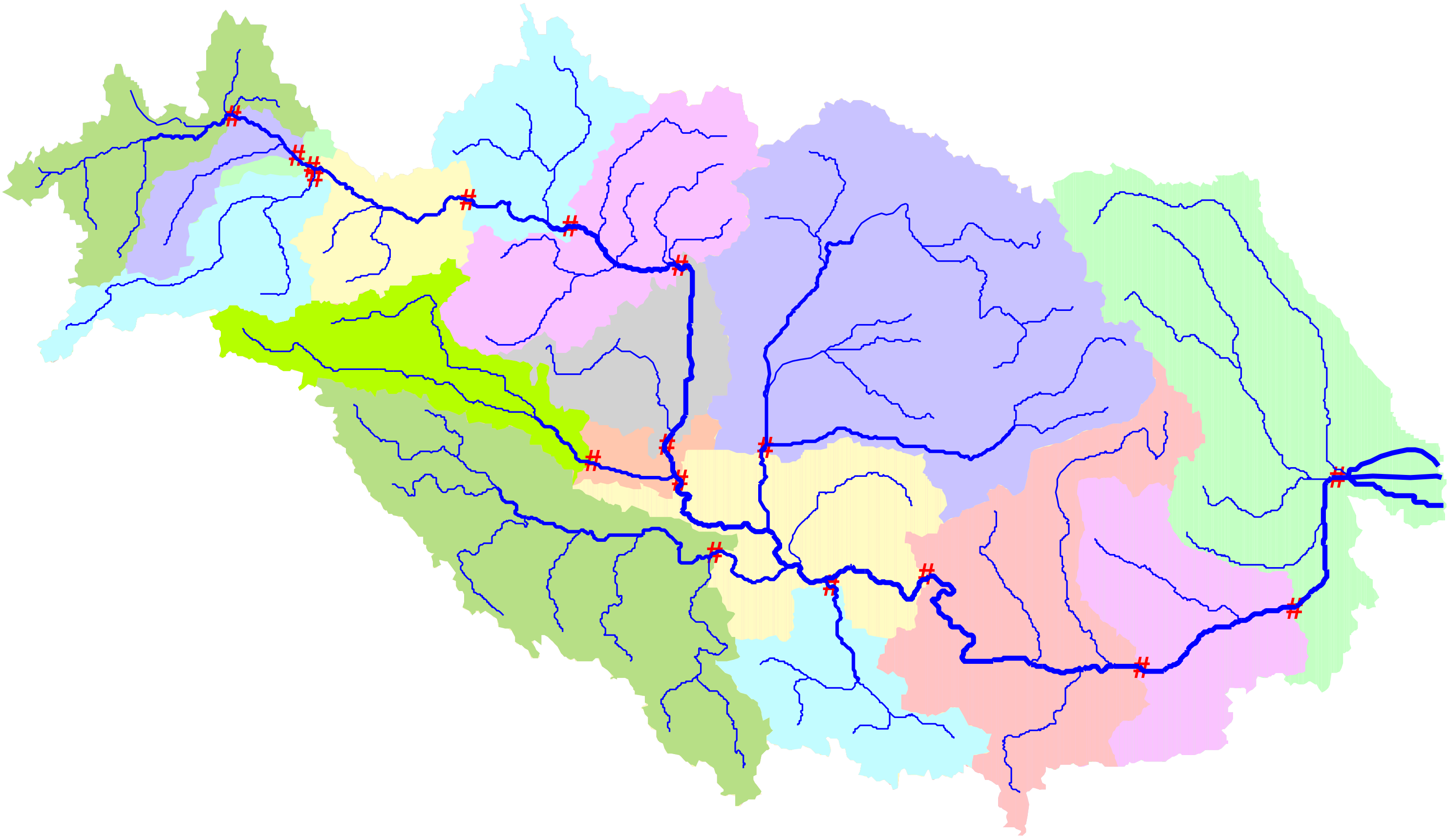


Figure 19: Simulated sub-basins

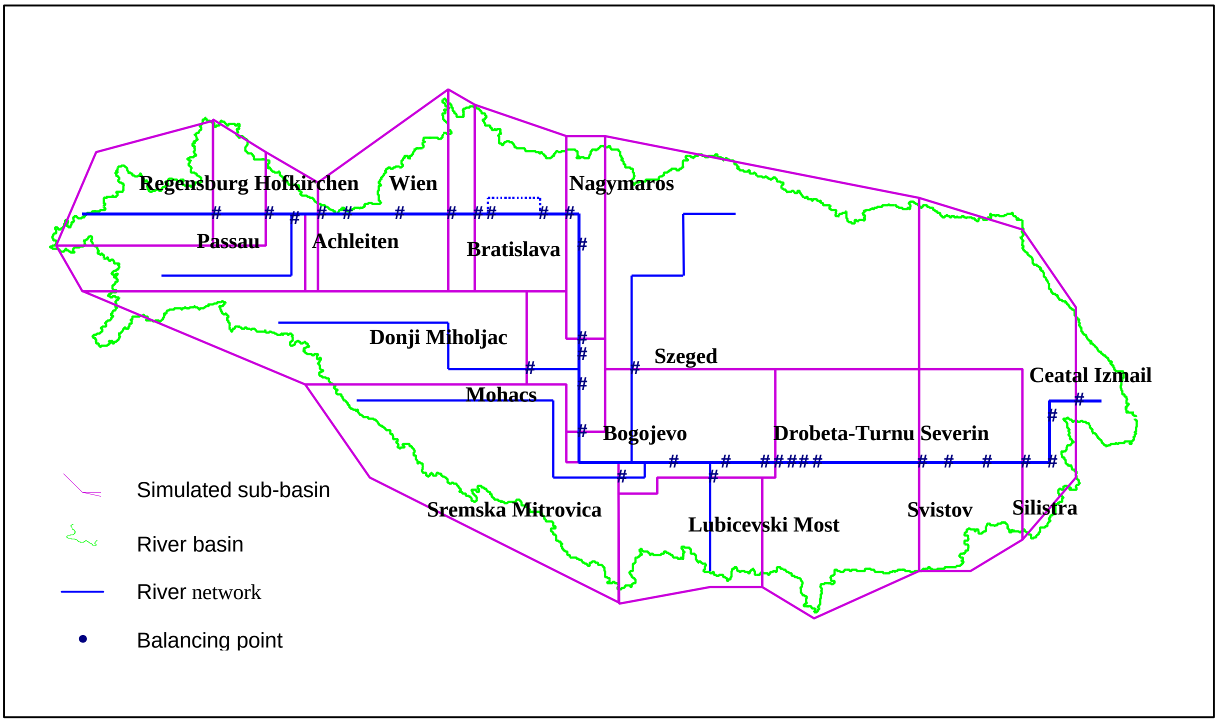
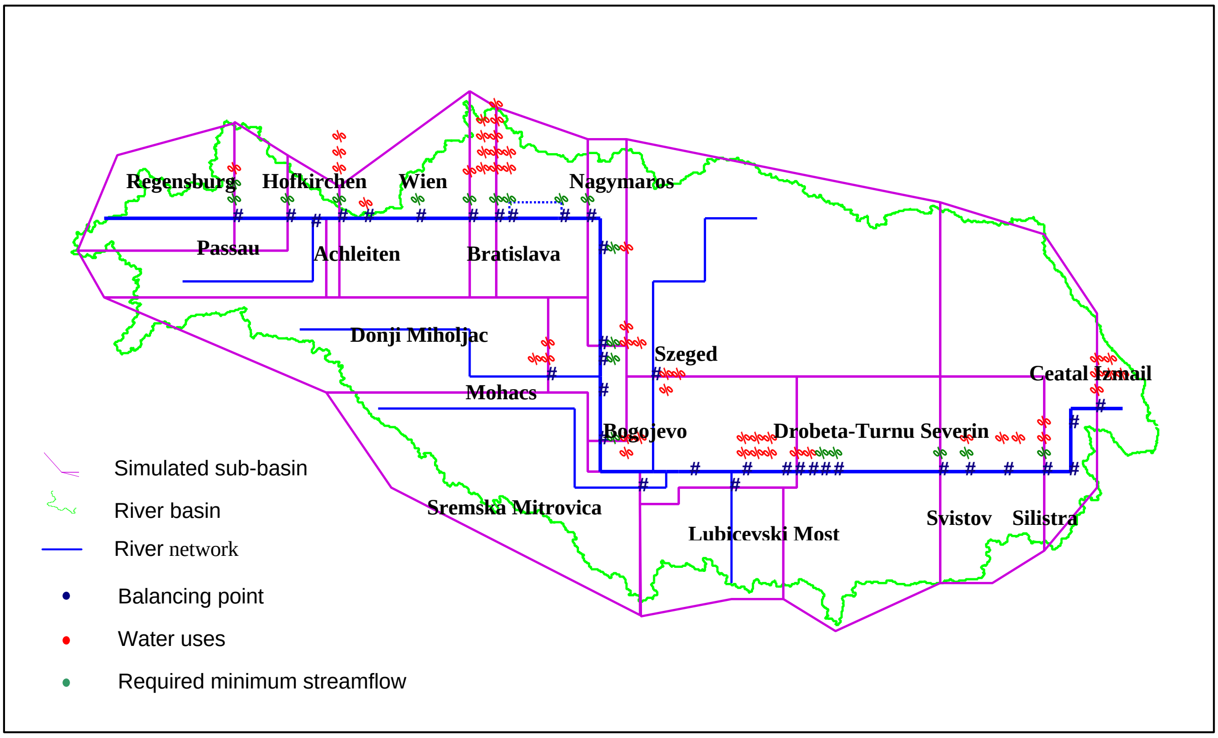


Figure 20: Water uses



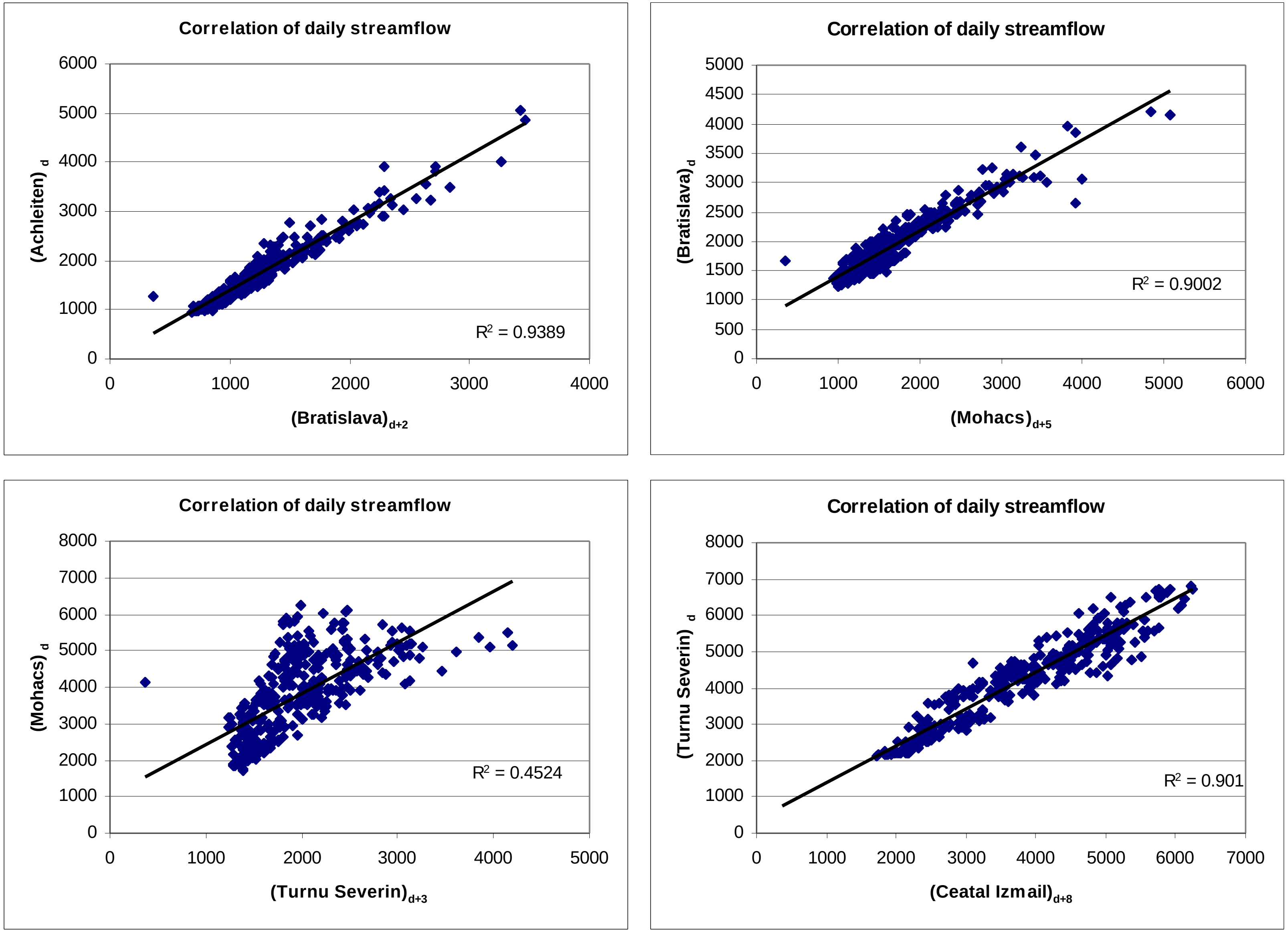


Figure 21: Estimation of flow times in the main river by correlation

Figure 27b: Exceedance of minimum navigational streamflow Q_{RNW} at Mohacs in comparison

