IMPACT OF A POTENTIAL CLIMATE CHANGE UPON THE WATER SUPPLY BEING OBSERVED DURING THE OPERATION OF THE VIHORLAT RESERVOIR

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Abstract: This paper presents an attempt to answer the question, how the expected climate change would influence the inflow into a multipurpose reservoir (water reservoir Vihorlat) and how the reservoir will be able to supply a real demand for water during its life so far. These changes were calculated by rainfall-runoff balance model WBMOD that works with a monthly time step. The input data series of precipitation and air temperature (climatic scenarios) and the observed reservoir outflows were used to express the expected changes of the total runoff and the required reservoir capacity. Input data were modified every month according to the last climate scenarios estimated for the Vihorlat reservoir catchment by the CCCMprep GCM. Failures in the required water supply for this climate change scenario were compared with those observed during the real life reservoir operation. Climate scenarios of temperature and precipitation changes for the Laborec catchment above gauging station Laborec-Humenné were used.
Key words: rainfall-runoff monthly balance model, water reservoir, and climate change scenarios.

EINFLUSS DER POTENTIELLEN KLIMAÄNDERUNGEN ÜBER DIE BISHER BEOBACHTETE WASSERENTNAHME AUS DEN OSTSLOWAKISCHEN WASSERSPEICHER VIHORLAT

Zusammenfassung : In dem Beitrag sucht man eine Antwort auf die Frage, wie kann die erwartete Klimaänderung die so weit (seit der Inbetriebnahme der Speicher) beobachtete Wasserversorgung aus dem Mehrzweckspeicher Vihorlat beeinflussen. Dieser Einfluß bewirkt sich durch Speicherzuflußänderungen von dem Fluß Laborec, die nach dem veränderten klimatischen Scenario mit Hilfe des Niedeschlag – Abfluß Bilanzmodell WBMOD in einem Monatsschritt berechnet wurden. Als Modeleingabe wurden die klimatisch veränderten Datenserien der Einzugsgebietsniederschläge und Temperatur benutzt, sowie auch die bisher beobachtete Serie der Wasserentnahme aus dem Speicher. Aus den Ergebnissen wurde dann die Serie der Speicherwasserinhalte berechnet. Die Eingabedaten wurden für jeden Monat nach dem letzten für das Laborec Einzugsgebiet bis Pegel Humenné modifiziertes klimatisches Szenario CCCM benutzt. Dann die Wasserabnahmestörungen wurden berechnet für verschiedene Manipulation mit der Höhe des Speicherwasserspiegels und verglichen mit jenen für die historische reale Periode 1971 – 1998. Die Ergebnisse mit Verwendung dieser klimatischen Szenario (CCCM) deuten nur eine sehr geringe Senkung des Sicherheitsfaktor der Wasserentnahme im Vergleich mit dem historischen Betrieb seit der Inbetriebsnahme des Speichers.
Schlüsselwörter: Niederschlag – Abfluß Wasserbilanzmodell, Wasserspeicher, Szenarien von Klimaänderungen.

Laborec River Basin and water reservoir Vihorlat

Under the present conditions, the importance of storage function of water reservoirs is growing. The water reservoirs, as a component of drinking water supply systems, are particularly important in ensuring continuous water supply to large towns and regions.

Water reservoir Vihorlat is located in the East Slovakia Lowland (ESL), which is a plain part of the Bodrog River Basin in Slovakia and it has above 2000 km^2.
Water conditions of ESL have been markedly influenced by rivers Topľa, Ondava, Laborec, Čierna voda, Uh, Latorica and Bodrog, (Fig. 2). The Bodrog River Basin is composed of

Latorica and Ondava rivers. Total catchment area of the Bodrog river is 11 355.8 km^2, 60% of this area is on the territory of Slovakia. Upper parts of the catchment have characteristics of a mountain stream with slope 15-20%. Character of lower part is changed and catchment has slope 2-0.3‰. Due to this sudden change of a river slope rivers had insufficient capacity. In the past it was a cause of floods especially during snowmelt periods or during intensive rainfalls.

Water reservoir Vihorlat was constructed as a part of the water management measures in the ESL and was put into operation in 1965. It is placed in a terrain wave, on the left side of the river Laborec. It is enclosed on the north by Vihorlat slopes, on the east and west by earth dykes and by terrain wave on the southwest. The weir Petrovce on the Laborec river serves as the intake and distribution structure, together with headrace canal from the weir to the side reservoir. The weir Petrovce divides discharges of the Laborec so, that a discharge of the $Q_{min}=1,4 m^3.s^{-1}$ is ensured in the Laborec river channel at Michalovce, and all other discharges are diverted into the headrace canal. The maximum discharge in the Laborec channel at Michalovce during flood situation is $Q_{max}=100 m^3.s^{-1}$.

