Pol. J. Environ. Stud. Vol. 24, No. 5 (2015), 2231-2239

DOI: *10.15244/pjoes/39068*

Original Research

Analyzing a Multi-Function Storage Reservoir under Circumstances of Low Flow

Tomasz Walczykiewicz*, Ilona Biedroń

Division of Water Management, Institute of Meteorology and Water Management – National Research Institute, Branch in Cracow, Piotra Borowego 14, 30-215 Cracow, Poland

Received: February 20, 2015
Accepted: May 14, 2015

Abstract

Under circumstances of low flow, storage reservoirs, which by evening out the flows allows for their periodic augmentation that ensures water for users and for ecosystems located downstream of reservoirs, become particularly important. The authors are of the opinion that it is vital to use simulation analyses of the work of multi-task storage reservoirs, which in unfavourable hydrologic conditions may be useful in the preparation of crises plans concerning supplying with water and may constitute a base for revising the instructions of water management in reservoirs. This article presents the results of the research carried out for one of those reservoirs – Klimkowka on the Ropa River in the upper Virtual catchment.

Keywords: resorvoir, task, storage, flow

Introduction

Water resources, as well as other components of the environment, are particularly vulnerable to changes and changeability of the climate. Climate changes are defined as the ongoing process of physical and chemical changes in the structure of the atmosphere. Factors causing that process lead to the establishment of a new balance of the whole climate system in relation to the starting point. These changes may follow from natural internal processes or from outside influence and permanent anthropogenic changes in the atmosphere, and the use of the surface of the earth. On the other hand, changeability of the climate should be defined as deviations from the average state and changes in statistical values concerning the components that characterize the climate, such as standard deviation or extreme values. Analogically, as it is in the case of climate change, changeability may follow from internal processes in the climate system or from anthropogenic influence.

One of the possible effects of climate change as well as climate changeability is the possible threat to the continuity of providing users with water in quantities guaranteed by a water use licence.

For Poland, changeability of the occurrence of surface water resources is the most problematic for their management. This changeability, resulting from climatic phenomena, is not compensated enough by retention capacity. In dry years, the indicator of resources drops to 1,100 $m^3 \cdot year^{-1}$ per inhabitant, whereas in wet years it reaches 2,600 $m^3 \cdot year^{-1}$ per inhabitant.

Research on climate, including that of Europe, confirms the existence of recurrent changeability in precipitation, which in Scandinavia, Great Britain, and Germany is characterized by a 16-year recurrence period and a 22-year recurrence period in southern Europe [1]. The influence of evaporation on recurrence of precipitation periods is also underlined [2].

Research on changes of flow, carried out for select rivers, confirms the dependence of changes on oceanic and atmospheric circulation [3]. What is interesting, according to [3], is that statistical analyses have not confirmed any long-term changes (increases or decreases) in flow in 18 major European rivers between 1850 and 1997.

*e-mail: tomasz.walczykiewicz@imgw.pl

Also, the results of research carried out in the Institute of Meteorology and Water Management National Research Institute (polish acronym IMGW PIB) [4] show that it is possible to discern phases in changeability of precipitation. The research carried out in southern Poland allows for specifying 13-15 year phases with changeability of precipitation (dry and humid phases). A humid phase in the Carpathians finished in 1980. A dry phase (a diminished total annual sum of precipitation) lasted from 1980 to 1995. Next, there were humid years with excessive summer precipitation in the period between 1996 and 2010 (except for 2006). Insufficient atmospheric precipitation causes a lack of humidity in the soil and in the next phases it causes the lowering of flow in rivers and the lowering of the groundwater table.

Low flows and the time-span of their occurrence have a significant influence on all water users. According to WFD philosophy, the natural environment is recognized as a water user having equal rights to those of people, industry, or agriculture.

In numerous projects and programmes, measures are taken to support decision-making processes and to analyze scenarios in cases of low flow [5]. Bearing in mind the significance of the low flow issue, the World Meteorological Organisation (WMO) published in 2008 a manual on the assessment and forecasting of low flow [6].

Under circumstances of low flow, storage reservoirs become particularly important, because through the function of levelling out the flows they allow for periodic augmentation of the flow, thus ensuring the provision of water to users and ecosystems located below reservoirs [7].

Problems in the Exploitation of Storage Reservoirs under Circumstances of Low Flow

Recurring cases of droughts also cause trouble with feeding of storage reservoirs and, in consequence, trouble with their exploitation.

Low flow may be caused by climatic factors [6]:

- Long periods of drought leading to a climatic deficit of water where the value of potential evaporation exceeds the value of precipitation
- Long periods of drought and low temperature when precipitation is accumulated in the form of snow

Processes that occur in catchments are also among the factors that exert influence on the occurrence of low flow. These include the intensity of surface run-off and the humidity of soil and filtration.

