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THE ROLE OF RESERVOIRS IN MITIGATING THE CONSEQUENCES OF CLIMATE CHANGE: CASE STUDY OF THE VRBAS RIVER BASIN

Abstract

The consequences of climate change are becoming increasingly evident in all aspects of human activity, particularly in the field of water, affecting the availability and accessibility of water resources, and intensifying extreme phenomena such as droughts and floods. These impacts, in combination with existing vulnerabilities, can have significant consequences for society as a whole. Consequences of climate change in the Vrbas River basin, with a special focus on flood protection, particularly in the city of Banja Luka, and the provision of water for irrigation in the downstream part of the basin, were analyzed in the article. It analyzes the role of existing and planned reservoirs in mitigating adverse events, emphasizing the importance of integrated water resources management.

Keywords: climate change, water storage reservoir, flood waves, irrigation, reliability

УЛОГА АКУМУЛАЦИЈА У УБЛАЖАВАЊУ ПОСЉЕДИЦА КЛИМАТСКИХ ПРОМЈЕНА: ПРИМЕР СЛИВА РИЈЕКЕ ВРБАС

Сажетак

Посљедице климатских промјена све су очигледније у свим аспектима људског дјеловања, а посебно су изражене у области вода, утичући на доступност и расположивост водног ресурса, посебно интензивирајући екстремне феномене као што су суше и поплаве. Ови утицаји, заједно са постојећим рањивостима, могу имати изражене посљедице на друштво у целини. У чланку су анализиране посљедице климатских промјена на сливу ријеке Врбас, са посебним освртом на заштиту од поплава, посебно града Бања Луке, и обезбијеђеност испоруке воде за наводњавање површина у најнизводнијем дијелу слива. Анализира се улога постојећих и планираних акумулација на ублажавање неповољних догађаја, наглашавајући значај интегралног управљања водним ресурсима.

Кључне ријечи: климатске промјене, акумулације, поплавни таласи, наводњавање, обезбијеђеност

1. INTRODUCTION

Adverse impacts of climate change, irrespective of greenhouse gas (GHG) emission scenarios, are expected to have profound effects on water systems and the entire water sector, thereby impacting society as a whole. This is primarily due to the fact that problems in the water sector, arising from water scarcity and inadequate reliability of water management systems, are transmitted to all other social, economic, urban, and other systems. There are numerous examples from the past [1, 2] that have shown that a disruption in the normal functioning of water management systems quickly led to the destruction of the social, economic, and other stability of the entire community. On the other hand, there are examples showing that the development of water management systems has been the strongest driver of the entire society, and through intensifying the development of water management systems, countries have created conditions for overcoming economic and social crises.

The consequences of climate changes are well documented by different authors [3], and the most important ones affecting the water sector are:

- Increased temperatures - the last decade, 2011-2020, has been the warmest on record. Each successive decade since the 1980s has been warmer than the previous one, with nearly all land areas experiencing more hot days and heat waves.
- More severe storms - destructive storms have become more intense and more frequent in many regions.
- Increased drought - climate change is changing water availability, making it scarcer in numerous regions. Global warming exacerbates water scarcity in already water-stressed regions, increasing the risk of agricultural droughts that impact crops, and ecological droughts that increase the vulnerability of ecosystems.

The consequences of climate change in the Vrbas River basin will be analyzed in the article and the role of existing and planned reservoirs in mitigating adverse events will be examined. The primary focus will be on flood protection and on increasing the reliability of water supply for irrigation purposes.

2. DESCRIPTION OF THE ANALYZED AREA

The Vrbas River is a right tributary of the Sava River and is the largest river in the western part of the Republika Srpska (Bosnia and Herzegovina). Total area of the Vrbas basin is about 6273 km^2, of which 63.5% belongs to the Republika Srpska, and 36.5% is in the Federation of B&H (Figure 1) [4]. Vrbas springs below the mountain Vranica at about 1715 m above sea level and flows into the Sava near Srbac at an altitude of 90 m above sea level. The total length of the watercourse is 248 km (of which 131 km flows through the territory of Republika Srpska). The Vrbas basin is a typical example of a mountain landscape that occupies 90% of the area and is mainly located in the upper and middle part. The remaining 10% is the lower river plain, primarily located in Lijevče Polje and the Skopaljska valley. The Vrbas drains important karst areas (especially the Pliva and Crna Rijeka river basins), so the exact boundaries of the sub-basins are difficult to determine, because the boundaries of the orographic and hydrographic basins often do not coincide.