Total storage capacity of the reservoir is 334 mil.m^3, flood control storage capacity is 100 mil.m^3, useful storage is 177 mil.m^3 and permanent storage is 57 mil.m^3 (Fig. 1). The project of water reservoir Vihorlat has some basic purposes from the water management point of view:

- *the project secures the required withdrawals of water for the thermal power plant Vojany, for irrigation of 54 000 ha of adjacent agricultural lands, and for increasing of minimum discharges in the river Laborec,*
- *the reservoir has a positive influence on flood regime of the river Laborec and partly also on the whole region on the ESL – it includes the protection of 8 900 ha of agricultural land, (the reservoir reduces flood discharges, above the Petrovce weir, from $Q_{100} = 600 m^3.s^{-1}$ to 100 – 300 $m^3.s^{-1}$ below canal outfall from the reservoir, according to the concrete operation),*
- *the reservoir is intensively used for recreation (this region has the most continental climate in Slovakia, with numerous sunny days over the period June-August).*

For a design of flood control storage capacity data of flood regime from the period 1931-1965 were used, when 55 flood discharges over Q=100 $m^3.s^{-1}$ were measured. According to that measurements storage of a „theoretical flood" ($Q_{max}=600 m^3.s^{-1}$ with duration of 7 days) was estimated. The reservoir-storage-elevation curve we obtained from Slovak Water management Enterprise - Bodrog and Hornád River Basin Administration, (Fig. 1).

