1 Introduction

The aim of this report is to evaluate past hydrologic and climate changes in the Thaya basin. The main objective is to present the steps and results of:

1. Hydrology modelling of impact of climate change

2. Water balance modelling

3. Adaptation measures

2 Concept of Hydrological and Water Balance Modelling of Climate Changes

The procedure for modelling the climate change impact on the hydrological regime (see Figure 1) may be concisely summarised as follows:

1. The chosen hydrological model is calibrated for selected catchment areas using observed data. The hydrological model should have a physical basis to make sure that it yields physically acceptable results also for unobserved conditions.

2. Input variables from a global or embedded regional climate model are transformed to scenario series for the individual catchment areas, namely by:
   a) statistical downscaling,
   b) Post-processing of the climate model output, i.e. by using the increment method or correction of systematic errors.

It is often necessary to relate the data from calculation cells of the climate model to the centre of a given catchment area by spatial interpolation. It is essential to have observed data at one's disposal in order to use all methods (a–b) correctly.

3. Simulation of hydrological balance for the scenario period is done using a calibrated hydrological model and scenario series.

4. Modelled discharge for the present and future periods are adjusted in the individual months using the quantile method.

5. Water balance model: WATERES.

6. Evaluation.

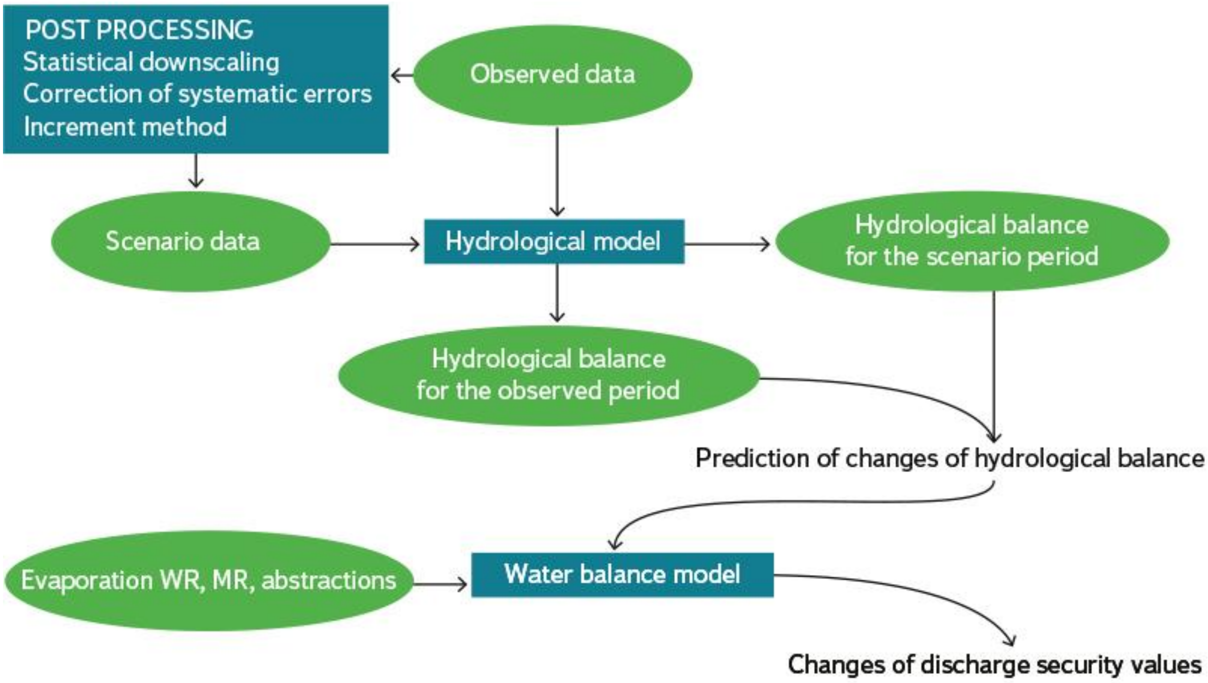

Figure 1 Scheme of hydrological modelling of climate change impacts

The evaluation of the climate change impact on hydrological characteristics has been followed by an assessment of the security of water demand with the help of the water balance method and simulation modelling of the storage function of water resources and supply systems. The simulation model simulates behaviour of the system in a chronological series of discrete time steps based on the knowledge of time series of natural discharges (unaffected by regulation and water abstraction/release), requirements for water use and maintenance of minimum discharges, technical parameters of the respective elements of the system (volume of the storage space of water reservoirs and water transfer capacity) and a model containing introduced rules of runoff regulation (handling rules). Time series of simulated activities are an output of the simulation: discharge and evaporation from the surface of water reservoirs, water demand, runoff from water reservoirs, water volume and water levels in the storage space of reservoirs. These time series are subsequently statistically evaluated. Security according to the duration of pt, defined in (ČSN 75 2405) has been evaluated as fundamental characteristics that expresses the security of water demand (to put it simply, it expresses a percentage share of the duration of a period during which water demand and minimum discharge requirements are secured out of the whole duration of the total assessed period).

2.1 Hydrological model

Hydrological model Bilan used for hydrologic modelling. An example of the resulting calibration for the DBC 4290 gauge station Janov, Moravská Dyje (DBCN 429000) is shown in Figure 2 (Bilan model). Other profiles in the area of interest in the Dyje/Thaya river basin were recalibrated and validated in a similar way for used hydrological balance models.

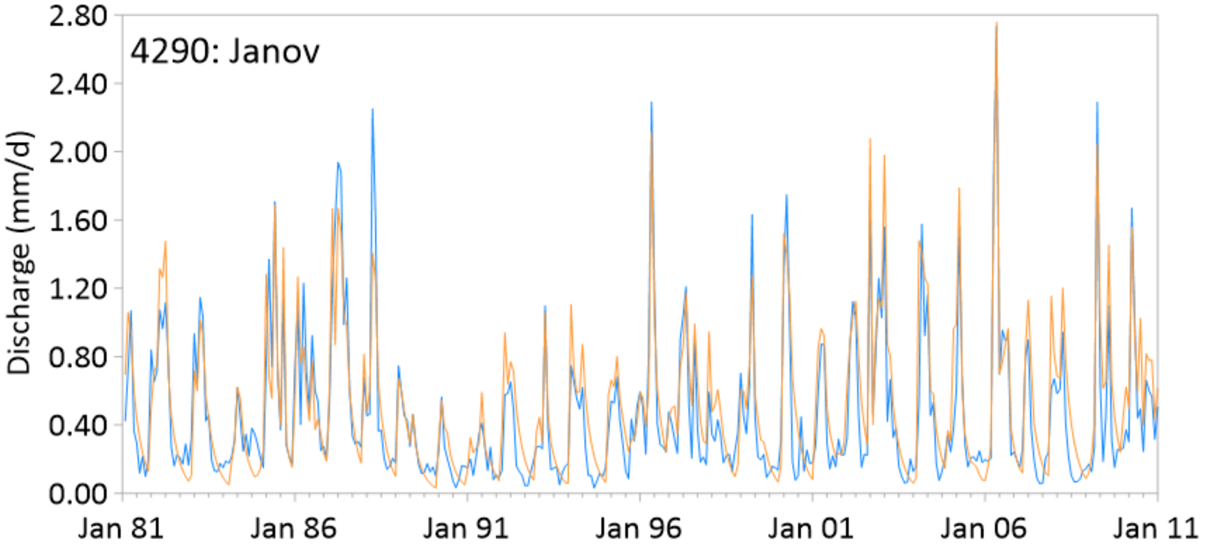

Figure 2 Comparison between observed (blue line) and simulated (orange line) monthly discharges at the Janov, Moravská Dyje gauge during the calibration period 1981-2010 (Bilan model).

2.2 Climate change scenarios

Climate change scenarios used in this study are based on CMIP6 simulations.

For all selected models of CMIP6-ScenarioMIP simulations downscaling was processed for SSP-scenarios 1-2.6, 2-4.5, 3-7.0 and 5-8.5, representing different socio-economic development pathways and including future development of anthropogenic emissions of greenhouse gasses and aerosols (Riahi et al, 2017):

- SSP1-2.6: Sustainable pathway
- SSP2-4.5: “Middle of the Road” scenario: Degradation of environmental systems, but some improvements concerning resource and energy use
- SSP3-7.0: “Regional Rivalry“ and conflicts allowing for only small economic development
- SSP5-8.5: “Fossil-fueled Development”

3 Water management model – description

To assess the availability of water resources, the institute of water balance is used, specifically the water balance of surface water and groundwater quantity. The water balance is defined in the study as a balance at two time levels:

a. *present/observations,*
b. *The periods affected by climate change.*

It can provide some indication of surface water problem areas only when its results (balance conditions) are evaluated over a longer period of time, provided that there have been no significant changes in water use and runoff control rules at the waterworks during this period. On the other hand, current and future water balances are a useful tool for assessing the availability of water resources in terms of their use requirements. The output of the surface water management balance is an assessment of the balance conditions and, consequently, the identification of sites that are or may in the future be problematic in terms of meeting water use needs (they are in a passive or stressed balance condition).

In the case of water quantity balances of current and future surface water quantities, the use of modelling methods is needed, especially in the case of the provision of water use requirements through water management systems. Simulation modelling of the storage function of the water management system can be applied as a suitable method (Vyskoč and Zeman, 2008).

Modelling the storage function of water management systems

The principle of the application of the simulation model of the storage function of a water management system can be described with a certain degree of simplification as follows (Vyskoč, Zeman, 2008):

A surface water management system is defined on a real catchment area, consisting of elements that characterize the behaviour of the system in terms of surface water quantity. These are elements/profiles (a) fulfilling the runoff regulation function (reservoirs and water transfers), (b) with influence/requirement on water resources (water abstractions and discharges, provision of minimum flows, levels and other activities) and (c) fulfilling the control function (evaluation of the influence of water use on the flow regime in the balance profiles). Thus, in the simulation model, the real system is represented only by these important profiles. The influence of the other elements is aggregated to the system profiles.

The water flow network, as the entity connecting the elements of the water system, is introduced into the model by a flow path, defining the sequence of elements in the direction of water flow. The simulation model simulates the behaviour of the system in discrete time steps based on the knowledge of the time series of natural flows (i.e. not influenced by water use and flow regulation), water use requirements, technical parameters of the system elements and the water management rules introduced into the model. The structure of the system elements and the water use requirements are assumed constant in the simulation model and the behaviour of the fixed system is investigated under different hydrological situations in the hydrological framework. The allocation of water from the sources to the users occurs at each time step according to the handling rules. In modelling terminology, this is the application of a static descriptive simulation model. The model simulates the storage function of the system over the length of the hydrological base.

