ATCZ 236 – IMPACT OF CLIMATE CHANGE ON THE CATCHMENT AREA OF THE THAYA/DYJE

Auswirkungen des Klimawandels auf das Einzugsgebiet der Thaya

Vlivy změny klimatu na povodí řeky Dyje

Interreg
EUROPEAN UNION
Austria-Czech Republic
European Regional Development Fund

1)

PREFACE

The water in Thaya/Dyje River Basin provides an essential source for drinking water supply, the regional water balance and multiple water use in the transboundary region of Lower Austria and Southern Moravia.

Along the Thaya until the confluence with the Morava river (fig. 1), there are important water supplies for the city of Znojmo and other communities, numerous industrial uses, hydropower production and irrigation.

In order to manage and optimize the various water uses, large water reservoirs have been built in the Czech part of the basin (Vranov, Znojmo, Nove Mlyny). These structures are used to manage the river runoff to maintain environmental flows in the Thaya and contribute to the other water uses. The changing climate, increased water demand and recent droughts in 2017 and 2018 have led to an unprecedented problem of filling the reservoirs with water in spring, which significantly impacts the water supply within the Thaya basin. The need for a closer water management cooperation and reconsideration of the management strategies have been identified as necessary tasks to ensure the future capacity of water resources for the entire transboundary region. The group of experts from the Austrian-Czech transboundary water commission called for improved water management of the Thaya and hence born the idea for this project.

Figure 1.
Thaya/Dyje river until the confluence with the March/Morava.

WATER KNOWS NO BORDERS, NEITHER IN THE CASE OF FLOODS NOR IN TIMES OF DROUGHT!

Aims: The main objective of the project is to examine the impact of changing climate on water resources in the Thaya/Dyje River Basin. The focus is on identifying the water availability under various uses and how water availability may change for future climate scenarios. For the first time, experts from both countries jointly assessed the impacts of climate change on the water cycle and formulated recommendations for harmonized water management in the transboundary Thaya region.

The project aims to provide a basis for formulating new operation rules for hydraulic structures of the Thaya. The results improve the understanding of the effects of management trade-offs under the change of climate and water demand and serve as a discussion platform for future water management cooperation in the frame of the Austrian-Czech transboundary water commission.

Figure 2. Catchment area of the Thaya/Dyje basin.

2)

HYDROLOGY OF THE PROJECT AREA

The first step of the analysis was to jointly develop a harmonized database of hydrometeorological and water use characteristics observed in the past 50 years. The time series of daily precipitation, air temperature, global radiation, wind and relative humidity from both countries have been quality-checked and homogenized in a unified way. For the Thaya basin, observations from 184 climate (Fig.3) and 52 discharge (Fig. 4) stations were observed.

In the next step, the spatial and temporal changes of key water balance parameters and their driving factors have been analyzed. The trends of annual and seasonal air temperature, precipitation, evaporation and discharge characteristics have been identified and attributed to their driving factors. In order to examine the rate of changes, the trend analysis has been performed for a longer historical period (1981-2020) and the recent two decades (2000-2020).

The focus of these analyses allows showing how climate and water supply have changed in the last decades and serve as a basis for estimating the future development of hydrological conditions in the Thaya region.

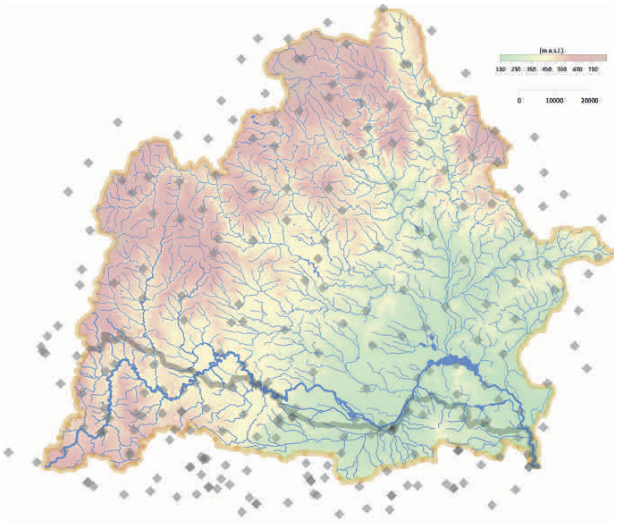


Figure 3. Location of climate stations (circles) with daily precipitation observations.

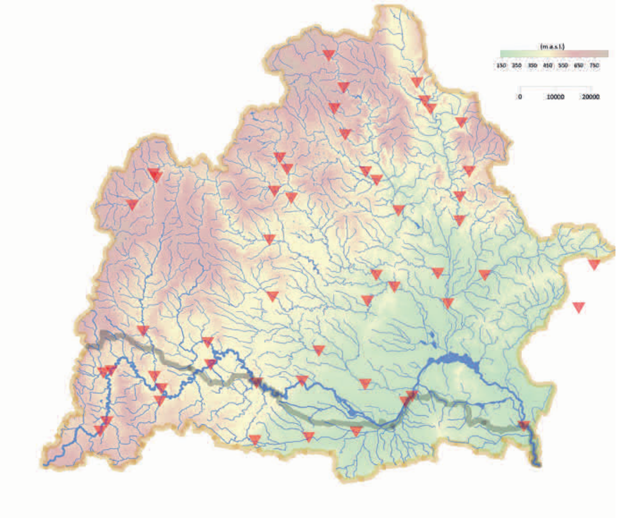


Figure 4. Location of stations (red triangles) with daily river discharge observations.

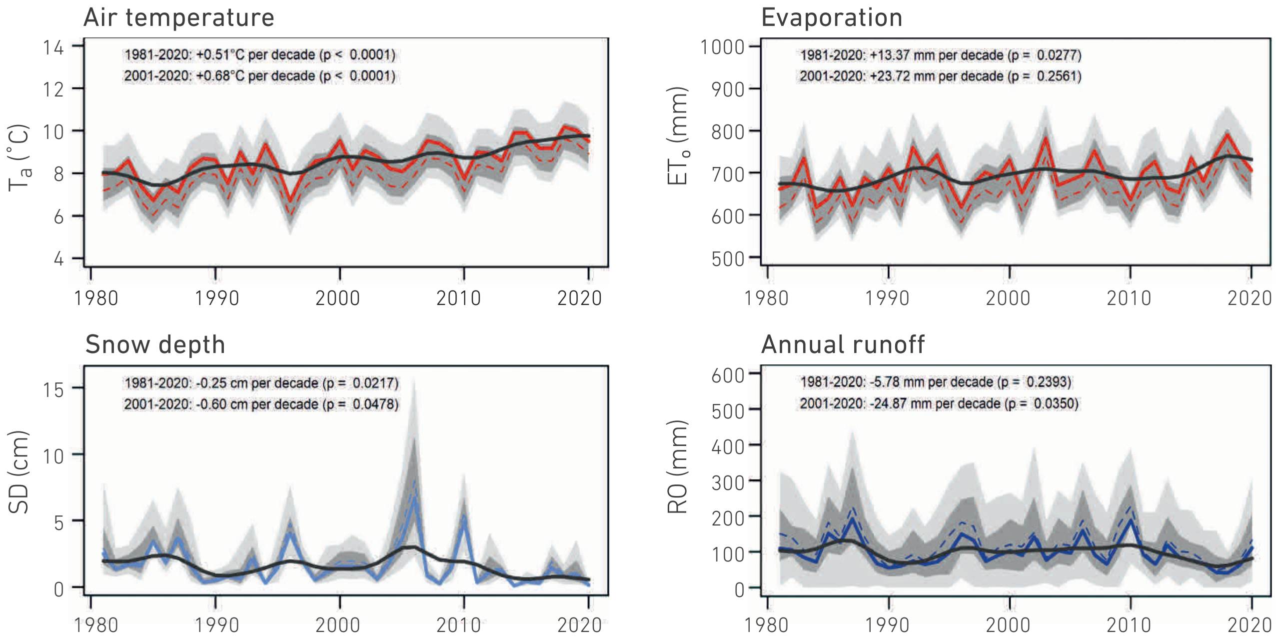


Figure 5. Temporal trends of air temperature (upper left), evaporation (upper right), snow depth (lower left), and runoff depth (lower right).

The solid colourful line depicts the trend over the entire basin, the dashed line is representing the median of trends of all subbasins, and the grey belts the 5, 25, 75 and 95 percentiles of from all sub-catchments.

