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CECILIA

Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

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D 5.1. Description of the rainfall-runoff models and of the reference basins, a revision of flood events from the analyze period, the input data, the schematization of the reference basins.

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PU	Public	**X**
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RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Description of the rainfall-runoff models and of the reference basins, a revision of flood events from the analyze period, the input data, the schematization of the reference basins.

The warming of the global climate caused by greenhouse effect can induce essential changes in the hydrological regime and water resources at a different time and space scale.

As water is fundamental to human life and many activities scientists from many European countries investigate, in present, the influence of climate change on water resources, the implications in the hydrological cycle, the water resources and their management in future.

The main aim of the WP 5 in Cecilia project is the evaluation of the impact of climate changes in water resources on the Buzău (5 264 km^2) and Ialomiţa (10 350 km^2) river basins from Romania, Hron river basin (5465 km^2) from Slovakia and Dyje river basin (17 800 km^2) from Czech Republic. The impact of climatic parameters modification, precipitations mainly, on frequency and characteristics of floods, are also analysed in Dyje river basin.

On the other hand, the assessment of impacts of the climate changes on hydrology, water quality, and management of surface water resources, for the upper Vltava River basin and the hydrodynamic process and water quality of existent reservoirs in this river basin are pursued.

Description of the reference basins

Buzău and Ialomiţa river basins

The area of Buzău and Ialomiţa river basins is located of the outside of Curvature of the Carpathian Mountains (*Figure 1),* into a zone where the altitude varies from 2500m to 50m.

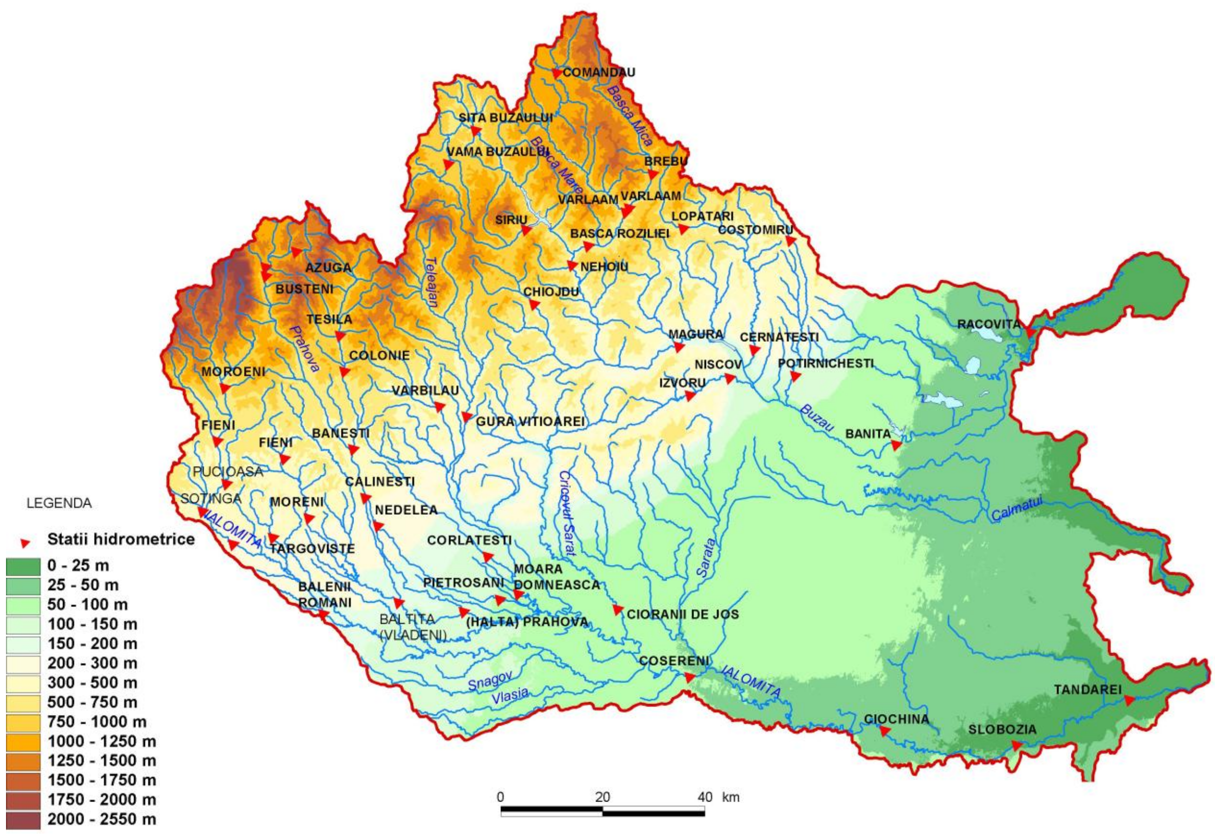


Figure 1. Buzău and Ialomiţa river basins area

In conformity of altitude, the annual precipitation varied from 1400 mm/year, in the mountainous area to 400 mm/year in the plane area and the evapotranspiration between 500 mm/year in the high area to 850 in the plane area. However, due to a very high variability of weather conditions, droughts as well as excessive humidity periods occur in the course of a year.

Morphology of these river basins and the climatic factors lead to a variation of vegetation and soils with the altitude.

In this area there are 8 reservoirs: Bolboci, Pucioasa, Dridu Paltinu, Măneciu in Ialomiţa Ialomita river basin and Siriu, Cândesti, Ciresu in Buzău river basin.

Data series of 17 meteorological stations have used to estimate air temperature, relative air humidity, wind speed and sunshine duration. For precipitation are used data series of 89 rain gauging stations.

In the analysed area the hydrological database includes data of 50 runoff gauging-stations. Due to very big differences in data sets, the period from 1970 till 2000 was chosen because of the highest quantity of hydrological stations operating without interruptions.

The mean monthly discharges at 4 gauging stations from the Buzău river basin and 13 gauging stations from Ialomiţa river basin are used for the analyse of flow modification in this area *(Table 1)*.