In the actual calculation, the required flow (generally the sum of the minimum residual flow and the withdrawal in the profile, or the amount of water required for use) is compared with the value (of the system function above the profile affected) of the inflow to the profile in each profile of the system (downstream of the flow path). If the profile is within the reach of an active source with the potential for over-improvement, any deficit from the source(s) (reservoirs, or through water transfers within the given handling rules) will be made up, with cooperation between the two if necessary. The system profiles then evaluate the activities of the system elements at each step of the solution (water content/levels in the reservoirs, abstractions and discharges made, quantities transferred, natural and influenced flows). The simulation model use requires the following input data:

- Spatial data on the position of
    - watercourse network,
    - phenomena/profiles (relevant in terms of surface water quantitative balance) with respect to the river network.
- Hydrological data and records
    - time series of no-impacted average monthly flow rates in all profiles representing the water management system in the model (hydrological balance outputs in water metering stations and flow rates derived by hydrological analogy),
    - time series of average daily flow rates at points of abstraction for water transfers (to determine the calculated transfer capacity in a solution with a time step of 1 month),
    - basic hydrological data in the system profiles (for hydrological analogy and determination of the minimum/ecological flow rate regime),
    - annual evaporation from free water surface and its monthly distribution for water reservoirs introduced into the model.
- Water usage requirements, i.e.
    - monthly values of surface water abstractions,
    - monthly values of discharges into surface waters,
    - monthly values of groundwater abstractions (and their impact on surface water),
    - requirements for water table level/flow rate regime (energy, navigation, recreation, etc.).
- Requirements for maintaining minimum flow rate or respectively for the flow rate management, resulting
    - from the current water management regulations and water permit regulations,
    - from the requirements to achieve good ecological status.
- Technical parameters of water management structures in the system profiles
    - distribution of reservoir volumes,
    - characteristics of the reservoirs (elevation contours of flood areas and volumes),
    - technical capacities for water transfers.
- Management rules for the regulation of flow through the reservoirs and water transfers
    - capacities actively provided by the water reservoirs and water transfers,
    - ways of interoperation of sources in ensuring requirements of source enhancement
    - rules of water management in the storage space of water reservoirs.

To meet the above data requirements, the following data sources are available in the Czech Republic:

- Records kept in accordance with Section 22, Paragraph 2 of the Water Act and Decree No. 391/2004 Coll., as a part of the public administration information system, namely:
    - records of watercourses and their basins,

    - records of water reservoirs,,
    - records of surface water quantities
    - records of surface water abstractions,
    - records of groundwater abstractions,
    - records of wastewater discharges,
    - records of mine water discharges,
    - records of surface water accumulation in water reservoirs,
    - records of river basin districts,
    - records of water bodies, including heavily affected water bodies and artificial water bodies.
- Water management rules of water reservoirs.
- Reported data for compiling the water balance according to Decree 431/2001 Coll.
- Water management permits/decisions.
- Data from the hydrological balance (reconstruction of natural average monthly flow rates).
- Records of watercourses and hydrological basins kept in the Digital Database of Water Management Data (DIBAVOD), especially the geographical layer of hydrological sections of watercourses in a fine and/or coarse resolution. Part of the records is a description of the structure of the river network according to HEIS standards (i.e. through the so-called structural model of watercourses).
- Regional water supply and sewerage system development plans (PRVKÚK), or other conceptual materials for regional development.

To assess ensuring of water usage requirements and minimum flow rates, the basic the characteristic considered is:

- secure provision over time over the duration p_t, which is defined by the equation

$$p_t = (m - 0.3) / (n + 0.4) x100 [\%] \qquad (1)$$

where

m - number of time series members in which the required purpose is secured,

n - number of members of the whole series.

To assess the preservation of flow rates to achieve good ecological status, the basic characteristic considered is

- the probability of exceeding the natural and simulated impacted flow rates (respectively the exceedance curve of the natural and impacted flow rates).

In addition to these characteristics necessary for the assessment of the balance states (see below), the following additional characteristics are further considered:

- p_o, i.e. secured supply according to recurrence, for the determination of which equation (1) can be applied when years are considered to be the members of a series;
- p_d, i.e. secured volume supply, expressed as a percentage of the volume of water actually delivered from the total required quantity;

- the magnitude of the supply failure, expressed as a percentage of the undelivered volume of water (in a given month) of the total required volume;
- duration of the supply failure, which expresses the continuous length of the time series (months in this case) in which the requirement for full water usage has not been assured;
- reserve (+) / deficit (-), which is the difference between the achieved flow rate and the required minimum flow rate at the required supply safety level according to duration.

The regime of water table levels and emptying of storage spaces of water reservoirs is characterized by:

- the probability field of exceeding the water levels in the reservoir, which expresses the water table elevation in the reservoir achieved with a given probability;
- the percentage of members of the time series (in this case months) and the number of continuous periods in which the reservoir storage space is emptied;
- the maximum length of the continuous period of empty reservoir storage space.

3.1.1 Evaluation of balance states

The evaluation of balance states in the WMS profiles is an extension of the simulation model intended mainly for the processing of the water management balance of the current and prospective state of surface water quantity - see (Vyhláška č. 137/1999).

For the water abstraction requirements or achieving the minimum flow rate in the watercourse in the profiles of the water management system (i.e. local requirements in the system profile, not the requirements aggregated for the upgradient profiles).

- required supply security,
- permissible magnitude and length of supply failure.

After performing the calculation, the required values are compared with the values obtained in the simulation and subsequently the balance state is evaluated for the given water supply requirement. If at least one criterion is not specified, the balance state is not evaluated. Defined balance states and criteria for achieving them are provided in the table:

Tab. 1 Balance state and water supply security

	Balance state	**Water supply security**
🟩	**Active**	Failure free (full) fulfilment of the requirement
🟨	**Balanced**	Requirements fulfilled with required security and with allowable supply failure duration and/or magnitude
🟥	**Passive**	Required water supply security is not achieved or the failure magnitude/duration is greater than allowed

If more requirements are evaluated in the monitoring profile (e.g. abstraction from the watercourse or water reservoir while maintaining the minimum flow rate or outflow from the reservoir, or more abstractions with different requirements for supply security), the resulting balance state of the profile is determined by the less favorable balance state resulting from partial evaluation of the individual requirements.

Uncertainties in the evaluation

For the application of the balancing procedures in the Czech Republic, an extensive database is established at the national or regional level. However, prior to its use, it is advisable to analyse the input data in more detail (due to their representativeness) in order to assess and possibly reduce (if more detailed data are available) the potential level of uncertainty in the assessment (especially in balance-stressed sites).

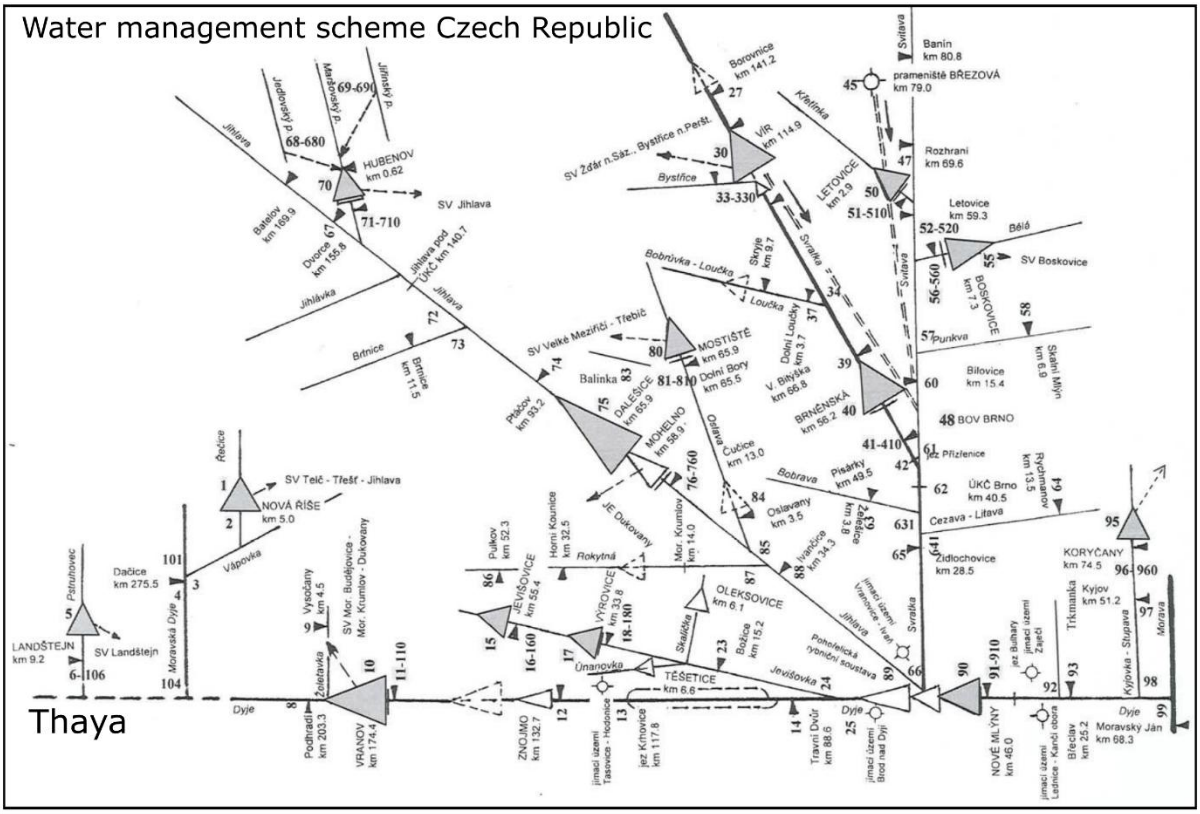

Figure 3 Water management scheme Czech Republic – spatial structure

3.2 WATERES, TGM WRI model

The main purpose of the Wateres package is calculation of various reservoir characteristics in order to evaluate its effectiveness. The package is focused on long-term reservoir balance in monthly time step, although some calculations for hourly and daily data are also supported. The model and vignettes (model settings, tutorials and example) are available on: https://github.com/tgmwri/wateres. The model were developed at WRI TGM (department of hydrology) and is part of the HAMR system: https://hamr.chmi.cz, which is based on models and the link is: SoilClim -> Bilan -> WATERES. The system provide weekly drought assessment and predictions for water bodies in the Czech Republic.

An R package Wateres focused on calculation of characteristics and performing simulations for water reservoirs. The model can be used to calculate:

- long-term water balance of reservoirs and their systems,
- water reservoir characteristics to estimate its effectiveness,
- deficit volumes for individual catchments and reservoirs and their systems,

- flood wave transformation.

Setting and input data

All input information about the reservoir is stored in an instance of the *wateres* class. To create this, a data frame with time series (currently date and average reservoir inflow in $m^3 \cdot s^{-1}$) of input data is needed. Alternatively, a file containing the series can be used.

Together with the time series, reservoir potential storage and corresponding flooded area have to be specified.

Evaporation from the flooded area of the reservoir can be set directly as time series (of the length equal to the length of the inflow data or 12 monthly values; in mm) or it can be estimated by a method according to the Czech Technical Standard, where evaporation is a function of reservoir altitude.

Similarly, time series of water use from the reservoir are set. The water use values can be both positive and negative, meaning water release to the reservoir (added to the water balance in any case) or withdrawal from the reservoir (i.e. water demand of lower priority than yield), respectively. The *set_wateruse* function accepts a constant value, 12 monthly values or complete time series (in m^3).

Precipitation is supposed to affect the reservoir flooded area corresponding with the maximum storage.

Calculating reservoir water balance

To calculate time series of water balance variables of the reservoir, use the *calc_series* function.

A required yield is the only argument to be set (as a fixed yield or a vector of values), however both maximum and initial storage can be also specified. Additionally, water levels can be calculated if elevation-area-storage relationship has been given and the *get_level* argument is set.

The output is returned as a *wateres_series* object, i.e. a data table with water balance variables. It can be easily visualized by its plot function using the ggplot2 package. Three plot types – flows, storage and levels are supported.

The *summary* function is a more convenient and concise way how to obtain reservoir characteristics. It employs the *summary* function and requires the same arguments. Moreover,

- a vector of reliabilities can be entered instead of a single value,
- a set of further characteristics is returned, including level of development, standardized net inflow, resilience and vulnerability.

The water model was compared with the water management model that has been used for a long time in the TGM WRI for the evaluation of water management systems. The results of the model are similar in terms of the evaluation of long-term balances, the differences are mainly in the input of boundary conditions, such as handling rules, which are simplified in the WATERES model.

