CHANGES OF REQUIRED WATER RESERVOIR CAPACITY UNDER CONDITIONS OF POTENTIAL CLIMATE CHANGE

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Abstract: The water reservoirs, as components of drinking water supply systems, are particularly important in ensuring continuous water supply. In addition to this function, the water storage is used to ensure required minimum flows in watercourses. Global changes in the regime of atmosphere could affect all basic conditions of life on the Earth, that is, in addition to the atmosphere, the energy, food and water resources. The paper presents an attempt to answer the question, what impact of the climate change upon multipurpose reservoirs (water reservoir Orava) can be expected and how the reservoir storage curve (necessary storage vs. uniform outflow) will be changed under various climate change (temperature, rainfall) scenarios. The changed reservoir inflow was calculated by rainfall-runoff balance model WBMOD. The input data series of precipitation and air temperature were used to express expected changes of the total runoff and required reservoir capacity. Input data were modified in each month according to the respective climate scenarios. The achieved results (Fig.2, Tab.6) indicate that all used climate change scenarios, for a particular reservoir uniform draft (outflow), require higher storage than under present hydrological regime. In other words, with an existing storage reservoir capacity, lower uniform reservoir output will be supplied after the climate change, compared with the present conditions of reservoir inflow.
Keywords: rainfall-runoff balance model, water reservoir, and climate change scenarios.

ÄNDERUNG DER NÖTIGEN WASSERSPEICHERKAPAZITÄT IN DEN BEDINGUNGEN DER ERWARTETEN KLIMAÄNDERUNG

Zusammenfassung: Wasserspeicher, Komponenten der Systemen für Trinkwasserversorgung, sind besonders wichtig für Gewährleistung von minimalen Durchflusses in Flüssen. Globaländerungen in der Regime der Atmosphäre können alle lebenswichtigen Bedingungen auf der Erde verursachen, ausser Atmosphäre auch in den Regimen der Energie, Nahrung und Wasservorräte. Der Beitrag bemüht sich die Antwort zu finden welche Folgen die zu erwartete Klimaänderung für einen Mehrzweckspeicher (Speicher Orava, Slowakei) haben kann, und wie sich die Speicherkurve (notwendige Speicherkapazität vs. gleichmässigen Bezug – Ausfluss) ändern will unter den verschiedenen klimatischen Szenarien (Temperatur, Niederschlag). Die Änderungen des Speichereinflusses wurden mit Hilfe des Niederschlag –Abfluss -Wasserbilanzmodells WBMOD berechnet. Darin stellen die Reihen der mittleren Gebietsniederschläge und Temperaturen die Eingabedaten dar, woraus Speicherzufluss und Speicherkurve berechnet wurden. Die Eingabedaten wurden nach dem entsprechenden klimatischen Szenario monatsweise modifiziert. Die erzielten Resultate (Abb.2, Tab.5) anzeichnen, dass für alle klimatische Szenarien für jeden gleichmässigen Speicherausfluss eine höhere Speicherkapazität notwendig wird, als für die jetzigen hydrologischen Bedingungen. In anderen Wörtern, für die jetzige Speicherkapazität, nach der Klimaänderung nur ein kleineres gleichmässiges Speicherausfluss kann gewährleistet werden, als bei den jetzigen Speicherzufluss.
Schlűsslwörter: Niederschlag-Abfluss Bilanzmodell, Wasserspeicher, Klimaänderung Szenarien

1. Climate change and climate scenarios

Global climate varies naturally on all time-scales (from inter-annual, to multi-decadal to century), due both to what we called “internal variability” within the climate system and to changes in external forcing unrelated to human activities (changes in the sun's radiation and volcanic activity). These processes will continue to exert an important influence on climate system, in addition to changes induced by rising concentrations of greenhouse gases. These natural variations are one reason why the precise impact of human activities on the greenhouse effect has not yet been ascertained. They are also reasons why predictions of future climates will never be precise.