Table 1. Gauging stations used for the analyse

River basin	***River***	***Cross- section***	***S (km^2)***
Buzău	Buzău	Nehoiu	1549
		Măgura	2273
		Baniţa	3980
		Racoviţă	5238
Ialomiţa	Ialomiţa	Moroeni	264
		Târgovişte	686
		Bălenii Români	901
		Siliştea Snagovului	1920
	Prahova	Câmpina	476
		Halta Prahova	986
		Adâncata	3682
	Teleajen	Gura Vitioarei	491
		Moara Domnească	1434
	Cricovul Sărat	Ciorani	601
	Ialomiţa	Coşereni	6265
		Slobozia	9154
		Ţăndărei	10309

In the study area Buzău -Ialomiţa there are 8 reservoirs (Bolboci, Pucioasa, Dridu Paltinu, Măneciu on Ialomiţa river basin and Siriu, Cândesti, Cireşu on Buzău river basin).

Dyje river basin

The catchment area of the river Dyje to the station Ladná is 12 280 km^2 (*Figure 2*) and the long-term average monthly discharge (Qa) is 41,655 m^3/s. The elevation above sea-level of water gauge's zero on the station Ladná is 157,38 m a.s. and so it represents the lowest point of the reference basin. The highest point of Dyje basin is the hill Javořice (837 m a.s.) about 13 km west by south of Třešť.

The river Dyje is actually formed on the junction of Moravská Dyje and Deutsche Thaya by austrian Raabs. The catchment area of Moravská Dyje is 630,34 km^2, the long-term average monthly discharge is 3,05 m^3/s and it springs by Spělkov in 635 m a.s. Deutsche Thaya springs between Schwegers and Allensteig in Manhart highlands in 650 m a.s. Its catchment area is 769,6 km^2 and the long-term average monthly discharge is 4,4 m^3/s. From the junction the river Dyje runs through many meanders in deep valley down to the Vranov reservoir. Under the Vranov reservoir down to Znojmo Dyje flows through the National park Podyjí (on the austrian side of river it is called Nationalpark Thaya). Then by Znojmo Dyje leaves the enclosed valley and flows into equal area. Above the Nové Mlýny reservoirs from the left Jevišovka River, with the catchment area 789 km^2, comes to Dyje and to the second reservoir of Nové Mlýny Jihlava river and Svratka river flow from the left too. The catchment area of Jihlava river is 2.998 km^2 and it has two most important affluents – Oslava river with the catchment area 868 km^2 and Rokytná river with the catchment area 585 km^2 – which both run to Jihlava river between Oslavany and Ivančice. The catchment area of Svratka River is 4.118 km^2 and its most important affluent is Svitava river with the catchment area 1.149 km^2, which comes to Svratka river in the south part of Brno. So, when Dyje river leaves the last third dam of Nové Mlýny reservoirs, it is only 14 km till its flow reachs the station Ladná and next 32,2 km to the entry of Dyje river to Morava river from there.