Setting up the UPOV network and the network of reservoirs in the UPOV

For the selected terminal water bodies (UPOV, i.e. the UPOV whose total runoff is of interest), a river network diagram is first drawn up (see

Figure 4 left). This diagram contains all water bodies (UPOVs) that contribute to the total runoff from the end UPOV and their connections within the constructed network. Within each UPOV, a diagram of the reservoir network (see

Figure 4, right) is also drawn up, i.e. their location (main or side stream), possible connection of side streams in the reservoir to the mainstream, etc.

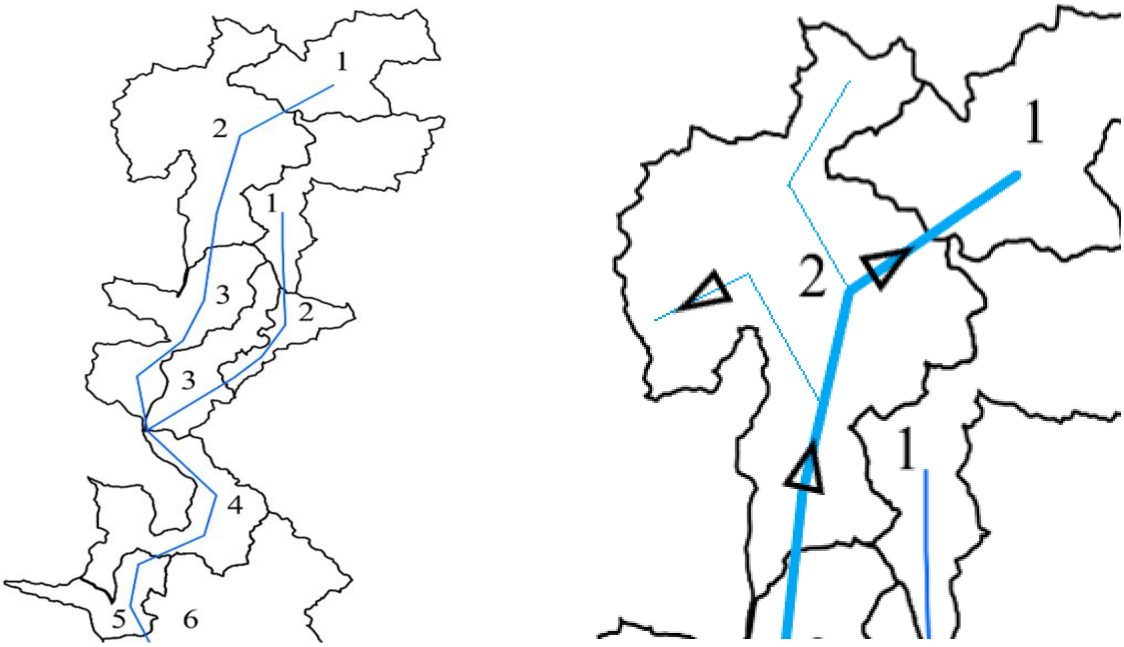

Figure 4 On the left a scheme of the river network consisting of 9 water bodies (UPOVs), the end UPOV is of the sixth order. Right figure of the network of reservoirs (black triangles) in the selected UPOV, bold blue shows the mainstream and thin blue the secondary streams

Channel transformation

Since the river networks created can be very large (e.g., the entire Dyje/Thaya river basin with the closure profile in Břeclav), it is necessary to introduce a channel transformation in the MRS that simulates the time delay of inflow from the upstream UPOVs to the downstream UPOV. This delay can be solved in WATERES by two methods:

1) lag and linear reservoir, which are always solved in a UPOV closure profile whose order is higher than 1. The lag method is based only on the time shift of the simulated runoff as it passes through the network [min]. The input here is a time series of the untransformed runoff (i.e. the sum of the transformed runoff from the upstream UPOV and the runoff from the solved UPOV) and a parameter determining the shift (lag parameter [min]). The output is a time series of the transformed runoff of the UPOV.
2) The second method is the linear reservoir method, which is based on numerical discretization of the storage equation (Ponce, 1989). The input here is also the time series of the untransformed runoff and the residence time parameter in the linear reservoir [min], a possible further input is the initial storage in the transformed reservoir [m^3].

Estimation of the transformation reservoir parameter

For the Dyje/Thaya system, the method of transforming the runoff through the channel using a linear reservoir was chosen. Therefore, it was necessary to estimate the value of the outlet coefficient of the reservoir for each UPOV. This estimation was done based on a proposed regression relationship where the independent variables were the average slope of the UPOV valley and the length of the main stream in the UPOV. The coefficients of the proposed regression equation were calibrated on a set of river networks where the total runoff from the terminal UPOV was known. The obtained equation was then implemented in the Dyje/Thaya system to estimate the discharge coefficient for any UPOV.

3.3 WATERES water balance model

The first part of the chapter describes the results for the current hydroclimatic conditions and the influence of water management on the flow regime based on simulations of hydrological models. In the second part, the impact of climate change based on different scenarios and different types of water management is presented.

Time of exceedance curve for current hydro climatic conditions based on water use scenarios and UPOV DYJ_1300 (representing outflows from the whole catchment Dyje/Thaya) is on Figure 5. It can be observed that the proposed impact of water management under the water supply scenarios is relatively small from a balance point of view for the whole catchment profile.

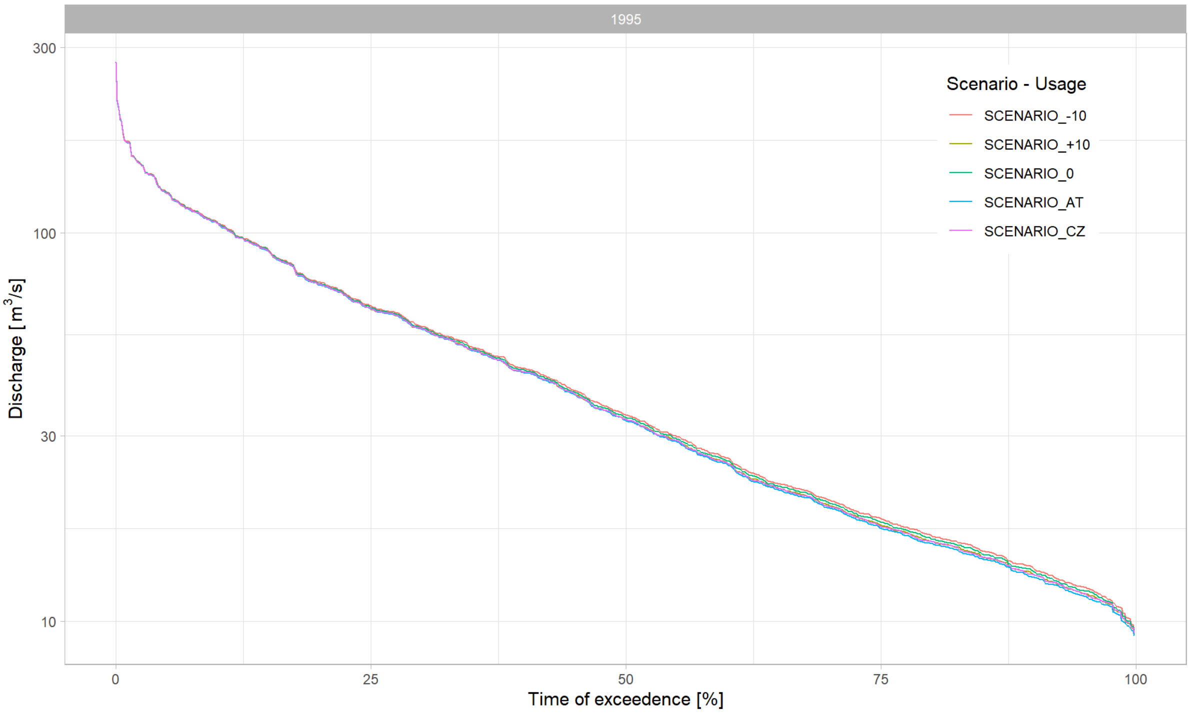

Figure 5 Time of exceedance curve for current hydro climatic conditions based on water use scenarios

The impact is mainly in locations where more significant abstractions occur with respect to the size of the water resources. This is illustrated in the Figure 6, which shows the mean relative changes (in percent) in flows under each water supply scenario. The change is relative to current water management (current abstraction). An increase in flows can be observed for the -10 percent loading scenario and a decrease in flows especially for the scenario called SCENARIO_AT. The maximum percentage changes in each water body are on average up to +- 10 percent. This phenomenon, is more escalated during periods of reduced water availability when water supply disruptions may occur.

The absolute changes of discharges are then shown in the Figure 7, with the visible differences being, of course, in the lower part of the catchment, where the effect of individual measures bases on water supply accumulates. The impact of the different scenarios compared to the current water management ranges on average from -2 to 2 m^3/s. This amount is no longer negligible in the drought and vegetation season.

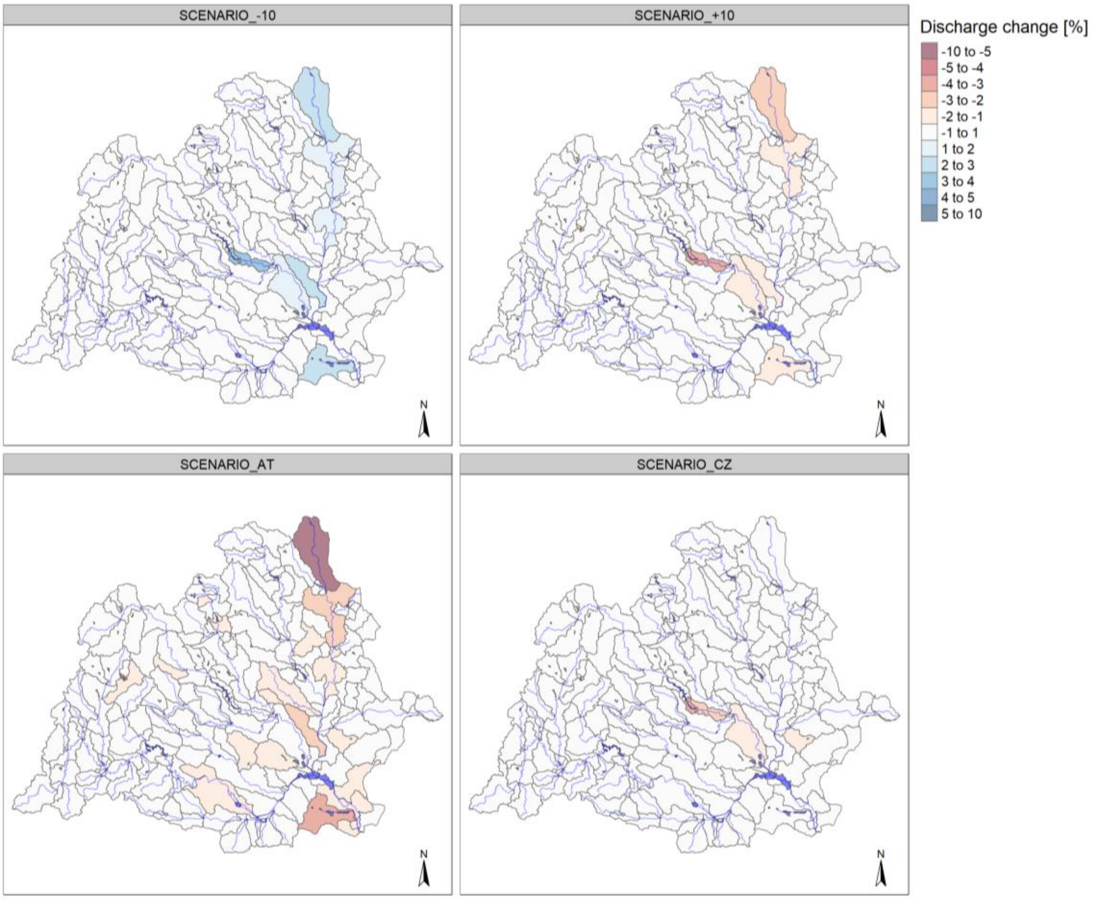

Figure 6 Relative changes in mean discharges (management scenario - current water management) in m^3/s for individual water bodies