Global changes in the regime of atmosphere could affect all basic conditions of life on the Earth, that is, in addition to the atmosphere, the energy, food and water resources. These global changes could change the basic conditions considerably. It could come to higher variability and consistent changes of boundary conditions of natural ecosystems as well as of economical and social activities, (National Climate Programme, Slovakia - NCP SR č. 2/95, SHMÚ). Therefore, the assessment of these impacts became one of the biggest issues of all humankind.

2. Impacts of potential climate change upon water resources and water management

2.1. Water resources

The majority of Slovak surface and subsurface water resources are supplied by precipitation. The best indicator of the changes of water resources is change of the average month and annual discharge of surface flows.

2.2. Dams and water reservoirs

The water reservoirs, as components of drinking water supply systems, are particularly important in ensuring continuous water supply to large towns and regions. In addition to this function, the water storage is used to ensure required minimum flows in watercourses. Inputs to the reservoirs are equal to the streamflow from upstream plus, for large reservoirs, direct precipitation falling on the reservoir surface. Inflows from upstream are generally the dominant supply source. Outputs from the reservoir include releases through the dam and, in hot and dry areas particularly, evaporation from the reservoir surface. The reliability of a reservoir, or its ability to meet the demands placed upon it, is a function of the inputs to the reservoir, evaporative outputs, and the characteristics of the reservoir (its storage capacity and release policy).

In the Slovak Republic the contemporary water requirements are supplied by several water reservoirs, which are able to distribute non-uniform (unstable) natural discharge according to water economy demands. Present foreign and internal research results are demonstrating that the impact of climate change to water management could be rather unfavourable. It is the uncertainty of climate changes that evokes uncertainty of the change in hydrological processes. These uncertainties, further on, result in uncertainty of future water reservoir utilisation.

Changes of hydrological conditions can influence a relation between the reservoir storage capacity, overall improvement of low flows and water supply certainty. The utilisation of present reservoir storage capacity can be influenced and changed too. The assessment of future requirements to water reservoir utilisation and water economy plays an important role in water management, (Majerčáková, O., 1997). Climate change could influence also small water reservoirs. New conceptual adaptation arrangements for water management are suggested in regions with small reservoirs, (Szolgay, J., Parajka, J., 1997).

2.3. Water management

One of the most important roles of water management is to assess the relation between water requirements and available water resources, both, as to their quantity and quality. According to possible climate changes it is necessary to take into consideration that climate change could influence not only water resources itself, but also the requirements of water as well.

3. Catchment of water reservoir Orava and used method

Growing quantitative and qualitative water resource demands on one side, and limited possibilities as to the new water resources on the other side, caused a development of new optimisation methods of water reservoir management. At the same time the demands for hydrological data reliability are growing. With respect to non-stationary water regime the solution of climate change problems is very significant.

3.1. Water reservoir Orava

Water reservoir Orava is situated in the valley of the Orava river between town Tvrdošín and village Ústie nad Oravou. The system consists of the main reservoir Orava (constructed in 1941-1953) and the smaller downstream compensating water reservoir Tvrdošín (constructed in 1972-1978).

Multipurpose water reservoir Orava is the second largest Slovak water reservoir in terms of total accumulation capacity. Dam is situated in very convenient morphologic profile, under the confluence of rivers White and Black Orava. Water reservoir is used to augment the low flows of Orava and Váh rivers, to supply water for power stations, industry and agriculture, to reduce peaks of flood discharge of Orava river, and for sport activities, (Abaffy, D., Lukáč, M., Liška, M., 1995).

3.2. Catchment of the water reservoir Orava

Catchment area of Orava water reservoir is 1 181.7 km^2, around 40% of it is forested (Table 1.). Approximately 35% of the catchment area (Black Orava catchment) is in Poland. From the hydrological point of view, almost whole catchment is rich in precipitation, annual average is around 1000 mm, but discharge during hydrological year is rather fluctuating.