In the downstream part of the basin, the river flows through Banja Luka, the capital of Republika Srpska with approximately 180,000 inhabitants. The Vrbanja River, a torrential tributary, flows into the Vrbas within the urban area. Banja Luka is protected from the flooding by passive protection measures - embankments along those two rivers. However, due to increasingly unfavorable flood events (such as the flood in 2014), which are a consequence of climate changes as well as changes in the watershed, additional protection measures are necessary in order to adequately protect the city.

Average annual temperatures range from 8.6°C in the southern part of the basin to 11.3°C in the northern part (Banja Luka meteorological station) [4]. The analysis of average annual temperatures for period 1961-2019, shows an increasing trend of around 0.5°C for each subsequent decade. The intra-annual temperature distribution is similar for the entire basin, with the lowest temperatures in the December-January-February season gradually increasing until the warmest months of June-July-August.

The average annual precipitation in the basin (period 1961-2019) is about 1000 mm and ranges from about 800 mm per year in the south, to about 1,500 mm per year in the northern part of the basin [4]. The average potential evaporation is 700-750 mm. In the summer months, evaporation exceeds the precipitation. Maximum precipitation occurs mainly in late spring and early summer (May and June), while minimum precipitation occurs in January and February.

The hydrographic network of the Vrbas river basin is relatively good developed. Figure 1 shows a simplified hydrographic map of the basin. Vrbas has 36 direct tributaries longer than 10 kilometers, of which 11 have catchment areas greater than 100 km^2. The most important tributaries are Pliva with Janja, Ugar, Crna Rijeka and Vrbanja. The months with maximum flows are March, April and May, and the minimum flows occur in August and September. Intra-annual flow irregularities are pronounced, with maximal average monthly values over 3 times higher than the minimal values.