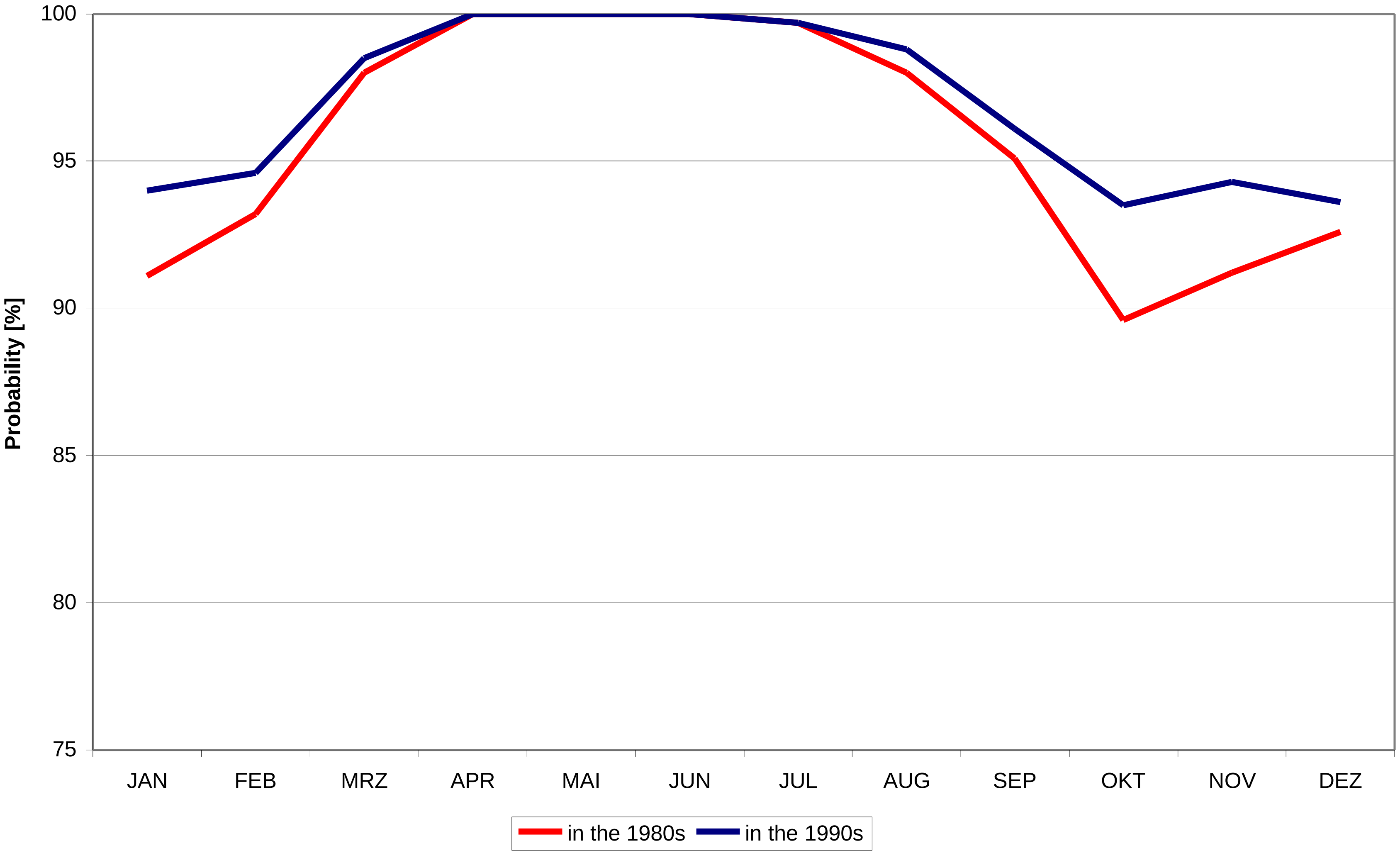


Figure 22: Observed and modelled streamflow

Figure 23a: Mean annual streamflow with probabilities of the exceedance (%) along the River Danube in the 1980s and the 1990s

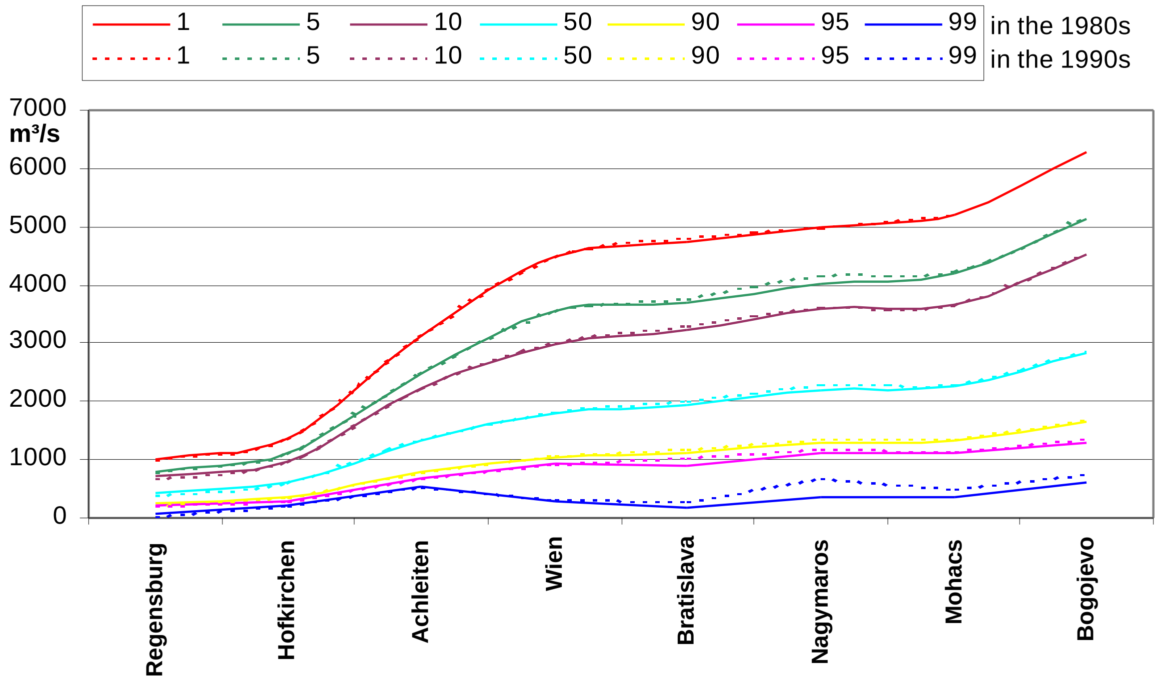


Figure 23b: Mean annual streamflow with probabilities of the exceedance (%) along the River Danube in the 1980s and the 1990s

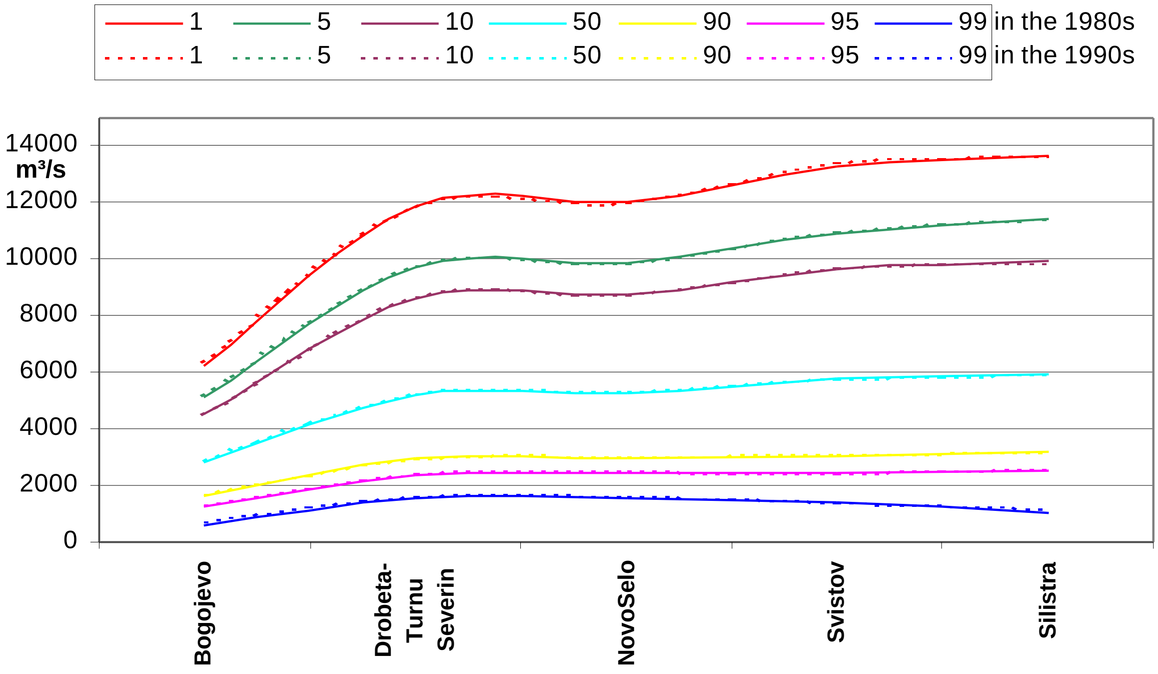


Fig. 24a:
Mean monthly streamflow with probabilities of the exceedance (ÜWK%) at the balancing point Bratislava