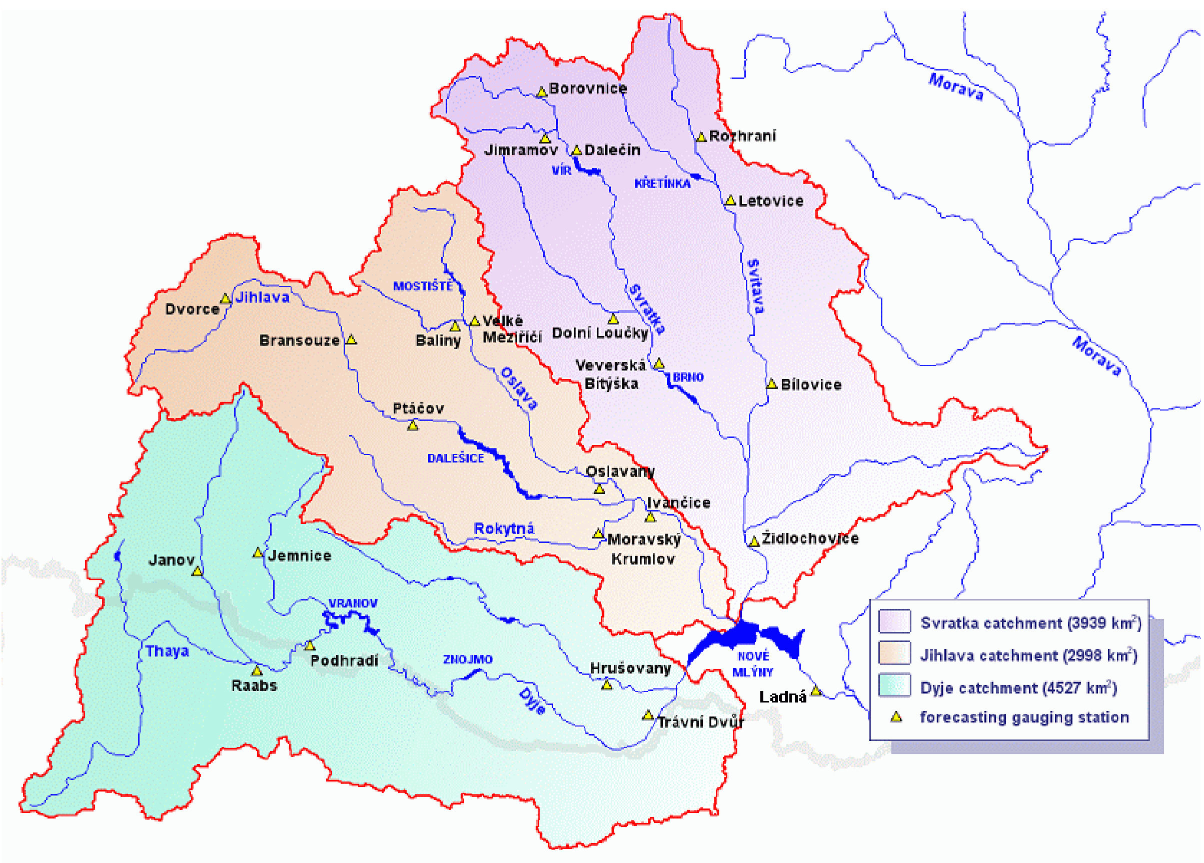


Figure 2. Dyje catchment

The upper Vltava river basin

The upper Vltava river basin with a closing profile at Vrane n/V is situated in the southern part of the Elbe River basin (Figure 3). The area of the basin is 17,780 km2 and the altitude ranges from 170 to 1380 m a.s.l.. Geography covers a range of different climate, hydrogeology, and land-use conditions from lowlands and upland plains used largely for urbanisation and agriculture to almost non-inhabited forested mountains. The river network comprises four larger rivers: the Vltava River, two right-side tributaries – the Luznice and Sazava Rivers, and one left-side tributary – the Otava River. The valley of the Vltava River is largely impounded with a cascade of reservoirs (Lipno, Hnevkovice, Orlik, Slapy, Stechovice, Vrane Res.) that have been built for a main purpose of hydropower. In addition, two important drinking water reservoirs are situated on side tributaries of the Vltava River, i.e. Svihov and Rimov Res. Main characteristics of the reservoirs are in *Table 2*.

Figure 3. A situation drawing of the upper *Vltava River basin (thick red line) within the Elbe River basin*

Table 2. Selected characteristics of reservoirs and their catchments with periods of available limnological data

Parameter	Rimov	Lipno	Svihov	Orlik	Slapy	Vrane
Catchment:						
area, km^2	489	952	1180	12110	12980	17780
inhabitants, cp per km^2	35	15	45	50	49	55
farmland/forest, %	40/50	3/77	62/29	52/45	52/45	55/42
min./max. altitude.	430/1111	710/1378	325/765	280/1378	213/1378	190/1378
Reservoir:						
volume, mil. m^3	33	310	267	704	270	11
surface area, km^2	2	49	14	26	14	2.5
max. depth, m	43	22	52	71	58	10
hydraulic retention time, d	90	270	430	100	39	2
Available data periods	1979-2004	1967-1968 1991-2004	1980-2004	1991-1993, 2000	1961-2004	1963-2004

Data and their main features

The period of study is from 1961 to 2004. Number of stations with available precipitation, climatic, hydrological, and water quality data for our study is summarised in *Table 3*.

Table 3. Number of monitoring stations in the sub-basins of the upper Vltava River used in this study

Sub-basin	Precipitation	Climate	Hydrology	Water quality
Vltava	12	4	14	10
Luznice	9	2	11	5
Otava	10	2	8	7
Sazava	10	2	16	6

The upper Vltava River basin belongs to the temperate, mildly cold climatic region. It is situated in a transient region between a wet oceanic climate of the west Europe and a dry continental climate of the east Europe. A long-term annual mean precipitation amount is about 680 mm. The distribution of precipitation amounts across the basin is uneven with more than 1,000 mm at the southern mountainous part (e.g., the station of Churanov, 1019 mm) and about 600 mm in the central and northern parts of the basin (e.g., the stations of Ceske Budejovice and Tabor). The annual mean temperature is about 9°C at the lowest parts of the basin and <5°C at altitude above 1,000 m a.s.l.. A highly significant increasing trend of temperature was detected at most climate monitoring stations in the basin during the period from 1961 to 2004 with an annual increase by 0.02 to 0.03°C.

The long-term (1961-2004) runoff from the upper Vltava River basin at the closing profile of Vrane n/V is 103 m^3/s, which equals 5.8 l/s km^2 or the runoff depth of 182 mm. At the mean precipitation amount of 680 mm it means that the evaporation in the basin is 508 mm (72% of precipitation). The runoff depth differs between the southern, mountainous part of the basin where mean values >500 mm are common and the northern part with mean values of about 150 mm. The coefficient of variation of annual mean discharge is relatively high; it varied between 27 and 40% at 14 selected stations in the basin during the period 1961-2004. More that 60% of the annual runoff volume from the basin occurs during the winter hydrologic period (November-April).

Water quality data include oxygen conditions (dissolved O2), 3 determinations of organic substances (biochemical oxygen demand (BOD5) and chemical oxygen demand by permangate

(CODMn) and dichromate (CODCr) methods), suspended solids (TSS) and their loss on ignition (LOI), nitrate nitrogen (NO3-N), ammonia nitrogen (NH4-N), phosphate and total phosporus (PO4-P and TP, respectively), chlorophyll-a etc. Examples of water quality development in different parts of the upper Vltava River basin during the studied period are given in *Figure 4*. The Vltava River experienced a period of heavy organic pollution from a paper mill situated at Vetrni (cca 30 km downstream from Lipno Reservoir) until 1990. The pollution with nitrate and phosphorus peaked during the early 1990s.