Recent years have shown numerous examples of problems with the feeding of storage reservoirs. For example, in 2013 in the state of Colorado, USA, the possibility of using reservoirs for recreation, among other activities, was limited due to low water levels. This was caused by the extremely hot summer of 2012 and scarce reserves of snow in the mountains that could have fed the rivers. In consequence, there wouldn't have been a chance to rebuild retention. Antero Reservoir is a specific case for that region [8]. This reservoir is one of the sources of water for the city of Denver. In 2002 it was closed due to a long-lasting drought and was not reopened until 2007, after a drought that lasted five years. Another example, this time from a European country, is Bewl Water Reservoir, which supplies the counties of Kent and Sussex in southern England. In winter 2011/12 due to a long-lasting drought (the greatest in 30 years), it was emptied to 40% of its storage capacity [9]. In autumn 2012 drought also affected Poland. The drop of water level in Solina Reservoir on the San River (the upper reservoir in the Solina-Myczkowce reservoir system) [10] was the largest in eight years. In order to retain the possibility of sustaining the supply of water below the reservoir and at the same time to provide water for ecosystems in the period of drought, when the inflow to the reservoir was extremely low the sustained discharge was six times larger. The above-mentioned system of reservoirs, like most reservoirs in southern Poland, has a multi-task character and is used to equalize the flow, for energetic purposes, and for flood protection by keeping the flood reserve at an appropriate level. In the period between spring and autumn, when the flood reserve in reservoirs is augmented, long-lasting periods of low flow occur. Therefore, the authors are of the opinion that it is vital to use simulation analyses of the work of multi-task storage reservoirs, which in unfavourable hydrological conditions may be useful in the preparation of crises plans concerning supplying with water, and may constitute a base for revising the instructions of water management in reservoirs[1)] [11]. Such analyses may help prepare appropriate scenarios of measurements, taking into account hydrological scenarios on the one hand, and water needs on the other [12]. The more distant the future that the analysis concerns, the greater the difficulty in carrying it out. This is because the uncertainty about the changes and the changeability of the climate and, in consequence, about the consequences of forecasts of water resources, overlaps with uncertainty concerning socio-economic development and, in consequence, uncertainty about the changes of water needs. Uncertainty in this case ought to be defined as a state in which the choice of a particular path may result in various consequences, while the probability of the occurrence of those consequences is unknown [13]. Exemplary analyses, with the perspective up to year 2030 for select reservoirs in southern Poland, were conducted within the KLIMAT project – "Impact of climate change on the environment, economy, and society" (changes, impacts, ways of limitation, proposals for science, engineering in practice,

1) Requirements concerning water management instructions are determined by the governance of the Minister of the Environment of 17 August 2006 on water management instruction. Depending on the object that the water instruction concerns, the scope of necessary information to include in a prepared document is different. Instructions are elaborated upon while taking into account regular conditions of use and use during a flood. The instructions include construction time, initial filling, and refitting of a water structure. In the event when a part of data (described below) required by law does not concern the water structure for which the instruction is made, one might resign from including this data when preparing water management instruction.

and economic planning) [14] realized in the IMGW PIB KLIMAT project – "Impact of climate change on the environment, economy, and society" (changes, impacts, ways of limitation, proposals for science, engineering in practice, and economic planning) within the framework of the Operational Project Innovative Economy[2)].

Assumptions

Forecasts of climate change developed on the basis of scenarios of greenhouse gas emission increases were the basis for both the KLIMAT project [14] and in the conducted analyses on storage reservoirs. These scenarios are defined on the basis of variant development forecasts for the world. In this project, for the purposes of further consideration, three scenarios out of those developed by the Intergovernmental Panel on Climate Change were chosen. Their code names, adopted in *Special Report of Emission Scenarios*, are A2, B1, and A1B [15, 16]. These scenarios were taken into account in two analyses: of possible climate change (including the level of precipitation influencing the capacity of water resources), and the analysis of water needs assumed in each scenario. The results of precipitation change forecast from the model ECHAM-5 [14] on the level of annual values indicate that in 2010-30 in relation to the period 1971-90, adopted as the reference point in the project, the change for Poland will be little (on the margin of error). In the conducted analyses, hypothetical water needs for 2030 were assumed for each scenario, taking into account that:

- Scenario A2 (market scenario) assumes the lowest economic growth and the lowest care for the environment
- Scenario B1 (regional scenario) puts emphasis on environment protection, which will contribute to a slightly slower economic growth than in the case of scenario A1B, but will ensure the preservation of natural resources for future generations
- Scenario A1B (balanced scenario) assumes the fastest development speed with moderate care for the environment

Analyzing the water needs in each scenario, two variants (ecological and dynamic), varied in size and based on different methods of calculation, were additionally assumed. This allowed for increasing the number of analyzed cases, which then made it possible to carry out a multi-variant examination of the sensitivity of the water supply system (Fig. 1).