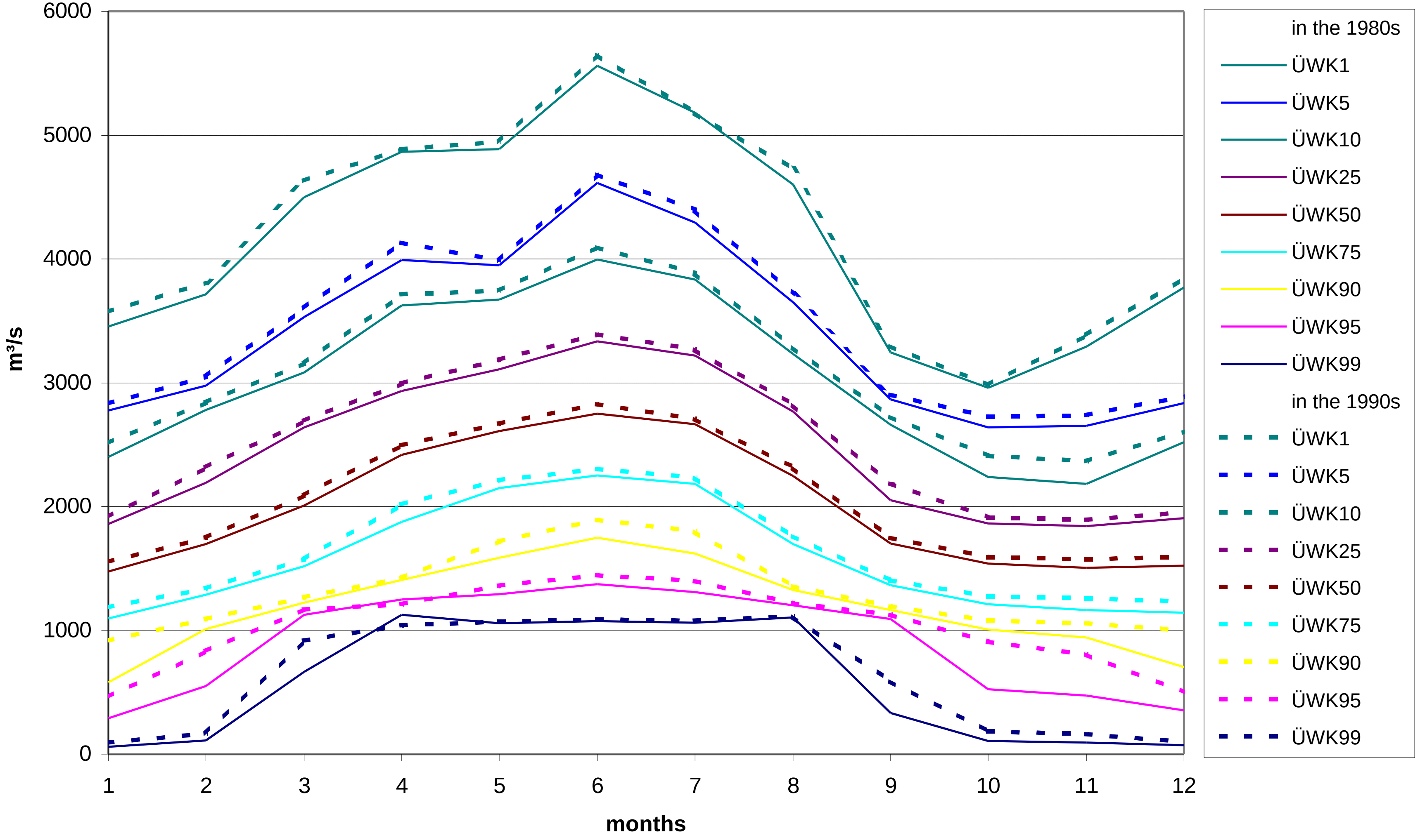


Fig. 24b:
Mean monthly streamflow with probabilities of the exceedance (ÜWK%) at the balancing point Mohacs in comparison

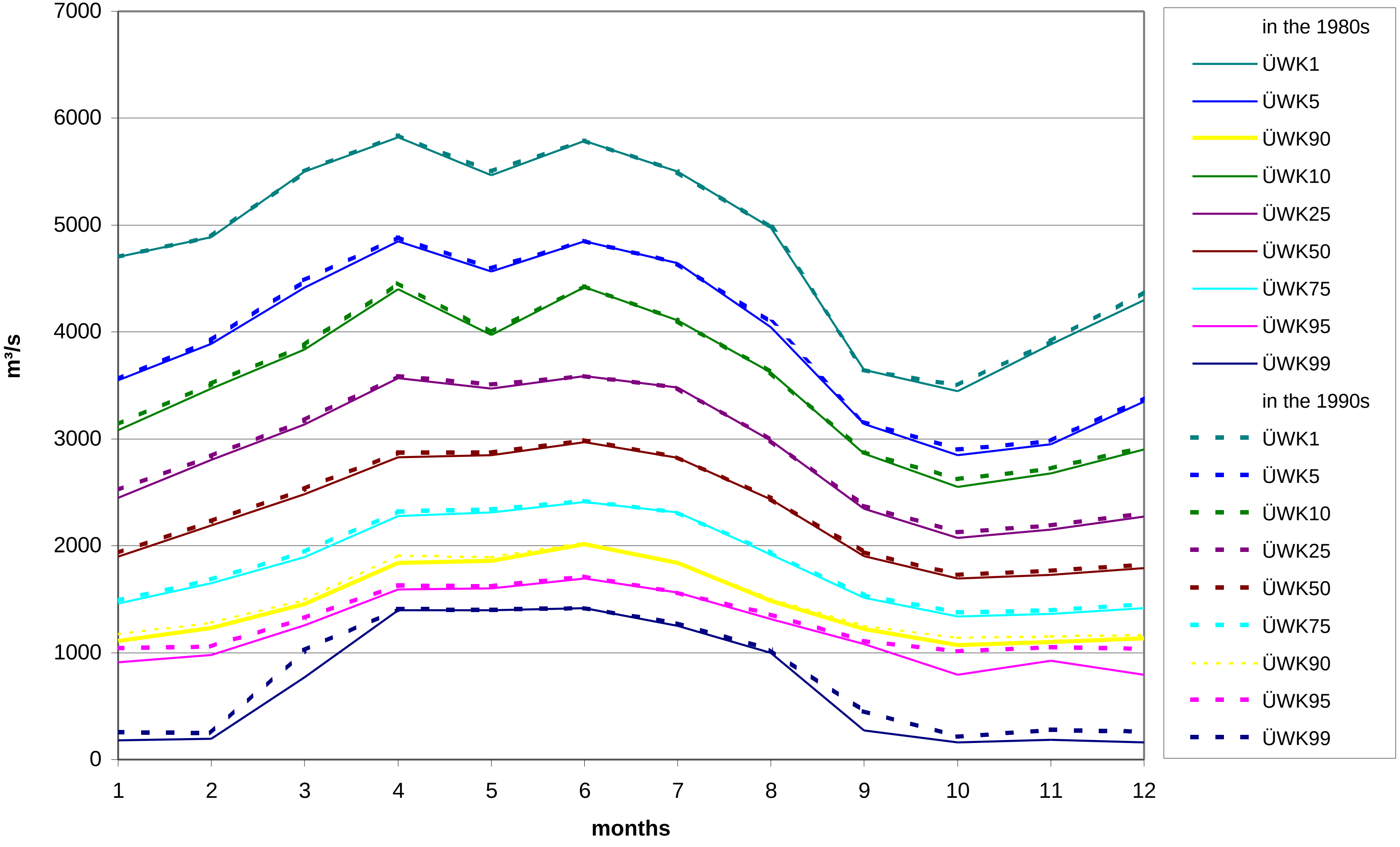


Fig. 24c:
Mean monthly streamflow with probabilities of the exceedance (ÜWK%) at the balancing point Svistov in comparison

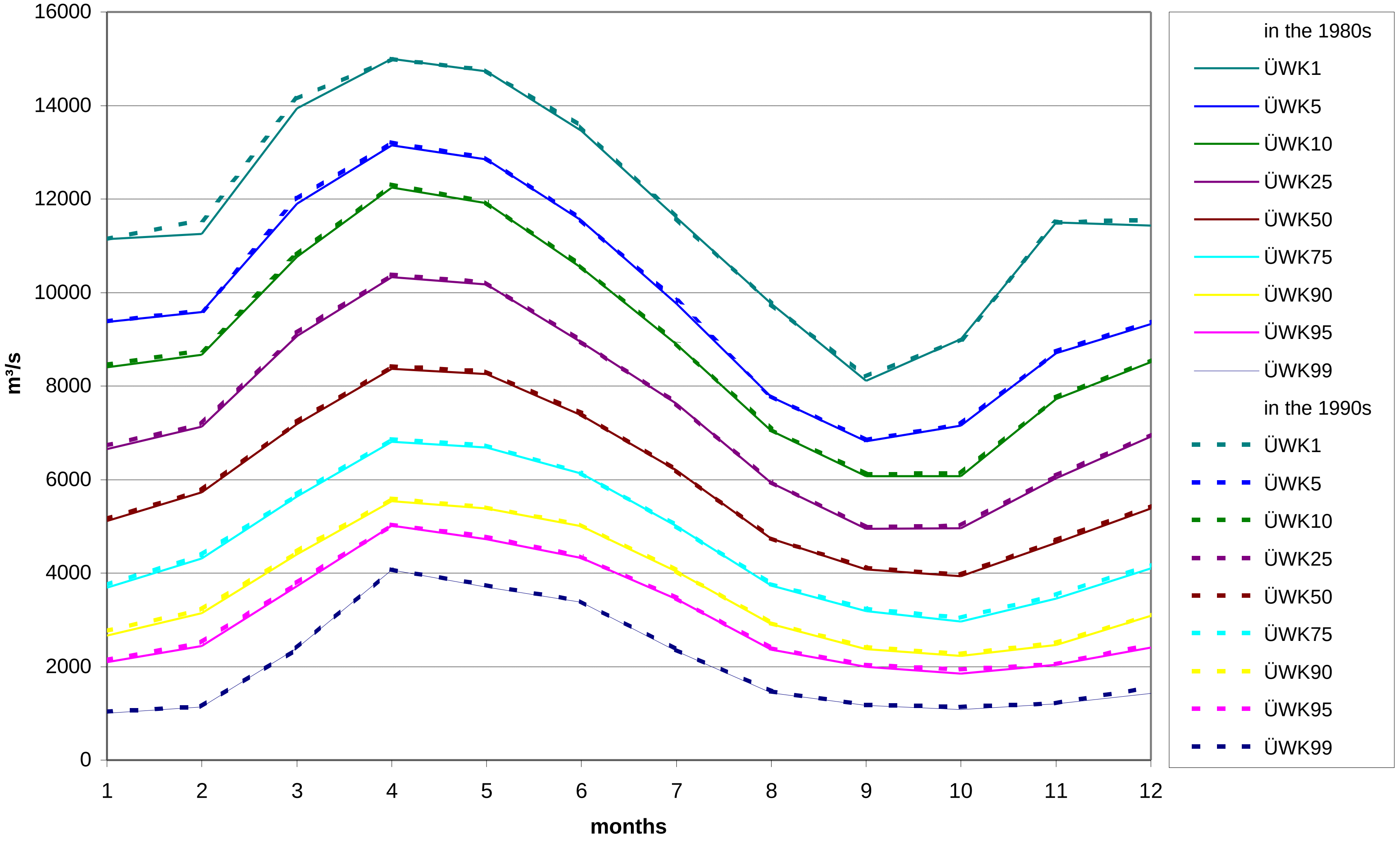


Figure 25a:
Exceedance and days of non-exceedance (UT) of the minimum navigational streamflow QRNW along the River Danube

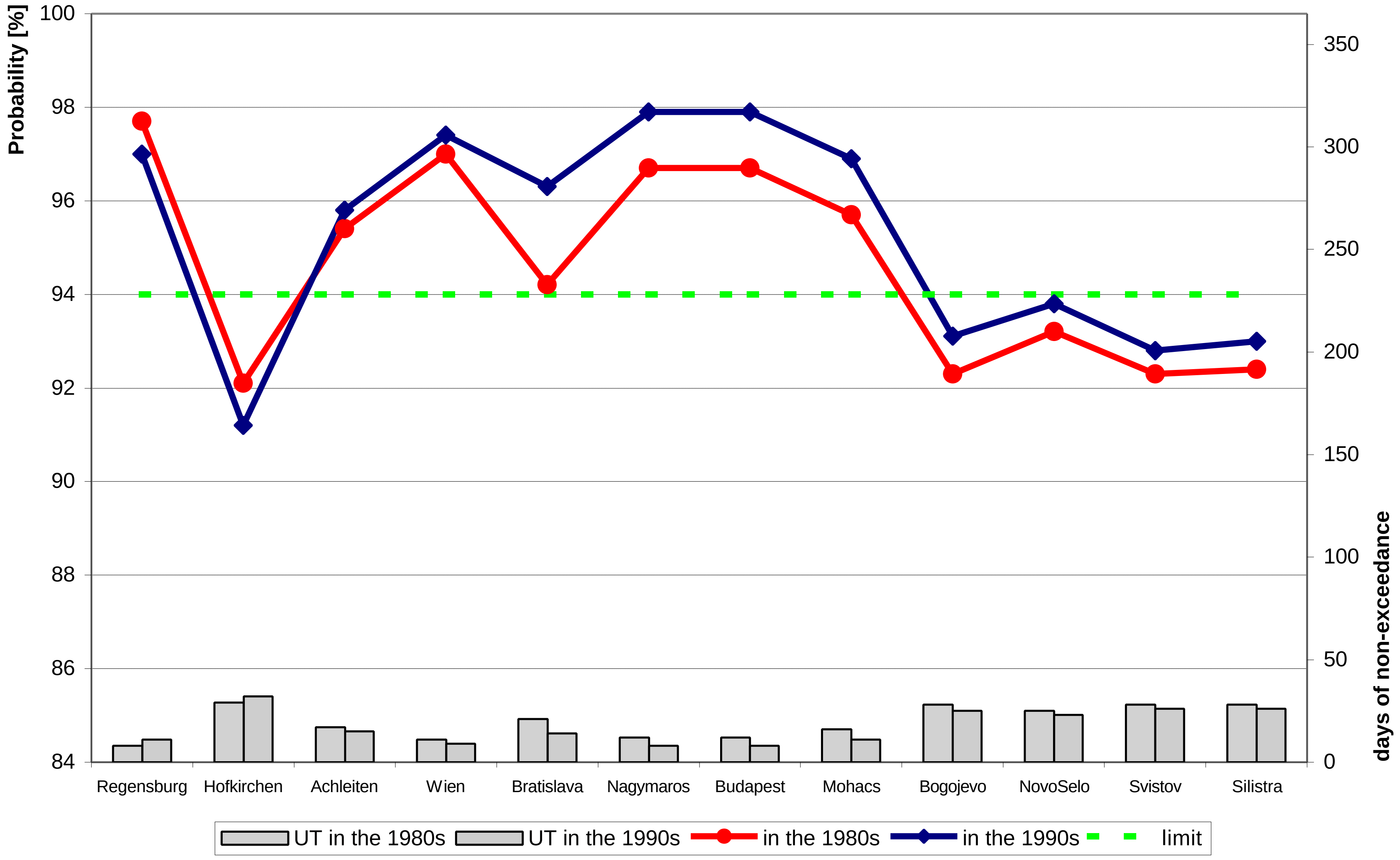


Figure 25b: Exceedance of the minimum navigational streamflow Q_{RNW} in October along the River Danube