Tab.1 Basic characteristics of water reservoir Orava catchment

Catchment area P[km^2]	Length of valley L[km]	Character of catchment shape (P/L^2)	Observation period
1181,70	45,4	0,57	1951-1980

<u>Precipitation</u>

The annual pattern is characterised by a continental type of precipitation regime with a simple seasonal wave usually having its maximum in July (August) and minimum in December, rarely in February. Winter precipitation is very important for spring runoff generation.

<u>Air temperature</u>

Geographic locality and the landscape relief affect also the distribution of temperature. The coldest month is January and the warmest is July. Winter snow accumulation, its regime and contribution to runoff, is influenced by temperature.

<u>Runoff</u>

The Orava reservoir catchment has fan shape. This shape and a high slope of White Orava and of tributaries in upstream areas, where they originate, create favourable conditions for high runoff and flood waves. Runoff in individual seasons of the year is following winter –16,2%, spring – 39,9%, summer –23,5%, autumn – 20,4%. The maximum monthly runoff of upper Orava occurs mainly in April and partially in March, the minimum monthly runoff in January (February) or August (September). The highest floods occurred in summer months. Spring floods are very often caused by fast snowmelt with concurrent precipitation, (Murín, Ľ., 1985). Reservoir inflow as input to the WBMOD model was evaluated from discharge data at gauging stations Lokca, Zubrohlava, Jasenica, Jablonka (flows of Čierna Orava) and Jablonka (flows of Piekelník), indicated in Fig.1.

4. Method

The WBMOD model (monthly water balance model or monthly rainfall-runoff model) is useful for planning and controlling of water resource systems and is particularly suitable for water supply systems. The monthly input data step of the model corresponds to the time step used in most air temperature and precipitation climate change scenarios. The climate change scenarios give us a distribution of air temperatures and precipitation in monthly values during the hydrological year. The model was developed at V.U.B.–Vrije Universiteit Brussel-Hydrologie, basic equations and scheme of the model were described in several papers, (Ni-Lar-Win, 1994), (Svoboda, A., 1996), (Halmová, D., 1997). The WBMOD model was later supplemented by a reservoir operation subroutine. This is using the WBMOD generated output (based upon the climate change temperature and precipitation input scenario) as the reservoir inflow, and for various values of the uniform reservoir draft Qs, calculates the required reservoir storage, with no failure of the water demand Qs during the whole simulation period (1951 – 1980).

WBMOD model was calibrated for the Orava reservoir catchment (the series of 30-years input data from the period 1951-1980 were used. The input data used for model calibration are monthly precipitation, mean monthly air temperature series and observed mean monthly flow series. Basic statistical characteristics of measured and modelled mean monthly discharge are presented in *Tab.2.* Concerning to monthly time step of input data the results of calibration are satisfactory.

Table 2. Basic statistical characteristics of measured and modelled average monthly discharge, (SUMA a MAX, MIN, STDEV v [mm/month]).

	obsfl	comfl	GIL	CCC	GIS	GFL	GFD	OSU	WPL	UKM
suma	12672	12663	8852	8775	8684	8512	8130	7852	7754	5556
max	185.6	221.1	87.9	138.1	110.7	131.2	75.8	147.0	82.5	68.3
stdev	26.9	28.1	16.1	20.1	16.8	19.2	16.5	19.4	17.5	13.5
average	35.2	35.2	24.6	24.4	24.1	23.6	22.6	21.8	21.5	15.4

Different types of climate change scenarios are used to evaluate the impact of climate changes on hydrology and water resources. Climate scenarios *GFD, UKM, GIS and OSU* originate from older versions of climate change scenarios, interpolated for northern part of Slovakia. Climate scenarios *GFL, GIL, CCC a WPL* were developed within the NCP SR (Lapin, M., 1997) (NCP SR), the used ones are for time horizon 2075 and also for northern part of Slovakia. Changes of temperature and precipitation due to the used climate scenarios are presented in Table 3. and Table 4. These climate scenarios for Slovak conditions result from GCM simulations.