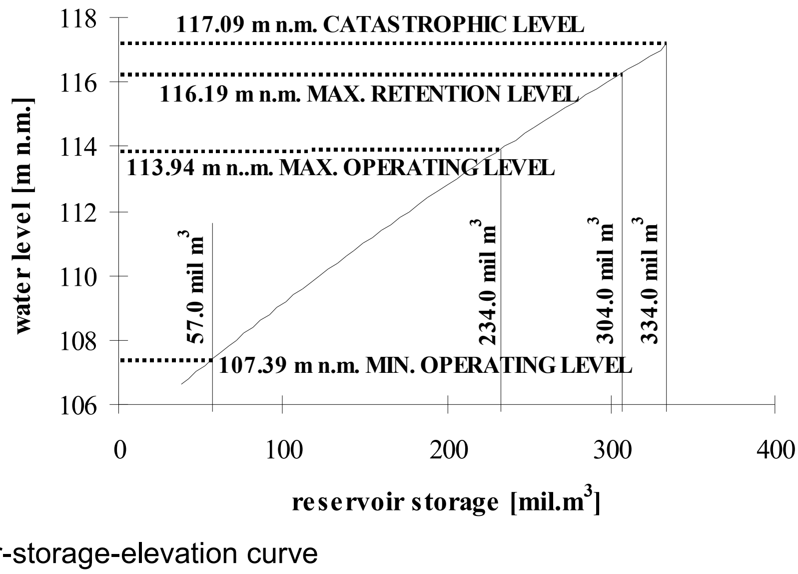

Fig. 1 Reservoir-storage-elevation curve

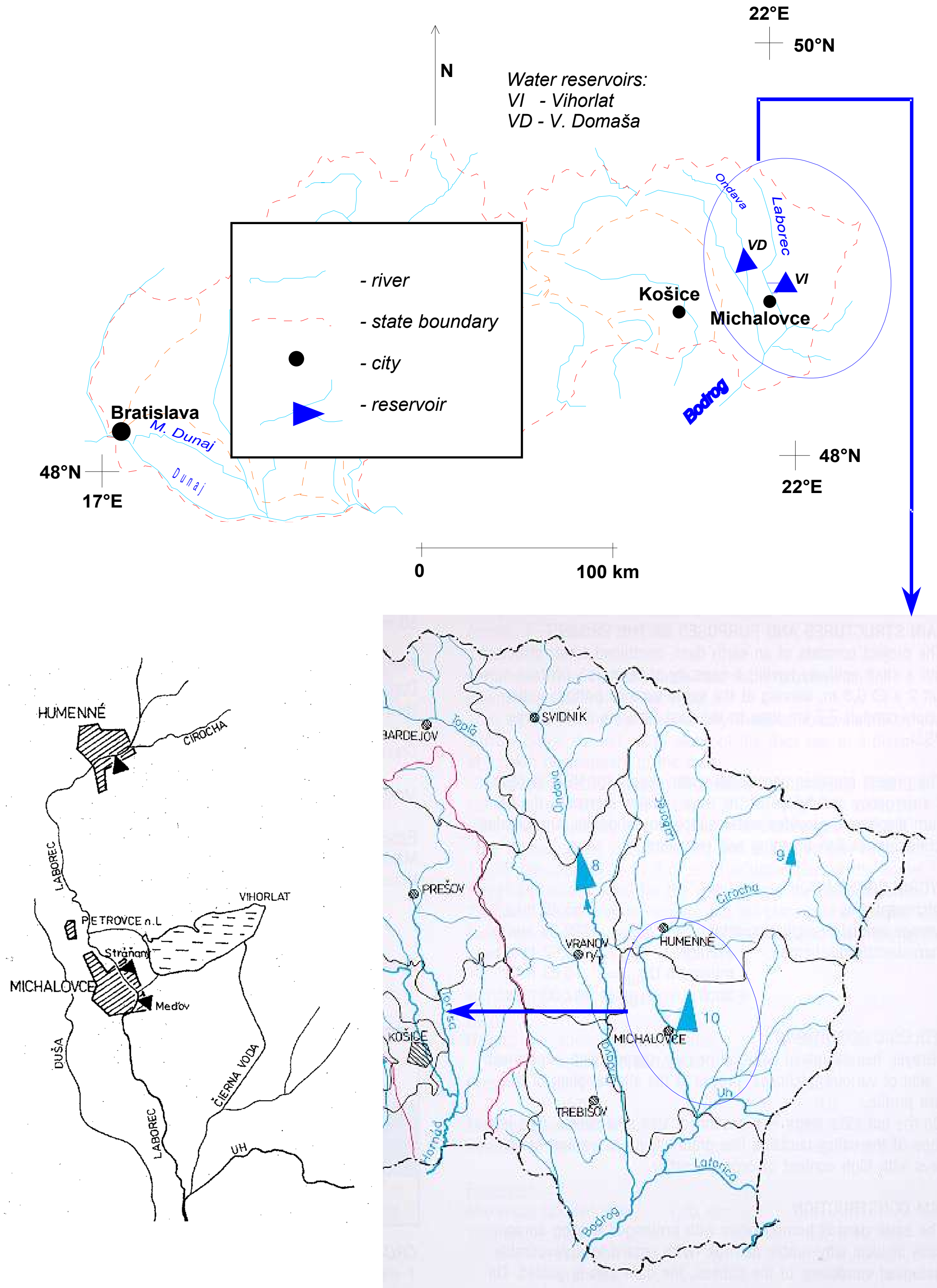

Fig. 2 Catchment of the water reservoir Vihorlat

Runoff regime of the Laborec river after the completion of water reservoir was significantly changed. Long-term annual discharge in Michalovce-Stráňany profile was decreased by 54%. Standard deviation, which is the most respondent indicator of discharge variability, was decreased by 48%. The variability of discharges concerning the average was increased, the coefficient of variability was increased by 14%. After processing of probability curves of water stages it is evident that water reservoir operation significantly decreased the average annual discharges.

Methodical approach

Water balance models with monthly time step

Water balance models, with monthly time step, would be appropriate tools for the solution of projects dealing with the water supply. The calibration of these models is easier as well as accessibility of the input data. The monthly hydrological forecasting would be used for the real time operation (for irrigation, energy generation).

Two examples of the monthly water balance model application were presented by ALLEY [1984], XU and VANDEWIELE [1995]. They used this type of model for runoff forecasting and for proposal of systems and their operation in water resources management.

Another problem that can be solved by monthly water balance model is related to the capacity of water reservoirs. Due to that, water reservoirs are constructed for water supply, it would be therefore useful to know a return period of water deficiency in relation to the reservoir water capacity.

Utilisation of hydrological models with monthly time step for implication of climate change

In the last years hydrological models were used for detection of climate change impact on water resources (GLEICK, 1986,1987; SCHAAKE, LIU, 1989; ARNELL, 1992), and this approach has some advantages.

- *Gleick* explored different approaches for determination of climate change impact on regional hydrology and presented some criteria for the best approach selection. He developed and tested monthly water balance model in Sacramento catchment for assessment of the impact of climate change. Results indicate that the application of this type of models would provide more information about the impact of climate change on regional hydrology.
- *Schaake and Liu* developed and used simple monthly water balance models to determine relationship between climate change and water reservoirs in more than 50 catchments (eastern China and south-eastern part of USA).
- *Arnell* used Tα-model (Thornthwait and Mathers) together with realistic scenarios of climate change (in 15 catchments of U.K.) for verification of some factors that regulate the impact of climate change. These 15 catchments represented large scale of climate and geological conditions of U.K. He favoured using of the conceptual models of water balance rather than physically oriented models or black-box models.