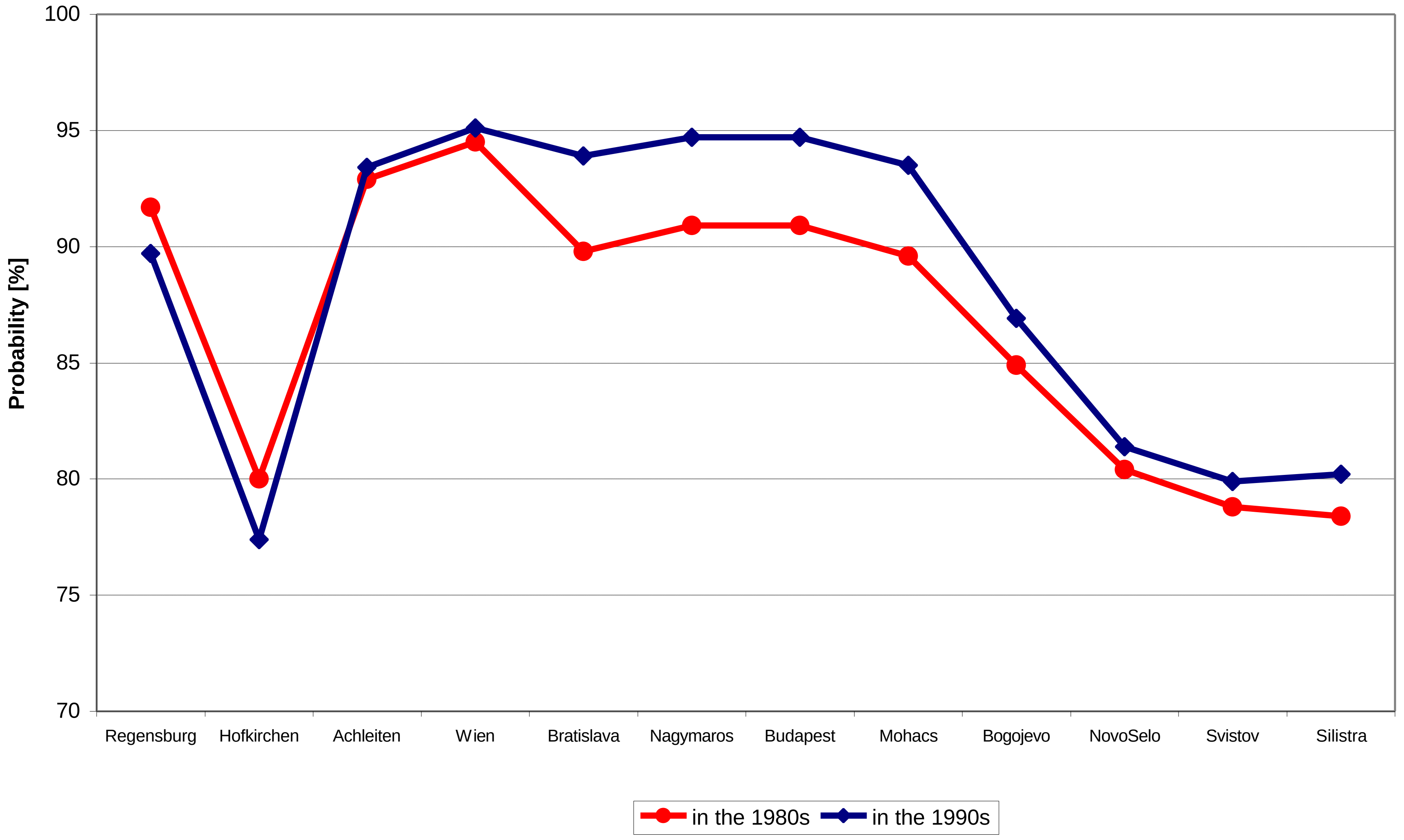


Figure 26: Long-term average of the water surplus above the minimum navigational streamflow Q_{RNW}

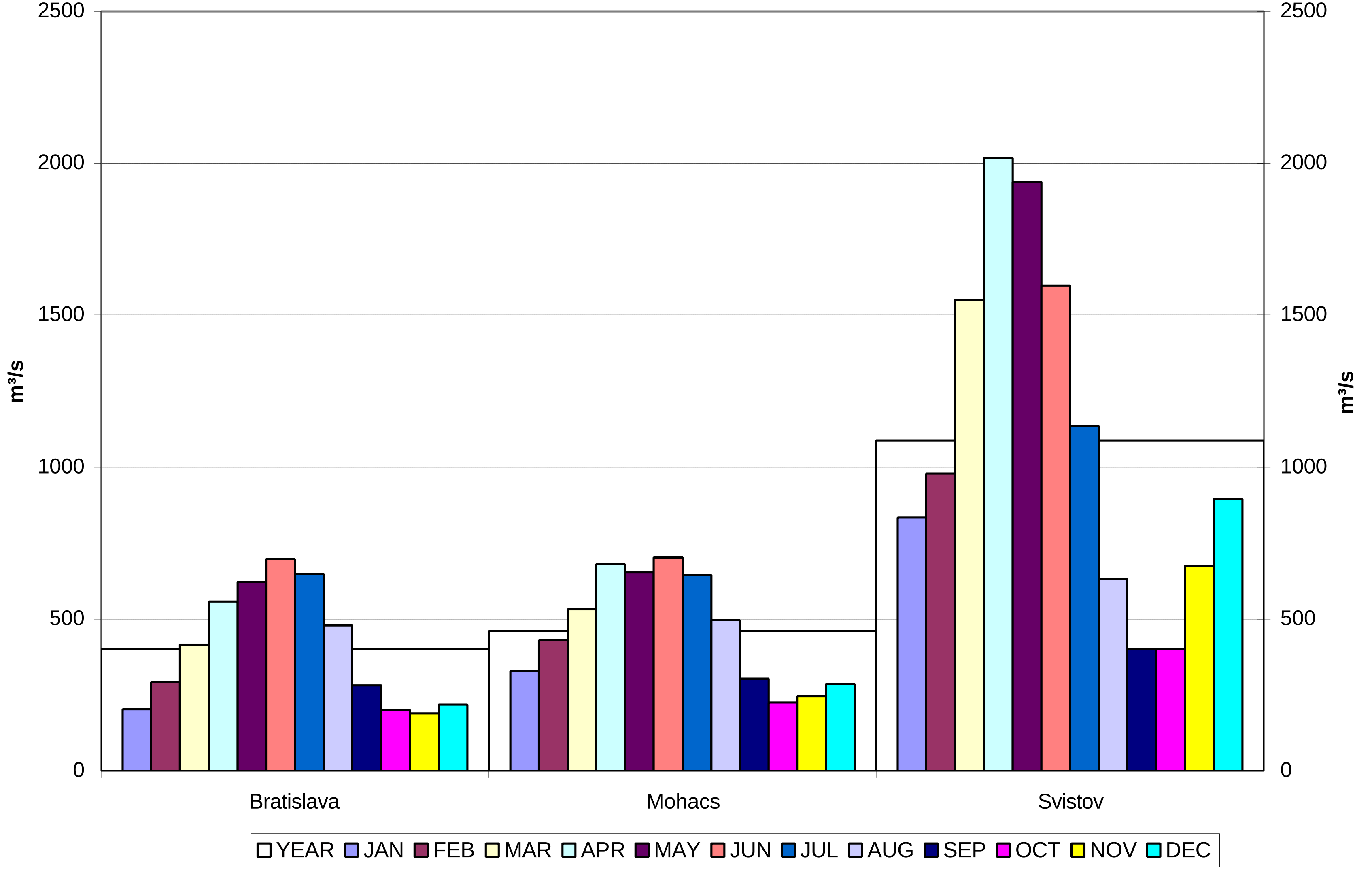


Figure 27a: Exceedance of minimum navigational streamflow Q_{RNW} at Bratislava in comparison