Tab.3 Climate scenarios of average monthly temperature changes [increments of °C].

SCENÁR	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCC	3,7	4,5	4,3	3,2	2,9	3,0	3,3	3,2	3,6	3,4	2,7	2,8
GFD	5,7	6,8	6,7	5,1	2,6	4,1	5,8	6,4	5,4	3,5	2,3	7,1
GFL	2,6	4,1	5,1	4,9	4,8	4,5	4,3	4,0	4,6	4,7	4,1	3,8
GIL	5,7	5,4	5,0	3,9	3,2	2,6	2,4	2,4	3,6	4,5	4,7	5,1
GIS	4,9	6,7	3,3	5,1	3,1	2,2	2,7	2,3	4,8	2,7	5,3	5,4
OSU	4,8	3,8	2,8	3,0	4,1	2,7	3,9	3,9	4,3	3,3	3,8	3,4
UKM	6,6	10,2	11,7	12,0	7,7	4,7	5,9	10,1	7,0	6,1	9,7	9,3
WPL	4,3	5,3	4,7	4,0	2,8	1,8	2,8	3,4	2,4	1,3	1,0	2,1

Tab.4 Climate scenarios of monthly precipitation (multiples of historical data)

SCENÁR	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
CCC	1,32	1,17	1,01	1,10	0,94	0,99	0,88	0,87	0,87	1,18	1,27	1,35
GFD	1,27	1,33	1,13	1,27	1,27	1,07	1,20	0,97	0,63	1,00	1,27	1,47
GFL	0,95	1,44	1,08	1,13	1,07	0,99	0,84	1,19	1336	1,45	1,44	1,01
GIL	1,16	1,31	1,27	1,34	1,18	1,07	1,08	1,06	0,84	1,25	1,31	1,04
GIS	1,13	1,17	1,30	1,30	1,17	1,07	1,07	1,07	0,57	1,30	1,33	1,03
OSU	1,10	0,97	1,33	0,97	1,33	0,93	0,87	1,13	0,73	0,9	1,07	1,20
UKM	1,20	1,23	1,53	1,77	1,50	1,23	0,90	0,87	1,20	1,20	1,17	1,37
WPL	0,95	1,05	1,12	1,14	1,15	1,08	0,93	0,79	0,73	0,80	0,96	0,97

Weighted monthly average precipitation (from stations Lokca, Novoť, Oravská Lesná, Oravská Polhora, Zakamenné a Trstená), the weighted averages of monthly average temperatures (from stations Oravská Lesná, Oravská Polhora a Trstená) and measured monthly average outflow (from profiles Lokca, Oravská Jasenica, Zubrohlavá, Jablonka - stream Piekelník a Jablonka – stream Čierna Orava) are used as inputs to WBMOD model, (Figure 1.). Hydrological and climate data were given by SHMI. Weights of particular observation stations were determined by Thiessen polygons.