Several papers e.g. in the Czech Republic as well as papers in Slovakia demonstrate that the impact of expected climate change in water reservoir management would be fairly negative. The uncertainty of climate change assessment is connected with the uncertainty of changes in hydrological processes and they may caused the uncertainty in assessment of water reservoir function in future climate conditions, [HLADNÝ et al., 1996a], [HLADNÝ et al., 1996b].

NACHÁZEL et al., 1995 researched consequences of climate change on available storage capacity of reservoirs (fictitious reservoirs on Želivka and Úpa rivers) by means of other hydrological models (BILAN1, BILAN2, and SACRAMENTO). They used GISS scenarios for time horizons 2030 and 2075 as well as incremental scenarios of temperature and precipitation. It was shown that the application of present hydrological models might lead to considerably different requirements on the necessary reservoir storage capacity. Even for the relatively low changes of precipitation and of the air temperature the authors confirmed that the consequences would be considerable.

A change of relationship between available storage capacity, total controlled increase of runoff by reservoir and certainty of the water supply under new hydrological conditions can affect the utilisation of the existing water reservoirs. The assessment of water demand and water management during the near future has the ultimate role for solution of this problem, [MAJERČÁKOVÁ, 1997], [NACHÁZEL et al., 1995].

Concerning long-term planning in water management it is necessary to decide already at present what is better: to realise expensive preventive measures that have investment character (construction of new water reservoirs etc.), or to develop methods of prediction that adapt water resources management to immediate conditions. This problem was discussed in some papers from NCP CR, [HLADNÝ, 1997], [PŘENOSILOVÁ, 1994a], [PŘENOSILOVÁ, 1994b].

Climate scenarios for the Laborec river basin upstream of the water level gauging station Humenné

Climate systems and water resource systems are intimately linked, so that any change in one of these systems induces a change in another one. The interplay between climate and water has been extensively tackled in the Third Assessment Report of the Intergovernmental Panel on Climate Change, [KUNDZEWICS, 2003].

In the past we used ***GFD, UKM, GIS a OSU*** scenarios that are valid for $2xCO_2$ conditions and result from older versions of GCMs interpolated for the central and western Europe, (NCAR, Denver, Co., USA), [SVOBODA, 1995; 1996]. Those scenarios were interpolated for Ondava and Laborec river basins. Other scenarios marked as ***GFL, GIL, CCC a WPL*** were developed by the National Climate Programme of Slovakia (NCP SR) [LAPIN, 1997] and hold for the time horizon 2075 and for northern part of Slovakia.

Afterward we used precipitation scenarios marked as ***CCCMprep*** and ***GISSprep***. Scenario CCCMprep was modified from model CCCM (Canadian Climate Centre, Downsview, Ont., Canada) for conditions of Slovakia (4 node points around Slovakia). Precipitation scenario ***GISSprep*** was modified by outputs from model GISS (Goddard Institute of Space Studies, Oregon, USA) for Slovak conditions. It is possible to interpolate these scenarios for other stations (rain-gauge, meteorological) around, [LAPIN, 2000], [LAPIN, MELO, 2000] and to use them for solution of different problems connected with the impact of climate changes to surface water, groundwater or soil water regimes.

In general, most of the historical hydrological data are available from the time period 1951-1980, therefore climatologists use this period as a reference climate period for climate scenario computations. According to the fact that for the presented study we had to use as input data real reservoir operation data, records of precipitation and temperatures from the time period 1971-1998, climate scenarios for time period 1951-1980 had to be re-counted for the untypical reference period 1971-1998.

Currently we use scenarios that are calculated by model CCCM2000 for each rain-gauge and meteorological stations of the Laborec catchment upstream of the city Humenné, for time horizons 2030 and 2075.

Water balance model WBMOD with monthly time step

The water balance model was described in some papers from 2002, by HALMOVÁ [2002a, 2002b]. The basic structure of the model isn't changed and on Fig. 3 there is depicted a simple version of the water movement in the catchment during the month „t“. The WBMOD model uses average monthly data of basic runoff components as well as the models mentioned above (GLEICK, 1986,1987; SCHAAKE, LIU, 1989; ARNELL, 1992). This model was developed at V.U.B.–Vrije Universiteit Brussel-Hydrologie, basic equations and scheme of the model were described in several papers, [XU, 1992]. The calculation technique (with submodel "reservoir"), which is applied, was developed on IH SAS following the model described in this paper.

Precipitation p_t is divided into snowfall g_t (in the upper part of the catchment) and rainfall v_t (in the lower part of the catchment). Snowfall is accumulated in storage k_t at the end of the calendar month "t"; storage h_t comes from k_t and contributes to total runoff q_t. Rainfall is accumulated in soil storage m_t at the end of the month "t" too. The storage m_t is reduced by actual evapotranspiration r_t, fast runoff of groundwater f_t and slow runoff of groundwater s_t.