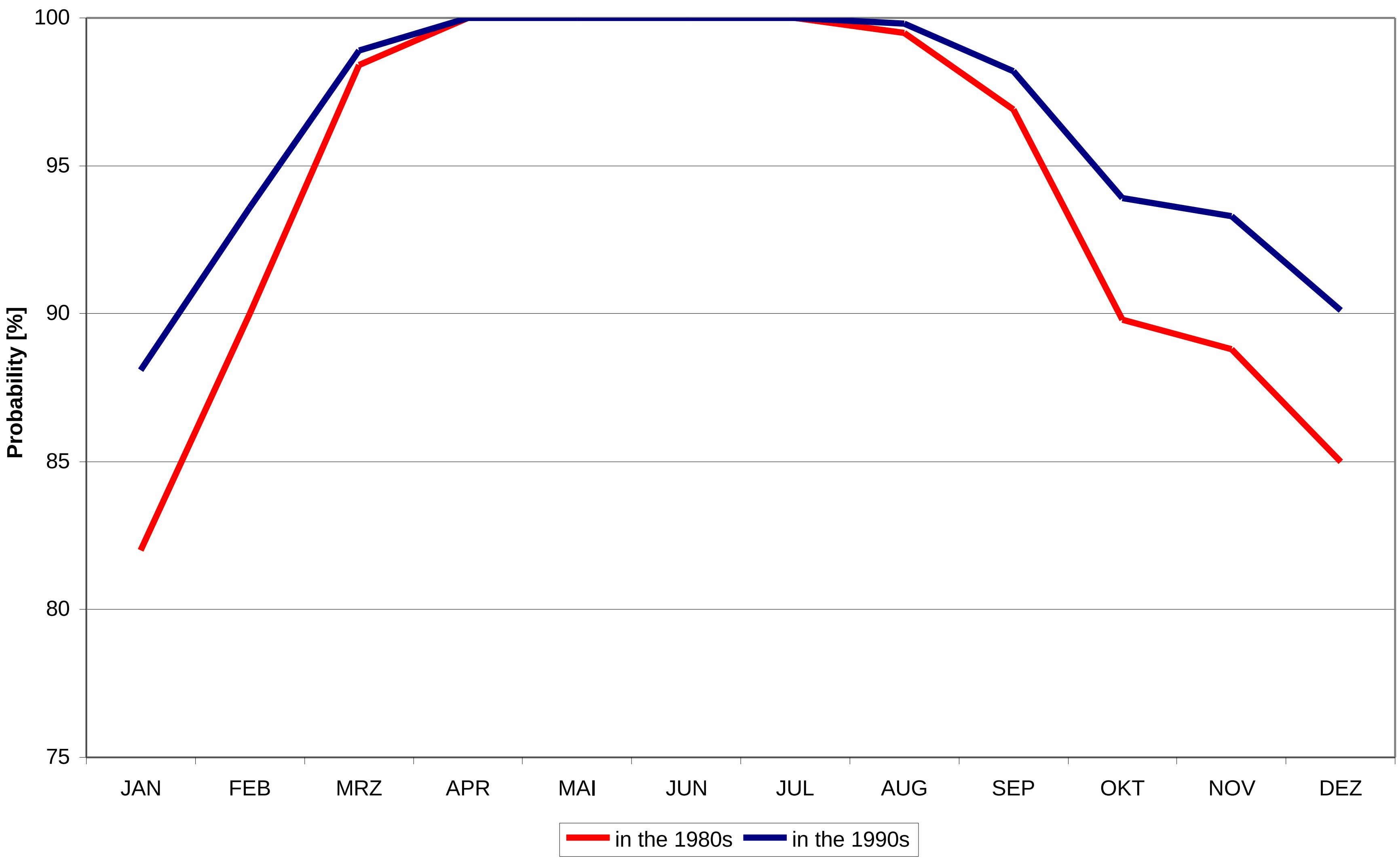
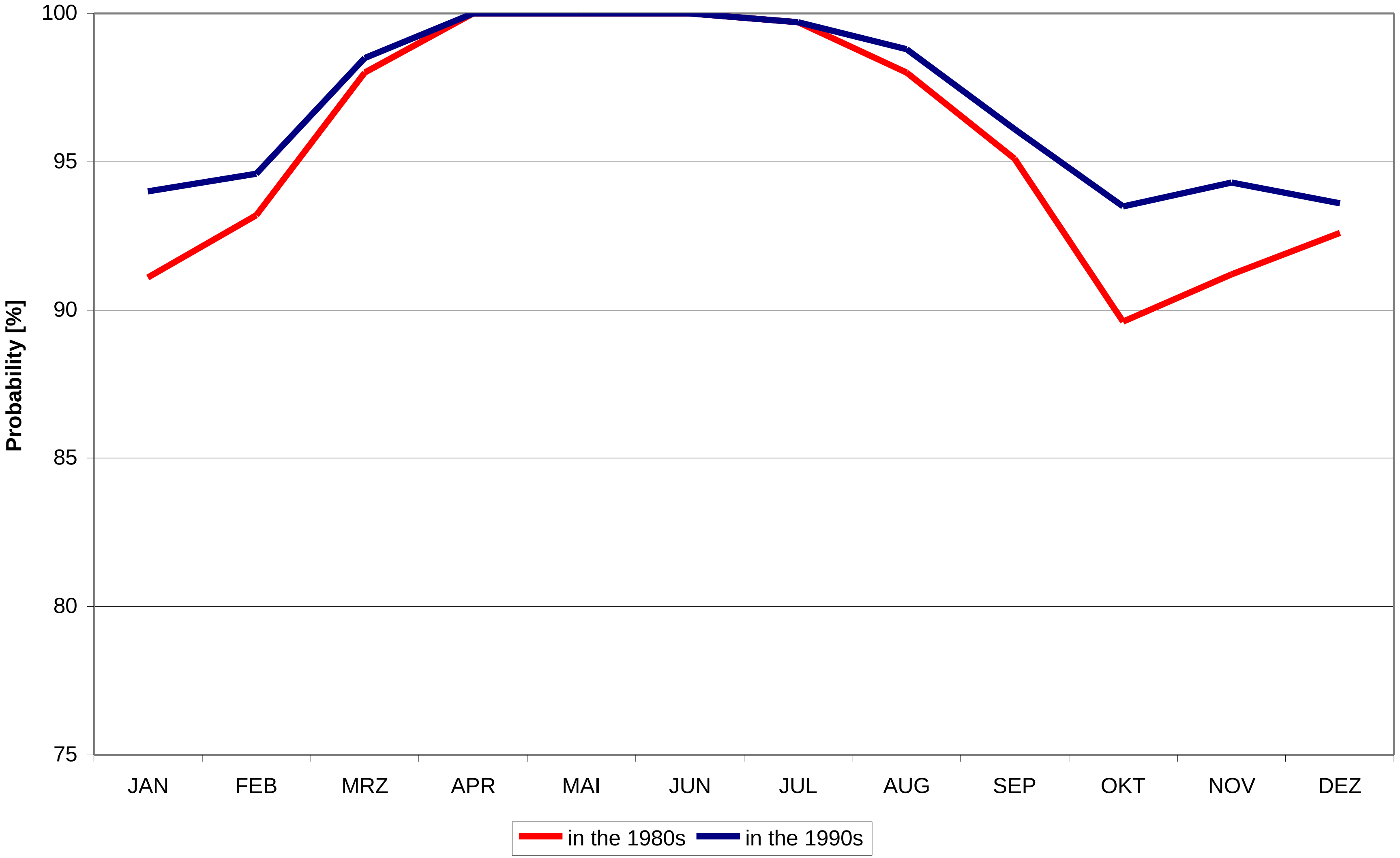


Figure 27b: Exceedance of minimum navigational streamflow Q_{RNW} at Mohacs in comparison



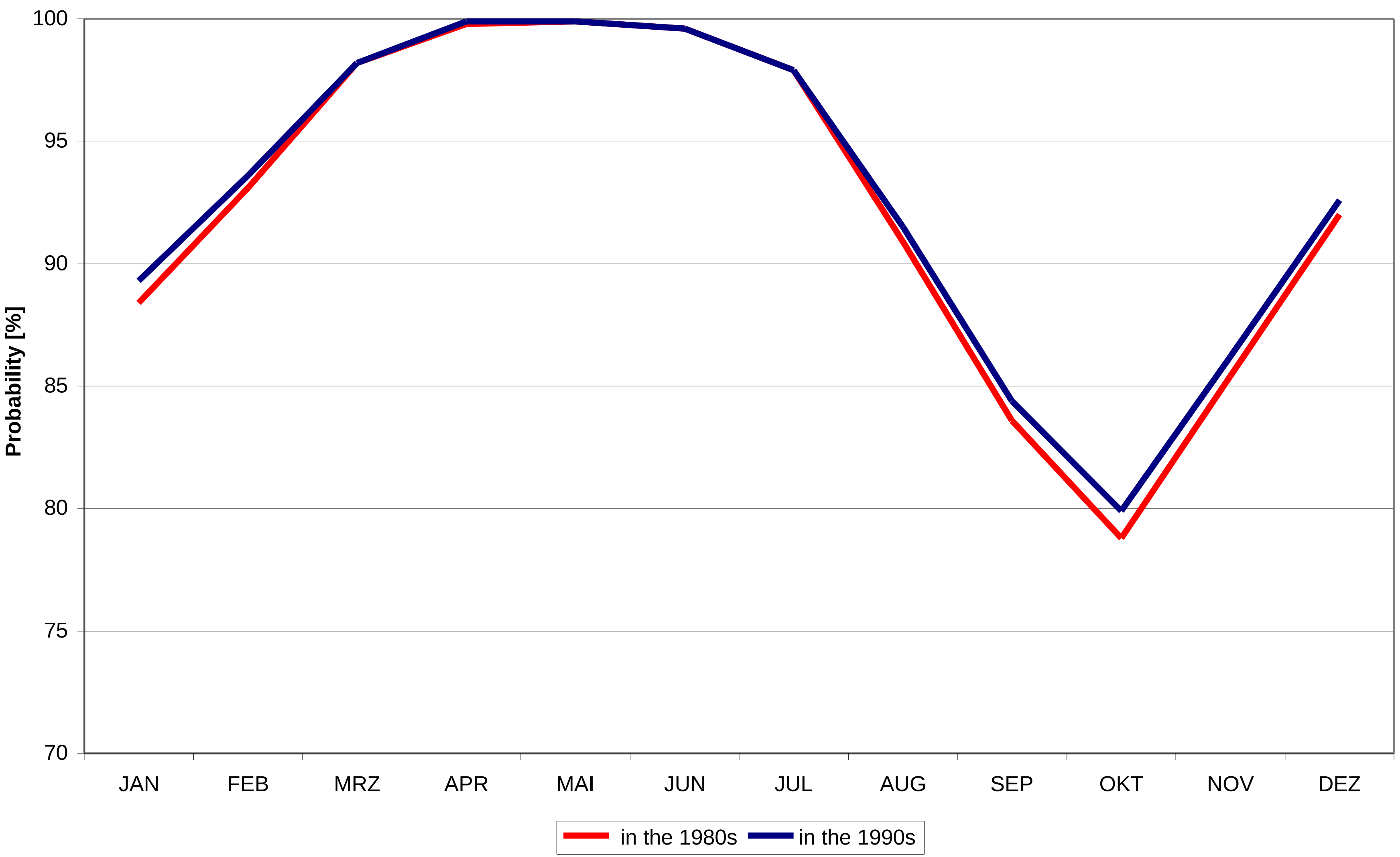


Figure 27c: Exceedance of minimum navigational streamflow Q_{RNW} at Svistov in comparison

Figure 28a:
Frequency of the monthly non-exceedance of minimum navigational streamflow QRNW at Bratislava in comparison (MQmon < QRNW)

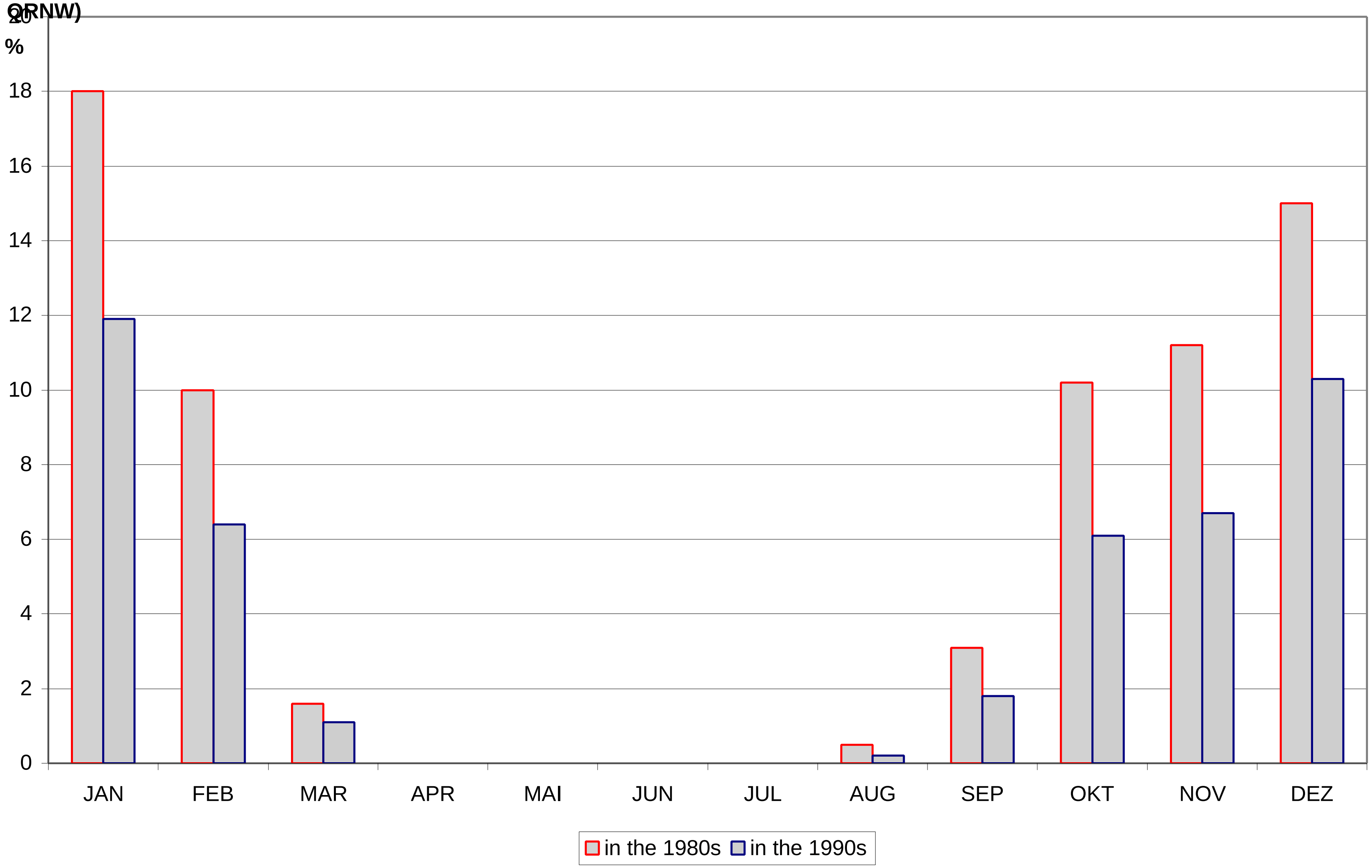


Figure 28b:
Frequency of the monthly non-exceedance of minimum navigational streamflow QRNW at Mohacs in comparison (MQmon < ORNW)