For the purpose of analyses in the project [14], the existing reservoirs performing, among other tasks, direct and indirect functions related to supplying water, were chosen and the most unfavourable, limited conditions of feeding were taken into account. This article presents the results of the research carried out for one of those reservoirs, Klimkowka, located on the Ropa River in the catchment of the upper Vistula. Similar analysis was done for the next two reservoirs: Dobczyce on the Raba River [17] and Besko on the Wislok River.

Klimkowka reservoir is a mountain reservoir, medium-sized for Polish conditions, with a distinctly differentiated shoreline. The fall of the riverbed from the river's sources to the dam is about 20‰. There is a strong bed erosion process in the river, the effect of which is transportation of eroded material. The river is characterized by low discharge and the occurrence of low flow. Creating this reservoir may in the future stimulate tourist and recreational functions of areas surrounding the lake and the Beskid Niski mountain region. The shore of the reservoir is gradually being developed and, additionally, in the near future Klimkowka has a chance to become an important water sports centre for the region.

The Characteristics of the Selected Reservoir and of the Data Adopted for the Purpose of Analysis

The priority task of Klimkowka Reservoir, commissioned for operation in 1993, is levelling out the flows on the Ropa in order to eliminate the deficits of drinking and processing water in the cross-sections of the cities of Jaslo

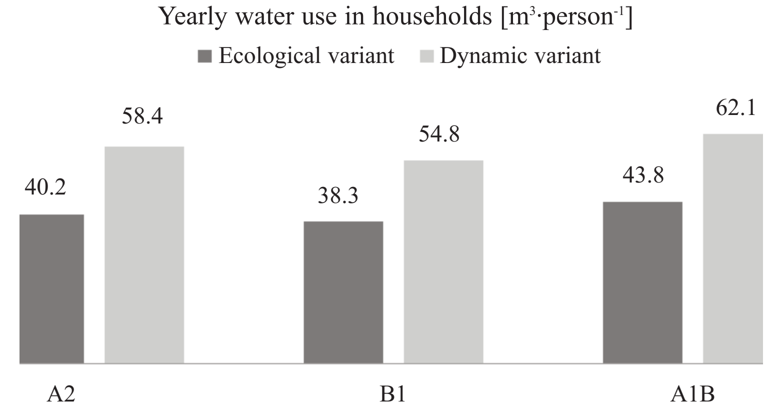

Fig. 1. Forecast of average water use in households until 2030 [18].

2) Innovative Economic Operation Program is implemented throughout the country, co-funded from European funds and developed within the framework of the National Cohesion Strategy.

and Gorlice; as well as reducing the culmination of a flood wave along the river course (Fig. 2).

The basic data on the reservoir (Table 1) were obtained from its administrator – the Regional Water Management Board in Cracow[3)].

The data included in the instruction of water management concerned the minimal outflow from the reservoir: instream flow, firm yield, flow through the water power plant, total capacity, minimal capacity, usable capacity, and the capacity of flood reserve storage.

Based on data on the usage of water obtained from the administrator, surface water intakes downstream of the reservoir within the assumed reach of its influence were located and the information on the level of the water use specified in water use licences was collected. The following water intakes (Fig. 3) downstream of the reservoir were analyzed:

1. Reservoir water intake in 54.4 km of the Ropa River (Q_{av}[4)]=0.46 $m^3 \cdot h^{-1}$; Q_{av}=11.2 $m^3 \cdot d^{-1}$) (water use from Klimkowka Reservoir at Ropa in the town of Klimkowka for municipal purposes)
2. Water intake for the purposes of supplying fish ponds in km 53.05 of the Ropa – periodical use from February to June Q_{max}[5)]=0.5 $m^3 \cdot s^{-1}$
3. Water intake in 50.0 km of the Ropa for the purposes of supplying fish ponds – periodic use from February to June Q_{max}=0.35 $m^3 \cdot s^{-1}$
4. Water intake in 39.4 km of the Ropa (Q_{max}=0.11 $m^3 \cdot s^{-1}$; Q_{av}=9.504 $m^3 \cdot d^{-1}$) Municipal Services Enterprise Ltd. in Gorlice (MPGK Ltd.)
5. Water intake in 32.3 km of the Ropa (Q_{max}=500 $m^3 \cdot h^{-1}$; Q_{av}=6000 $m^3 \cdot d^{-1}$) – (industrial purposes)
6. Water intake in 14.0 km of the Ropa (Q_{max}=55 $m^3 \cdot d^{-1}$) – (industrial purpose).

The analysis does not include water intakes used for filling fish ponds due to their lower position in the water supply hierarchy and periodic water use. Those industrial users which were in bankruptcy or whose levels of water use specified in water licences were low also were not included.