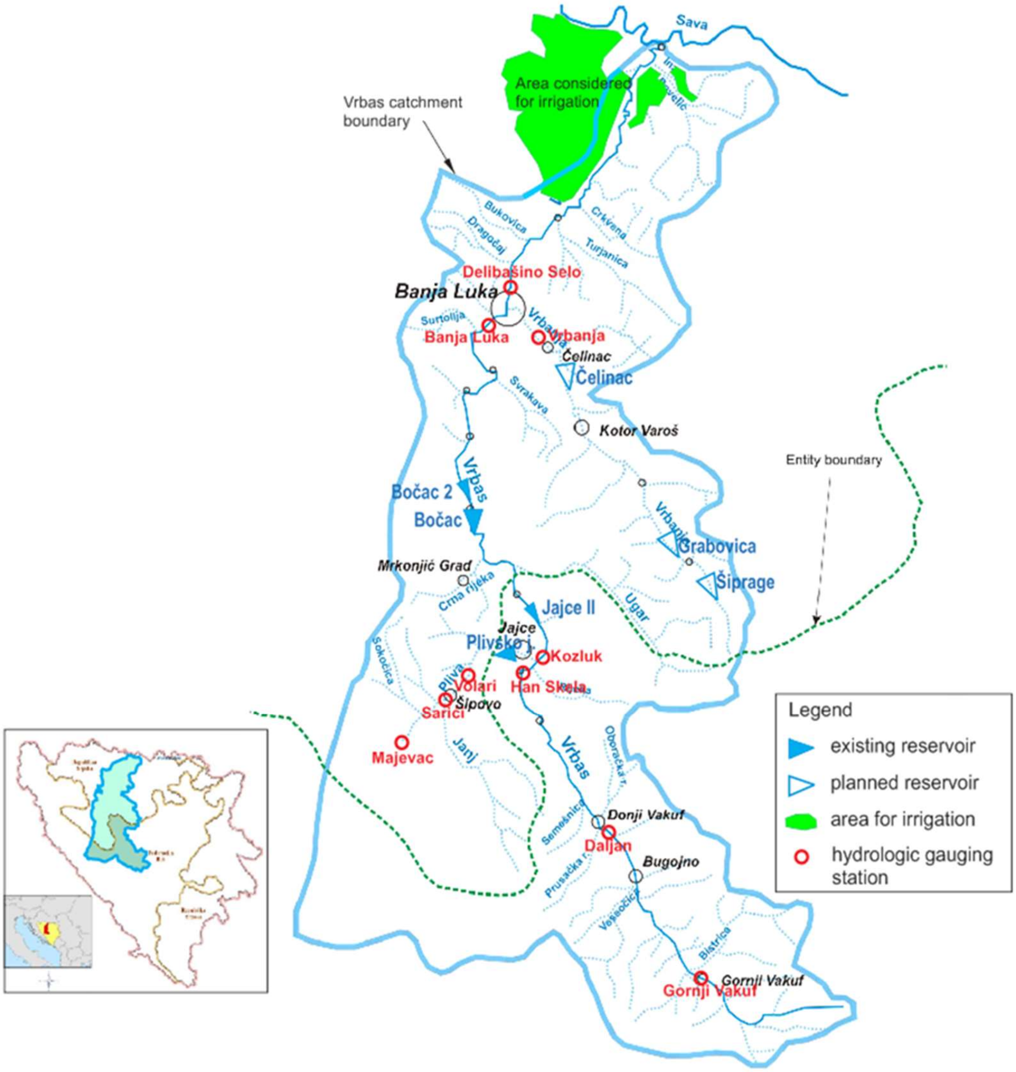

Figure 1. Hydrographic map of the Vrbas River basin (modified [4])

There are four reservoirs and hydroelectric power plants in the Vrbas river basin: Plivsko jezero with HPP Jajce I, Jajce II and Bočac with HPPs of the same name and Bočac 2 with the SHPP of the same name. The most significant reservoir is Bočac, with an active volume of 42.9 × 10^6 m^3, which can regulate the flow on a weekly level. Other reservoirs are with small active volumes enough just for daily flow regulation.

It is possible to irrigate about 36,000 ha in the area of the Vrbas river basin (the area that belongs to the Republika Srpska), but the most significant areas are located in the downstream part of the Vrbas River (Figure 1) – Lijevče polje, between Vrbas and Sava rivers. Net area for irrigation is about 20,000 ha. Based on the developed designs water abstraction for irrigation is planned: from the Vrbas River, from Vrbas - Osorna - Borna channel, by discharge of water from the water storage reservoirs, or, in limited quantities, from underground, because groundwater is reserved for water supply of Laktaši and Gradiška settlements.

3. CONSEQUENCES OF CLIMATE CHANGE IN THE VRBAS RIVER BASIN

Observations of climate parameters on the territory of Bosnia and Herzegovina, primarily precipitation and temperature, indicate the following important facts: there is an increase in temperature in all parts of the country, the average annual precipitation has not significantly changed, but the number of days with precipitation has decreased, and the number of days with intense precipitation has increased. These observed changes also lead to alterations in water regimes, which further affect ecological, economic, social, and other aspects. To timely mitigate the consequences of climate change, it is necessary to assess the magnitude of expected changes and their consequences in future time periods. The analysis of the consequences of climate change in the Vrbas River Basin has been considered in several studies, among which the most significant are: 'Study of the Economic Impact of Climate Change on the Energy and Agricultural Sectors of the Vrbas River' [4], and the Flood Risk Management Plan for the Vrbas River Basin of Republika Srpska.

The consequences of climate change on water regimes in the Vrbas River Basin have been studied for three common climate change scenarios (depending on the predicted concentration of CO_2 at the end of the century): A1B, A2, and RCP8.5. For more detailed analyses, scenario A2 was used, which is the middle of the three considered scenarios, assuming a CO_2 concentration of around 850 ppm at the end of the century [5]. Projections of changes were made for three 30-year intervals: 2011-2040 (near future), 2041-2070 (middle of the century), 2071-2100 (end of the century), with the base period being 1971-2000. The analysis included mean annual temperatures, intra-annual distribution of temperatures, mean seasonal temperature values, annual sum of precipitation, intra-annual distribution of monthly precipitation sums, and seasonal sums of precipitation. Based on data on precipitation and temperatures, as well as analyses of potential evapotranspiration (PET), the hydrological model MIKE NAM was used to determine daily flow rates at the locations of the gauging stations, enabling the analysis of flow rate changes in the considered time intervals until the end of the 21st century. Some indicators of climate, meteorological, and hydrological changes according to scenario A2 in the Vrbas River Basin are summarized.