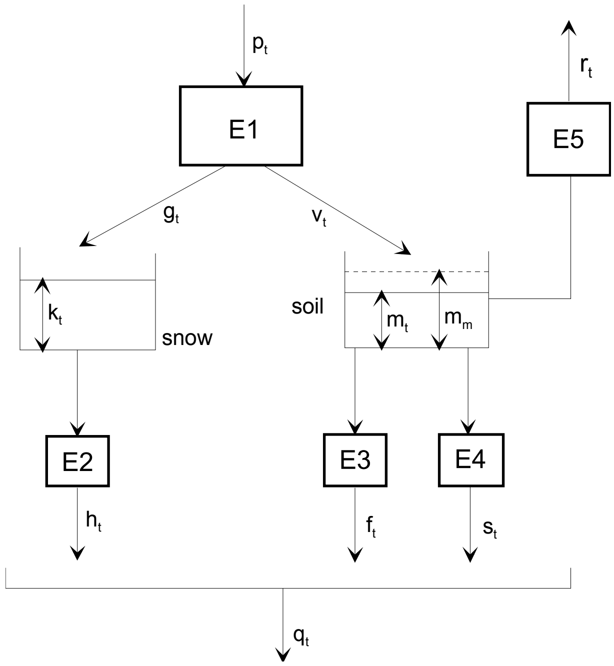

Fig. 3 Structure of the model WBMOD

Input data

Input data for the model WBMOD are:

- average discharge in water level gauging station: *Humenné*,
- monthly precipitation totals in rain-gauge stations: *Vyšné Čabiny, Habura, Kamenica nad Cirochou, Papín, Snina, Vinné*,
- monthly average temperatures in temperature gauging station: *Kamenica nad Cirochou, Medzilaborce, Michalovce*,

for the period 1971-1998.

In papers HALMOVÁ 1999a,b, c the ability of water reservoir Vihorlat to ensure constant outflow of various size during changed climate conditions was tested. Basically the relationship between the size of constant outflow, its certainty and the necessary storage volume was derived.

But the real Vihorlat reservoir operation differs considerably from the scheme oriented to constant outflow, which is typical for drinking water supply reservoir. The operational rules of the reservoir indicate considerable variability of the outflow from water reservoir. It was the reason why ensuring this real outflow (period 1971-1998) from reservoir in changed climate conditions was tested. Also new climate scenarios, that are used for calculation of the changed runoff conditions for the Laborec-Humenné gauge, were available [MELO, 2003; personal communication].

Chronological series of real historical withdrawal from reservoir were not readily available. Continuous water balance processing on SHMI (Slovak Hydrometeorological Institute) as well as regularly registered time course of water storage (at the beginning and at the end of the each month) processed by the Slovak Water Management Enterprise Banská Štiavnica, s.e., supplied to us the information about water storage of reservoir in individual months. Monthly outflow series from the Vihorlat reservoir during 27-years reservoir operation were calculated using these two data sources together with data of discharges at the Stráňany gauging station. Series of changed Laborec river inflow (according to climate scenarios) as well as alternative changes of minimum operational reservoir water level were compared with this real chronological series, which represents a historical target.

Changes of individual alternatives compared with the mentioned target are expressed by:

- *time series of the not supplied water volume during the failures in the demanded water supply,*
- *time series of the failures (duration of a period with lower water supply than required),*
- *total certainty of the supplied water volume (during the period of 27-years) in [mm],*
- *total certainty of duration with no-failure operation (during the period of 27-years) in [hours].*

Results and conclusions

The reservoir inflow changes are introduced in the runoff scenarios for Laborec-Humenné gauge, (CCCM temperature and precipitation climate change), and two time horizons, 2030 and 2075. Outputs from model WBMOD are denoted as C1X (2030), and C2X (2075).