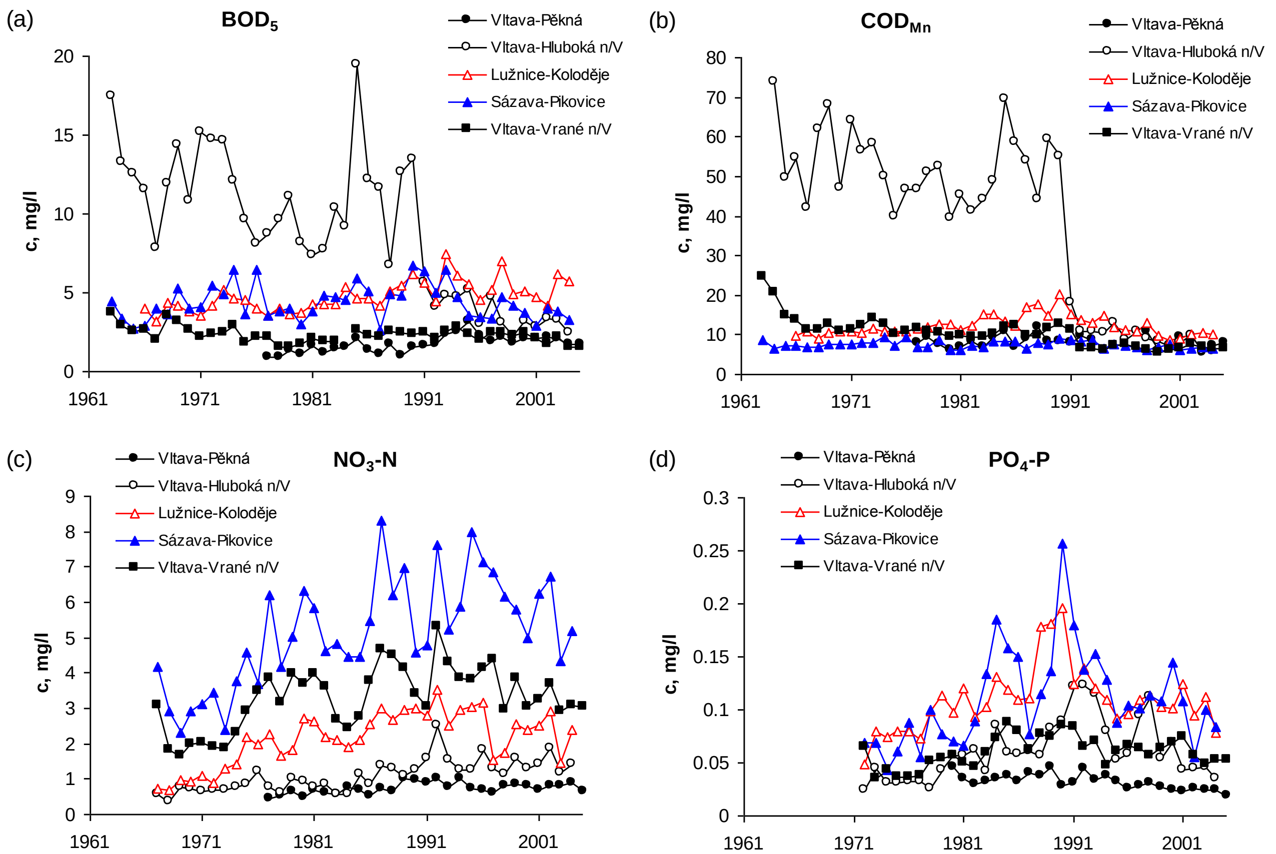


Figure 4. The time series of annual mean concentrations of (a) BOD_5, (b) COD_{Mn}, (c) NO_3-N, and (d) PO_4-P in selected monitoring stations in the upper Vltava River basin (see Figure 6 for their location) during available data periods

Hron river basin

The Hron River is a left-side tributary of the Danube River and its basin is located in Central Slovakia. The catchment is feather-shaped, located along the long main river with numerous shorter tributaries. It covers an area of 5465 km^2, its upper and middle parts are situated in the area of Inner Carpathian Mountains, while the lower part of the basin belongs to the Danubian Lowlands. The location of the catchment within the territory of Slovakia is shown in *Figure 5*.