Figure 5 shows the temporal dynamics of the hydrological variables air temperature, evaporation, snow depth and runoff depth for the entire catchment on average over the whole period. An increase in air temperature and evapotranspiration can be seen; in the case of snow depths, a decrease can be observed in recent years. The mean values of runoff show very clearly the dry periods at the beginning of the 1990s and the decrease of the runoff in the last years.

Table 1. Results of the trend analysis (AN = annual, GS = growing season)

1981 – 2020	**Changes per decade**						
	Variable	**Period**					
		AN	**GS**	**DJF**	**MAM**	**JJA**	**SON**
Air temperature	T_a (°C)	+ 0,51	+ 0,49	+ 0,49	+ 0,42	+ 0,69	+ 0,41
Precipitation	P (mm)	+ 7,01	+ 3,57	- 3,18	- 2,56	+ 4,29	+ 7,64
Evaporation	ET_o (mm)	+ 13,37	+ 12,70	+ 0,51	+ 5,24	+ 8,46	- 1,01
	$P – ET_o$ (mm)	- 6,45	- 13,54	- 3,11	- 8,41	- 3,63	+ 8,75
Runoff depth	**RO (mm)**	**- 5,78**	**- 2,93**	**- 1,13**	**- 5,53**	**- 0,30**	**- 0,29**

Discharge

The reduction in mean annual discharge in the upper sub-basins of the Svratka and Svitava rivers is mainly due to the decline in runoff in the spring and summer months. The most significant decrease in seasonal discharge is observed from April to July, with a maximum of 1-5 mm/10 years in April. A reduction in discharge in other months is observed only in exceptional cases (e.g. on the rivers Janov-Moravská Dyje and Zwingendorf-Pulkau).

A decrease in low water discharges is recorded mainly in the lower catchment of the Svitava, in the upper catchment of the Svratka and Oslava, in the catchment of the Rokytná and at the gauging station Janov-Moravská Dyje. A small increase in low water discharge (Q95) is observed at the Letovice (Svitava) station in the Czech part and at Hardegg/Thaya and Alt-Prerau/Thaya in the Austrian part of the Thaya catchment.

Precipitation

An increase in annual precipitation is observed at 22% (39 of 184) of the climate stations in the lower eastern and upper western parts of the Thaya. The increase is about 15-30 mm/year. The evaluation of seasonal changes in precipitation (i.e., trends in monthly precipitation) does not show a consistent pattern. Thus no significant increase or decrease in monthly precipitation is observed at most climate stations.

Air-Temperature

The increase in annual air temperature is observed at almost all climate stations in the Czech part of the basin. The stations in the Austrian region generally have a shorter record length, so the spatial pattern of the trend is less pronounced. The average rate of warming in the Thaya basin is 0.4°C/10 years on average and ranges from 0.2 to 0.8°C/10 years. Seasonally, the largest increase is observed in April, between June and August, and in November. The increase in mean monthly air temperature during these months ranges from 0.3 to 1.2 °C/10 yr.

Presentation of results

The trends in observations are compared for two different periods, i.e. 1981 – 2020 and 2000 – 2020. The results show that the changes/trends over the entire period are less pronounced than in recent decades, where the trends are more significant.

The trend in air temperature shows an increase or warming of the area for the entire basin in both observation periods. Regarding precipitation, it can be observed that there are no pronounced trends in precipitation over the entire period. Spatial differences are observed mainly in the shorter observation period. While in the eastern part of Thaya, a slight increase can be seen, a decrease in rainfall is observed in the remaining part. Similar spatial patterns are accordingly observed for discharges. These evaluations indicate that the climatic changes in the catchment are more pronounced in the northwestern part than in the southeastern part.

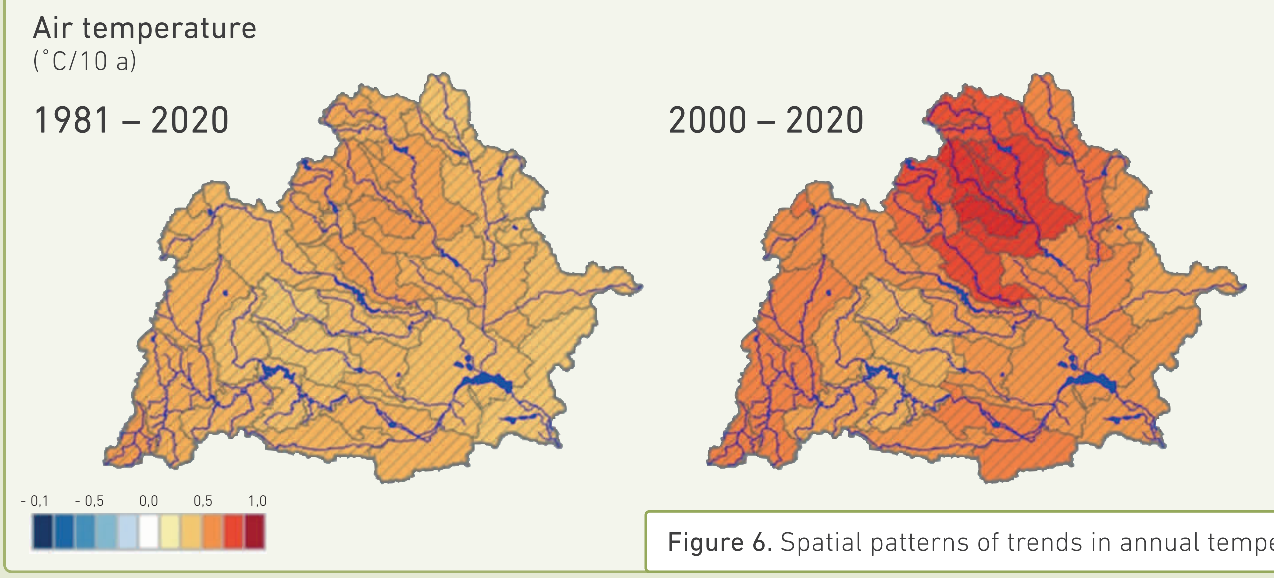


Figure 6. Spatial patterns of trends in annual temperature.

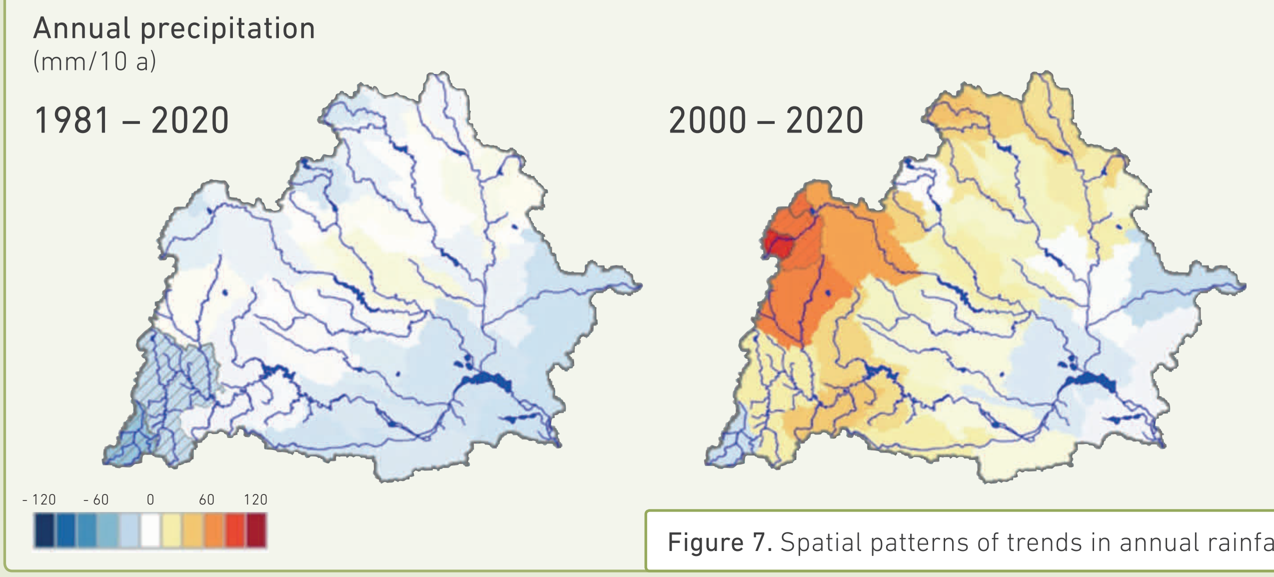


Figure 7. Spatial patterns of trends in annual rainfall.