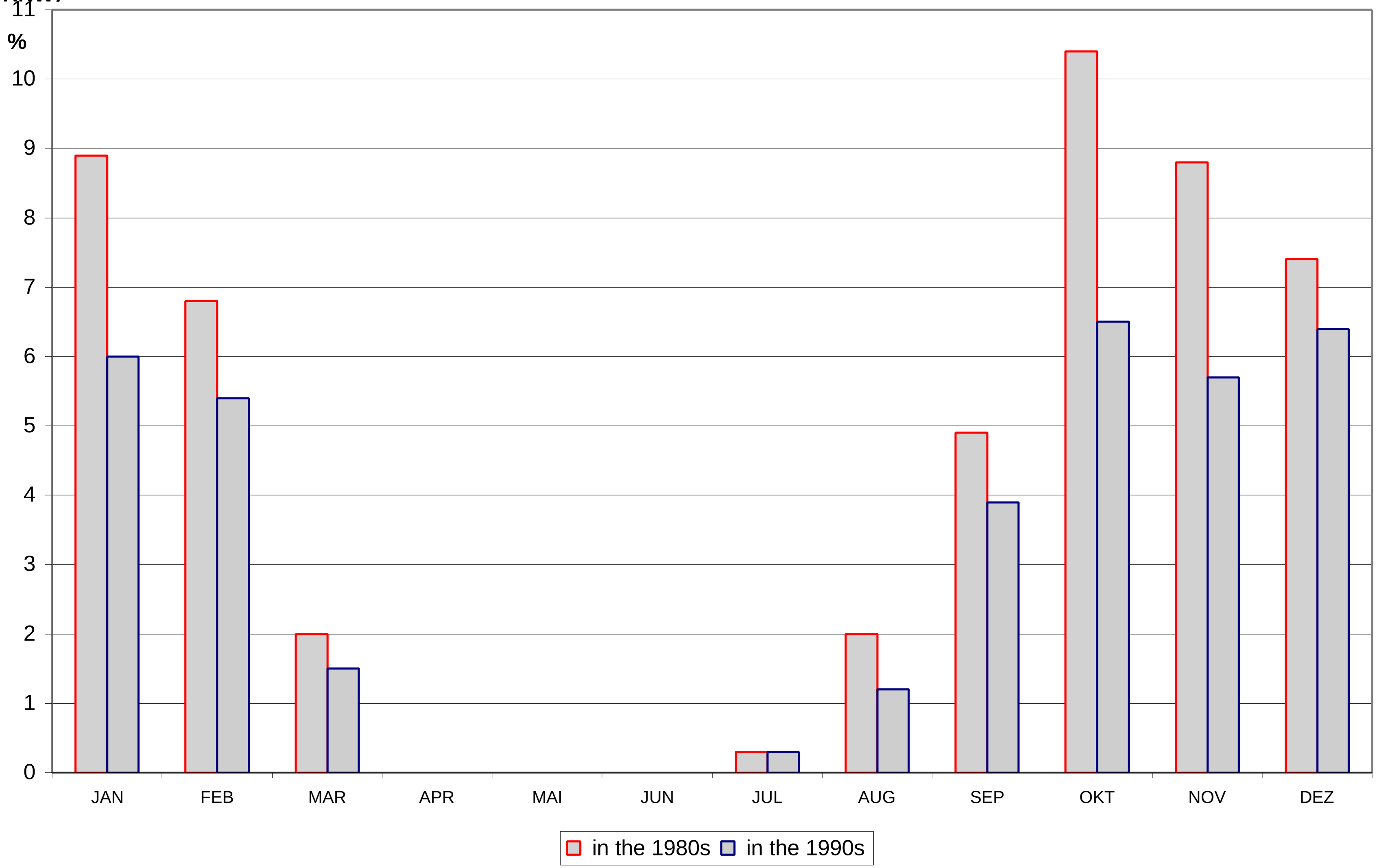


Figure 28c:
Frequency of the monthly non-exceedance of minimum navigational streamflow QRNW at Svistov in comparison (MQmon < QRNW)

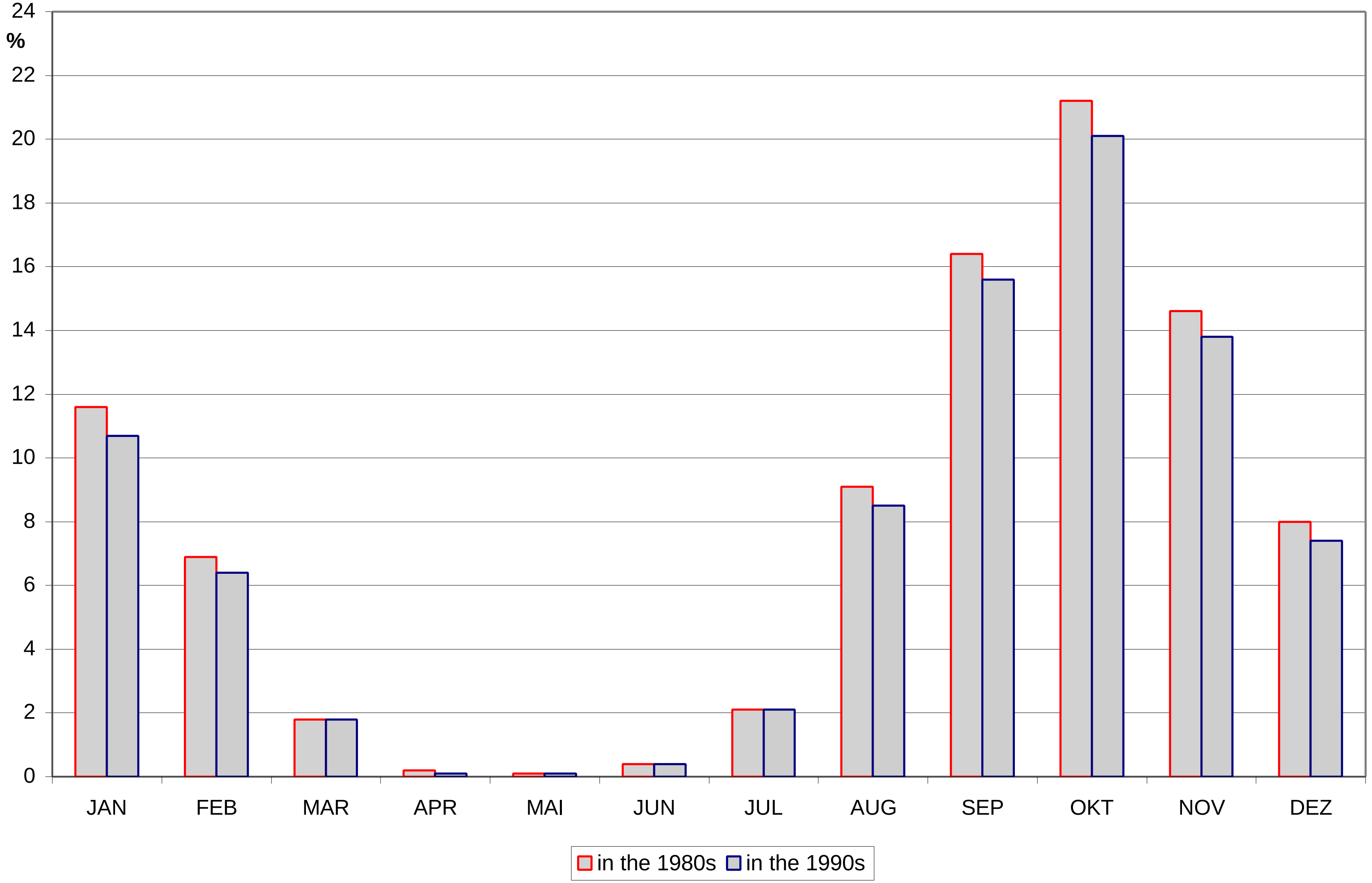


Figure 29a: Percentile satisfaction of minimum navigational streamflow Q_{RNW} at Bratislava in comparison

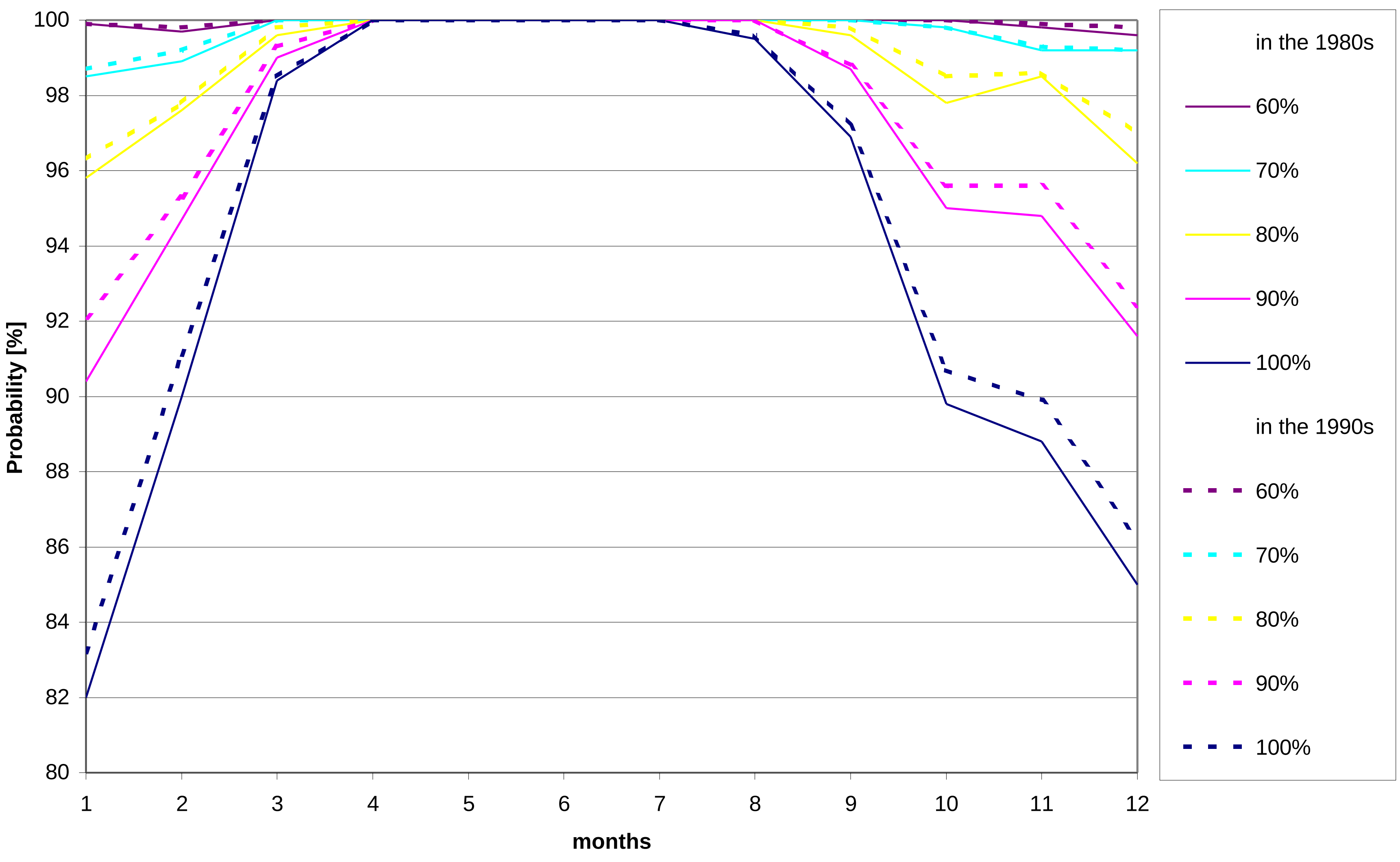


Figure 29b: Percentile satisfaction of minimum navigational streamflowQ_{RNW} at Mohacs in comparison