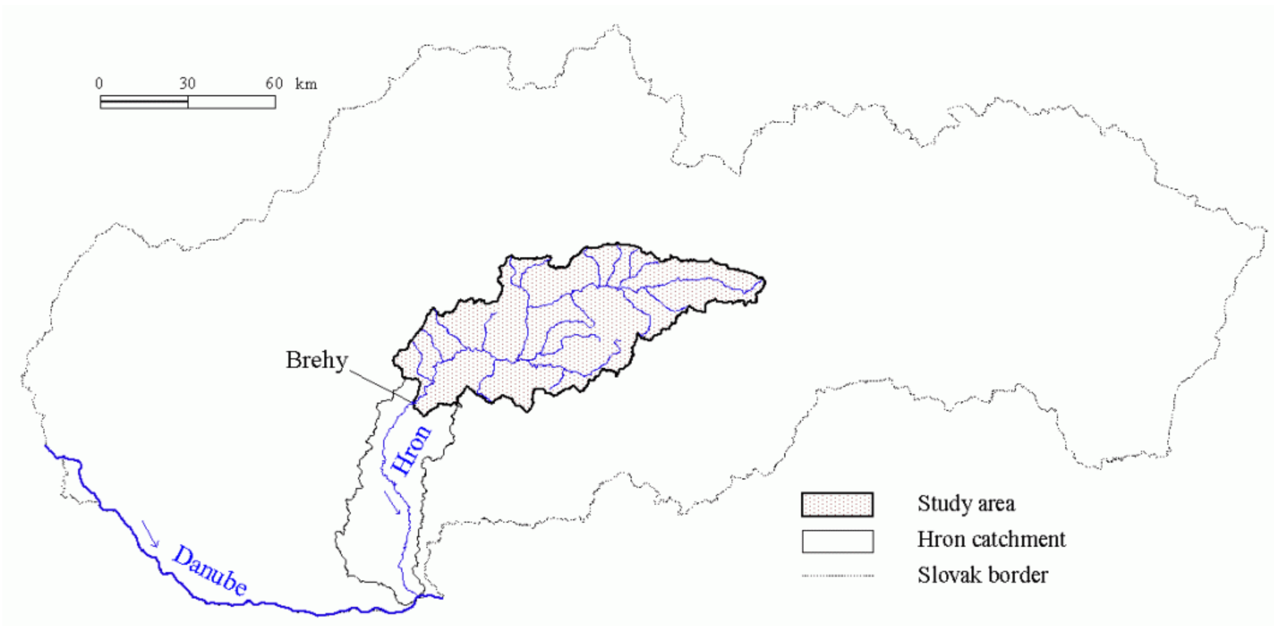


Figure 5. Location of the Hron River basin in Slovakia

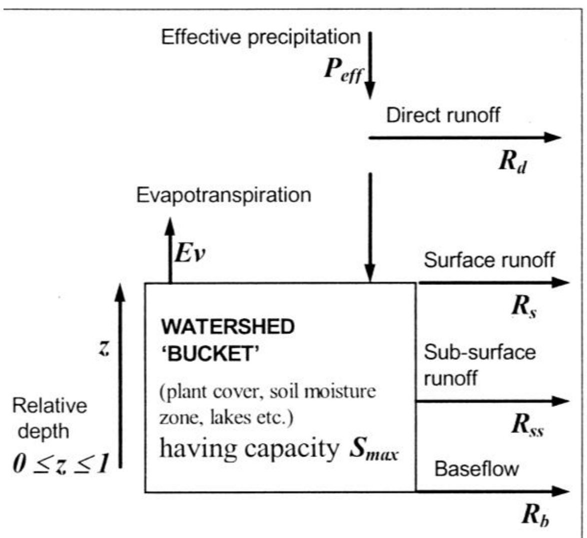
Description of the models

The rainfall-runoff model WatBal

For assessing the impact of the climate changes upon the water resources, the WatBal model is used. This is a water balance with monthly time step model and it is combined with the Priesley-Taylor method for calculating the potential evapotranspiration.

WatBal is an integrated water balance model developed for assessing the impact of climate change on river basin runoff.

The WatBal model contains two key parts required for modelling. The conceptual diagram of the WatBal model and main equations *(Yates, 1994)* are presented into the *Figure 6*.



$$(1)\quad S_{\max}\frac{dz}{dt} = \left[P_{eff} - R_d(\beta)\right] - R_s(z,t) - R_{ss}(z,t) - Ev(PET,z,t) - R_b$$

$$(2)\quad R_d = \beta P_{eff}$$

$$(3)\quad R_s = \begin{cases} z^{\varepsilon}(P_{eff} - R_b), & \text{if } P_{eff} > R_b \\ 0, & \text{if } P_{eff} \le R_b \end{cases}$$

$$(4)\quad R_{ss} = \alpha z^{\gamma}$$

$$(5)\quad Ev = PET\left(\frac{5z - 2z^2}{3}\right)$$

$$(6)\quad P_{eff}(i) = mf(i)A(i);\quad mf(i) = \begin{cases} 0, & \text{if } T(i) \le T_S \\ 1, & \text{if } T(i) \ge T_L \\ \dfrac{T(i) - T_S}{T_L - T_S}, & \text{if } T_S < T(i) < T_L \end{cases}$$

Figure 6. Conceptual diagram of the WatBal model and main equations

Where:
Smax – maximum reserves,
Peff – effective precipitation,
Rd – direct runoff,
Rs – surface runoff,
Rss – sub-surface runoff,
Ev – evapotranspiration,
Rb – baseflow,
z – relative depth of water reserves in the basin,
PET – potential evapotranspiration,
ß – direct runoff coefficient,
ε, α and γ – coefficients determined during model calibration,
A(i) – snow accumulation in the basin per month,
mf(i) – snow melt factor in month i,
T(i)– average air temperature in month i,
TS – mean monthly temperature at which snow cover will appear (solid phase of precipitation),
TL – mean monthly temperature at which all snow cover disappears (liquid phase of precipitation)

The first part is the water balance using functional relations for the purpose of estimating water movement in a basin. The other component is the potential evapotranspiration, and estimation according to the Priestly–Taylor, Thornthwaite (modified Penman) method is used. In the general system, water balance is expressed as a differential equation, while all potential reserves of the basin are grouped into one block called the maximum storage capacity. The composition of the water balance parts is determined by the objectives pursued in specific researches and the calculation methods used. Applying the WatBal water balance model and forecasting changes of the hydrological regime, the main parts of the balance were subdivided into smaller components: effective precipitation and potential evapotranspiration were calculated and analysed. Total runoff was subdivided into direct, surface, subsurface runoff and baseflow. The model input components were as follows: precipitation, air temperature, relative air humidity, wind speed, sunshine duration, runoff, potential total evapotranspiration, net radiation, albedo.

The output components were potential evapotranspiration, evapotranspiration, total modelled runoff, direct runoff, surface runoff, subsurface runoff, relative depth of water reserves in the basin, effective precipitation.

The model is distinctive, because evapotranspiration in the water balance calculations may be determined by choosing one of three analytical methods. Any estimate of climate change impact on water resources depends on the ability to relate changes in actual evapotranspiration to predicted changes in precipitation and potential evapotranspiration. This goal can be achieved by applying analytical methods used in the WatBal model, therefore this model was chosen as a suitable tool for modelling the impact of climate change on water balance structure.

By adapting the values of meteorological and hydrological data sets for modelling using the WatBal model, spatial interpolation will conducted for the precipitation, temperature, relative air humidity, wind speed and sunshine duration data measured in the monitoring points.

Meteorological observation data – monthly averages of air temperature (°C), relative air humidity (%), sunshine duration (hours), wind speed (m/s) and precipitation (mm) will be included into the database.

The WatBal model will be adjusted to the local conditions of a specific region before modelling river basin water balance. In order to complete this task, calibration for each river basin under research was conducted. The length of data sets and time steps used for calibration were determined by the objectives pursued and actual conditions.

The water balance model BILAN

For simulation of changes in future runoff and other water balance components in Dyje basin because of the climate change it will be used the BILAN water balance model. This model has been developed by the staff of T.G.M. Water Research Institute in Prague for assessing water balance components of a catchment in a monthly step. It is structured as a system of relationships between these components on the land surface, in the soil zone of aeration, including the effect of vegetation cover, and in the groundwater aquifer. Air temperature is used as an indicator of energy conditions, which affect significantly equilibrium between the water balance components.

The model generates monthly series of basin potential evapotranspiration, actual evaporation, infiltration to the zone of aeration, percolation of water towards the groundwater aquifer, and water storage components in the snow cover, zone of aeration (soil) and groundwater aquifer. The total runoff consists of three components: direct runoff, interflow and base flow.