Several alternatives of model runs were executed, for several initial conditions of the reservoir water levels. Only that water storage was used located between the minimum (107.39 m a.s.l., 57 mil.m^3) and maximum operating (113.94 m a.s.l., 234 mil.m^3) water level in Vihorlat reservoir (Fig. 1). These alternatives are introduced in Tab. 1. Initial and boundary conditions in Tab. 1 are quantified in mil.m^3 above minimum operating level 107.39 m a.s.l. and above dead storage capacity 57 mil.m^3. Initial and boundary conditions as described in Tab. 1 are:

- *STMA – maximum operating storage in water reservoir,*
- *STMIL – minimum accepted operating storage during summer months May–September,*
- *STMIZ - minimum accepted operating storage during summer months October – April,*
- *SVZPO – initial water storage in water reservoir at the beginning of each model run.*

Tab.1 Boundary conditions of reservoir operation and certainty of the reservoir operation (as to the volume of supplied water – ZZO, and to the duration of no-failure operation - ZZT) for time horizons 2030 and 2075

nomenclature of alternative	Operation water level at STMIL storage m a.s.l.	STMA mil.m^3	STMIL mil.m^3	STMIZ mil.m^3	SVZPO mil.m^3	ZZO	ZZT
C1M	107.39	177.0	0	0	0	0.982	0.963
C2M	107.39	177.0	0	0	0	0.975	0.960
C1A	113.9	177.0	177.0	40.4	40.4	0.798	0.764
C1B	113.0	177.0	149.1	39.7	39.7	0.879	0.851
C1C	111.0	177.0	92.7	39.7	39.7	0.962	0.966
C1D	109.0	177.0	39.7	39.7	39.7	0.971	0.957
C1E	108.0	177.0	14.6	14.6	14.6	0.978	0.960
C2A	113.9	177.0	177.0	40.4	40.4	0.794	0.761
C2B	113.0	177.0	149.1	39.7	39.7	0.873	0.851
C2C	111.0	177.0	92.7	39.7	39.7	0.957	0.950
C2D	109.0	177.0	39.7	39.7	39.7	0.966	0.957
C2E	108.0	177.0	14.6	14.6	14.6	0.972	0.957

Note: explanation of short cuts is thereinbefore.

Last two columns in Tab. 1 inform us about the calculated certainty given water supply (= real water withdrawal from reservoir during 1971-1998) in amount (water storage) (***ZZO***) and in duration of non-failure operation (***ZZT***) for particular alternatives. These alternatives (C1A–E, C2A–E) differ in minimum allowed summer water level (STMIL), regarding to recreational purpose of Vihorlat reservoir. Minimum summer water level limit can be connected with higher risk in supply of given water amount. Relationship between certainty of the water supply and minimum summer operating water level is displayed on Fig.

4. It is obvious that till summer water level wouldn't rise above the water level 111.0 m n.m., certainty of the water supply from reservoir wouldn't be considerably reduced. Even in the case of the minimum water level limit in summer operating level 113.94 m n.m., certainty of the water supply during 27 years would be approximately 80%, during some summer seasons would be higher.

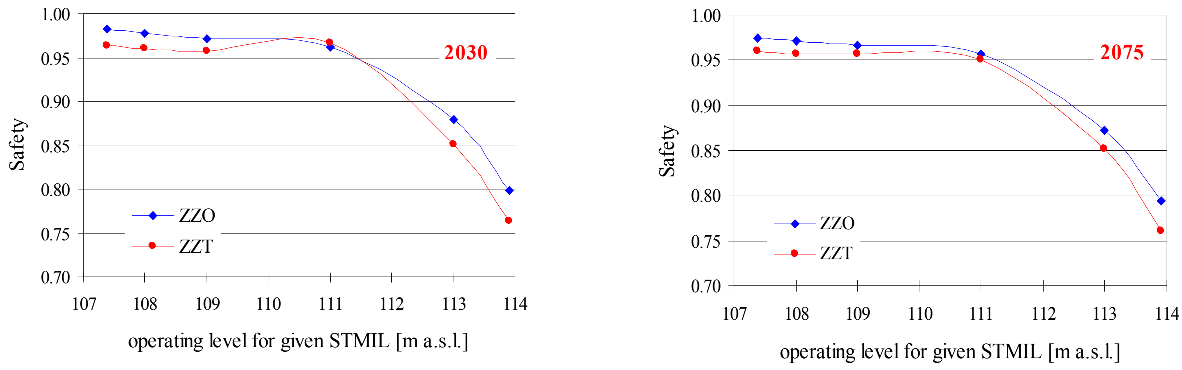

Fig. 4 Certainty of the supplied water (ZZO) and of the duration with no-failure operation (ZZT) for time horizon 2030 and 2075

Figures 5, 6 and 7 inform about another results from different computation alternatives with the WBMOD model. Fig. 5 shows accumulative deficiencies of the water supplies in time and critical time periods. The course of water storage (as well as water level) in the reservoir during 27-years period is shown in Fig. 6. Total deficiencies for individual alternatives are quantified in Tab. 2 and shown in Fig.7.