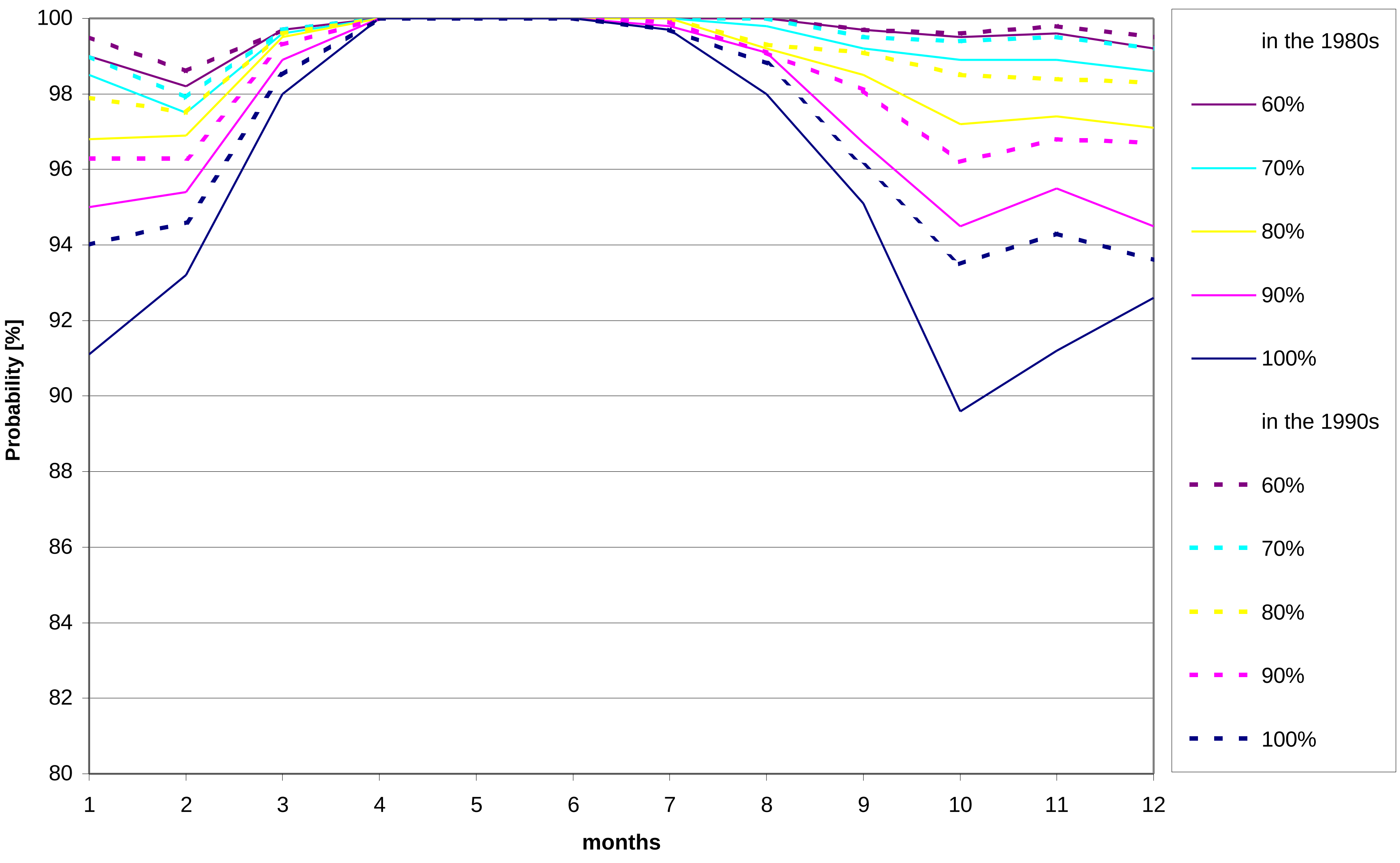


Figure 29c: Percentile satisfaction of minimum navigational streamflow Q_{RNW} at Svistov in comparison

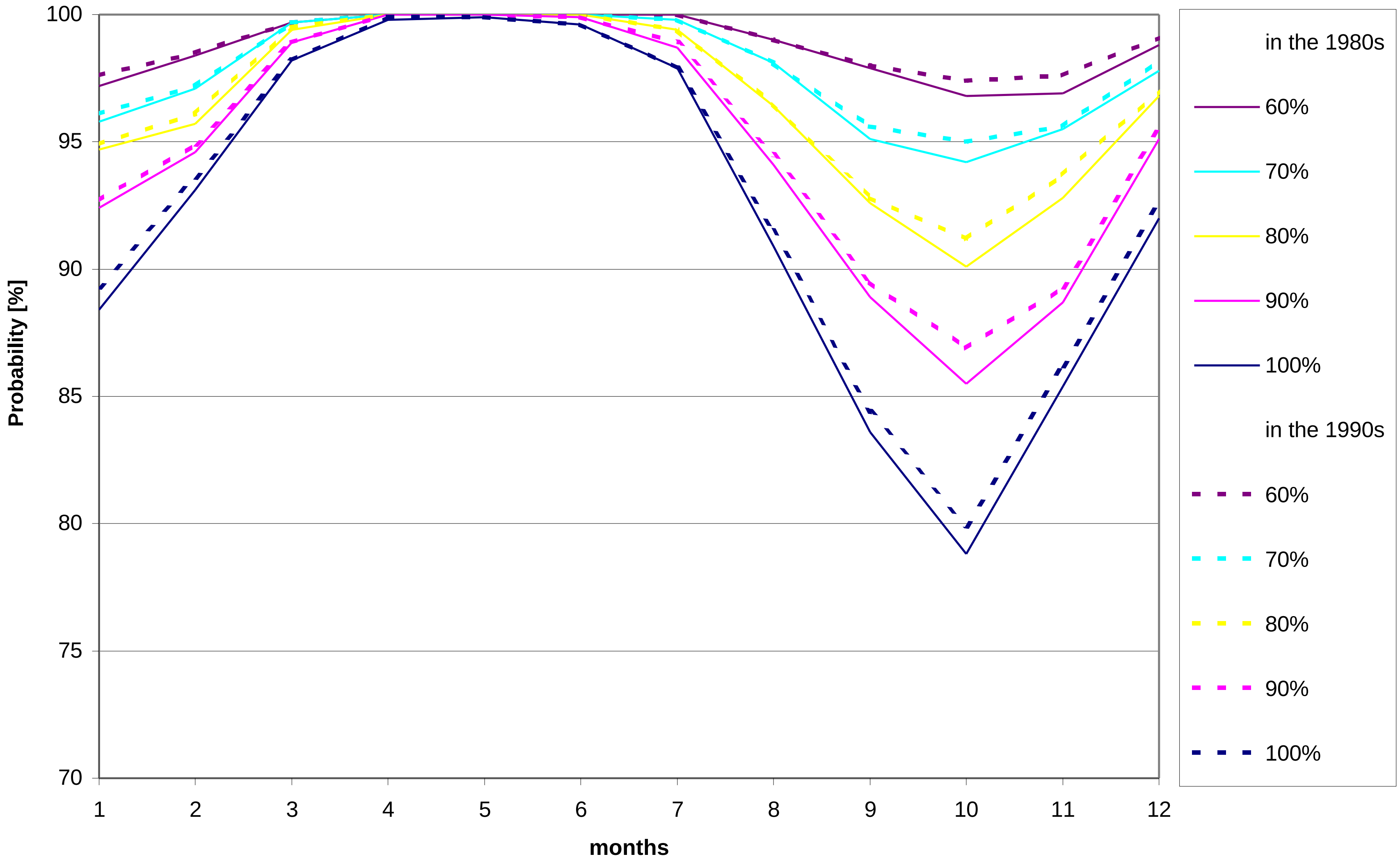


Table 1:
Mean monthly streamflow and discharge per unit area in the River Danube and its main tributaries

	Basin area [km^2]	Streamflow [m^3/s]			Discharge per unit area [l/s.km^2]		
		Q_min	MQ	Q_max	q_min	Mq	q_max
Regensburg	35399	177.	445.	991.	5.00	12.57	28.00
Hofkirchen	47496	267.	643.	1435.	5.62	13.54	30.21
Achleiten	76597	721.	1421.	2753.	9.41	18.55	35.94
Wien-Nussdorf	101700	971.	1919.	3767.	9.55	18.87	37.04
Bratislava	131338	1028.	2044.	4163.	7.83	15.56	31.70
Nagymaros	183533	1059.	2310.	4643.	5.77	12.59	25.30
Mohacs	209064	1069.	2356.	4663.	5.11	11.27	22.30
Bogojevo	251593	1482.	2946.	5670.	5.89	11.71	22.54
Orsova/ Drobeta-Turnu Severin	576232	2556.	5485.	10154.	4.44	9.52	17.62
Svistov	650340	2704.	6074.	10824.	4.16	9.34	16.64
Silistra	689700	2814.	6284.	11005.	4.08	9.11	15.96
Ceatal Izmail	807000	3087.	6515.	11406.	3.83	8.07	14.13
Passau / Inn	26084	416.	733.	1311.	15.95	28.10	50.26
Donji Miholjac / Drava	37142	272.	542.	1136.	7.32	14.59	30.59
Sremska Mitrovica / Sava	87966	470.	1574.	3475.	5.34	17.89	39.50
Szeged / Tisza	138408	199.	835.	2417.	1.44	6.03	17.46
Lubicevski Most / Vel.Morava	34345	55.	236.	663.	1.60	6.87	19.30

Table 2: Area and population of the States in the Danube basin

	Area [1000 km^2]	Country share [%]	Basin share [%]	Population living in river basin [Mill.]
Albania, Italy, Poland, Schwitzerland	2.3	0.1		0.3
Yugoslavia	80.7	79.2	10.1	8.41
Ukraine	29.5	2.5	3.7	1.32
Slovenia	16.3	80.5	2.0	1.57
Slovak Republic	46.8	96.2	5.9	5.17
Romania	231.	97.9	29.0	23.05
Moldava	12.2	3.62	1.5	1.62
Hungary	92.7	100	11.6	10.31
Germany	52.3	14.7	6.5	11.97
Czech Republic	21.1	26.8	2.6	2.77
Croatia	33.9	30.1	4.2	1.51
Bulgaria	47.2	42.6	5.9	3.81
Bosnia-Herzegovina	38.1	74.1	4.8	1.97
Austria	80.1	95.7	10.0	7.42

Table 3: Available time series of monthly streamflow data (GRDC database)

GRDC database						
GRDC-Nr	Gauging station	Area [km²]	From	To	Data gaps [%]	Completed from
6342500	Ingolstadt	20001	1931	1987	9.4	German Hydrological Yearbook
6342600	Regensburg	35399	1931	1970	0	Yearbook of the Danube Commission
6342800	Hofkirchen	47496	1901	1994	0	Hydaba database
6342900	Achleiten	76597	1901	1991	0	Hydaba database
6242100	Linz/Aschach	79490	1931	1970	0	Yearbook of the Danube Commission; Hydrographic Yearbook for Austria
6242401	Kienstock	95970	1976	1995	0	before 1975 station Stein-Krems
6242400	Stein-Krems	96045	1951	1975	0	from 1976 station Kienstock
6242500	Wien-Nussdorf	101700	1931	1970	0	Yearbook of the Danube Commission; Hydrographic Yearbook for Austria
6142200	Bratislava	131338	1901	1990	1.1	
6442450	Dunaalmas	171720	1948	1995	1.7	
6442500	Nagymaros	183533	1931	1995	4	
6442600	Mohacs	209064	1931	1995	1.7	
6542100	Bezdan	210245	1931	1984	0	Yearbook of the Danube Commission
6542200	Bogojevo	251593	1931	1984	16.7	Yearbook of the Danube Commission
6542500	Pancevo	525009	1931	1970	0	
6542600	Veliko Gradiste	570375	1931	1970	0	
6742199	Orsova	576232	1839	1970	0	from 1971 station Drobeta-Turnu Severin
6742200	Drobeta-Turnu Severin	578300	1971	1988	0	Yearbook of the Danube Commission
6842200	Novo Selo	584900	1937	1970	0	Yearbook of the Danube Commission
6842400	Lom	588860	1941	1970	0	Yearbook of the Danube Commission
6842700	Svistov	650340	1931	1970	0	Yearbook of the Danube Commission
6842800	Ruse	669900	1931	1970	0	Yearbook of the Danube Commission
6842900	Silistra	689700	1941	1969	0	Yearbook of the Danube Commission
6742800	Vadu-Oii-Hirsova	709100	1931	1970	0	IHP
6742900	Ceatal Izmail	807000	1921	1985	0	IHP
	Passau Ingling	25665	1931	1991		Hydaba database
6546800	Donji Miholjac	37142	1921	1984	3.1	IHP
6444100	Szeged	138408	1921	1995	6.7	Yearbook of the Danube Commission
6545800	Sremska Mitrovica	87966	1926	1984	0	Yearbook of the Danube Commission
6547500	Lubicevsky Most	34345	1931	1984	1.1	Yearbook of the Danube Commission