- The change in average annual temperatures at all considered weather stations (Banja Luka, Bugojno, Jajce) ranges from 0.7 to 0.9°C in the near future, from 2.1-2.4°C in the middle of the century (distant future), to 4.4-4.7°C by the end of the century.
- The change in average monthly temperatures ranges from 0.1 to 1.8°C in the near future, 1.4-2.9°C in the distant future, and 3.6-5.8°C in the far future. Larger increases in monthly temperatures are expected in winter and summer months, while in spring and autumn, these changes are somewhat smaller.
- The change in the annual sum of precipitation ranges from 1.3-3.7% in the near future, -0.7-2.1% in the middle of the century, and -9.5-13% by the end of the century. Note: towards the end of the century, the decrease in annual precipitation is greater.
- Changes in monthly precipitation amounts range from -20 to 21% in the near future, -31 to 26% in the distant future, and -46 to 43% in the far future. It is very concerning that the largest reductions in monthly precipitation are expected in the summer months (June, July, and August), precisely during the growing season when precipitation is most needed. The reduction in summer precipitation in the near future is around 10%, around 20% in the middle of the century, and over 40% by the end of the century.
- The average annual flows at all 10 considered gauging stations: Delibašino Selo, Banja Luka, Kozluk, Han Skela, Daljan, Gornji Vakuf, Vrbanja, Volari, Sarići, Majevac (Figure 1), show similar trends. According to the A2 scenario considered, there could be some increases in mean annual water volumes by 2-8%, while a decrease in flows of up to 7% and 20-45% is expected by the middle and end of the century, respectively. Thus, a significant decrease in mean annual flows in the Vrbas River Basin can be expected towards the end of the century.
- The change in average monthly flows varies widely from -30 to 57% for all months in the near future, -41 to 33% in the distant future, and -58 to 36% in the far future. The greatest reduction in average monthly flow is in August, while the greatest increase in flow is possible in December.
- According to indicators of high-flows, extreme flows with a duration curve of Q1% (duration of 4 days) could increase by an average of about 13% (between -3 and 32% depending on the station) in the near future compared to the reference period. A similar

situation can be expected in the middle of the century, while by the end of the century, a very slight average increase in the flow of duration 1% is expected, with large differences between basins of -33 to 25%.

- All characteristic indicators of low-flows are changing unfavorably: low-flows are becoming less frequent and with longer durations. In the near future, this decrease is not significant, while their decrease in the middle and end of the century is significant. The flows of duration 80% (292 days) on average decrease by about 30% by the middle of the century, and by 61% by the end of the century. The largest decrease in low-flows is in the lower course of the Vrbas River basin, including the Vrbanja River, precisely in areas where the most valuable soil resources are located.
- The values of quantiles of high-flows are increasing on average, with this increase being particularly pronounced in the lower course of the Vrbas River with similar values for the entire period considered. Quantiles of low-flows are significantly decreasing at all stations, with the decrease increasing towards the end of the century. This decrease in the Banja Luka area, for a return period of 100 years, ranges from 40% in the near future to 75% by the end of the century. For the Delibašino selo station, the situation is somewhat more unfavorable, and for the Vrbanja River, these values range from -124% to -100% for the same return period.

The concise conclusion is that, as a result of climate change in the Vrbas River basin, a significant increase in temperatures is expected throughout the year, along with a decrease in total precipitation. However, there will also be an increase in the frequency and intensity of extreme precipitation events, accompanied by extreme flows. More frequent large flood waves with higher peaks than those observed during the last century can be expected, making flood protection conditions much more complex. It will be necessary to use reservoir management based on simulation and optimization models as a measure of active flood defense [6]. On the other hand, the most adverse consequence of climate change is the decrease in both precipitation and flows during the vegetative part of the year, leading to more frequent and longer-lasting droughts. As a result of climate change, the slope of the curve of flow duration becomes steeper in the future, implying that there will be increases in the flows of large, short-duration floods, up to 4 days, but decreases in flows of longer durations, especially those of long duration in the zone of small flows on the flow duration curve. The water sector is facing an increasingly challenging reality: extreme destructive flood waves may occur during the same year, followed almost immediately by a long dry, low-flow period. The downstream area of the Vrbas River basin, where the most valuable soil resources are located, is particularly endangered. The conditions for protecting these areas from floods will become more difficult. At the same time, agricultural production on these soils of the highest quality classes will become increasingly complicated over time and almost impossible without irrigation.

4. FLOOD WAVES AND THEIR MITIGATION

Detailed analyses of the impact of climate change on flood events indicate complex conditions which will require combined mitigation measures, including hydrological simulations and optimization models for reservoir management. The results of the management model for Bočac reservoir, that provides optimal management of the releasing facilities on the dam (gates on spillways, valves on bottom outlets, operation of turbines in hydropower plant) in the case of flood event, according to the criterion of minimizing flow in the downstream urban area [6] are presented. In addition to the flood wave in the main course of the Vrbas River, that can be mitigated by the Bočac reservoir, there is also a flood wave from Vrbanja River. It comes from the part of the catchment between the reservoir and the urban area (Banja Luka town), with no facilities to mitigate the flood wave (uncontrolled part of the catchment).