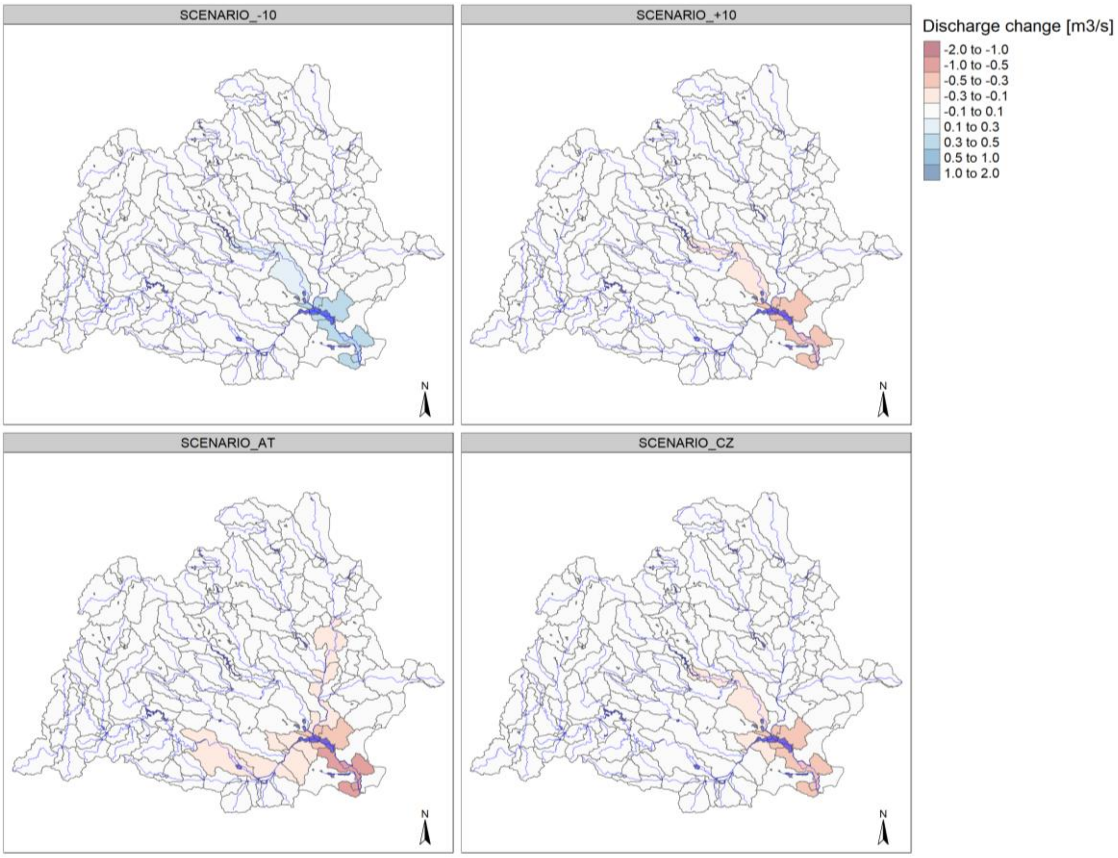

Figure 7 Absolute changes in mean discharges (management scenario - current water management) in m^3/s for individual water bodies

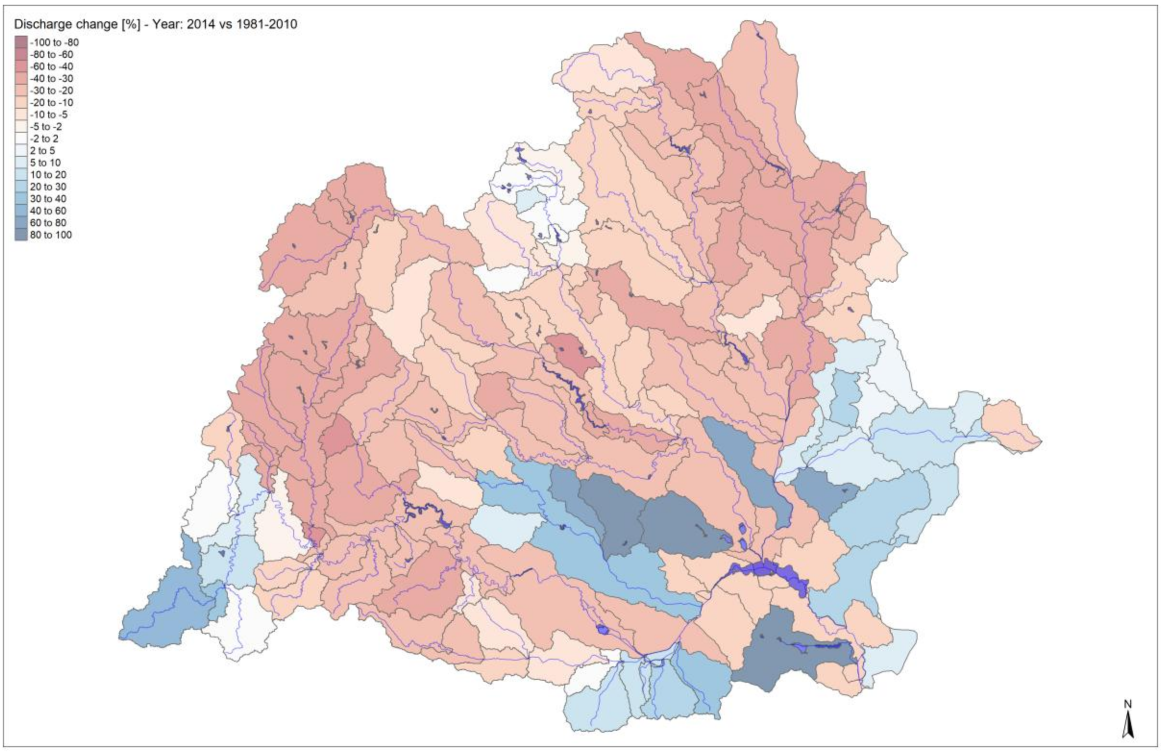

Figure 8 Relative discharge change (mean annual discharge 2014 vs reference period 1981-2010)

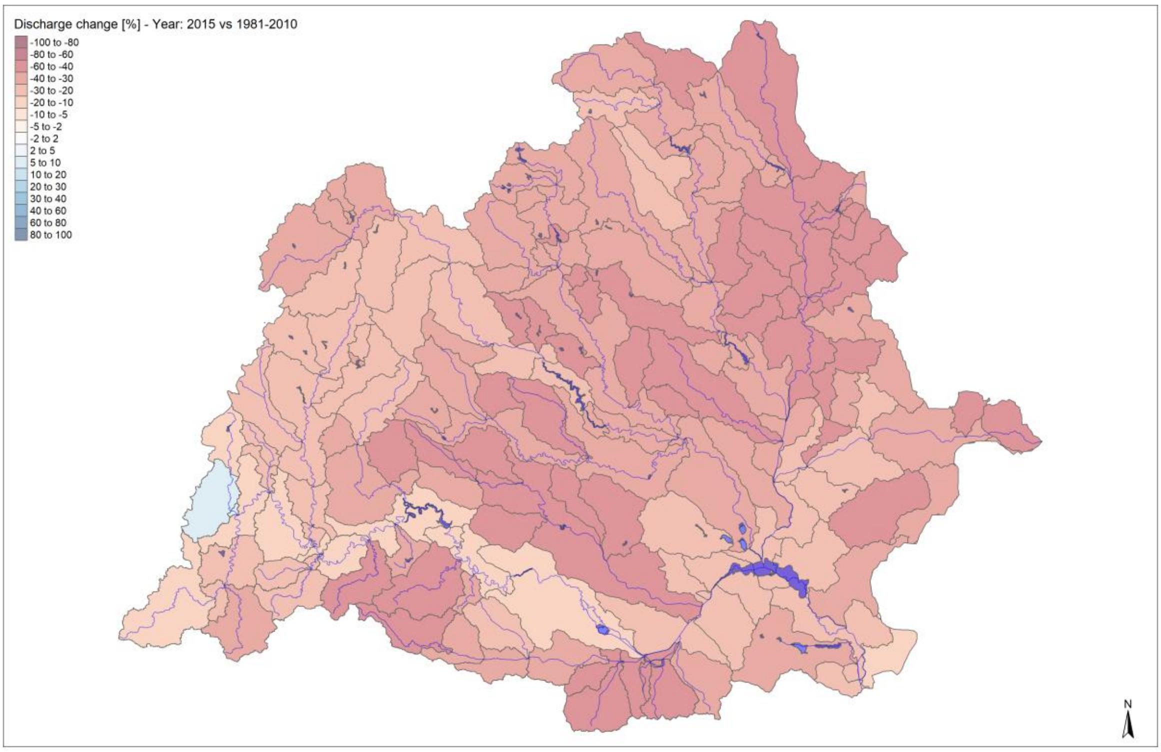

Figure 9 Relative discharge change (mean annual discharge 2015 vs reference period 1981-2010)

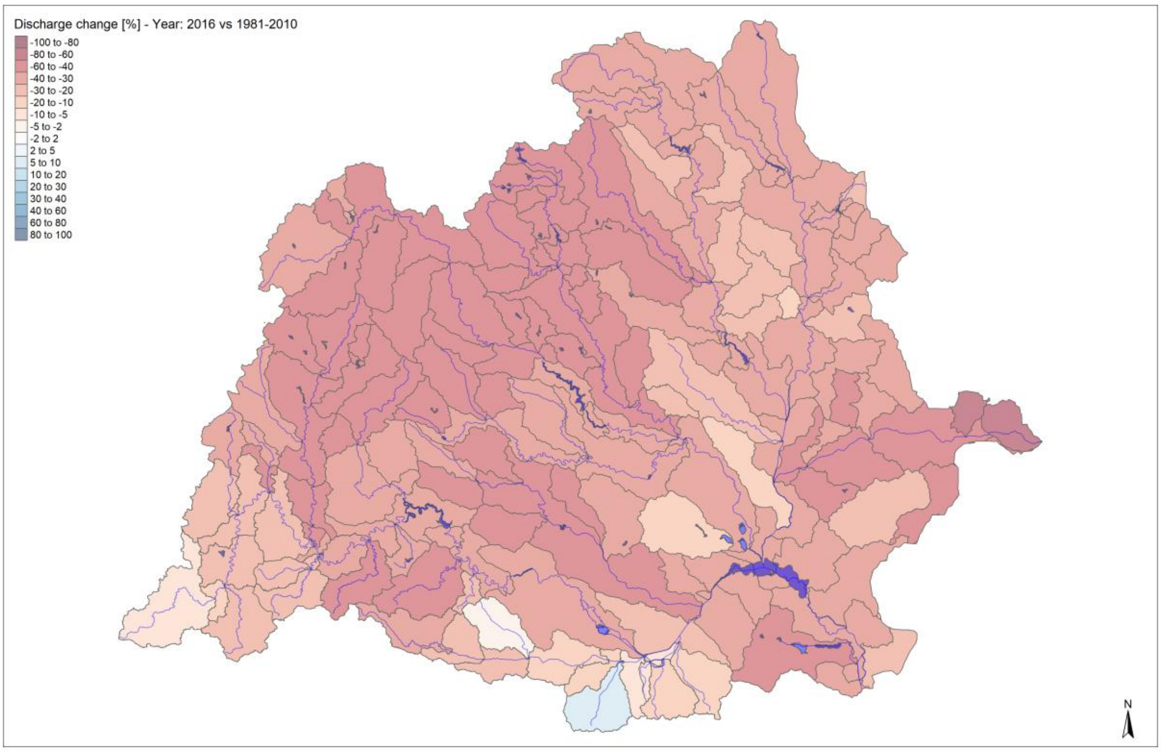

Figure 10 Relative discharge change (mean annual discharge 2016 vs reference period 1981-2010)