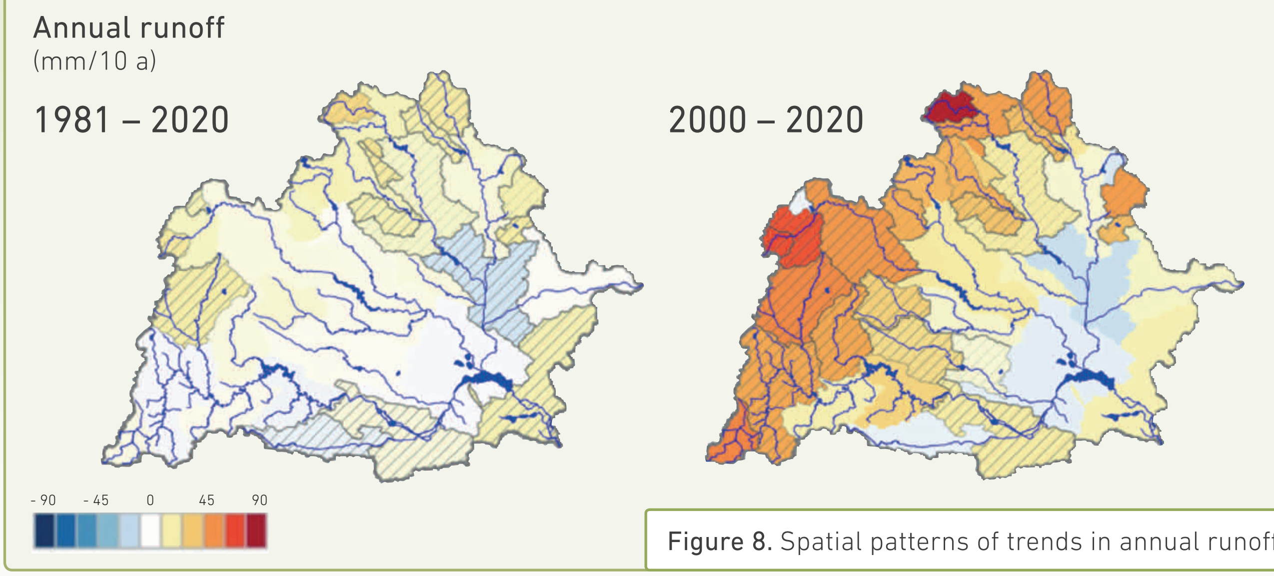


Figure 8. Spatial patterns of trends in annual runoff.

In addition to the hydrological data, the existing water uses on the Austrian and Czech sides are also an important precondition for assessing large reservoirs' current and future operation (Vranov, etc.). For this purpose, all known water uses in the Thaya region were summarized and provided to the project partners for further analyses and simulations. Based on the current water uses, different scenarios for future water use development were jointly created for Austria and Czechia. Besides a scenario based on national studies, two other scenarios with reduced and increased water use were developed.

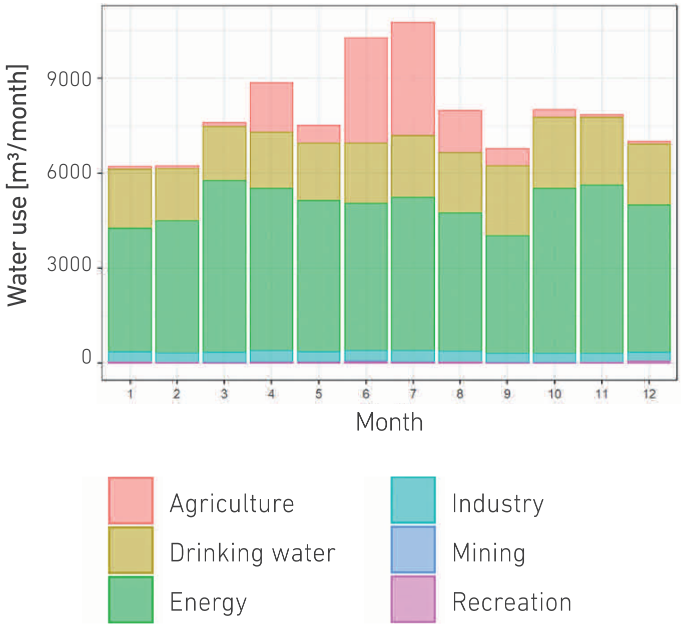
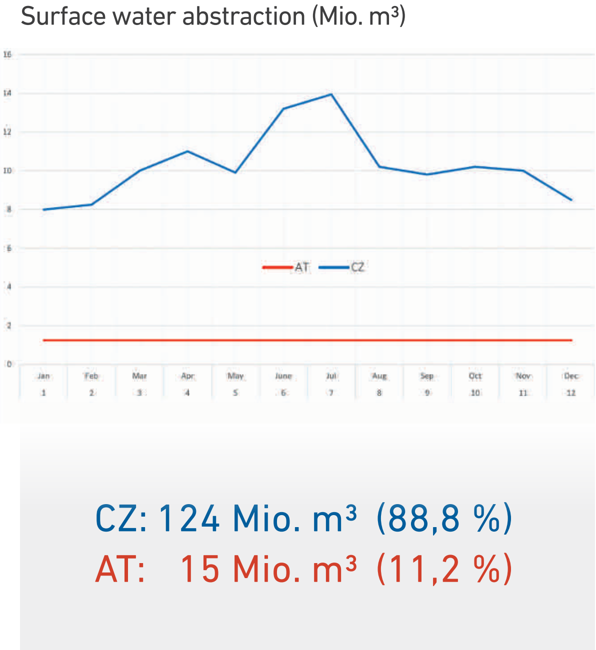


Figure 9. Water use data for categories in the catchment area (surface water).



CZ: 124 Mio. m³ (88,8 %)
AT: 15 Mio. m³ (11,2 %)

Figure 10.
Seasonal water use data.

3)

MODELLING OF THE PROJECT AREA

For the description of the water balance in the Thaya catchment up to the confluence with the Morava River, mathematical precipitation-runoff models were developed, calibrated and validated. Through hydrological modelling, it is possible to describe the low water situation at the Thaya, and the relevant water uses in a process-oriented way. Within the project, the traditional approach to assessing climate change impacts on water resources in a transboundary river basin was extended by a bilateral modelling approach (Figure 11).

For the projection and assessment of possible future scenarios, two different hydrological models (BILAN in the Czech Republic and TUWmodel in Austria) were developed for the entire project area and used to simulate past and future runoff conditions. The precipitation-runoff models consist of modules for calculating snowmelt, evapotranspiration and runoff and also include the soil moisture balance and groundwater recharge. The models also simulate in a simplified way the water uses, both withdrawals and discharges, as well as the hydraulics of the main water structures in the basin (e.g., the Vranov reservoirs). Observations at 52 temperatures and 184 precipitation stations from 1961 to 2020 were available as input data for the models. All data from both countries were quality controlled and homogenized for further use in the models. The realistic process description and the identification of suitable and robust model parameters represent the starting point for the assessment of the current climatic and water management situation, as well as its future development under changing boundary conditions. The structural design and calibration of the rainfall-runoff models for the entire Thaya catchment were carried out spatially distributed for sub-catchments. The model is able to simulate hydrological differences in the Thaya catchment. The identification of the initial model parameters is based on the available data on geology, soils, land use, catchment boundaries and the river network. Model parameters were fine-tuned using existing discharge data at numerous gauging stations in the project area (Figure 4).