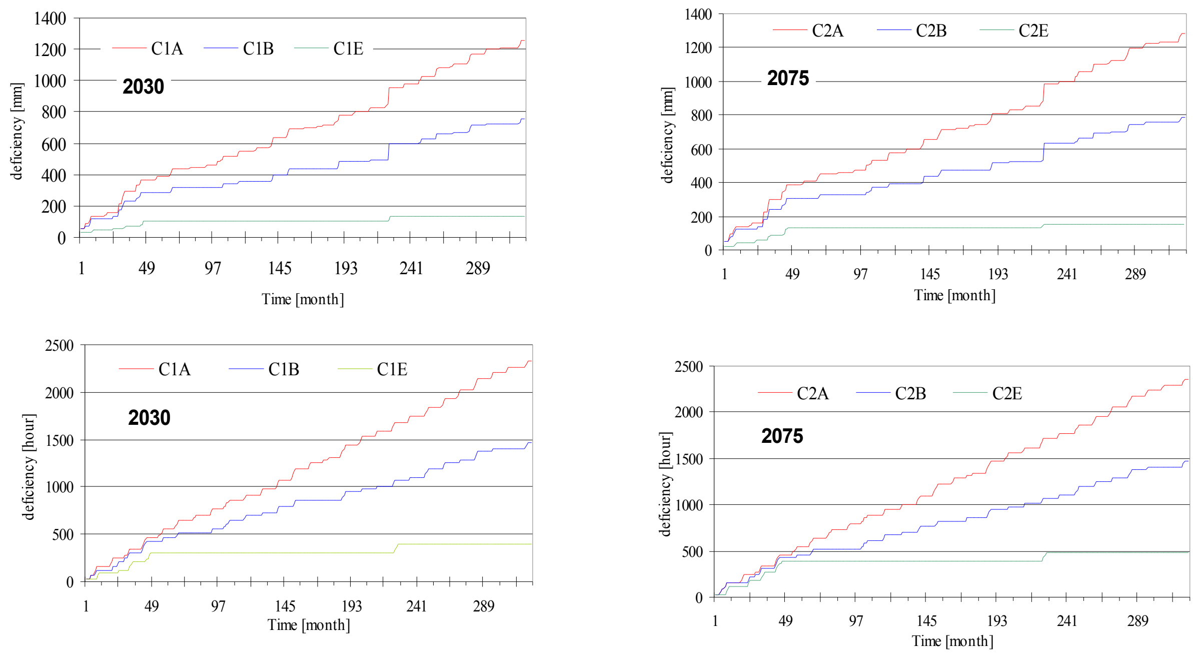

Fig. 5 Summation curves of deficiencies for different computation alternatives [hour, mm]