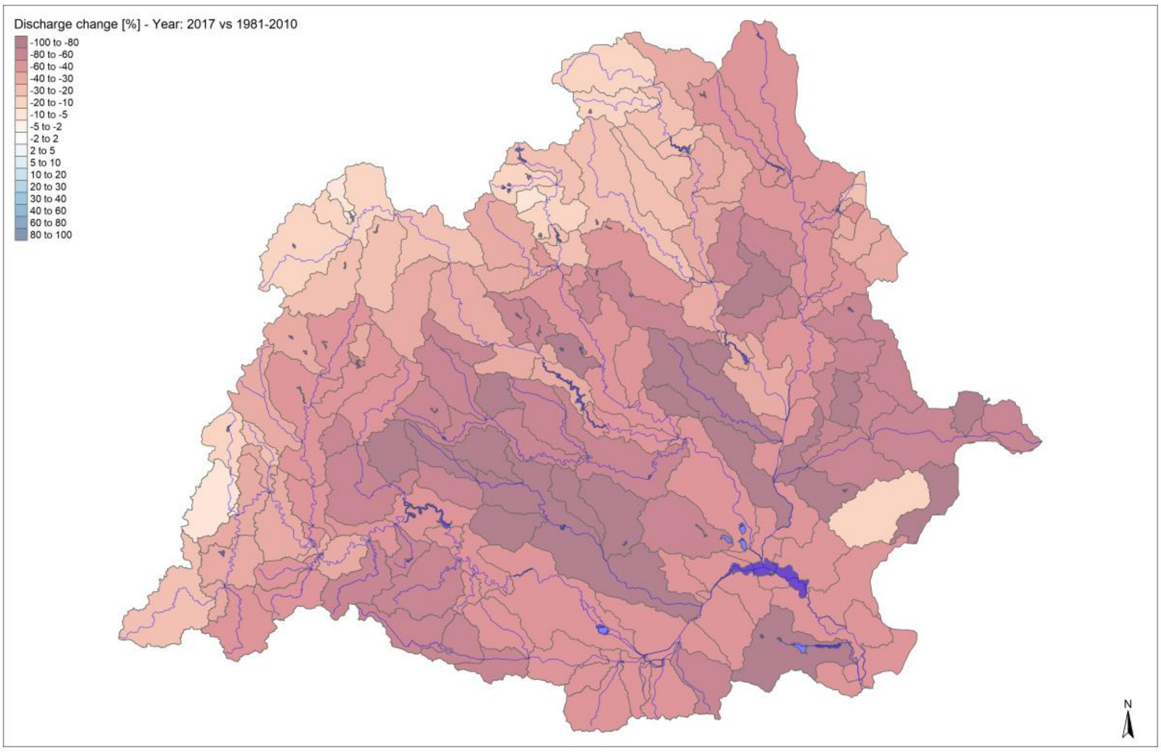

Figure 11 Relative discharge change (mean annual discharge 2017 vs reference period 1981-2010)

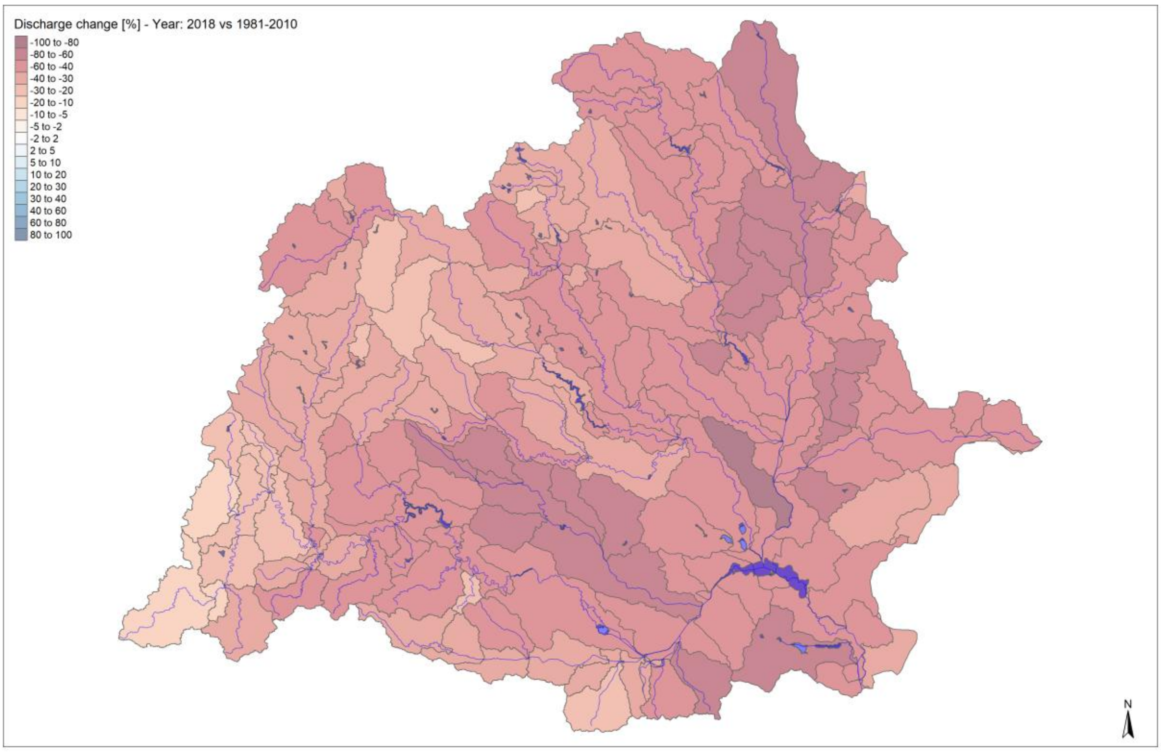

Figure 12 Relative discharge change (mean annual discharge 2018 vs reference period 1981-2010)

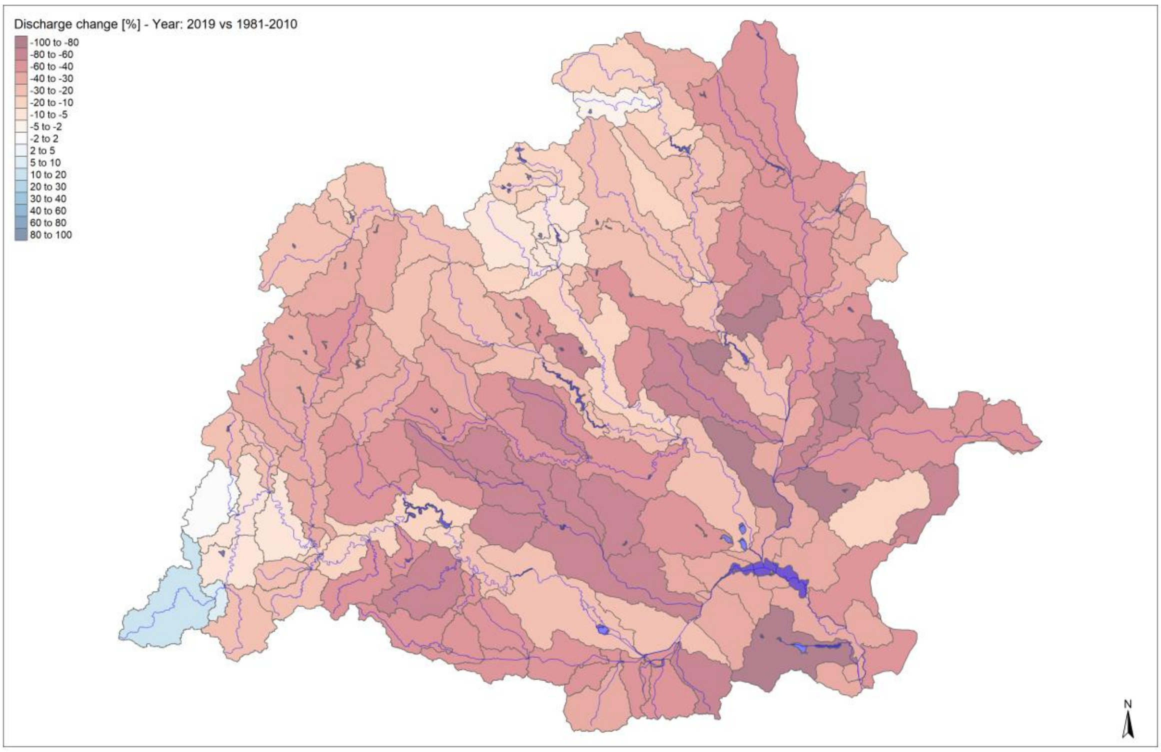

Figure 13 Relative discharge change (mean annual discharge 2019 vs reference period 1981-2010)

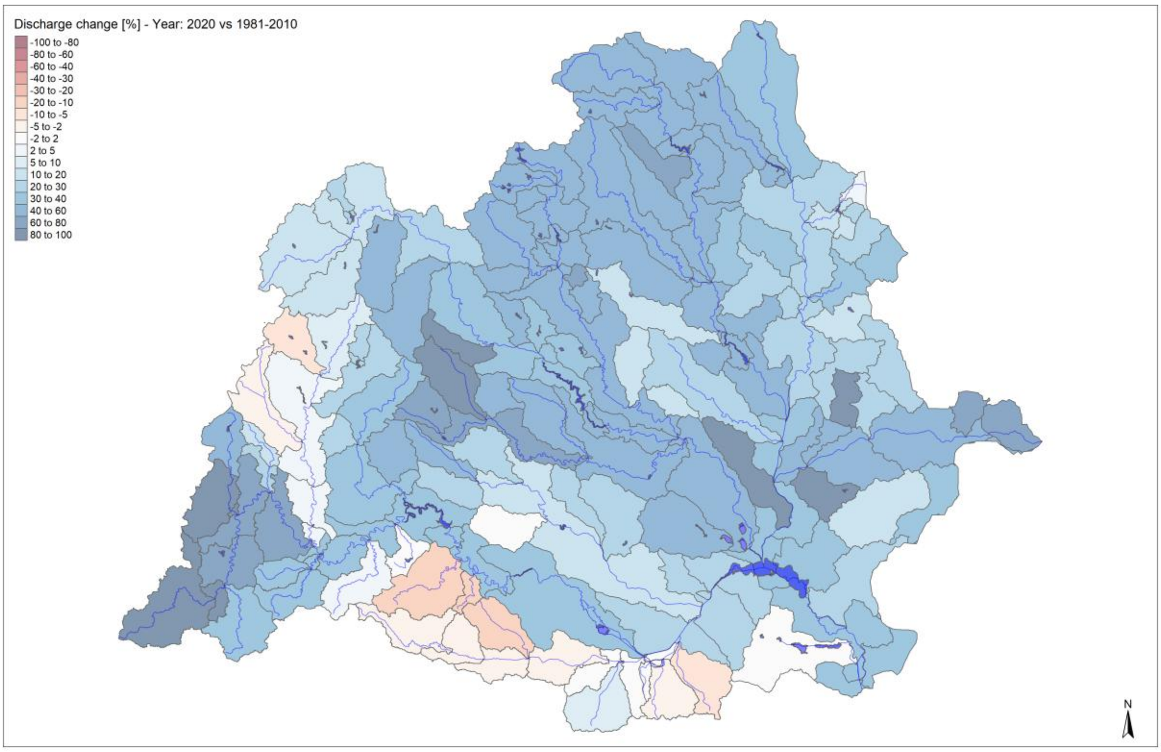

Figure 14 Relative discharge change (mean annual discharge 2020 vs reference period 1981-2010)

Figure 15 shows an example of the overall variability of the discharges according to the individual RCM/GCM simulations for station DBCN 480500. The blue line is the current state.