As a result, for further analytical study the surface water intake of MPGK Ltd., which supplies water to the city of Gorlice and a part of Gorlice Commune, was selected (Fig. 3). The intake's efficiency is about 9,500 $m^3 \cdot d^{-1}$; at present the water treatment plant produces about $1.46 \cdot 10^6$ m^3 yearly.

The only significant changes of precipitation in the catchment of the analyzed reservoir are expected in the event of scenario A1B, where in autumn precipitation in the catchment will decrease by 20% on average. The purpose of the hydrological analysis was an examination of low flow periods, when the river is supplied mostly with groundwater. The analysis of low flow is based on statistical analysis of all available data [6]. In this case the first of eight procedures of the so-called "cube of low flow" was used [14]. Hence, sequences of daily data on flows were utilized in the analyses. Due to averaged character of data which is a result of statistical models (average changes in multi-annual period 2010-30 as per annum and per season in relation to reference data from the multi-annual period 1971-90), changes in precipitation were omitted in the research, and the study was based on historical data.

In the utilities sector for households in the KLIMAT project maximum water needs were assumed at the level of 62.1 $m^3 \cdot person^{-1}$ (dynamic variant, scenario A1B [18] –

Table 1. Basic data for Klimkowka reservoir.

River	Ropa
Km	54.40
Area of catchment [km^2]	210.00
Year of commissioning for operation	1993
Dam height [m]	34
Maximum Dam height (Max DH) [m]	398.60
Normal Dam height (NDH) AMSL from 01.10 to 28.02 [m]	396.30
Normal Dam height (NDH) AMSL from 01.04 to 31.08 [m]	395.80
Minimal Dam height (MinDH) AMSL [m]	375.10
Reservoir surface at MaxDH [ha]	306
Total storage [10^6 m^3]	42.59
Dead storage [10^6 m^3]	2.16
Usable storage in compliance with management instruction from 16.09 to 14.05 [10^6 m^3]	32.43
Usable storage in compliance with management instruction from 15.05 to 15.09 [10^6 m^3]	33.98
Instream flow Q_n [$m^3 \cdot s^{-1}$]	0.47
Firm yield [$m^3 \cdot s^{-1}$]	2.00
Licenced discharge [$m^3 \cdot s^{-1}$]	70.00
Flow through hydro-power plant [$m^3 \cdot s^{-1}$]	2.00

3) Practical reorganization of water management in Poland began in the early 1990s. The amendment of the Act on Water Law of 1990 authorised the Minister of the Environment, Natural Resources, and Forestry to constitute organisational units realising the tasks of water management within hydrographic system. In 1991 seven regional water management boards (RZGW) were constituted. On 18 July 2001 a new Act on Water Law was passed, which introduced the system of water management that takes into account the division of the country into catchments and water regions. This act finalized the long-lasting process leading to the creation of a stable water management system in Poland. The Regional Water Management Board in Cracow operates in the water regions of the Upper Vistula, the Czarna Orawa, and the Dniestr.

4) Q_{av} – average discharge

5) Q_{max} – maximum discharge

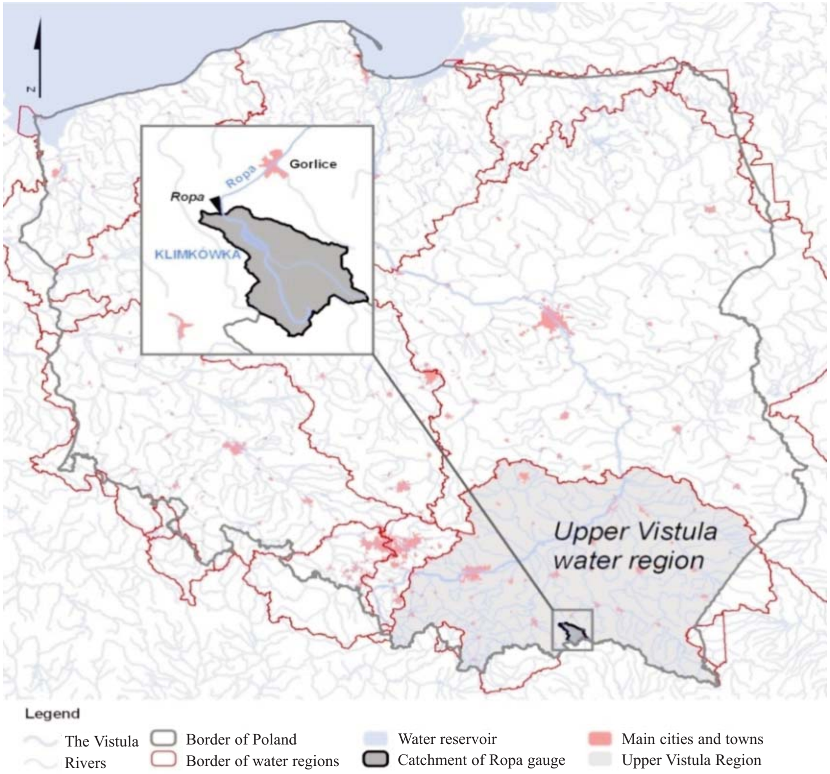

Fig. 2. Location of the reservoir and its water regions.