Table 4: Minimum navigational streamflow at the main gauging stations along the River Danube

Gauging station	Distance from the mouth [km]	Streamflow at RNW* [m³/s]
Regensburg-Schwabelweis	2376	186
Hofkirchen	2257	354
Kienstock	2015	870
Wien-Reichsbrücke	1929	855 (without Danube Canal)
Bratislava	1869	1010
Nagymaros	1695	1040
Mohacs	1447	1080
Bezdan	1426	1150
Bogojevo	1367	1530
Novo Selo	834	2710
Svistov	554	2848
Ruse	496	2865
Silistra	376	2928

RNW - from german **Regulierungs**n**iedrig**w**asser* (RZdD 1997)

Table 5: Simulated sub-basins and their relative shares

Balancing point	**Simulated sub-basin (STG)**	Basin area [km²]	Sub-basin area [km²]		Danube basin share	relative share in the sub-basins
1.1	**Regensburg**	35399		**35399**	0.04	1.000
2.1.	**Hofkirchen**	47496		**12097**	0.01	1.000
4.1	**Achleiten**	76597		**3436**	0.00	1.000
5.1	Linz/Aschach	79490	2893		0.00	0.115
5.2	Kienstock	95970	16480		0.00	0.656
5.3	**Wien-Nussdorf**	101700	5730	**25103**	0.03	0.228
6.1	**Bratislava**	131338	29638	**29638**	0.04	1.000
7.1	Dunaalmas	171720	40382		0.00	0.774
7.2	**Nagymaros**	183533	11813	**52195**	0.06	0.226
8.1	Budapest	184767	1234		0.00	0.048
8.2	**Mohacs**	209064	24297	**25531**	0.03	0.952
10.1	Bezdan	210245	1181		0.00	0.219
10.2	DTD-Kanal				0.00	0.000
10.3	**Bogojevo**	251593	4206	**5387**	0.01	0.781
10.4	Pancevo	525009	47042		0.00	0.713
10.5	Veliko Gradiste	570375	11021		0.00	0.167
14.1	**Drobeta-Turnu Severin**	578300	7925	**65988**	0.08	0.120
15.1	Novo Selo	584900	6600		0.00	0.092
15.2	Lom	588860	3960		0.00	0.055
15.3	**Svistov**	650340	61480	**72040**	0.09	0.853
16.1	Ruse	669900	19560		0.00	0.497
16.2	Oltenita	684900	15000		0.00	0.381
16.3	**Silistra**	689700	4800	**39360**	0.05	0.122
17.1	Cernavoda	707000	17300		0.00	0.147
17.2	Vadu-Oii-Hirsova	709100	2100		0.00	0.018
17.3	**Ceatal Izmail**	807000	97900	**117300**	0.15	0.835
3.1	**Passau Ingling**	**25665**			0.03	1.000
9.1	**Donji Miholjac**	**37142**			0.05	1.000
11.1	**Szeged**	**138408**			0.17	1.000
12.1	**Sremska Mitrovica**	**87966**			0.11	1.000
13.1	**Lubicevsky Most**	**34345**			0.04	1.000

Table 6a: Input data — **Variant for the 1980s**

TYPE	INDEX NUMBER	NAME	SITE of WITHDRAWAL	SITE of RETURN	STORAGE RESERVOIR	RANKING NUMBER
AB	102.2000	Hydro power station Djerdap I			102.1000	302.2000
N	102.5000	Power generation Dierdap I	14.2000	14.3000		302.5000
AB	103.2000	Hydro power station Djerdap II			103.1000	303.2000
N	103.5000	Power generation Dierdap II	14.3000	15.1000		303.5000
N	301.1000	QRNW Regensburg	1.1000			10.0000
N	302.1000	QRNW Hofkirchen	2.1000			20.0000
N	304.1000	QRNW Linz	4.1000			30.0000
N	305.2000	QRNW Kienstock	5.2000			40.0000
N	305.3000	QRNW Wien (ohne Donaukanal)	5.3000			50.0000
N	306.1000	QRNW Bratislava	6.1000			60.0000
N	307.1000	QRNW Komarno	7.1000			130.0000
N	307.2000	QRNW Nagymaros	7.2000			140.0000
N	308.1000	QRNW Budapest	8.1000			160.0000
N	308.2000	QRNW Mohacs	8.2000			180.0000
N	310.1000	QRNW Bezdan	10.1000			200.0000
N	310.3000	QRNW Bogojevo	10.3000			210.0000
N	315.1000	QRNW NovoSelo	15.1000			310.0000
N	315.2000	QRNW Lom	15.2000			320.0000
N	315.3000	QRNW Svistov	15.3000			330.0000
N	316.1000	QRNW Ruse	16.1000			340.0000
N	316.3000	QRNW Oltenita	16.3000			350.0000
AEND		Storage reservoir Djerdap I			102.1000	302.9000
AEND		Storage reservoir Djerdap II			103.1000	303.9000
DYN		Maxima				400.0000
DYN		Correction for effects of reservoir				0.5000
DYN		Compensation of negative streamflow				0.9000

* QRNW - minimum streamflow for navigation, from german Regulierungsniedrigwasser
** Qmin - minimum streamflow for ecological reasons

Table 6b: Input data — **Variant for the 1990s**

TYPE	INDEX NUMBER	NAME	SITE of WITHDRAWAL	SITE of RETURN	STORAGE RESERVOIR	RANKING NUMBER
AB	101.2000	Hydro power station Gabcikovo			101.1000	101.2000
N	101.5000	Diversion for Gabcikovo	6.2000	7.1000		101.5000
AB	102.2000	Hydro power station Djerdap I			102.1000	302.2000
N	102.5000	Power generation Dierdap I	14.2000	14.3000		302.5000
AB	103.2000	Hydro power station Dejrdap II			103.1000	303.2000
N	103.5000	Power generation Dierdap II	14.3000	15.1000		303.5000
N	201.2000	Diversion to Rhine basin	1.1000	1.1000		5.0000
N	300.0100	Qmin Kelheim	1.1000			1.0000
N	300.0500	Qmin Donau Cunovo	6.2000			50.0000
N	301.1000	QRNW Regensburg	1.1000			10.0000
N	302.1000	QRNW Hofkirchen	2.1000			20.0000
N	304.1000	QRNW Linz	4.1000			30.0000
N	305.2000	QRNW Kienstock	5.2000			40.0000
N	305.3000	QRNW Wien	5.3000			50.1000
N	306.1000	QRNW Bratislava	6.1000			60.0000
N	307.1000	QRNW Komarno	7.1000			140.0000
N	307.2000	QRNW Nagymaros	7.2000			150.0000
N	308.1000	QRNW Budapest	8.1000			160.0000
N	308.2000	QRNW Mohacs	8.2000			180.0000
N	310.1000	QRNW Bezdan	10.1000			200.0000
N	310.3000	QRNW Bogojevo	10.3000			205.0000
N	315.1000	QRNW NovoSelo	15.1000			310.0000

Table 6b: Input data (continued) **Variant for the 1990s**

TYPE	INDEX NUMBER	NAME	SITE of WITHDRAWAL	SITE of RETURN	STORAGE RESERVOIR	RANKING NUMBER
N	315.2000	QRNW Lom	15.2000			320.0000
N	315.3000	QRNW Svistov	15.3000			330.0000
N	316.1000	QRNW Ruse	16.1000			340.0000
N	316.3000	QRNW Oltenita	16.3000			350.0000
N	401.0000	Domestic water use Germany	4.1000	4.1000		21.0000
N	402.0000	Domestic water use Austria	6.1000	6.1000		71.0000
N	403.0000	Domestic water use Czech Rep	6.1000	6.1000		81.0000
N	404.0000	Domestic water use Slovak Rep	6.1000	6.1000		91.0000
N	405.0000	Domestic water use Slovenia	9.1000	9.1000		170.0000
N	406.0000	Domestic water use Hungary	8.2000	8.2000		190.0000
N	407.0000	Domestic water use Croatia	10.3000	10.3000		210.0000
N	408.0000	Domestic water use Bosnia-Herzegowina	10.5000	10.5000		220.0000
N	409.0000	Domestic water use Yugoslavia	10.5000	10.5000		230.0000
N	410.0000	Domestic water use Ukraine	11.1000	11.1000		240.0000
N	411.0000	Domestic water use Bulgaria	16.3000	16.3000		360.0000
N	412.0000	Domestic water use Romania	17.3000	17.3000		370.0000
N	413.0000	Domestic water use Moldova	17.3000	17.3000		380.0000
N	501.0000	Industrial water use Germany	4.1000	4.1000		22.0000
N	502.0000	Industrial water use Austria	6.1000	6.1000		72.0000
N	503.0000	Industrial water use Czech Rep	6.1000	6.1000		82.0000
N	504.0000	Industrial water use Slovak Rep	6.1000	6.1000		92.0000
N	505.0000	Industrial water use Slovenia	9.1000	9.1000		171.0000
N	506.0000	Industrial water use Hungary	8.2000	8.2000		191.0000
N	507.0000	Industrial water use Croatia	10.3000	10.3000		211.0000
N	508.0000	Industrial water use Bosnia-Herzegowina	10.5000	10.5000		221.0000
N	509.0000	Industrial water use Yugoslawia	10.5000	10.5000		231.0000
N	510.0000	Industrial water use Ukraine	11.1000	11.1000		241.0000
N	511.0000	Industrial water use Bulgaria	16.3000	16.3000		361.0000
N	512.0000	Industrial water use Romania	17.3000	17.3000		371.0000
N	513.0000	Industrial water use Moldova	17.3000	17.3000		381.0000
N	601.0000	Water for irrigation Germany	4.1000	4.1000		23.0000
N	602.0000	Water for irrigation Austria	6.1000	6.1000		73.0000
N	603.0000	Water for irrigation Czech Rep	6.1000	6.1000		83.0000
N	604.0000	Water for irrigation Slovak Rep	6.1000	6.1000		93.0000
N	605.0000	Water for irrigation Slovenia	9.1000	9.1000		172.0000
N	606.0000	Water for irrigation Hungary	8.2000	8.2000		192.0000
N	607.0000	Water for irrigation Croatia	10.3000	10.3000		212.0000
N	608.0000	Water for irrigation Bosnia-Herzegowina	10.5000	10.5000		222.0000
N	609.0000	Water for irrigation Yugoslawia	10.5000	10.5000		232.0000
N	610.0000	Water for irrigation Ukraine	11.1000	11.1000		242.0000
N	611.0000	Water for irrigation Bulgaria	16.3000	16.3000		362.0000
N	612.0000	Water for irrigation Romania	17.3000	17.3000		372.0000
N	613.0000	Water for irrigation Moldova	17.3000	17.3000		382.0000
N	701.0000	Water use Linz	4.1000	4.1000		30.1000
N	702.0000	Water use Wien	5.3000	5.3000		50.2000
N	703.0000	Water use Bratislava	6.1000	6.1000		60.1000
N	704.0000	Water use Budapest	8.1000	8.1000		160.1000
N	705.0000	Water use Bukarest	15.3000	15.3000		330.1000
N	706.0000	Water use Ruse	16.1000	16.1000		340.1000
AEND		Djerdap I			102.1000	302.9000
AEND		Hrusova			101.1000	101.9000
AEND		Djerdap II			103.1000	303.9000
DYN		Maxima				400.0000
DYN		Compensation of negative streamflow				0.9000

* QRNW - minimum streamflow for navigation, from german Regulierungsniedrigwasser
** Qmin - minimum streamflow for ecological reasons