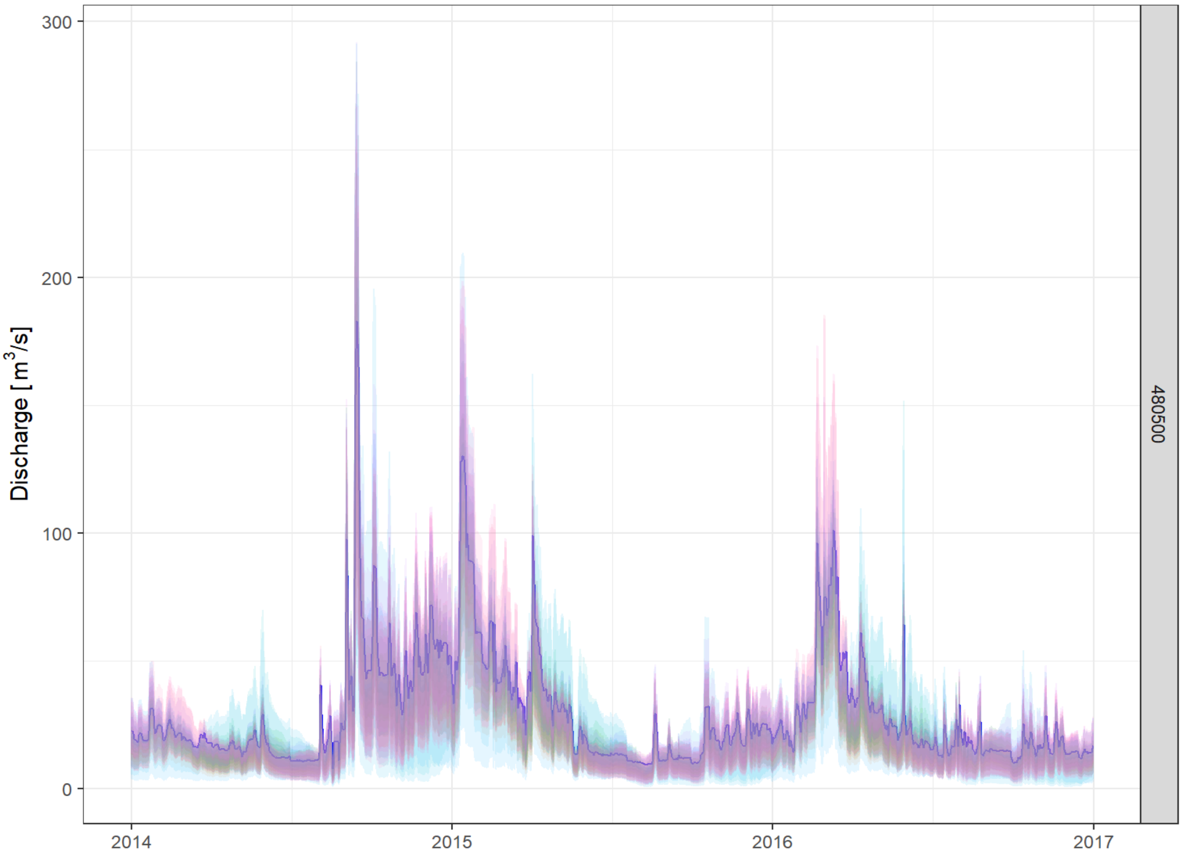

Figure 15 Demonstration of flow variability for station DBCN 480500 and the period to 2050

Similarly, the time of exceedance curve were generated from these data and are shown in Figure 16-Figure 19 for the 2030, 2050, 2070 and 2085 time horizon's and the individual simulations (split into graphs based on the emission scenarios). A decrease of discharges can be observed under most simulations and the variability is many times higher than under the use of water management scenarios.

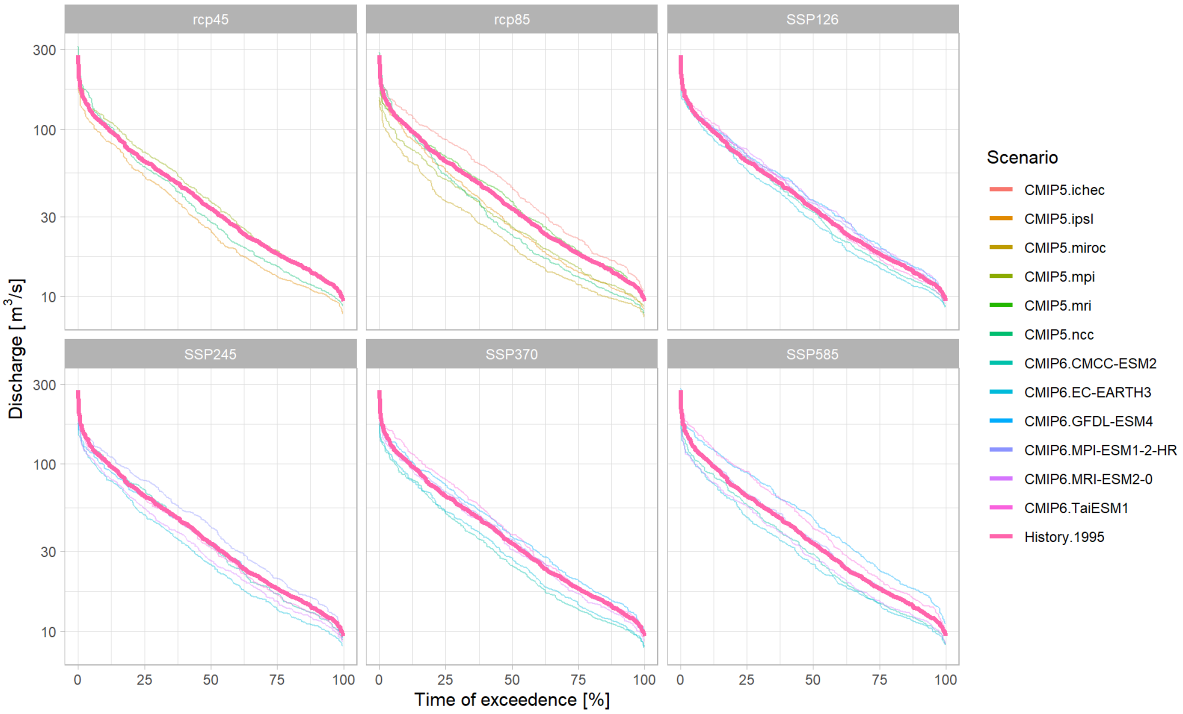

Figure 16 Time of exceedance curve for the 2030 time horizon and individual simulations (broken down into graphs based on emission scenarios)

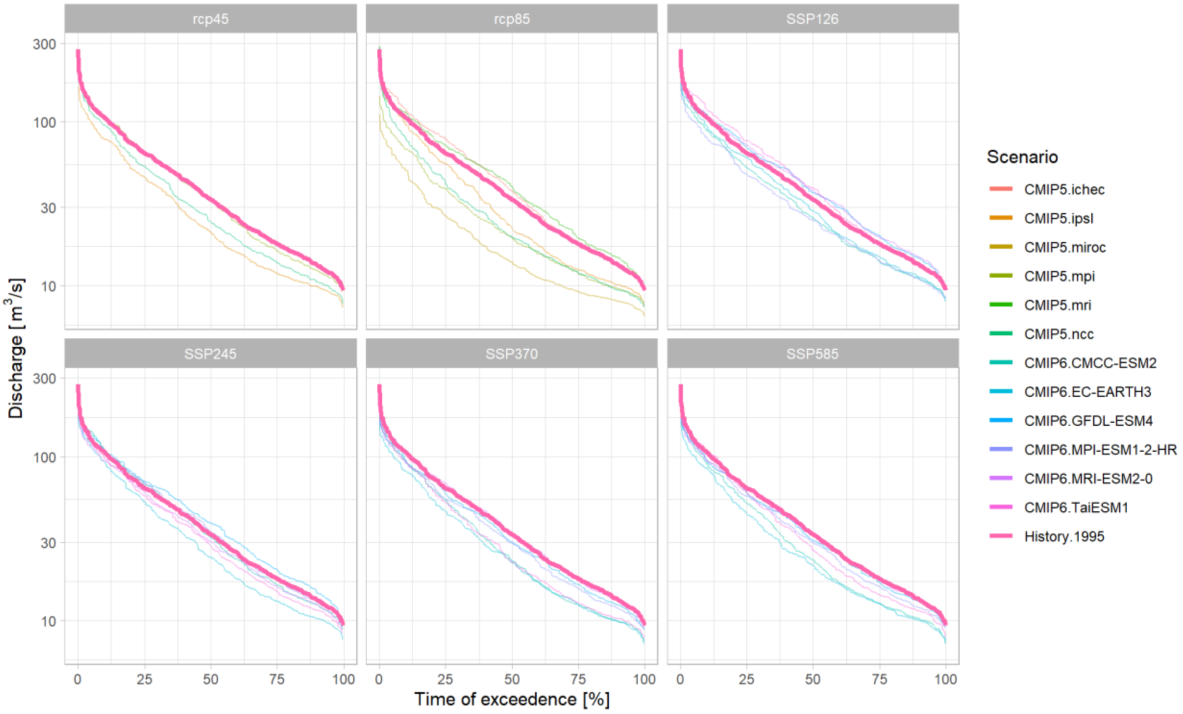

Figure 17 Time of exceedance curve for the 2050 time horizon and individual simulations (broken down into graphs based on emission scenarios)