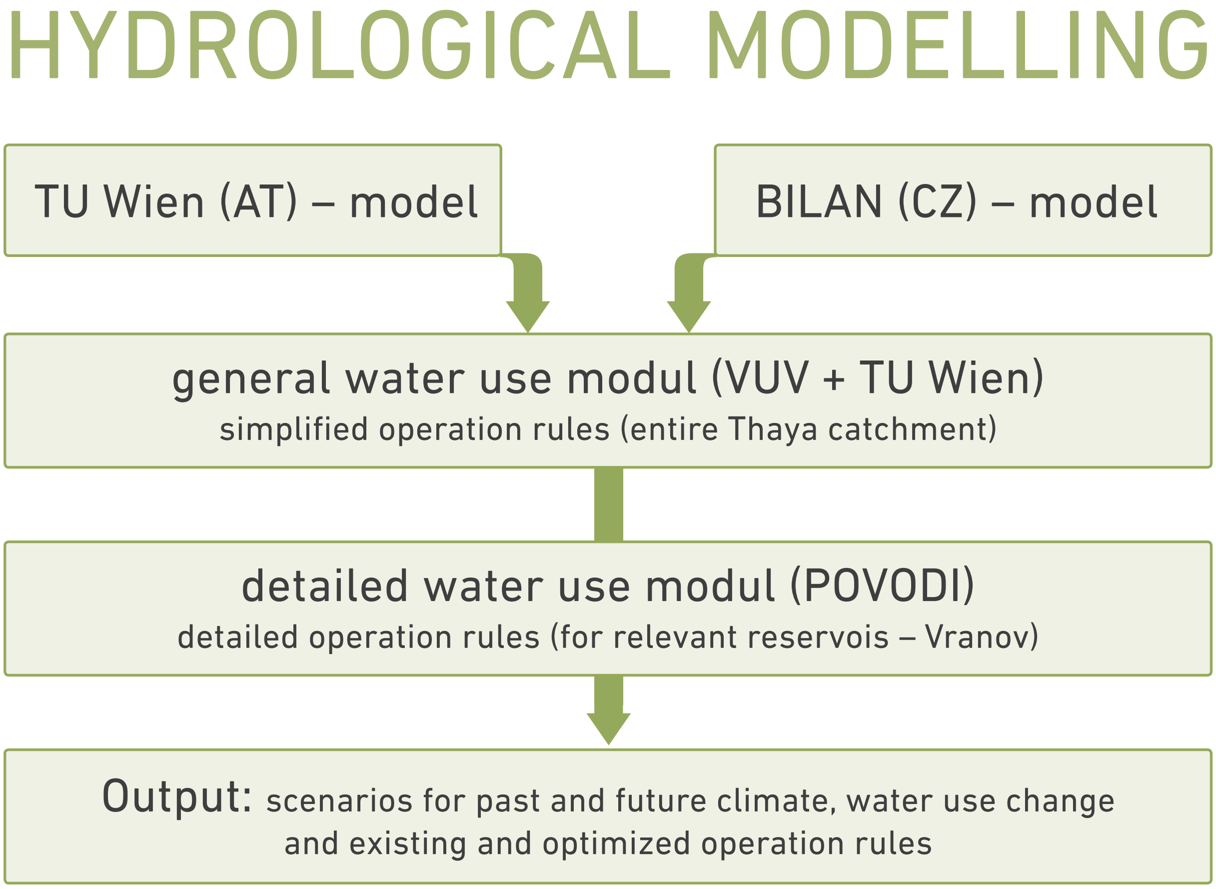
Various complementary data sets (satellite data, such as snow cover patterns) were used to calibrate and validate the model parameters and also the model structure. The evaluation of the simulation performance of both models shows a very good agreement with the observed runoff data (Figure 12). This approach ensured that the models are capable of adequately describing the hydrological water balance under different environmental conditions and also represents a solid tool for simulations of the water balance for different meteorological future scenarios with changed hydrometeorological framework conditions.

To describe the influence of water management on the hydrologic situation in the basin, the following elements were implemented in the hydrologic models:

- Reservoirs and water diversions,
- Water withdrawals and discharges,
- Minimum flow rates and water levels,
- Balancing of water uses in calculation profiles.

In the simulation model, the real system is represented in a simplified way by these important profiles. The schematic of the management system as used for hydrologic modeling in this project is shown in Figure 13.

Figure 11. Structure of the hydrological model chain.



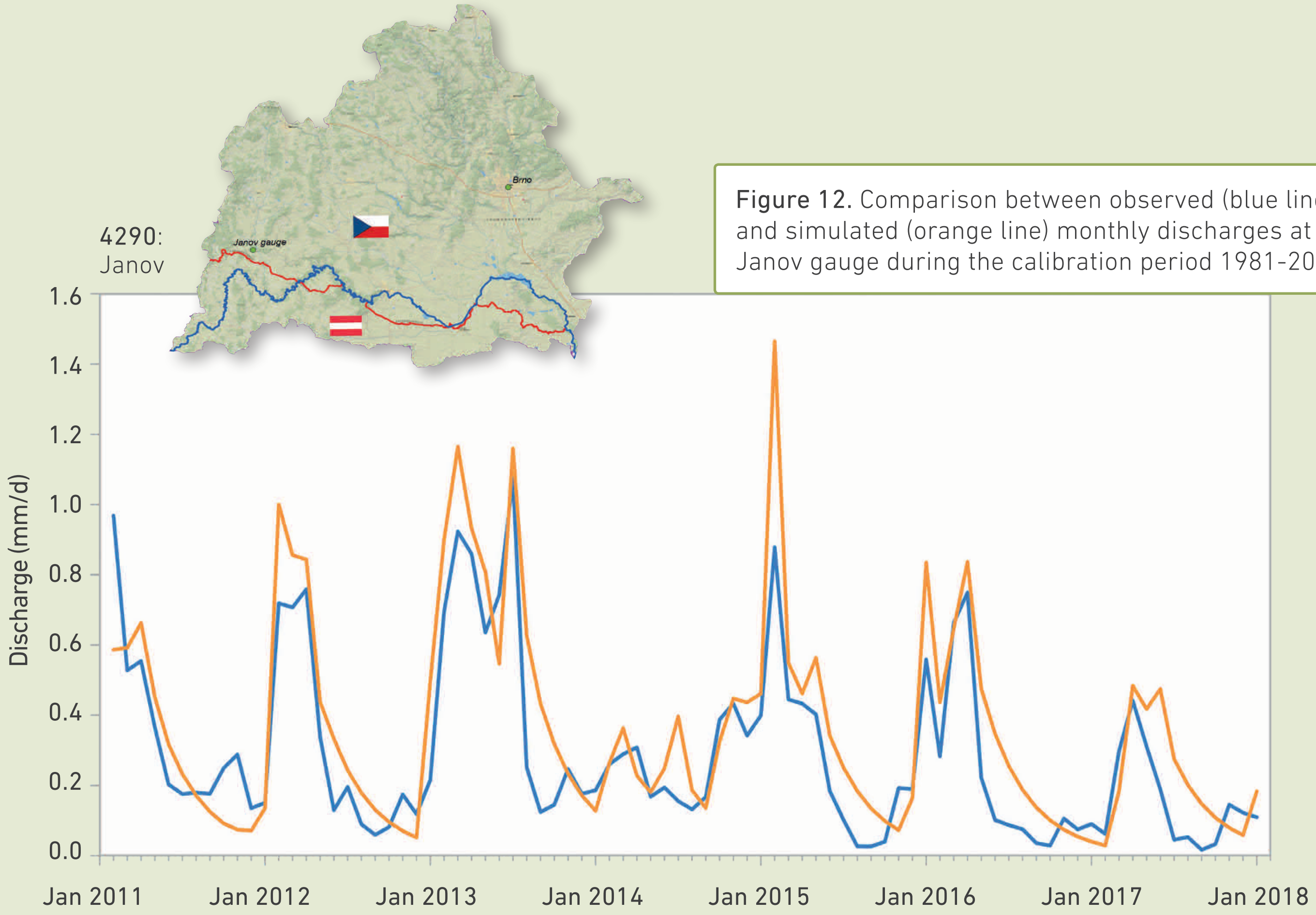


Figure 12. Comparison between observed (blue line) and simulated (orange line) monthly discharges at the Janov gauge during the calibration period 1981-2010.