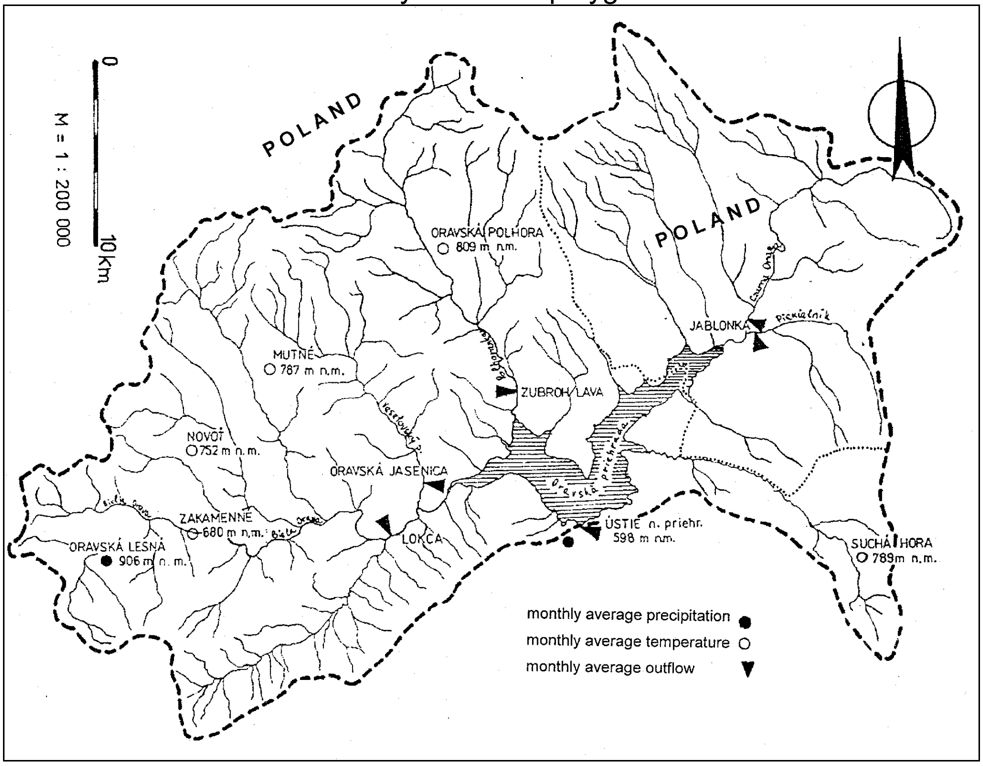

Figure 1. Catchment of the water reservoir Orava

Relationship between V_z (reservoir storage capacity) and Q_p (constant demand) derived for observed monthly flow series and those simulated by the WBMOD model for individual climate scenarios is depicted on Figure 2., Table 5. From the figure it could be seen to what extent reservoir with existing storage capacity would be able to supply constant water demand in conditions of climate change for various scenarios.

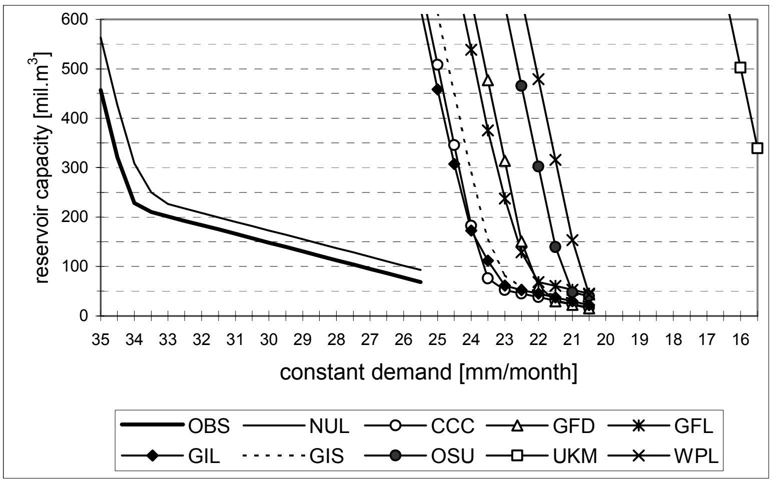

Figure 2. Relationship $V_z = f\ (Q_p)$ derived for observed monthly flow series and those simulated by the WBMOD model for individual climate change scenarios

Table 5. Constant water demands and eligible accumulate storage capacities of water reservoir Orava in contemporary and climate change conditions