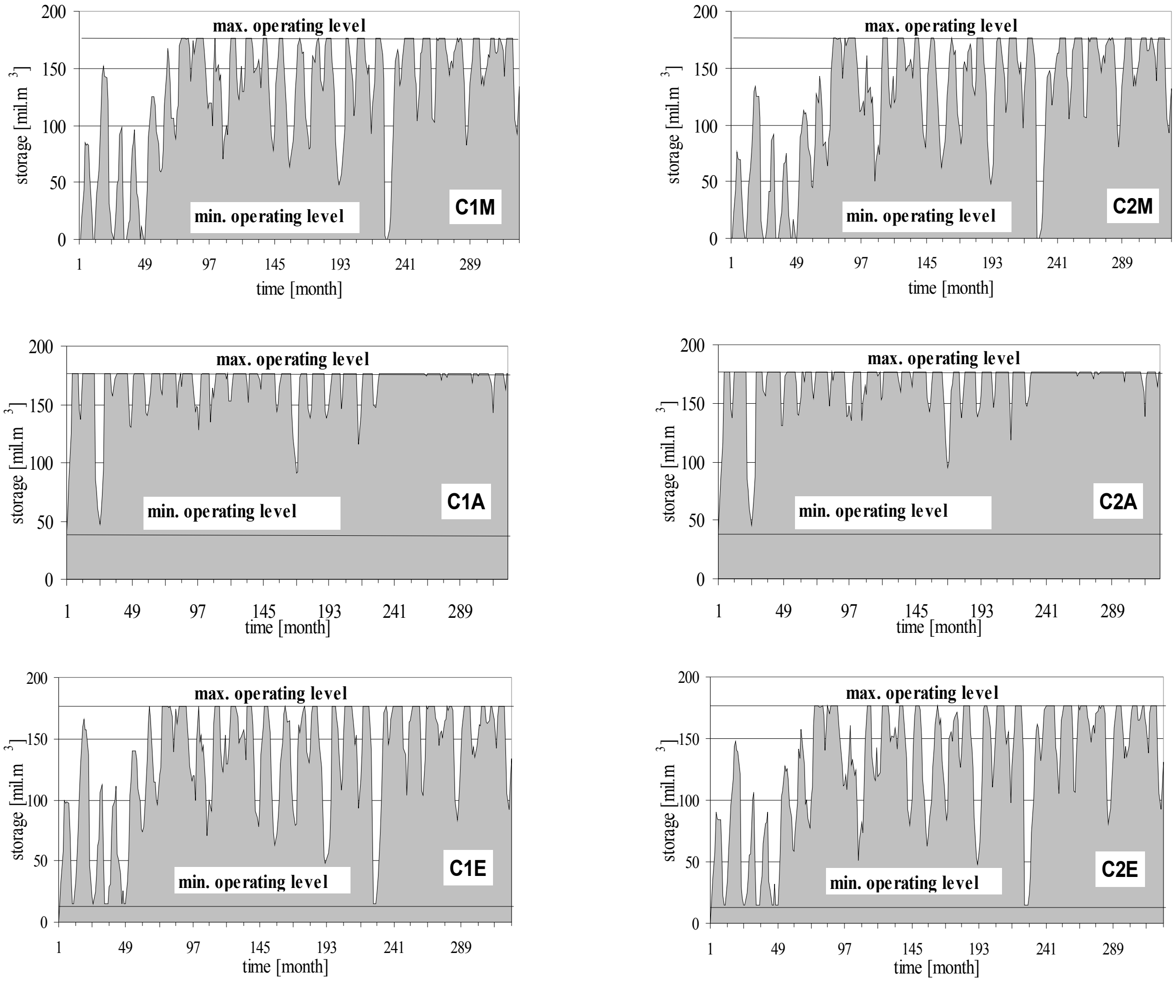

Fig. 6 Course of water storage within operation, using the whole operation storage of reservoir (C1M), with zero available storage during summer (C1A) and with reduced available storage capacity during winter and summer by about 90% (C1E)

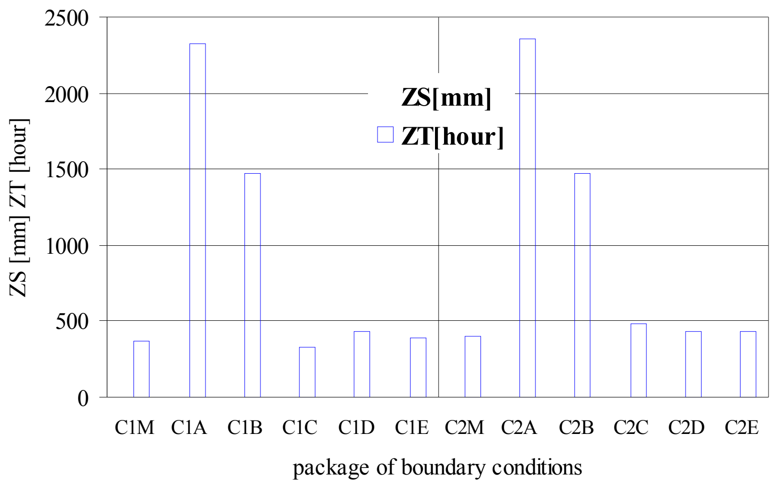

Fig. 7 Total not supplied water volume and total time with failures in water supply

Tab. 2 Total required water supply volume ZOC, total failures in water supply volume ZO [mm], total time period ZTC and time period with non-ensured water supply ZT [hour] during 27-years of simulation

	ZOC[mm]	ZO[mm]	ZTC[hour]	ZT[hour]
C1M	6227.6	115	9855	366
C1A	6227.6	1259.1	9855	2328
C1B	6227.6	752.7	9855	1469
C1C	6227.6	233.8	9855	334
C1D	6227.6	182.8	9855	427
C1E	6227.6	136	9855	396
C2M	6227.6	154	9855	397
C2A	6227.6	1284.3	9855	2357
C2B	6227.6	787.9	9855	1470
C2C	6227.6	266.7	9855	488
C2D	6227.6	211	9855	427
C2E	6227.6	175	9855	427

Presented conclusions, which result from WBMOD simulations, indicate potential possibilities of model utilization for reservoir operations, for particular reservoir utilisation for recreation, for analysis and development of models for seasonal runoff forecasts. In general, it can be concluded, that in this particular case of the Vihorlat reservoir the expected climatic change scenario (the temperature and precipitation regimes according to the last results of the CCCMprep general circulation model) would influence the certainty of the water supply from the reservoir only to a minimum extent. This conclusion, of course, pertains only the same water supply realised during the so far historical operation (1971 – 1998) of the structure.

The developed tool can be of use for alternative hypothetical reservoir operation runs with various variants of the water supply regime defined as a time series, and also for case studies for other similar water reservoirs.

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