Water management scheme Czech Republic

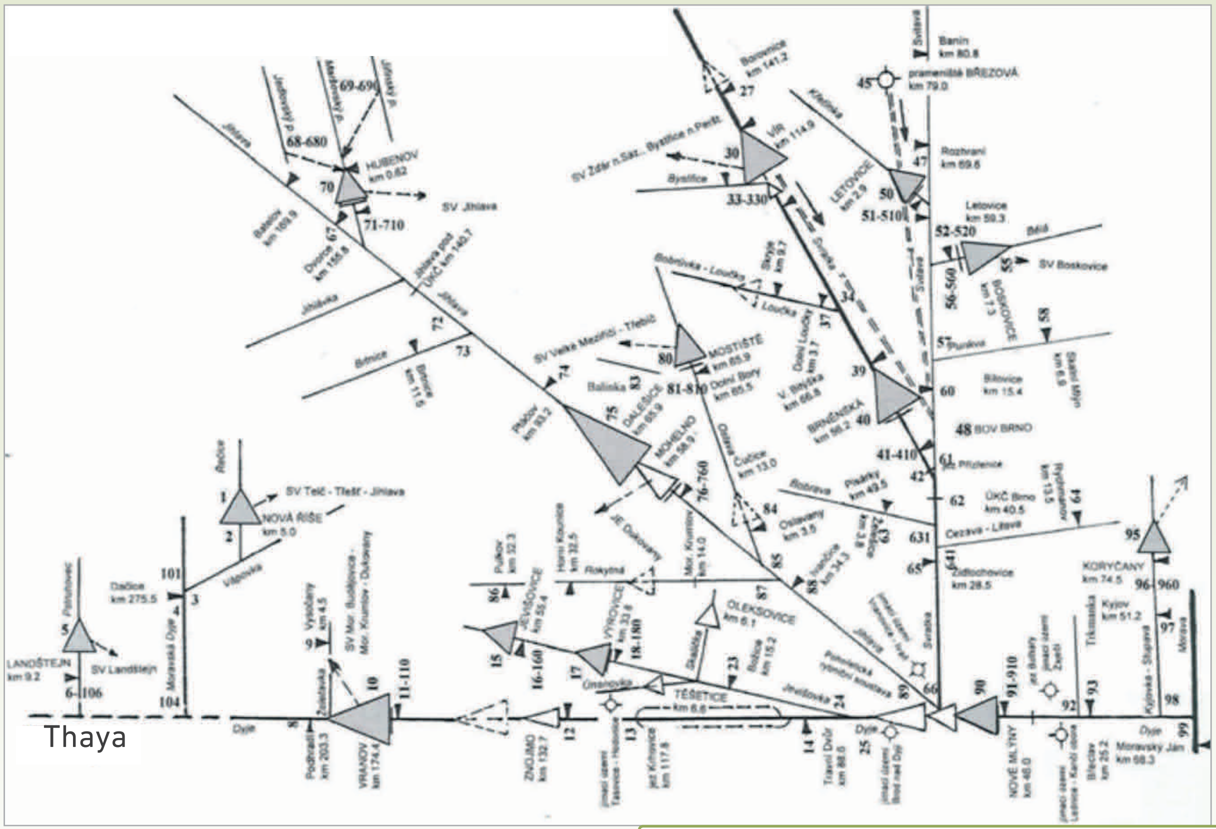


Figure 13. Water use model – spatial structure

4)

CLIMATE SCENARIOS

To estimate future hydrological conditions in the Thaya basin, climate projections from climate models under different emission pathways are prepared to feed into rainfall-runoff models. Many realizations of these global climate simulations are available from the latest two generations of models (Climate Model Intercomparison Project Phase 5 and 6 – CMIP5 and CMIP6). CMIP models use future emissions defined by different so-called Representative Concentration Pathways (RCPs for CMIP5) and Shared Socioeconomic Pathways (SSPs for CMIP6). These scenarios provide projections for radiative forcing due to future emissions (Figure 14). Global general circulation models (GCMs) which provide CMIP5 and CMIP6 projections generally operate on spatial scales of around 100 km. The horizontal resolution is too coarse to use the data directly as input for hydrological rainfall-runoff models. Therefore, downscaling approaches, i.e. methods for the regionalization of the global scale climate projection, are necessary to transfer the coarse climate information to the local scale.

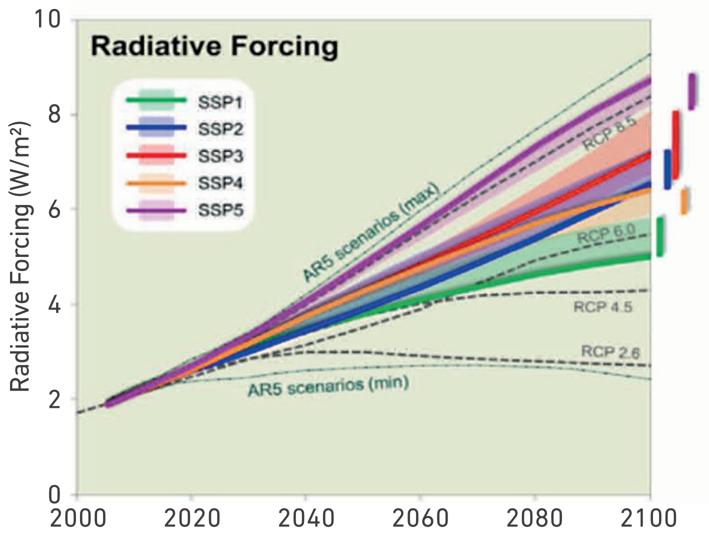
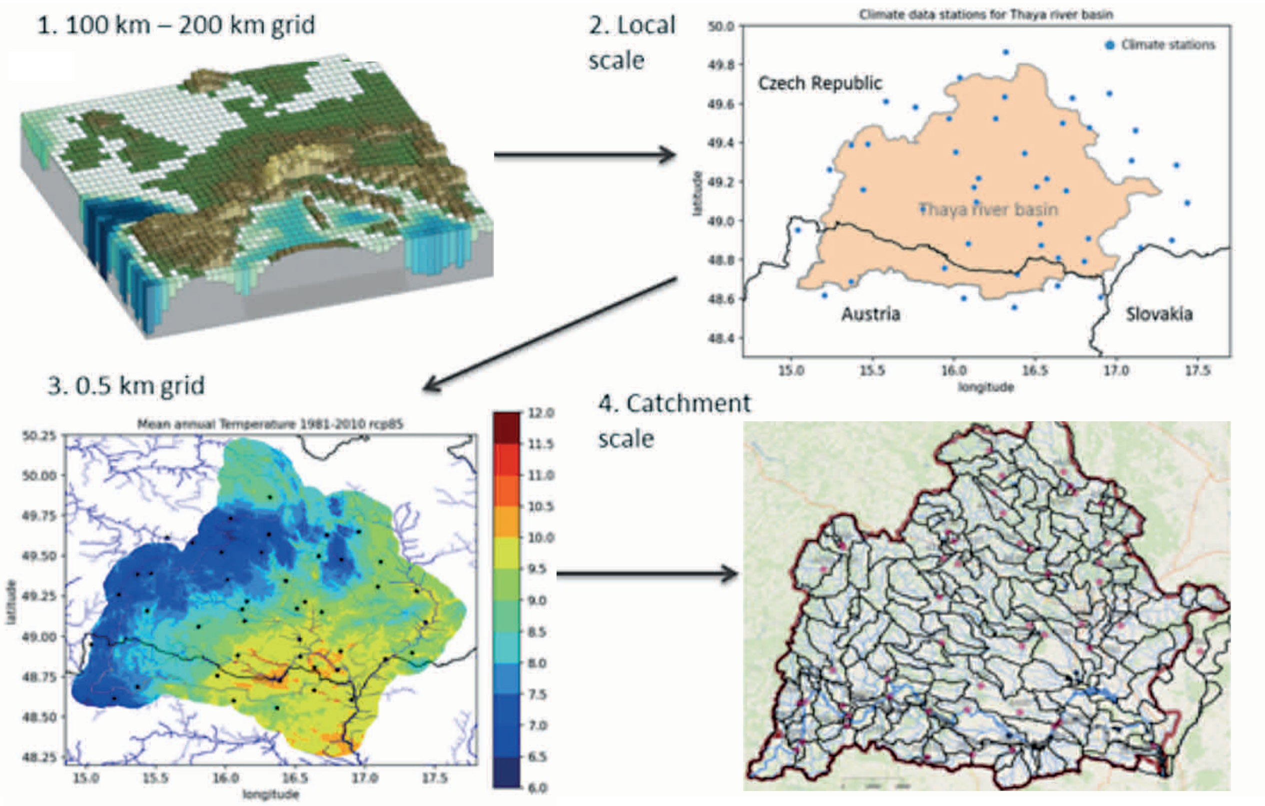


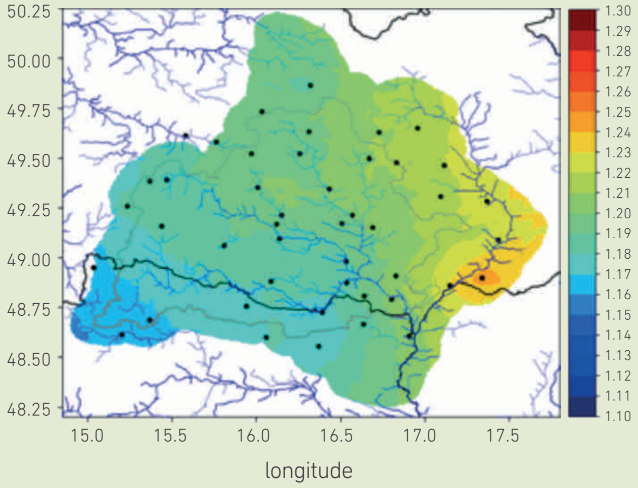
Figure 14. Emission pathways. Anthropogenic radiative forcing for the 21st century in the ScenarioMIP design, from Riahi et al. (2017).