Scenarios	**OBS**	**CCC**	**GFD**	**GFL**	**GIL**	**GIS**	**OSU**	**UKM**	**WPL**
Constant demand [mm/month]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]	max Vz [mil.m^3]
35,0	456,9	4324,8	5174,3	4708,9	4289,1	4498,5	5439,6	8299,6	5611,3
34,5	321,0	4112,1	4961,6	4502,1	4082,3	4285,7	5226,9	8086,9	5398,6
34,0	228,7	3899,4	4748,9	4295,3	3875,5	4073,0	5014,2	7874,2	5185,9
33,5	210,3	3690,6	4536,2	4088,5	3668,7	3864,9	4801,5	7661,5	4973,2
33,0	201,4	3483,8	4323,5	3881,7	3461,9	3657,5	4588,8	7448,8	4760,5
32,5	192,6	3277,0	4110,8	3674,9	3255,1	3450,1	4376,1	7236,0	4547,8
32,0	183,7	3070,2	3898,1	3468,1	3048,3	3242,7	4163,6	7023,3	4335,0
31,5	174,8	2863,4	3685,4	3261,3	2841,5	3035,3	3950,7	6810,6	4122,3
31,0	166,0	2656,7	3472,7	3054,5	2634,7	2828,5	3738,0	6597,9	3909,6
30,5	157,1	2449,9	3260,0	2847,7	2427,9	2621,7	3525,3	6385,2	3696,9
30,0	148,3	2243,1	3047,3	2640,9	2221,1	2414,9	3312,6	6172,5	3484,2
29,5	139,4	2036,3	2834,6	2434,1	2014,3	2208,5	3101,8	5959,8	3271,5
29,0	130,5	1841,8	2621,9	2227,3	1807,6	2002,3	2895,0	5747,1	3058,8
28,5	121,7	1650,0	2409,2	2024,7	1600,8	1796,1	2688,2	5534,4	2846,1
28,0	112,8	1487,0	2196,5	1843,1	1436,7	1590,7	2481,4	5321,7	2633,4
27,5	103,9	1323,9	1989,3	1680,1	1273,6	1427,6	2274,6	5109,0	2421,6
27,0	95,1	1160,8	1783,1	1517,0	1110,5	1264,5	2067,8	4896,3	2214,8
26,5	86,2	997,7	1576,9	1353,9	947,4	1101,5	1861,0	4683,6	2008,0
26,0	77,4	834,7	1370,7	1190,8	784,4	938,4	1654,2	4470,9	1801,2
25,5	68,5	671,6	1164,5	1027,8	621,3	775,3	1447,4	4258,2	1620,7
25,0	-	508,5	966,0	864,7	458,2	612,2	1280,6	4045,5	1457,6
24,5	-	345,4	803,0	701,6	307,5	449,2	1117,5	3832,7	1294,5
24,0	-	182,4	639,9	538,5	172,6	289,6	954,5	3620,0	1131,5
23,5	-	76,1	476,8	375,5	111,6	153,7	791,4	3407,3	968,4
23,0	-	52,2	313,7	237,7	61,4	83,3	628,3	3194,6	805,3
22,5	-	45,1	150,8	128,6	52,7	57,0	465,2	2981,9	642,2
22,0	-	38,0	60,5	68,4	45,0	49,3	302,2	2769,2	479,2
21,5	-	30,9	29,8	60,7	37,3	41,6	139,1	2556,5	316,1
21,0	-	23,8	22,7	53,0	29,6	33,9	47,7	2343,8	153,0
20,5	-	16,8	15,6	45,3	22,0	26,2	40,0	2131,1	43,0
20,0	-	-	-	-	-	-	-	1918,4	-
19,5	-	-	-	-	-	-	-	1705,7	-
19,0	-	-	-	-	-	-	-	1497,0	-
18,5	-	-	-	-	-	-	-	1317,8	-
18,0	-	-	-	-	-	-	-	1154,7	-
17,5	-	-	-	-	-	-	-	991,7	-
17,0	-	-	-	-	-	-	-	828,6	-
16,5	-	-	-	-	-	-	-	665,5	-
16,0	-	-	-	-	-	-	-	502,4	-
15,5	-	-	-	-	-	-	-	339,4	-

5. Results and conclusions

Due to differences between individual results, it is impossible to formulate definite conclusions. These differences are caused by differences between individual climate change scenarios. The development of rainfall-runoff models and minimisation of climate scenario differences could improve the assessment of climate change consequences on water resources and water management.