The model has eight free parameters and its optimisation technique uses observed data for their calibration. The optimisation is aimed at attaining the best fit between the observed and simulated runoff series.

The entry data of the model are monthly series of basin precipitation, air temperature and relative air humidity. To calibrate the parameters of the model observed monthly runoff series at the outlet from the basin are used.

In this case to calibration of the model over the selected period 1970-2000 there will be used monthly runoff series at the station Ladná. However, this station is running only since 1988, so that the runoff series over the period 1970-1987 had to be re-counted with a coefficient from the station

Dolní Věstonice, which had been running to 1988, when it was flooded by the third reservoir of Nové Mlýny.

For assessment of basin air temperature and relative air humidity there will be used measured data series of air temperature and relative humidity from 12 climate stations and for assessment of basin precipitation there will be used measured data series of precipitation from these 12 climate stations too and from next 13 precipitation stations. All these stations are situated on the Czech part of Dyje river basin.

The rainfall-runoff model HYDROG

For simulation of potential future flood events (hydrological extremes) the model HYDROG will be used. HYDROG (*Starý, 1991-2005*) is a distributive event rainfall-runoff model, which has been used routinely in Czech Hydrometeorological Institute since 2000 for operative discharge prediction in several rural catchments of typical area about thousands of square kilometers.

The basic principles of HYDROG are as follows. If we perform a schematization of a catchment by subdividing it into subcatchments with constant properties (slope, roughness, hydraulic conductivity in a saturated environment), the rainfall-runoff process can be solved in a simplified way, i.e. as a one-dimensional problem. When simulating the flow of water through a subdivided catchment (spatial-surface runoff and concentrated runoff), the Saint-Venant Equations (continuity equation and an equation based on the law of motion preservation) simplified by a kinematic wave approximation (*Stephenson and Meadows, 1986*) are used for the description of the dynamic performance of the system. For the computation of the dynamic change of groundwater runoff a conceptual regression model (McCuen and Snyder, 1986), which uses only groundwater storage, is used. Of the hydrological losses, an important one is the infiltration loss - for its calculation the model use the modified Horton method *(Jacobsen, 1980)*, which estimates the amount of initial infiltration from the rainfall sum that occurred in the preceding period (week). Other losses are included in the initial threshold value, when the aerial surface runoff is triggered off only after this value is exceeded.

HSPF model and their setup

The HSPF model (Bicknell et al. 2001) is a conceptual precipitation-runoff model with a modular structure that enables simulations of transport of multiple substances from the catchment and their transformations in the river network. Simulations are accomplished in user-defined separate parts of the catchment and of the river network that have similar soil, water ecosystem, and climate conditions. The separation of the upper Vltava River basin into 69 sub-catchments is in *Figure 7*.

Each sub-catchment is composed of 5 segments that represent farmland, low-slope (<8°) areas, high-slope (>8°) areas, flood areas (maximum distance of 100 m from the channel and with slope <1°), and impervious areas. The modules comprise water balance of pervious and impervious (PWATER and IWATER), snow cover (SNOW), soil moisture (MSTL), soil erosion and transport (SEDMNT, SOLIDS), and phosphorus transport from the catchment (PHOS). The river network of each subcatchment is divided into two segments. The first, upper one represents 1st to 3rd-order (Strahler) streams and the second one stream of higher orders. Within the stream and river segments the HSPF model uses modules of flow transformation (HYDR), advective transport of substances (ADCALC), transport, sedimentation, and resuspension of erosion particles (SEDTRN), nutrient transformations (NUTRX) a phytoplankton growth (PLANK). The model outputs in a format of text files are used as input files for the subsequent simulations with the reservoir model CE-QUAL-W2.

The two-dimensional, laterally averaged numerical reservoir model CE-QUAL-W2 v. 3.2 (*Cole and Wells, 2003*) is used in this work. The reservoirs are approximated with a finite-difference grid that typically consists of segments 300 m to 1 km in length and 0.5 to 1 m thick. Water quality simulations include the following quantities: temperature, water age, dissolved oxygen, biomass of 3 phytoplankton groups (ALG1, ALG2, ALG3), labile and refractory dissolved and particulate organic matter (LDOM, RDOM, LPOM, RPOM), orthophosphate P (PO4-P), NO3-N, and NH4-N.