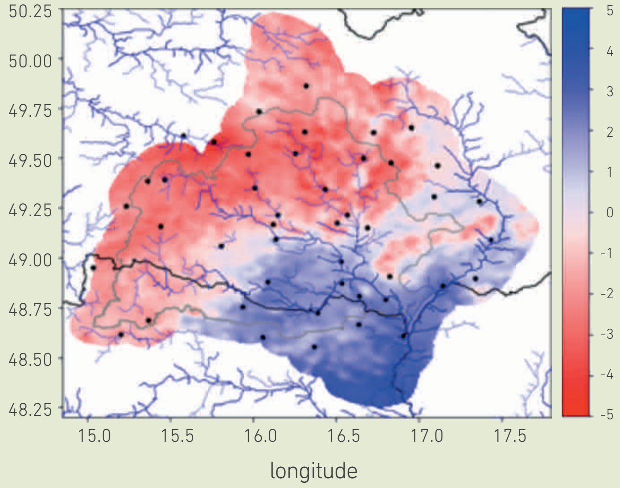
A strategy of combining different statistical downscaling approaches is adopted for generating climate projections for the Thaya basin to strengthen the robustness of climate change signals. The EPISODES-method is applied to regionalize CMIP5 simulations (six different models) whereas an Advanced Delta-Change approach is used on CMIP6 models (six different models). Considering the emission pathways, RCP8.5 (worst case with increasing emissions) and RCP4.5 (emission stabilization until 2100) are used for CMIP5, and SSP1-2.6 (meeting the Paris agreement), SSP2-4.5 (middle of the road), SSP3-7.0 (local rivalry) and SSP5-8.5 (fossil-fuel intensification) for CMIP6, see Figure 14 for details. Both downscaling methods have in common that they use local observations of past periods to deduce bias-corrected and regionalized future climate information from global models. This variation of models and methods was

necessary for estimating the uncertainty of future climate projections. The future climate information was directly downscaled from GCMs to 45 climate stations within and surrounding the Thaya river basin. Downscaling is carried out for precipitation and all variables necessary to derive potential evapotranspiration (air temperature, relative humidity, wind speed and global radiation). Subsequently, these time series are interpolated to a regular 0.5 km grid covering the entire Thaya basin and then aggregated to sub-catchments (Figure 15).

Figure 15. Work stages for creating the database for hydrological modeling from global scale climate information in T3: Downscaling from GCMs to climate stations, interpolation to a regular 0.5 km grid and aggregation to catchment units.




Temperaturänderung (˚C) 2021 – 2050


Niederschlagsänderung (%) 2021 – 2050

Future climate change in the Thaya basin is characterized by substantial warming, similar to Europe and the global development. Annual mean temperatures towards mid-century are expected to rise by approximately 1.2 °C compared to the reference period of 1981-2010 (Figure16). Both methodological approaches yield similar results in this respect. However, towards the end of the century, different warming levels are visible depending on the emission scenario under consideration. For the worst-case scenarios (RCP8.5 in CMIP5 and SSP5-8.5 in CMIP6) a projected increase in annual mean temperature is in the range of +3 °C to +5 °C. For the moderate mitigation scenarios (RCP4.5 in CMIP5 and SSP2-4.5 in CMIP6) the warming towards the end of the century is lower, around +2 °C for both model generations. Moreover, there is also larger spread of the climate simulations towards the end of the century. All in all, the temperature projections for the Thaya basin show a very consistent and clear tendency towards warmer conditions.

Due to the complex nature of precipitation generation signals of future changes are more ambiguous than those for temperature and near term changes towards mid-century show only minor changes (Figure18). Considering annual precipitation sums (Figure 19) CMIP5 based

Annual mean temperature,
ref: 1981 – 2010

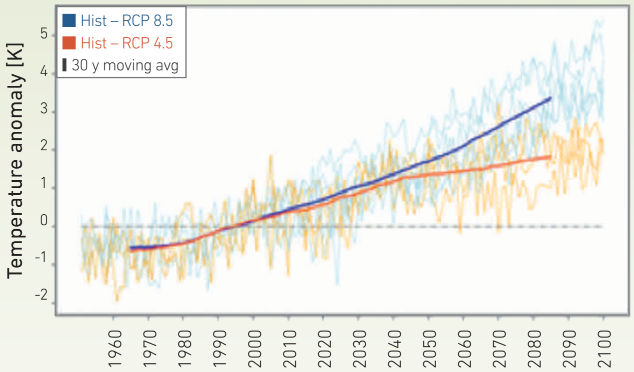


Figure 16. Development of annual mean temperature in the period 1981-2010.

Annual mean temperature

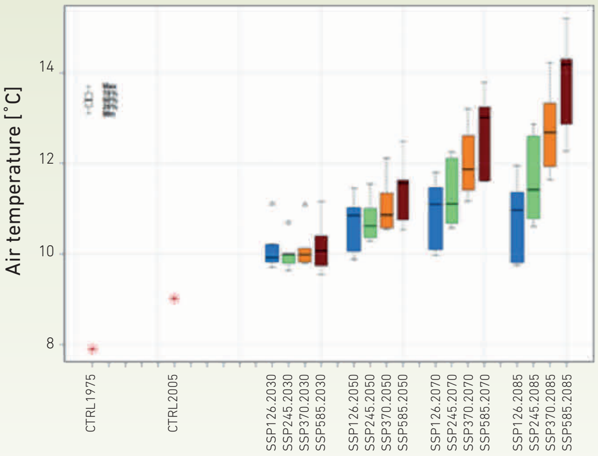


Figure 17. Comparism of air temperature in different climate models.

simulations tend towards dryer conditions for the second half of the 21st century, while CMIP6 models show an increase in precipitation for the mitigation scenarios (SSP1-2.6 and SSP2-4.5) whereas a decrease is apparent for the emission intensive scenarios (SSP3-7.0 and SSP5-8.5). These changes seem to be contradictory at first sight. However, they reflect the mean changes of the selected Global Climate Models and we have to keep in mind that the overall spread of the models as well as the year-to-year variabilities are much larger than the climate signals itself (+/- 40% year-to-year variability compared to +/- 10% mean climate trends). Changes of future climate conditions differ notably among the seasons (Figure 5). Particularly during summer, and to a lesser extent in autumn, a decrease in precipitation is visible for both the CMIP5 and CMIP6 based projections. Worst-case emission scenarios RCP8.5 and SSP5-8.5 clearly stand out in this respect with a precipitation decline towards the end of the century of around 20 % in summer. On the other hand, winter and spring are both showing some increases in precipitation amount. As for the summer months, high-end emission scenarios show a more pronounced increase than mitigation scenarios, particularly for the CMIP6 based projections.

Annual precipitation anomalies,
ref: 1981 – 2010

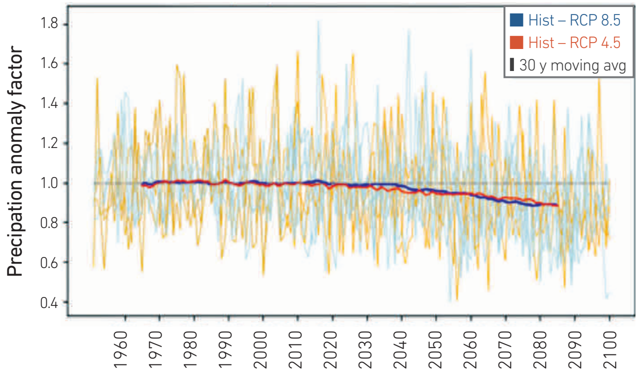


Figure 18. Development of the annual precipitation.