Analyzes were performed for flood waves of different return periods: 20, 50 and 100 years (FW20, FW50 and FW100), which were determined by applying a hydrological model based on the simulation of rain episodes [5]. The rain duration in the upstream part of the catchment was 12 hours, with total precipitation from 87 mm to 103 mm (for the 100 years return period). In the downstream part of the catchment (Banja Luka region), the rain duration was 24 hours, with total precipitation of 169 mm. All current rules for managing the release structures (gates, hydropower plant, outlets etc.) were incorporated in the model. The analyses were performed under the assumption that the initial water level in the reservoir was at 281 m a.s.l (working level), the maximum water level was 282 m a.s.l., and the minimum level was 271 m a.s.l. (during the intensive emptying of the reservoir).

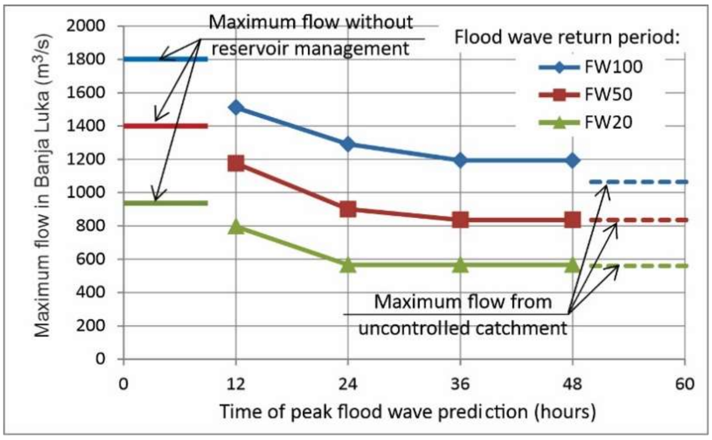

Figure 2. Maximum flows in Banja Luka for different flood waves return period and different times of peak flood wave prediction

The results of performed analyses show that despite the relatively small reservoir volume it is possible to significantly reduce the maximum flows in the city of Banja Luka (Figure 2). By effectively managing the reservoir, it is possible to delay the peak of the flood wave from the Vrbas River, avoiding its coincidence with the wave from the Vrbanja River. This is particularly important for mitigating floods in Banja Luka due to the rapid occurrence and high peak flows of the Vrbanja flood waves. When the optimal reservoir management strategy begins 36 hours before the peak flow, the maximum flows through Banja Luka do not exceed the maximum flows from the uncontrolled part of the catchment (Vrbanja River flood wave), for flood waves FW20 and FW50. Water is mostly discharged through the HPP Bočac. Gated spillways are open only a few hours (5 h for FW20 and 16 h for FW50). For FW100 maximum flow is higher than the maximum flow from uncontrolled catchment (by 130 m^3/s), and about 600 m^3/s lower than the flow that would occur without the Bočac Reservoir. Even if the optimal reservoir management begins one day before the peak flow, significant mitigation of flood wave is possible. Maximum flow through Banja Luka in that case is slightly above maximum flow from the uncontrolled catchment for FW50, and flood wave FW100 can be significantly mitigated, with maximum flows 230 m^3/s higher than the maximum flows coming from the Vrbanja River.

Planned reservoir Čelinac could further reduce the flood waves through the city of Banja Luka. The reservoir is planned in the downstream part of the Vrbanja river at site that controls an area of 607 km^2, with an average discharge of 13.2 m^3/s. The planned volume of the reservoir is 56×10^6 m^3, and the active volume is 43×10^6 m^3. An analysis of the effects of the reservoir on mitigation of flood waves was conducted using an approximate method, because all necessary data for detailed analysis were not available. The spillways are equipped with gates, allowing flexible flow management. The dam also has a bottom outlet and a hydroelectric power plant, with an installed flow rate of 30 m^3/s. The possible mitigation of the flood wave peak was carried out based on the balance equations of water inflow and outflow from the reservoir. Two calculation variants were performed: 1. with a constant maximum value of the outflow wave flow rate, and 2. with a gradual increase in the outflow flow rate. The first variant provides smaller maximal flood rates of the outflow wave and represents the upper limit of possible wave mitigation. According to the second variant, smaller reductions in the peak of the wave are obtained, but these values more closely correspond to realistic reservoir management. The analysis was performed for several initial water level values in the reservoir (PNV), or for several levels of pre-flooding: PNW = KNU = 233 m a.s.l., PNV($0.8 \times Vk$) = 230.45 m a.s.l., PNV($0.6 \times Vk$) = 227.6 m a.s.l. The calculation results for variant 1 show that it is possible to reduce the maximum flow rate of a 100-year return period wave by between 25% (without pre-flooding of the reservoir) and 63% if the water level is lowered to 227.6 m a.s.l. According to variant 2, for the same wave, reductions are slightly smaller, ranging from 3% (without pre-flooding) to 44% for pre-flooding up to 227.6 m a.s.l. Waves of smaller return periods can be significantly mitigated (Figure 3). From the results presented, it is clear that the Čelinac reservoir would significantly impact the mitigation of flood waves in the city of Banja Luka.