Fig. 1) and such needs were juxtaposed with the current values specified in the water use licence for MPGK Ltd.

Consequently, based on the assumptions made for variant II of scenario A1B, 85% of inhabitants of the town and commune of Gorlice are served through the water pipe network (39,200) and losses in the water pipe network are around 17%. The annual water use for household purposes may reach about $3 \cdot 10^6$ m^3 by 2030.

For the purposes of assessing water resources, the gauging section Ropa on the Ropa River, representing inflow to the reservoir, was selected. Analyzing the available hydrological data for the water-gauge the most unfavourable

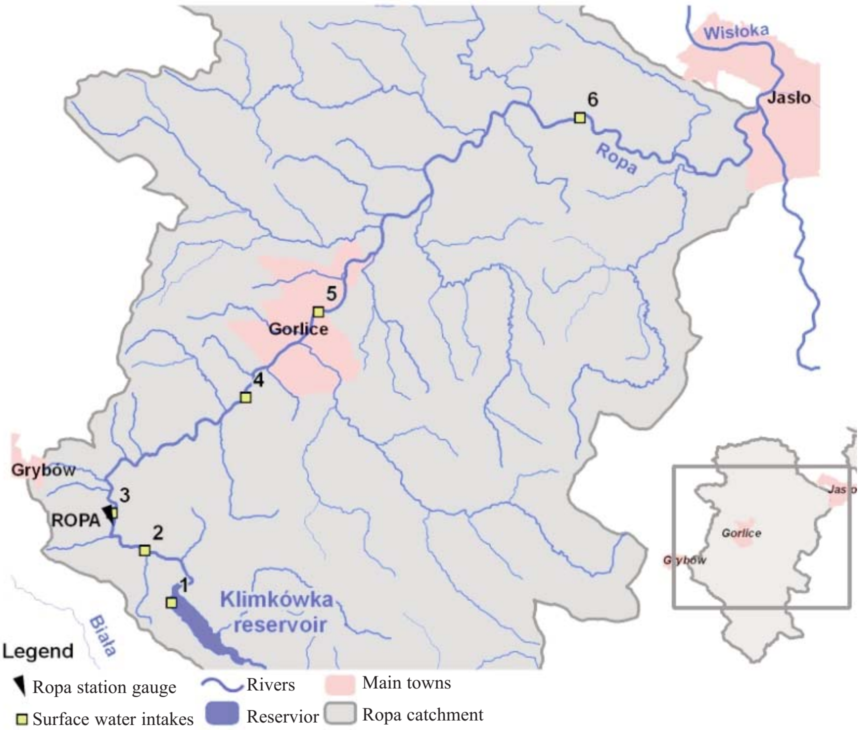

Fig. 3. Location of surface water intakes within the influence range of Klimkowka Reservoir.

Table 2. Hydrological characteristics – gauging section Ropa on the Ropa River.

Period	SNQ [$m^3 \cdot s^{-1}$]	SSQ [$m^3 \cdot s^{-1}$]
1960-91 (excluding 1964)	0.36	3.34

SNQ – the average discharge of low values from a multi-annual period
SSQ – the average discharge of average values from a multi-annual period

hydrological situation was assumed: the longest lasting periods of low flow.

The gauging site Ropa is situated downstream from Klimkowka at km 48.7 of the Ropa. The available data on discharge covers the period from 1960 until the closing of the site in 1991. There are gaps in hydrological data for the entire year 1964 (Fig. 4). Klimkowka was commissioned for use in 1993, hence hydrological data does not cover the functioning of the reservoir. The average characteristics that were calculated for the gauging section concern both the entire period and also the reference period assumed in the KLIMAT project, namely the period between 1971 and 1990 (Table 2).

In the KLIMAT project the changes in water resources projected for 2030 have been determined only for average characteristics (annual and seasonal) for the multi-annual period 2011-30 in relation to the reference multi-annual period 1971-90. In the analyzed catchment, only in the case of scenario A2 may one may expect a negative change of both the average annual discharge and the average discharge for the summer half of the year, where the change is between -10% and -5%.

Analysis of Hypothetical Impoundment Levels of Klimkowka Reservoir at Low Flow Periods

Based on the available data representing water resources, the value of instream flow was calculated using the Kostrzewa method [18], in accordance with the hydro-biological criterion – Q_n. The hydro-biological criterion is determined using the formula $Q_n = k \cdot SNQ$, in which the discharge is determined on the basis of characteristics $SNQ_{1960-91}$, and k parameter is dependent on the type of watercourse determined on the basis of the size of unit flow and inversely proportional to the size of the catchment.