Annual mean of daily precipation

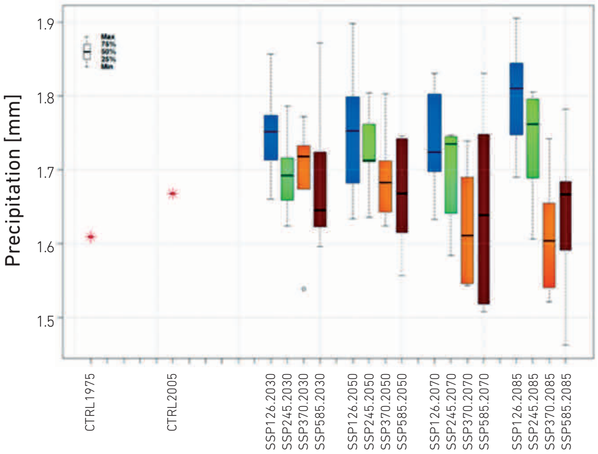
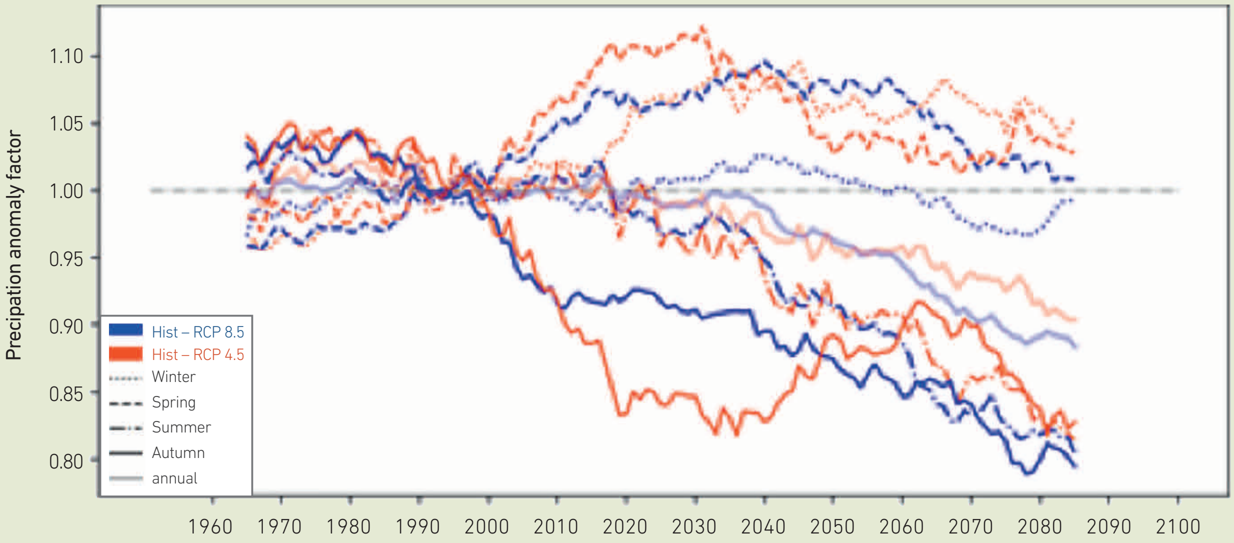
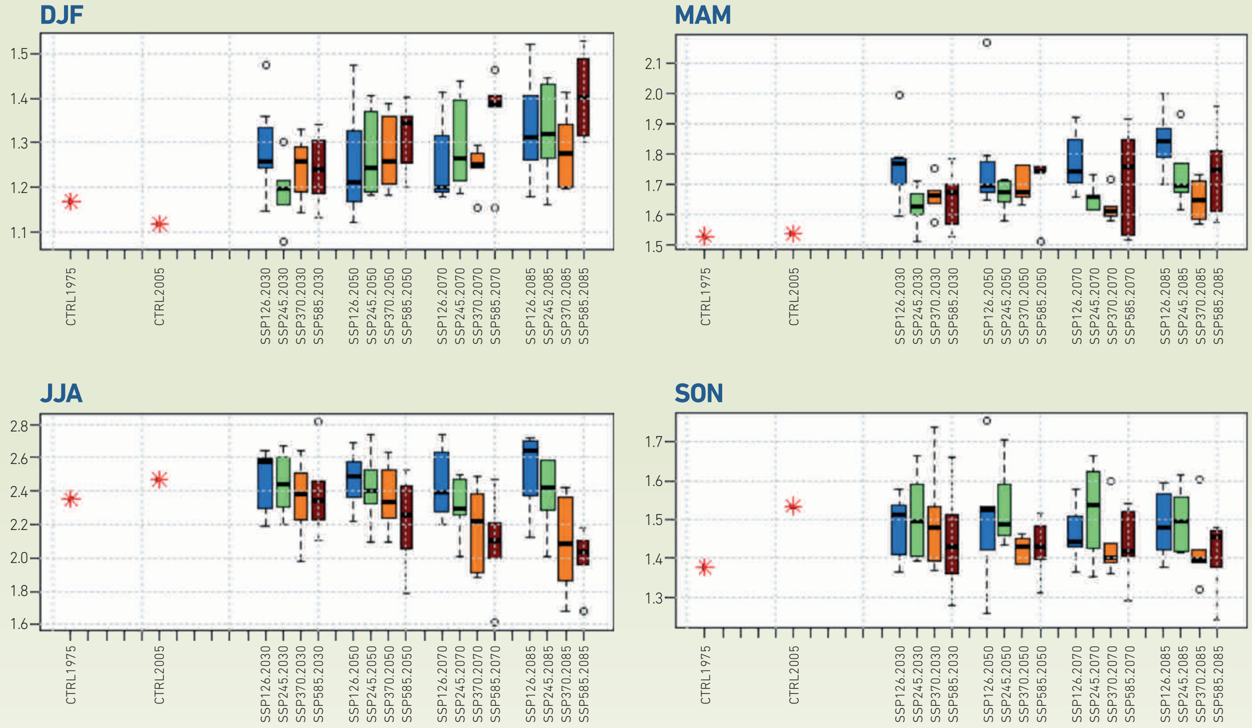


Figure 19. Annual mean of daily precipitation sums for the Thaya basin based on advanced delta-method.

Precipitation anomalies – 30 y moving average, ref: 1981 – 2010



Mean of daily precipitation [mm]



ZAMG model CMIP5; CzGlobe model CMIP6; ZAMG Model summer CMIP5; red = RCP4,5 / blue = RCP8,5

Climate change signals for mean annual air temperature and precipition sum	Emission scenario – worst case		Emission scenario – worst case		Emission scenario – worst case	
	2021 / 2050	2071 / 2100	2035 / 2064	2071 / 2100	2021 / 2050	2071 / 2100
Temperature	+1,0 °C/+1,2 °C	+1,8 °C/+3,4 °C	+1,2 °C/+1,7 °C	+3,0 °C/+5,0 °C	+1,6 °C/+1,9 °C	+2,8 °C/+4,1 °C
Precipitation	-2%/-1%	-10%/-12%	+8%/+9%	+12%/+15%	-6%/-4%	-20%/-20%

5)

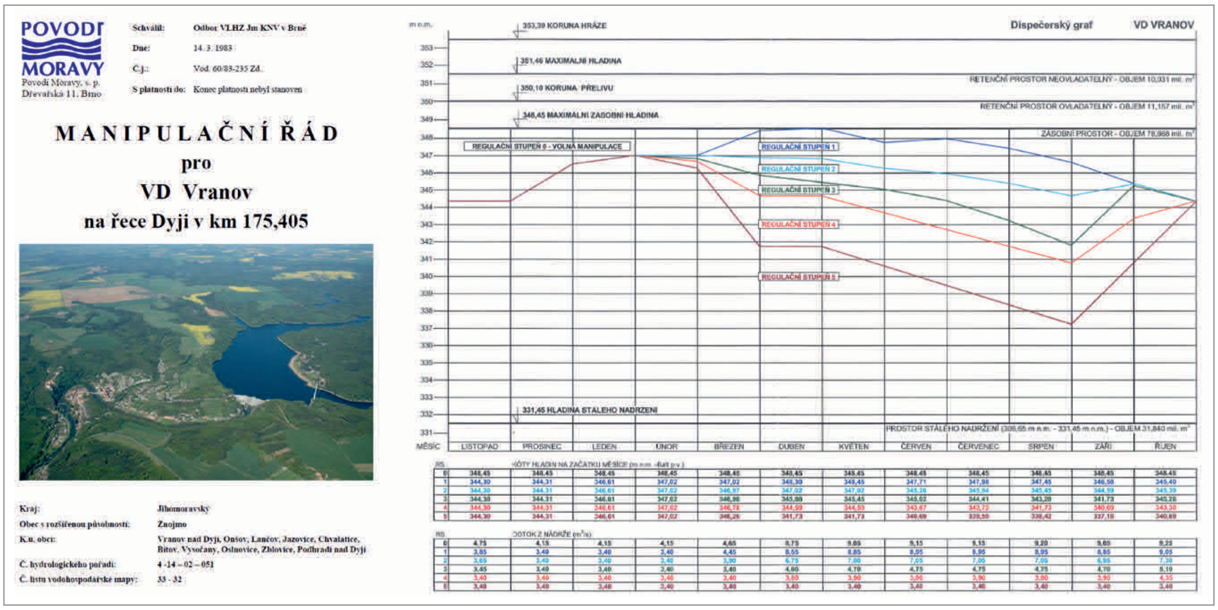
OPTIMIZATION OF EXISTING OPERATION RULES