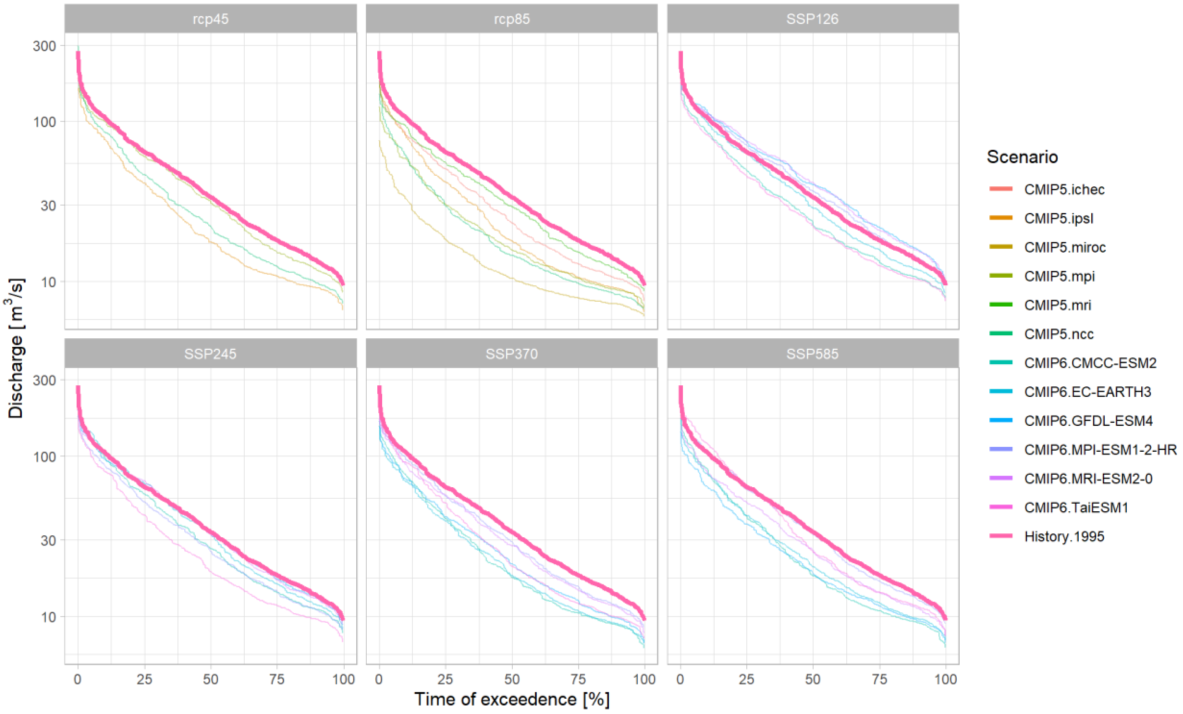

Figure 18 Time of exceedance curve for the 2030 time horizon and individual simulations (broken down into graphs based on emission scenarios)

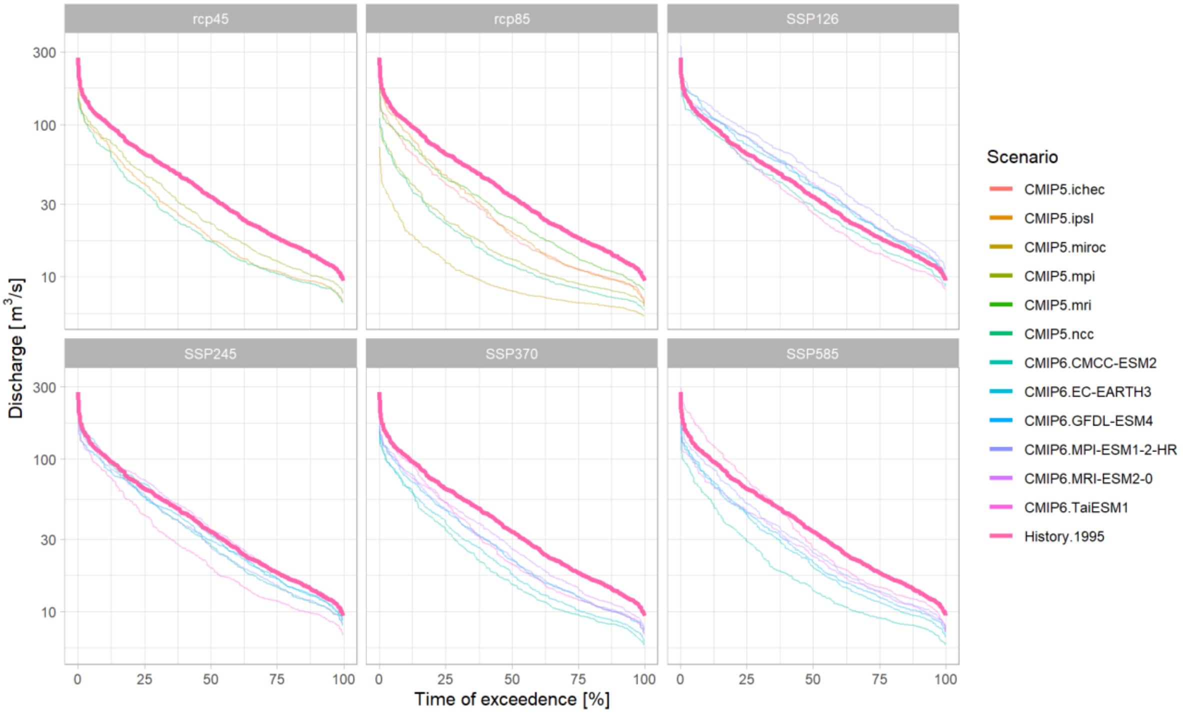

Figure 19 Time of exceedance curve for the 2085 time horizon and individual simulations (broken down into graphs based on emission scenarios)

An example of one of the outputs showing the change in mean absolute discharges according to the GCM and NCC simulation for emission pathway SSP245 and the time horizon 2030 is shown in Figure 20. The change is related to the current hydro climatic condition and current water abstraction. Less change can be observed in the figure between the different water use scenarios than for the history (1991-2020), which is due to the greater influence of climate on the discharges.

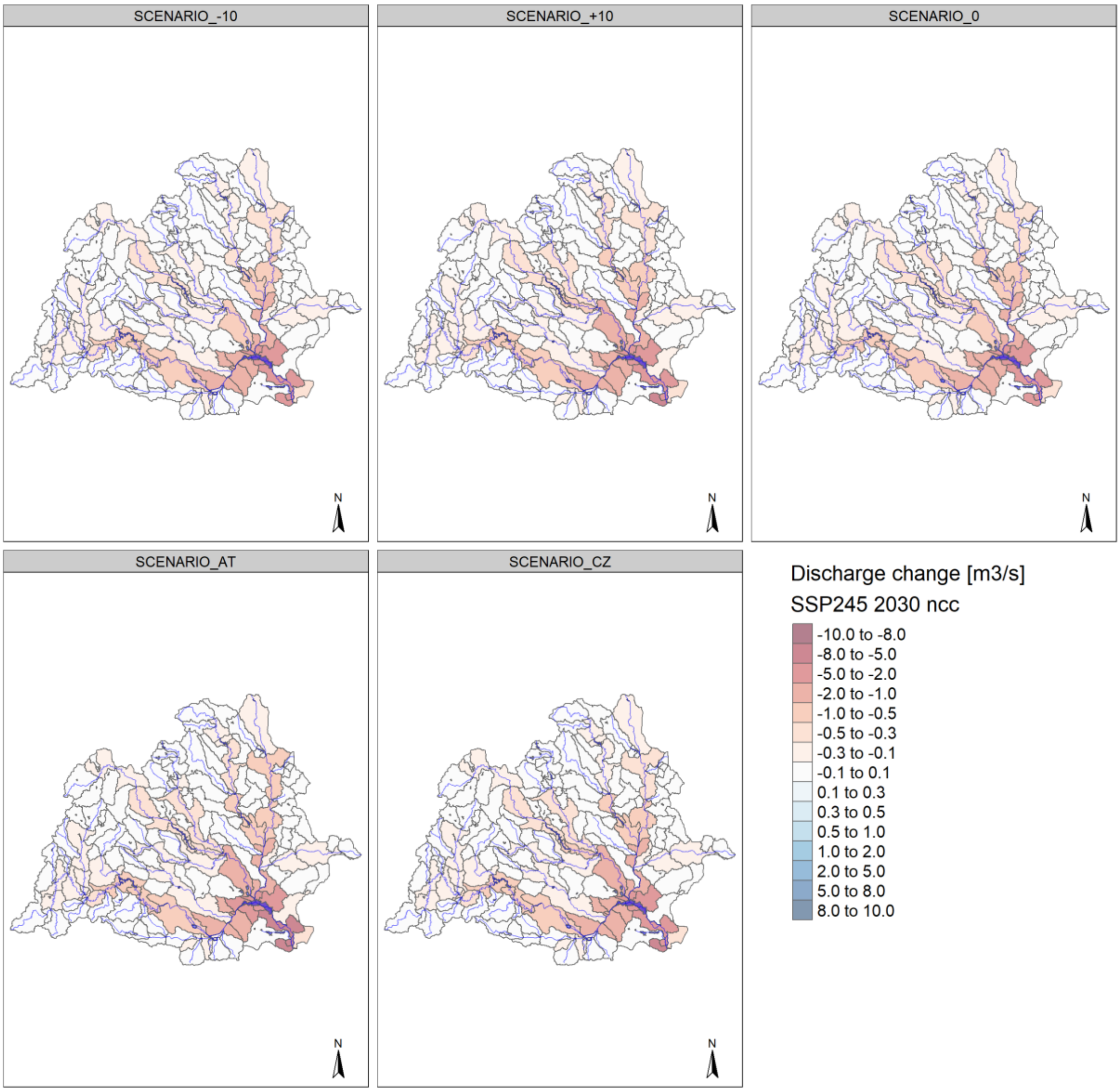

Figure 20 Absolute mean change of discharges for period 2030 and run SSP245-ncc

Sensitivity analysis

A sensitivity analysis (due to significant uncertainties in GCM/RCM simulations of rainfall totals) based on Bilan/WATERES was performed as part of the solution. The input data (for the present) were warmed by 1, 1.5, 2, 2.5, 3 and 5 °C and simultaneously the precipitation totals were corrected by factors of 0.9, 0.95, 1, 1.05 and 1.1 (e.g. 1.1 means a total increase in precipitation of 10%). The adjusted climate series were input to the Bilan model and subsequently to the WATERES model. Figure 21 Mean discharges according to the sensitivity analysis (absolute temperature changes on the x-axis, relative precipitation changes on the y-axis) shows the average discharges and shows the high variability of the flows especially in the water bodies on the lower part of the Dyje/Thaya, where are the absolute changes higher (logically, there are higher discharges). Lower part of catchment is on Figure 22. Outflow (mean annual discharges) from Dyje/Thaya catchment varies based on climate scenarios (changes in precipitation and temperatures) from 14 m^3/s (increasing of temperature 5 °C and 10 % decreasing of precipitation) to 49 m^3/s (no changes in temperature and increasing of precipitation 10 %). At this location (gauge station DBCN 4805), the long-term average discharges for the period 1991-2020 is 34.1 m^3/s, with a basin-wide mean annual precipitation of 595 mm/year.