The next step was finding in the sequence of data on daily discharge the longest possible period of the average value lower than the calculated value Q_n. Due to the purpose of the calculation in the selected period of 147 days with low flow lower than the assumed borderline value on the level of instream flow, there occurred five-day- and 11-day-long periods of low flow taking place separately one after the other. However, the purpose of this analysis was to determine the longest period resulting in gradual emptying of the reservoir. For the analyzed period lasting between 03 June 1963 and 27 October 1963 the average value lower than calculated value Q_n was 0.48. Theoretically, this period could be extended; however, the above-mentioned break in observations carried out in 1964 made such an assessment impossible. In the analyses, it was also considered how a planned increase of flood storage reserve could affect the risk of a loss of an up-to-date guarantee of supplying users with water.

The average value of daily discharge lower than Q_n from the gauging section was calculated for the dam section profile proportionally to the surface area of the catchment. The hypothetical volume of water inflowing within the selected period was calculated while searching for the most unfavourable situation of reservoir replenishment.

Analysis 1

At first it was calculated how the usable capacity would decrease should there occur the assumed inflow and for the initial replenishment equal to the usable capacity in the times of an increased flood reserve storage determined in the water management instruction and its use with firm yield on the level of 2 $m^3 \cdot s^{-1}$. In the calculations below,

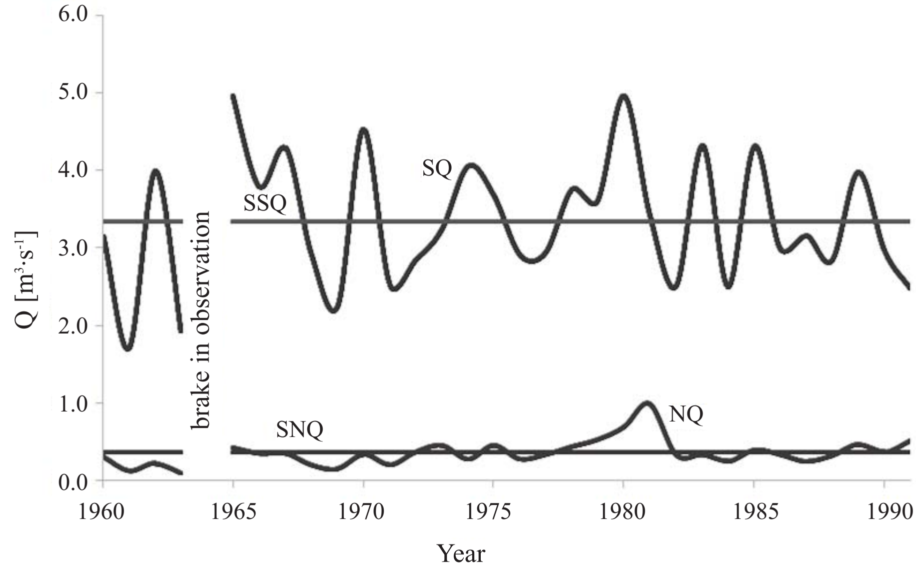

Fig. 4. Discharge characteristics in gauging section Ropa on the Ropa River.

Table 3. Data tabulation for the gauging section representing Klimkowka Reservoir.

Gauging site	Ropa
Area of catchment [km^2]	242.87
Selected resource presentation period	1960-91
Qn in gauging section [m^3·s^{-1}]	0.54
Longest period of low flow	03-06-1963 – 27-10-1963
Number of days with average daily discharge <Q_n	147
Average value of 147 daily discharge in gauging section [m^3·s^{-1}]	0.48

Table 4. Tabulation of calculation results for the assumed hydrological situation based on historical data on discharge for the reservoir – Analysis 1.

Number of days with average daily discharge <Q_n	147
Hypothetical inflow to the reservoir [m^3·s^{-1}]	0.41
Firm yield [m^3·s^{-1}]	2.00
Inflow to the reservoir [10^6·m^3]	5.25
Outflow from the reservoir [10^6·m^3]	25.40
Water loss [10^6·m^3]	20.15
Assumed initial usable capacity [10^6·m^3]	32.43
Final usable capacity [10^6·m^3]	12.28

water loss in the reservoir related to leakages and evaporation was not taken into account. The table below (Table 3) presents the results of this analysis.

Based on calculations, it was ascertained that for the hypothetically assumed hydrological situation the final usable capacity would amount to about 38% of the initial usable capacity, i.e. the water loss would reach circa 20·10^6 m^3 within 147 days (Table 4).

Analysis 2

Next for the purposes of further analysis (Fig. 5) the following assumptions were made related to supplying the reservoir on the level of instream flow and the firm yield 2.0 m^3·s^{-1}:

Variant 1 – The longest-lasting unfavourable hydrological situation exploiting the entire usable capacity of the reservoir.