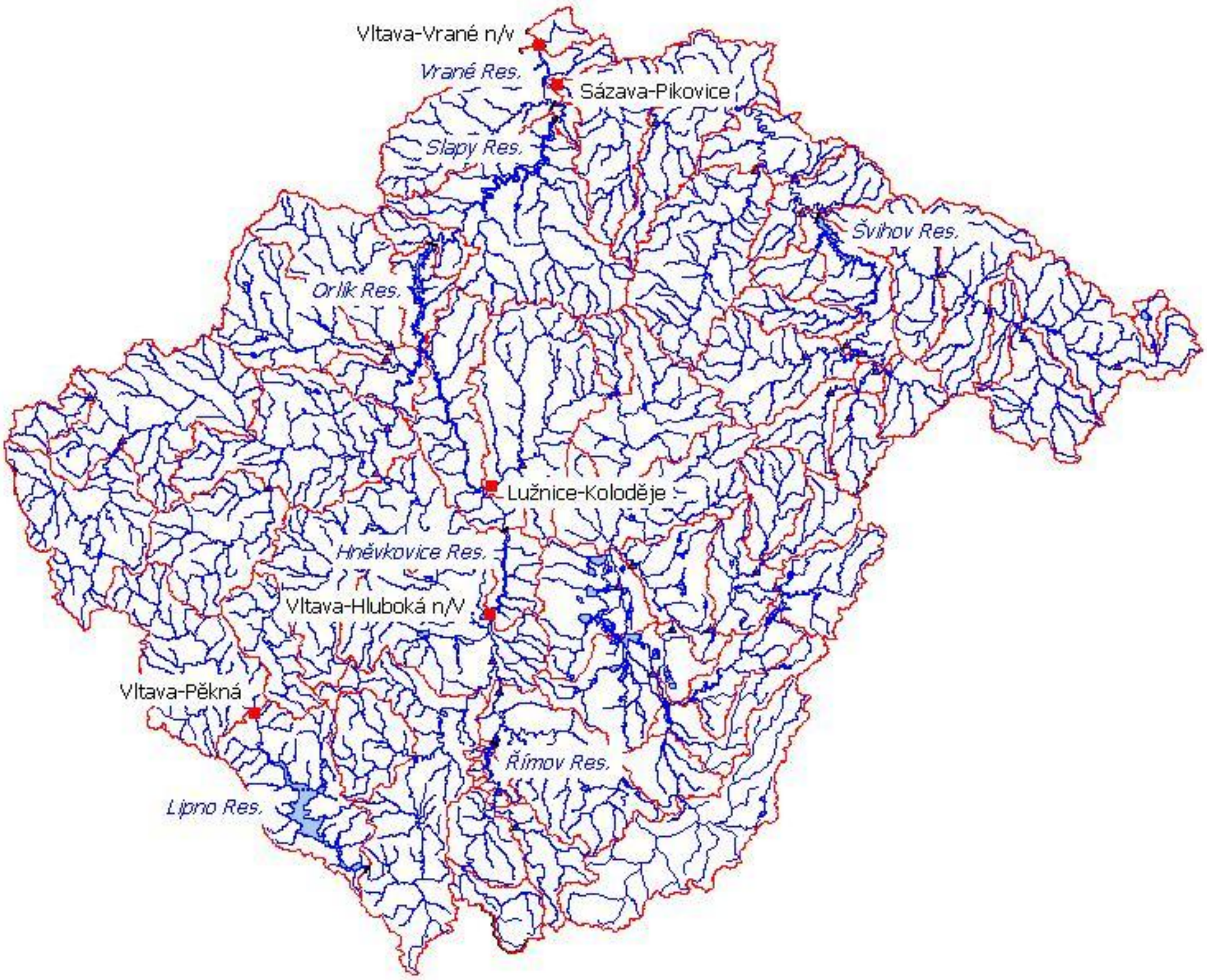


Figure 7. Upper Vltava River basin with major rivers, streams, and reservoirs. Blue triangles – discharge monitoring stations, red squares – selected water quality monitoring stations. The red lines outline sub-catchments used in HSPF modelling.

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Description of the KVHK hydrological balance model

For estimating the changes in the seasonal runoff distribution, the conceptual hydrological balance model KVHK developed at the Slovak University of Technology will be used. This model is a refinement of the WatBal model which was chosen as a reference model in the CECILIA project. The KVHK model simplifies the river basin into 2 nonlinear reservoirs, and it simulates runoff from impermeable areas in the basin, snowmelt and water accumulation in the basin, evapotranspiration, surface and subsurface runoff and baseflow. The inputs required for the modelling water balance in a monthly time step are: the mean monthly precipitation for the basin, the mean monthly discharges in the outlet of the basin and the mean monthly potential evapotranspiration (PET). For calculating the potential evapotranspiration, various methods can be used (the Tomlain, Thornthwaite, Ivanov and FAO methods) and additional climate data (the mean monthly air temperature values, the mean monthly hours of sunshine duration, the mean monthly values of the relative air humidity, the mean monthly values of wind speed, the monthly values of cloudiness and number of days with snow cover in a month) are required.

The basic mass balance equation in the model is written as:

$$S_i - S_{i-1} = \left(P_i\left(1 - drc\right)\right) - Rs_i - Rss_i - Ev_i - Rb \qquad (7)$$

where:

- S_i, S_{i-1} current water storage in the basin in months *i* and *i* -1 [mm],
- *i* time step [month],
- P_i basin's average precipitation in the month *i* [mm],
- *drc* direct runoff coefficient ($0 \le drc \le 1$) [–],
- Rs_i surface runoff in the month *i* [mm],
- Rss_i subsurface runoff in the month *i* [mm],
- Ev_i basin's average actual evapotranspiration in the month *i* [mm],
- *Rb* baseflow [mm].

The scheme of the model is illustrated in *Figure 8*.

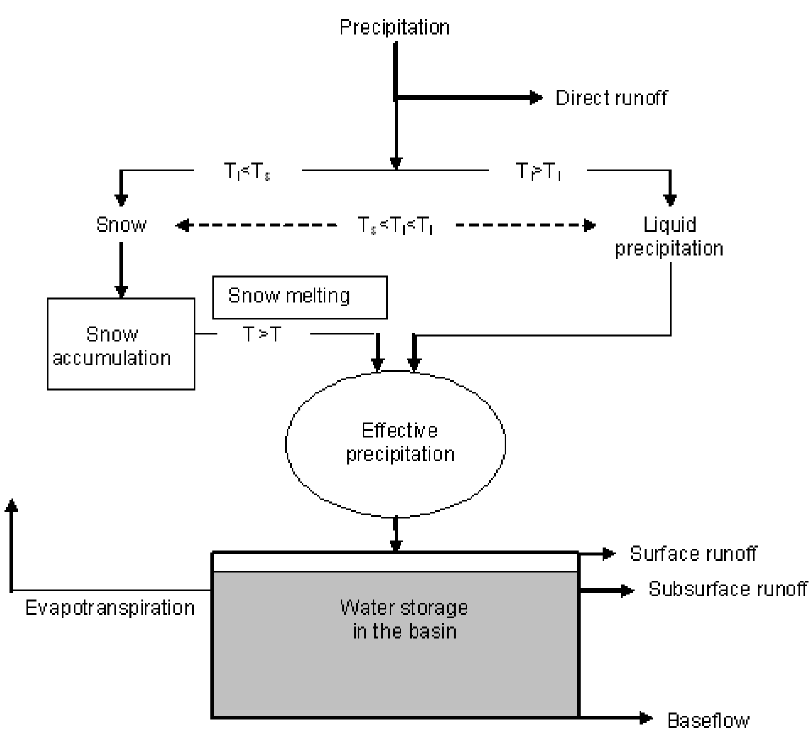

Figure 8. Scheme of the hydrological balance model.