In general, certainty of constant demand from the reservoir Orava is influenced by climate change considerably. The constant demand from water reservoir will be 34,6 mm.month^{-1} (15,52 m^{3}s^{-1}) if the whole accumulate storage of the reservoir (345-mil.m^3) is used for this aim. Simulations with individual climate scenarios produced for the same conditions and presently available storage the following constant demands: CCC – 24,5 mm.month^{-1} (10,98 m^{3}s^{-1}), GFD – 23,10 mm.month^{-1} (10,36 m^{3}s^{-1}), GFL – 23,39 mm.month^{-1} (10,49 m^{3}s^{-1}), GIL – 24,63 mm.month^{-1} (11,04 m^{3}s^{-1}), GIS – 24,18 mm.month^{-1} (10,84 m^{3}s^{-1}), OSU – 22,13 mm.month^{-1} (9,92 m^{3}s^{-1}), UKM – 15,52 mm.month^{-1} (6,96 m^{3}s^{-1}), WPL – 21,59 mm.month^{-1} (9,68 m^{3}s^{-1}).

These results indicate that the impacts of climate change on hydrological regime would evoke a rise in required reservoir storage capacities, if the existing demands were to be satisfied, or, on the other hand, a considerable reduction of the reservoir release would be the result with the presently available Orava storage. Similar conclusions are also presented in report (Hladný, J., 1997) carried out by Czech researchers, who studied the impact of climate change on the required storage capacities of reservoirs in the Czech Republic. But we could not forget that our results are for constant water demand assumption and for the whole reservoir capacity utilisation. In the case of using the part of today's storage capacity for flood retention the results should be even more extreme.

However, not much has been done so far to compensate negative impacts of the climate change for the foreseeable future. From the existing studies it follows that the most effective would be the increase of existing reservoir storage in the most important river basins. In contrary, no major reservoir in Slovakia is neither under construction, nor planned in the near future. In addition to that, some environmental organisations and/or individuals spread widely the idea that river flow control, for any purpose, by reservoirs is harmful to the natural environment and that exactly the great water structures are those which damage it most. They are of the opinion, that only natural water storage in soil and vegetation, under correct management of forestry and agriculture, would guarantee a "sustainable development" of natural resources, among other also of the water. They do not accept the fact that there is no sustainable development of water resources, that water in its disposable amount for life on the earth is limited by the water cycle driven by extraterrestrial energetic sources. And in addition to that, that the expected climate change is even likely to reduce this limited resource. Thus the only way out of this situation is elimination of fluctuations in the water resources availability, requiring great storage, the greater the longer are the cycles of dry and wet periods, and the greater is the natural variability of the resource. However, there is nowhere on the Earth (except in basins with great lakes) a natural environment with enough water storage to control runoff in cycles longer than one year, corresponding to the present water demands, not to speak about the sustainable developed future.

In view of the above presented results it follows, that the expected climate change will require a complex combination of measures to adapt to the changed situation. These measures will concern all sectors of the economy related to use of the water. So it will have on one side a political aspect depending on correct actions of political decision – makers. Such should be based on a correct scientific knowledge of the problem. On the other side, the climate change impacts as presented, are not exact forecasts. There are still uncertainties in the General Circulation Models (GCMs), as well as in the rainfall – runoff models outputs. Progress in modelling techniques for both is permanent and fast. So the research in climatology, hydrology, and in water resources management should be a continuous task also for future years and decades.

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