Variant 2 – The longest-lasting unfavourable hydrological situation with the increased flood reserve storage by 20% exploiting the entire usable capacity of the reservoir.

Variant 3 – The longest-lasting unfavourable hydrological situation with the increased flood reserve storage by 20% (10·10^6 m^3) and extended period of maintaining the reserve from 01 April to 30 September exploiting the entire usable capacity of the reservoir.

Discussion of Results

Determination of low flow requires long sequences of data, preferably without any gaps in measurements. The calculations were conducted for hypothetical situations by means of simplified mathematical methods, hence the results ought to be treated as approximations showing differences in the levels of utilizing the usable capacity of a reservoir when assuming various hydrological situations and various types of reservoir water management. The time perspective assumed in the analysis (year 2030), the uncertainty about the remaining data (including water needs), and the possibility of further subdivision into variants all justify the adopted methodology in the opinion of the authors.

A significant user dependant on the functioning of the reservoir was ascribed the maximum values of water use as permitted by a water use licence. Adopting values in such a way was justified by the conducted analyses, based on ascertaining that those values do not exceed the calculated maximum water needs when the assumptions follow the most water-consuming scenario – dynamic variant II A1B

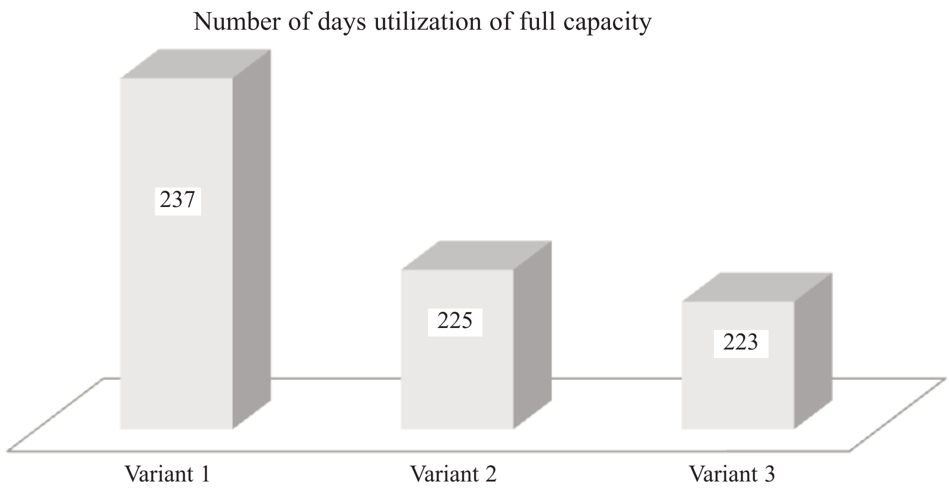

Fig. 5. Variant utilization of full capacity of Klimkowka Reservoir in days – Analysis 2.

[14]. Here it must be underlined that in Poland there is often a discrepancy when actual water use is compared to the values of water use specified in water licences. Similarly to the analyzed case, the value of water use specified in the water licence is only partly used by users. This discrepancy may be a result of the system of environmental charges that functions in Poland, i.e. paying a fee for the actual value of the used water.

Water resources (inflow to the reservoir where the average value of daily discharge was lower than instream flow Q_n) were determined on the basis of historical hydrological data for the Ropa water section. It was also determined how long such an unfavourable hydrological situation would have to last so that the firm yield from the reservoir of the value 2 $m^3 \cdot s^{-1}$ would lead to full exploitation of usable capacity.

The conducted analysis was confronted with one of the cases in the functioning of Klimkowka Reservoir as presented by its administrator. In 2003, as a result of a long low flow period that started in June and continued for about half a year, gradual emptying of the reservoir occurred. As a consequence, the Voivod of Lesser Poland, responsible for granting water use licences, made a decision to change the water instruction in force on that reservoir. The instruction determined differentiation of firm yield in relation to the water damming level in the reservoir. It was stated in the instruction that when the damming level is 380.50 m AMSL, the firm yield will be lowered to the value 1.0 $m^3 \cdot s^{-1}$, and to 0.5 $m^3 \cdot s^{-1}$ when the damming level is lower than 380.00 m AMSL. At this level of water table the total storage capacity of the reservoir is $6.27 \cdot 10^6$ m^3. According to this decision, the outflow on the level of 0.5 $m^3 \cdot s^{-1}$ is the necessary minimum required to ensure drinking water for the inhabitants of Gorlice and for instream flow. At the point of issuing that decision the water level was 381.00 m AMSL – 14.8 m lower than the normal water damming level. As a result of the decision, over the next 31 days the outflow from the reservoir was 1.0 $m^3 \cdot s^{-1}$ and for the next 6 days 0.79 $m^3 \cdot s^{-1}$. After this period, i.e., from 5 February 2004 came a period of filling the reservoir and the firm yield was augmented to the level of 2.0 $m^3 \cdot s^{-1}$. The described situation led to achieving the total capacity of the reservoir on the level of $7.26 \cdot 10^6$ m^3, leaving 5.01 $m^3 \cdot s^{-1}$ of usable storage capacity.