At the beginning of simulation a part of the precipitation fallen down to impermeable or the water surface is extracted as a direct runoff. The rest of the precipitation goes to the first snowmelt and snow accumulation nonlinear reservoir, which enables distinction between solid and liquid precipitation on the basis of the threshold temperatures. In this reservoir, the effective precipitation which further participates on the runoff formation is calculated as:

$$Peff_i = mc_i \, (A_{i-1} + P_i) \qquad (8)$$

Where: $mc_i = 0$ if $T_i \le T_s$

$mc_i = 1$ if $T_i \ge T_l$

$mc_i = \left[\frac{(T_i - T_s)}{(T_l - T_s)} \right]^{PeffPar}$ if $T_s < T_i < T_l$ (3)

$Peff_i$ - effective precipitation for the basin in the month *i* [mm],
P_i - basin's average measured precipitation in the month *i* [mm],
$A_{i\text{-}1}$ - snow accumulation in the month *i*-1 [mm],
mc_i - snow melting factor in the month *i* [–],
T_i - mean air temperature in the month *i* [^{o}C],
PeffPar - parameter for calculating basin's average effective precipitation [–],
T_s - threshold air temperature for snow accumulation [^{o}C],
T_l - threshold air temperature for snow melting [^{o}C].

If the current air temperature in the month *i* is higher than the threshold temperature T_l, all precipitation is considered to be liquid and it will participate on runoff formation in this month. If the current air temperature is lower than the threshold temperature T_s, all precipitation is accumulated in the snow cover. In the case if the current air temperature is in between T_s and T_l ($T_s < T_i < T_l$), a part of liquid and a part of accumulated precipitation is calculated according to the snow melting factor *mc*. Relationships between the snow melting factor and the mean monthly air temperature are shown in *Figure 9*, these are controlled by the model parameter *PeffPar*.

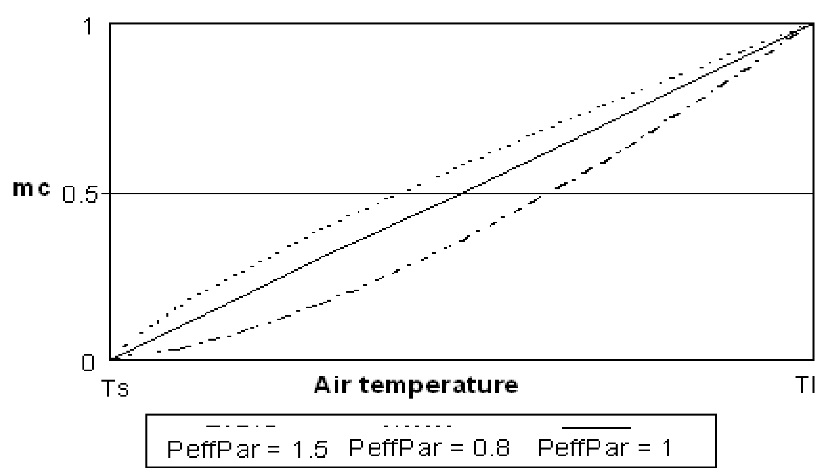

Figure 9. Relation between the snow melting factor, the mean monthly air temperature and the PeffPar parameter.

Snow accumulation is calculated by the equation:

$$A_i = (1 - mc_i)(A_{i-1} + P_i) \qquad (9)$$

where: A_i and A_{i-1} is snow accumulation *[mm]* in months *i* and *i-1*.

Surface runoff *Rs* is calculated as a function of the ratio between the current and maximum water storage in the second nonlinear (water accumulation) reservoir, parameter ε and a difference between effective precipitation and baseflow *Rb*. The baseflow *Rb* is a model parameter. If the effective precipitation in the month *i* is lower than the baseflow value, surface runoff is equal zero. Otherwise, the surface runoff is expressed as:

$$Rs_i = \left(\frac{S_i}{S_{\max}}\right)^{\varepsilon} \left(Peff_i - Rb\right) \qquad (10)$$

where: S_{max} - maximum water storage in the second nonlinear reservoir [mm],
S_i - current water storage in the second nonlinear reservoir in the month *i* [mm],
$Peff_{\mathrm{i}}$ - effective precipitation in the month *i* [mm],
Rb - baseflow [mm],
ε - a model parameter [-].

Subsurface runoff is a function of the ratio between current and maximum water storage in the second water accumulation reservoir, and parameters α and γ:

$$Rss_i = \alpha \left(\frac{S_i}{S_{\max}}\right)^{\gamma} \qquad (11)$$

Actual monthly evapotranspiration for the basin is calculated as a function of monthly potential evapotranspiration for the basin and the ratio between current and maximum water storage in the second water accumulation reservoir. Actual monthly evapotranspiration is than expressed in the form:

$$Ev_i = E_{0i}\left[1-\left(1-\left(\frac{S_i}{S_{\max}}\right)\right)\right]^{ActEpar} \qquad (12)$$

Where: $E_{0\mathrm{i}}$ is the potential evapotranspiration in the month *i* and *ActEpar* is a model parameter.

The total runoff R_t is calculated as the sum of the four runoff components R_s, R_{ss}, R_b *and* R_d, where R_d is direct runoff.

In the calibration procedure of the hydrological balance model, 11 model parameters are optimized (S_{max}, α, γ, ε, *PeffPar*, T_s, T_l, *Rb*, *ActEpar*, *drc* and $Z_{initial}$). The parameter $Z_{initial}$ is an initial value of the ratio between S_i and $S_{\max}$. In the model a genetic algorithm (*GA*) is built in to calibrate the model parameters and several criteria (or their combinations) are used as an objective function. Basic optimization criteria are: the Nash-Sutcliffe criterion, the sum of squared differences between measured and simulated values, the sum of squared differences between logarithms of measured and simulated values and the Nash-Sutcliffe criterion for the long-term mean monthly values.

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