The Objective of the project is to simulate the future development of the water management situation and, based on the results of this simulation, to propose and optimize a new set of operation rules for the water management infrastructure on the Thaya that is sustainably adapted to the effects of climate change on the Thaya catchment area, to ensure the expected water use in the future.

2018 and 2019 has shown that successive dry periods (e.g. due to low snow masses in the Thaya catchment) can lead to lower reservoir fillings and reduced water supply. A new strategy shall optimize the water distribution over the year.

For this purpose the available water quantities shall be distributed throughout the year in such a way that reserves are build in times of sufficient water flows, which is available and used during dry periods. This also means a more economical use of the available water quantities throughout the year.

Figure 20. Extract of the existing weir operating rules of Vranov reservoir on the regulatory levels of management (povodi moravy, sp).



POVODÍ MORAVY
Povodí Moravy, s. p.
Dřevařská 11, Brno

Schválil: Odbor VLHZ Jm KNV v Brně
Dne: 14. 3. 1983
Č.j.: Vod. 60/83-235 Zd.
S platností do: Konec platnosti nebyl stanoven

MANIPULAČNÍ ŘÁD
pro
VD Vranov
na řece Dyji v km 175,405

Kraj: Jihomoravský
Obec s rozšířenou působností: Znojmo
K.ú. obcí: Vranov nad Dyjí, Onšov, Lančov, Jazovice, Chvalatice, Bítov, Vysočany, Oslnovice, Zblovice, Podhradí nad Dyjí
Č. hydrologického pořadí: 4 -14 – 02 – 051
Č. listu vodohospodářské mapy: 33 - 32

KÓTY HLADIN NA ZAČÁTKU MĚSÍCE (m n.m. -Balt p.v.)

RS	LISTOPAD	PROSINEC	LEDEN	ÚNOR	BŘEZEN	DUBEN	KVĚTEN	ČERVEN	ČERVENEC	SRPEN	ZÁŘÍ	ŘÍJEN
0	348,45	348,45	348,45	348,45	348,45	348,45	348,45	348,45	348,45	348,45	348,45	348,45
1	344,30	344,31	346,61	347,02	347,02	348,30	348,45	347,71	347,98	347,45	346,58	345,40
2	344,30	344,31	346,61	347,02	346,97	347,02	347,02	345,26	345,94	345,45	344,59	345,39
3	344,30	344,31	346,61	347,02	346,90	345,88	345,45	345,02	344,41	343,20	341,73	345,28
4	344,30	344,31	346,61	347,02	346,78	344,59	344,59	343,67	342,72	341,73	340,69	343,30
5	344,30	344,31	346,61	347,02	346,26	341,73	341,73	340,69	339,59	338,42	337,18	340,69

ODTOK Z NÁDRŽE (m^3/s)

RS	LISTOPAD	PROSINEC	LEDEN	ÚNOR	BŘEZEN	DUBEN	KVĚTEN	ČERVEN	ČERVENEC	SRPEN	ZÁŘÍ	ŘÍJEN
0	4,75	4,15	4,15	4,15	4,65	8,75	9,05	9,15	9,15	9,20	9,65	9,25
1	3,85	3,40	3,40	3,40	4,45	8,55	8,85	8,95	8,95	8,95	8,85	9,05
2	3,65	3,40	3,40	3,40	3,90	6,75	7,00	7,05	7,05	7,05	6,95	7,30
3	3,45	3,40	3,40	3,40	3,40	4,60	4,70	4,75	4,75	4,75	4,70	5,10
4	3,40	3,40	3,40	3,40	3,40	3,60	3,90	3,90	3,90	3,90	3,90	4,35
5	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40	3,40

For the simulation of the future water balance based on water uses and different climate scenarios, a detailed water management model was developed, in which not only the water uses but also the operating rules of the relevant reservoirs have been simulated. As input data for the detailed water management model, the hydrological scenario simulations (climate past and climate future) of the two rainfall-runoff models were used.

To ensure the permissible withdrawals from the water management system Vranov - Znojmo, 68 different scenarios (34 each from the Czech model Bilan and Austrian model TUW) were calculated. In daily steps the difference between the inflow and the total outflow the change in the level of the reservoir is determined. The discharge into the watercourses and the withdrawal quantities are given by tables, their level is determined depending on the current water level.

The following basic conditions were set for the calculations:

- the profiles Podhradí n. Dyjí/Thaya and Vysočany/ Želetávka as relevant inflows
- different climate scenarios
- control stages of the new proposal of the weir operation rules of the Vranov waterworks
- Balancing in resolution of daily values (corresponding to CZ regulation ČSN 75 2405 Water management solutions for reservoirs)
- Starting level for the calculations is the maximum water level in the reservoir of 348.45 m above sea level

Results and conclusions:

By working up the hydrological situation in the period from 1971/1981 to 2020 in the Thaya catchment, it could be shown that a warming of about 0.4 °C / 10 years has to be expected in the following decades. With regard to the water balance, it could be confirmed that in the future, a trend observed in recent years of increased low water situations, a prolongation of the vegetation periods and a regionally different reduced water balance must be assumed. Due to the reduced water balance, restrictions in use cannot be excluded, which will make it necessary to adapt the existing management in the entire catchment area of the Thaya. In order to ensure the management, a proposal of a new weir operation regulation for the water management junction Vranov, based on the research results of the project, was examined with a water management model by the Czech operators within the framework of the project.

The calculations regarding the assurance of withdrawals from the Vranov reservoir showed that the newly designed control stages can ensure optimized water management in most scenarios, provide higher safety, and better absorb irregularities of the reservoir than the existing control stages. Potentially reduced inflows due to climate change impacts can severely impact the region's water balance and cause problems in the region, a trend that was observed in 2015-2018. With the redesigned control stages, more is now being retained during times when excess water is available to provide it during times when inflows are low.

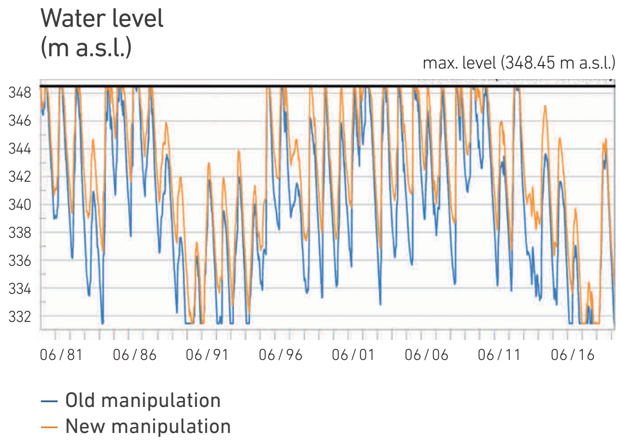


Figure 21. Water level in the Vranov reservoir / comparison of the existing weir management regime (blue) with the proposal of the new management regime (orange); the new weir management regime can optimize the water level in the reservoir.

The results of the project regarding the potential climatic changes in the catchment area of the Thaya on the water balance now provide a solid technical basis for further discussions and measures. The newly formulated proposal of operation rules adapted to climate change for the water management hub Vranov will now be used as a basis for discussion for the expert groups in the Austrian-Czech Border Water Commission.

FACTS AND FIGURES

Project name:
Auswirkungen des Klimawandels auf das Einzugsgebiet der Thaya/
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