As a result of the conducted analyses one may assume that the hypothetical functioning of Klimkowka Reservoir in long-lasting periods of low flow will serve its purpose of supplying water. It is worth emphasizing that the analyses were conducted on the level of steady outflow of 2.0 $m^3 \cdot s^{-1}$, and the values of water use determined in the water licence for MPGK Ltd. in Gorlice are higher than the calculated values of use in the most water-consuming scenario dynamic variant of A1B. However, it is worth remembering that downstream of the reservoir there are at present other users operating, and in the perspective of 2030 and the assumed economic growth, water needs in economic sectors may increase. Additionally, the projected negative changes for precipitation in autumn, reaching 20% (scenario A1B), may further stimulate intensification of low flow.

Multi-functionality of storage reservoirs in certain events of crisis often leads to a situation where the functions remain in conflict. In the described case of Klimkowka, when the firm yield is lowered to 1.0 $m^3 \cdot s^{-1}$, the outflow from the reservoir is realized through bottom outlets that disable functioning of the hydro-power plant. At the same time, constantly increasing flood storage reserve, which guarantees the safety of people downstream of the reservoir, diminishes its usable capacity used to level out the levels of discharge.

Changeability of climatic phenomena requires flexible operation instructions. In the authors' opinion and in the view of the above, the following become particularly important: accurate forecasting of inflow to the reservoir supported by meteorological forecasts and hydrological analyses, as well as verifying water licences of users together with determining their hierarchy in water use.

References

1. VINES R.G. European Rainfall Patterns. Int. J. Climatol. **5**, (6), 607, **1985**.
2. BISSELINK B., DOLMAN A. J. Recycling of moisture in Europe: contribution of evaporation to variability in very wet and dry years Hydrol. Earth Syst. Sci. Discuss., **6**, 3301, **2009**.
3. PEKAROVA P., MIKLANEK P., PEKAR J. Long-term trends and runoff fluctuations of European rivers. Climate Variability and Change -Hydrological Impacts IAHS Publ. 308, **2006**.
4. Drought in Poland in 2012. Climatic information. IMGW PIB **2012**, [In Polish].
5. MAUSER W., MARKE T., STOEBER S. Climate Change and Water Resources: Scenarios of Low-flow conditions in the Upper Danube River Basin; IOP Conference Series, Earth and Environmental Science 4 **2008**.
6. Manual on Low-flow prediction and estimation. Operational Hydrology No 50. World Meteorological Organization WMO-No1029; **2009**.
7. LORENC H. Climate as a threat. Contemporary Issues Extreme Environmental Risks, II Ogólnopolska Szkoła, IMGW Jachranka **2000**, [In Polish].
8. HANDY R.M. Draught will dry up Antero reservoir, The Gazette; March 17, **2013**.
9. STRAUS R.R. The Amazing reservoir pictures that show we really are facing a draught: Water levels at just 40% in the middle of winter. The Daily Mail, February 18, **2012**.
10. http://solina.pl/
11. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions an EU Strategy on adaptation to climate change COM(2013) 216 final, Brussels **2013**.
12. GIACOMELLI P., ROSSETTI A., BRAMBILLA M. Adapting Water Allocation Management to drought scenarios; Natural Hazards and Earth Systems Sciences **8**, 293, **2008**.
13. WALCZYKIEWICZ T. Risk in Integrated Water Resources Management, IMGW-PIB, Warsaw **2010** [In Polish].
14. KLIMAT project – "Impact of the climate change on environment, economy and society" (changes, impacts, ways of limitation, proposals for science, engineering in practice and

economy planning)" grant No. POIG.01.03.01-14-011/08– http://klimat.imgw.pl; **2008**.
15. IPCC Special Reports on Climate Change – Complete online versions IPCC's Working Groups. Prepared and published for the Web by GRID-Arendal in 2001 http://www.grida.no/publications/other/ipcc_sr/?src=/climate/ipcc/emission/, **2001**.
16. UNEP, Global Environment Outlook 4. Environment for development. UNEP, Nairobi (http://www.unep.org/geo/geo4/), **2007**.
17. BIEDROŃ I., WALCZYKIEWICZ T., WOŹNIAK Ł. Analysis of options to meet the needs of water from Dobczyce Reservoir in the light of the possible effects of climate change. Wiadomości Meteorologii Hydrologii Gospodarki Wodnej. **V**, (3), (LV), **2011**, [In Polish].
18. KOSTRZEWA H. Verification of the criteria and the value of the instream flow for rivers in Poland Materiały Badawcze. Seria Gospodarka Wodna i Ochrona Wód, IMGW, Warsaw **1977** [In Polish].