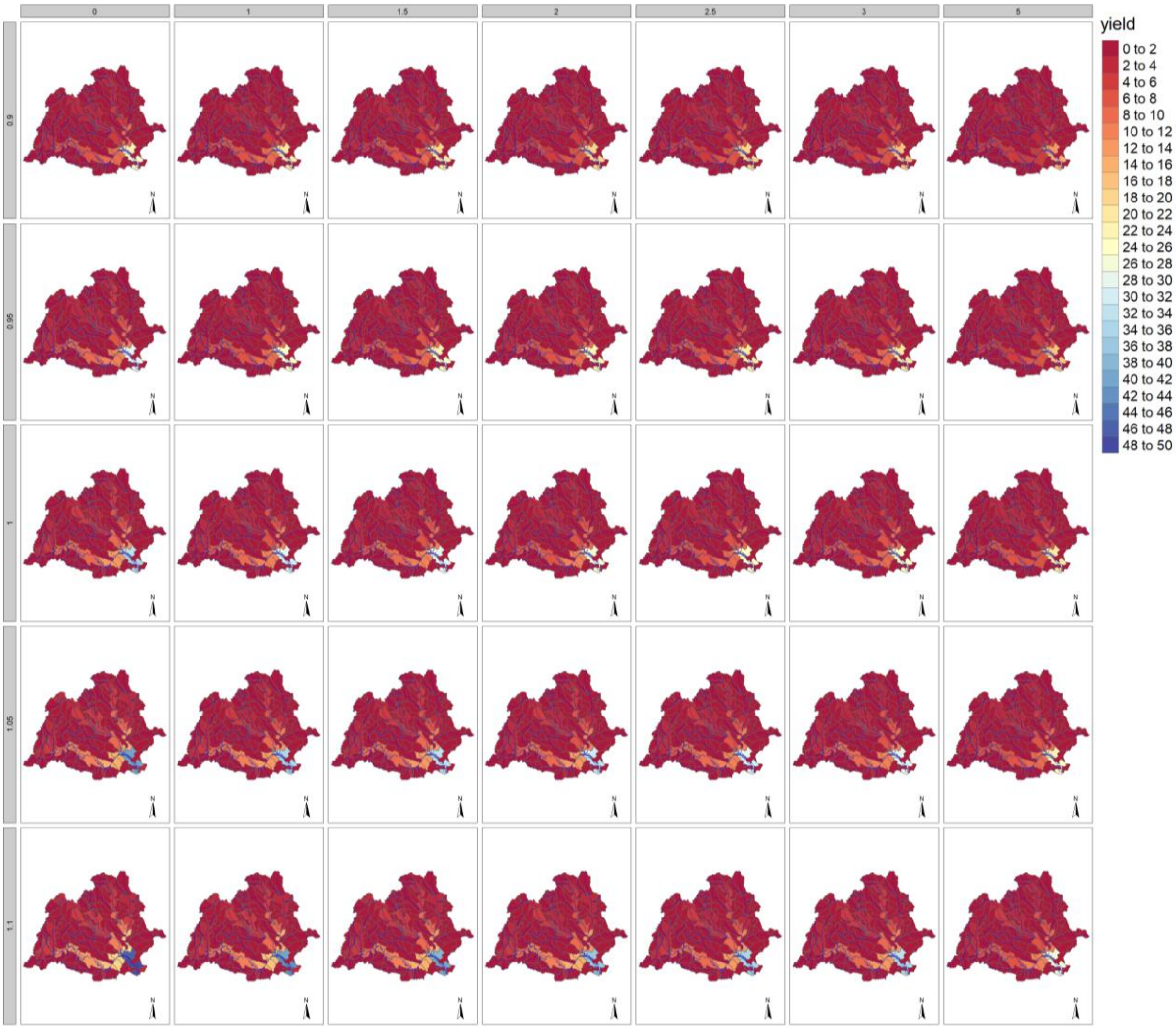

Figure 21 Mean discharges according to the sensitivity analysis (absolute temperature changes on the x-axis, relative precipitation changes on the y-axis), whole Dyje/Thaya catchment

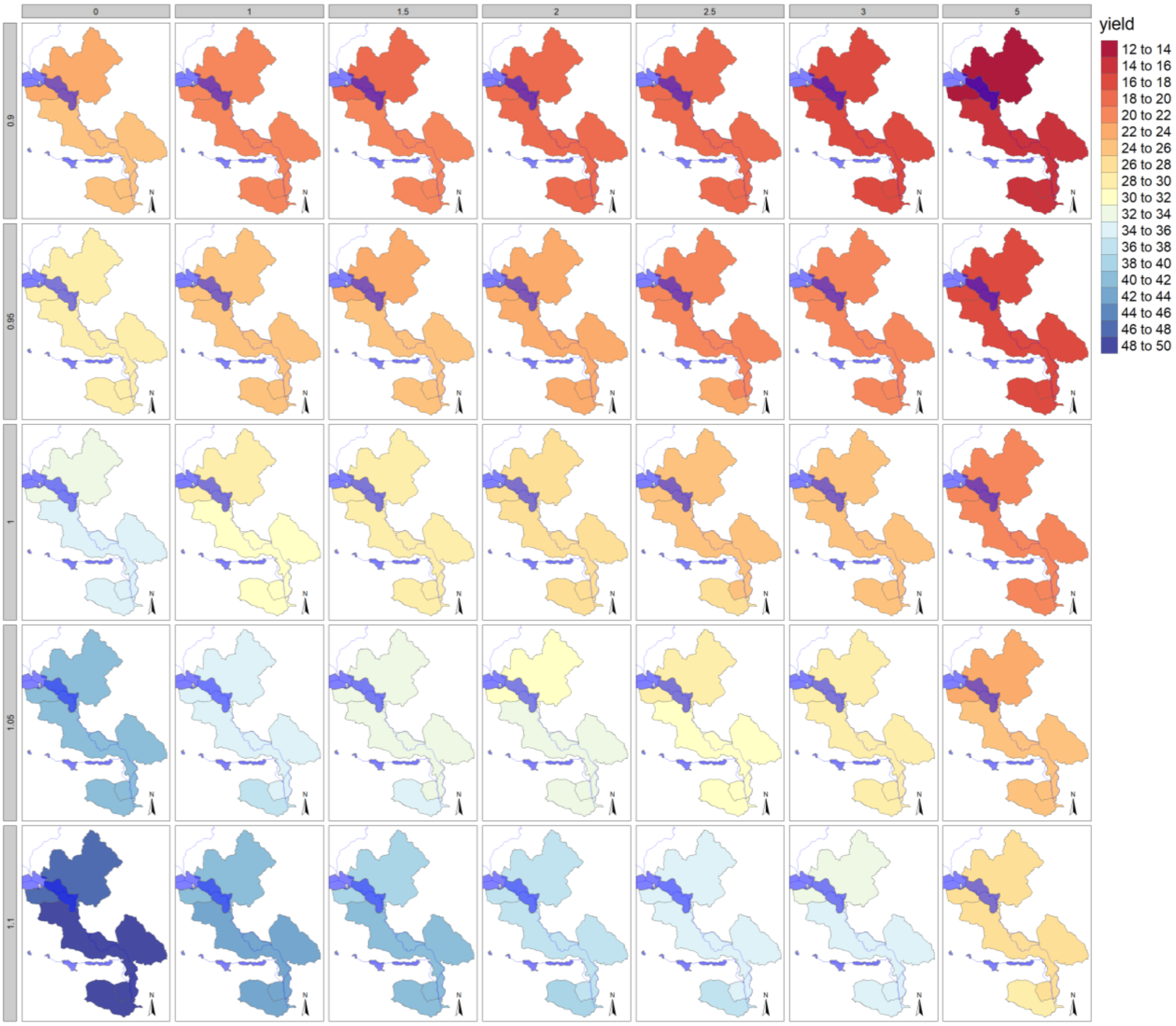

Figure 22 Mean discharges according to the sensitivity analysis (absolute temperature changes on the x-axis, relative precipitation changes on the y-axis), selected UPOVs which representing outflows from whole Dyje/Thaya catchment

3.4 Adaptation measures

Classes of adaptation measures (based on the Concept of drought protection for the territory of the Czech Republic, approved by the Government of the Czech Republic, 2017):

I. The first class of adaptation measures includes preventive adaptation measures. They can be introduced continuously and their aim is to prevent the occurrence of an undesirable condition or to reduce the consequences of adverse drought conditions.

Promoting the use of modern technologies in the water sector
During dry periods, the quality of surface water deteriorates mainly due to inadequate mixing of water due to lower flows in watercourses. There is a need to introduce state-of-the-art wastewater treatment methods to help ensure the production of drinking water, even from raw water of poor quality. However, in the first instance, efforts should be made to prevent deterioration in quality by eliminating pollution in the catchment area and, if these measures are not sufficient, to move to the next step, which may be the introduction of more modern technologies in the water sector.

Promoting the modernisation and development of agricultural irrigation

The current system of irrigation of agricultural land suffers from high water losses, for example due to evaporation during spraying. Losses can also be caused by wear and tear on the pipes that bring water to the land. By investing in water efficiency for irrigation, in particular by using modern irrigation methods (drip irrigation), a significant reduction in water abstraction can be achieved.

II. In the second class are measures to increase the resilience of the system. These measures lead to the strengthening of individual elements of the water system for better resilience to drought.

Water transfers between river basins and increased integration of water management systems

If there are surface water resources with a positive water balance surplus in a location vulnerable to drought impacts, consideration can be given to transferring this surplus to watercourses or reservoirs where there is a water balance deficit. The connection of existing reservoirs to water management systems seems to be very appropriate. Appropriate manipulation of the reservoirs can achieve efficient water resource management and ensure water abstraction in areas affected by water shortages. The potential use of water transfers should be assessed on the basis of the amount of water they can provide, together with the economic cost of the measure. The advantage is the possibility of transferring water not only within a river basin but also between river basins.

Connecting group and local water supplies to water supply systems

If there are several independent networks of group and local water supply systems, connecting them to water supply systems with sufficient resources can be a very effective measure. A secured group water supply can strengthen the function of a water supply network that may have problems in securing sufficient water resources. The measure is particularly complex when dealing with the ownership of the networks and analysing the existing water supply infrastructure.

Interconnecting water supply systems

The possibility of interconnecting several independent water supply systems that can subsidise each other in case of problematic periods for water supply. Accurate identification of available water supply systems is necessary.

Rehabilitation of existing and construction of new irrigation reservoirs

The establishment of an irrigation storage reservoir from which irrigation on agricultural land will be provided is a solution for those sites where filling of the reservoir from an existing watercourse (at times of sufficient flows) can be envisaged, or a transfer of water from nearby water sources (reservoir, watercourse) can be considered.

Application of artificial infiltration and bank infiltration technologies to increase groundwater resources

Artificial infiltration technology has a long tradition and great potential in the Czech Republic, but it is still used only to a small extent. By infiltrating precipitation water into the rock environment, it creates a water supply in the groundwater resources and prevents rapid surface runoff without benefit. The infiltrated water is 'stored' in underground aquifers and ready for use.

III. If the previous classes of measures cannot be implemented or fail, the most costly and procedurally complex adaptation measure of the last third class must be resorted to.

New multi-purpose reservoirs

The construction of new reservoirs is usually the most effective adaptation measure to address the problem of scarcity of water resources, both to provide abstractions for drinking purposes and to ensure minimum environmental flows. Reservoirs on watercourses can hold large volumes of water, which can most efficiently make up for deficits in the water system.

Article 4.7 of Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy states that Member States shall not infringe this Directive where the failure to prevent deterioration from very good to good status of a surface water body is due to new permanent human development activities, where the benefits provided by the alteration of the water body cannot, for reasons of technical impracticability or disproportionate cost, reasonably be achieved by other means which would be significantly better in environmental terms. It follows that a reservoir proposal should include a demonstration that the desired objectives cannot be achieved by other means. This means that it must be assessed whether the required benefits can be achieved by other measures at a proportionate cost.

There are 65 sites protected for surface water storage (hereinafter referred to as LAPV) in the territory of the Czech Republic, these sites are listed in the document 'Generel of sites protected for surface water storage and basic principles of use of these sites', which was prepared jointly by the Ministry of the Environment of the Czech Republic and the Ministry of Agriculture of the Czech Republic in 2011. The presence of LAPVs in areas of interest affected by a lack of water resources provides an opportunity for their potential use.

New significant groundwater resources

Significant new groundwater resources have been declining in recent years, but they are still present, albeit to a limited extent. When identifying a new groundwater source, it is necessary to consider the impact on existing abstractions in the catchment area and also to assess the constraints in terms of minimum levels and minimum residual flows in watercourses downstream of these groundwater sources.

Adaptation measures are listed sequentially, according to the time and financial cost of their eventual implementation. However, it is not necessary to proceed sequentially from Class I onwards in their application, but to select the most effective measure for a given situation according to the consideration of the specific case and its priority. A combination of feasibility, economics and reliability of the function in the long term should be considered. For example, in the case of long-term problems with the provision of water for drinking purposes, the most effective Class III (II) measures, such as the design of new reservoirs or the design of inter-basin transfers, should be taken directly.

The degree of effectiveness of individual measures must be assessed on a case-by-case basis. It is also possible to consider changing the time step of the calculations from monthly to daily if necessary.