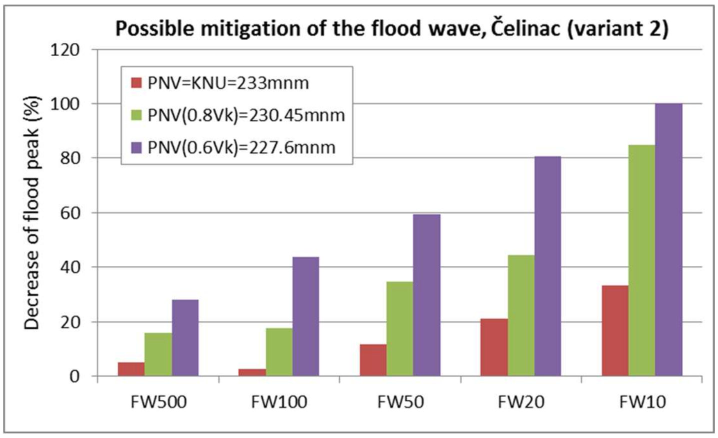

Figure 3. Reduction of the maximal flow of the Vrbanja River downstream of the Čelinac reservoir, for different water levels in the reservoir at the time of flood wave arrival (various pre-release volumes)

5. ISSUES IN THE LOW-FLOW PERIOD

Another equally important issue is the management of reservoirs during low-flow periods. This problem is significant because the lower part of the Vrbas basin contains high-quality soil resources that need irrigation. Therefore, it is necessary to consider the possibilities of irrigation under existing system conditions (primarily the effects of the existing Bočac reservoir), as well as measures that should be taken to enable reliable irrigation [7]. To meet this goal, the effects of reservoirs on the Vrbanja River (planned within the strategic documentation), were considered.

5.1. IRRIGATION WATER DEMAND

The required amount of water for irrigation is determined on the basis of climate parameters - calculating potential evapotranspiration and effective precipitation. The values are determined for the reference period, as well as for future periods taking into account climate changes.

Potential evapotranspiration was determined as a product of the reference evapotranspiration (calculated according to the Penman-Monteith method, which is recommended by FAO) and the crop coefficient, under irrigation conditions [4]. For areas that would be irrigated, a projection of sowing structures has been defined, based on previous production, as well as based on expected changes towards intensifying livestock feed production. Sowing is predicted on at least 15% of the area, and sowing structure related to on-demand irrigation systems has been adopted, considering that the majority of arable land is in private ownership and that it generally consists of small parcels.

Effective precipitation was determined using the USDA, SCS method. Since effective precipitation in irrigation is defined as the portion of total precipitation that the plant can utilize, it was calculated only for months of the growing season and for precipitation greater than 2 mm.

Previous analyses were finalized by determining the water requirements (PV) [8]. The total water requirement in an average year is 209 mm, while in the hypothetical dry year, it is 332 mm, which is about 60% higher. This methodological approach yields the insight that water requirements in agricultural areas should be viewed as a dynamic category, especially considering unfavorable climate changes.

Having in mind previously described increase in air temperature and decrease in precipitation in the future, it is clear that an increase in water demands for irrigation can be expected. Especially unfavorable is the fact that the described changes will be most pronounced in the summer months, when the needs for irrigation water supply are the highest. The structure of agricultural production was adopted on the basis of previous production, as well as on the basis of the expected change in the direction of intensifying the production of animal feed. A sowing structure related to on-demand irrigation systems has been adopted. Changes in water requirements were analyzed in detail for scenario A2. The cumulative annual value of PV for an average year in the period 2011-2100 is 269 mm, which is about 40% higher compared to the reference period 1971-2000 (191 mm). This indicates an obvious increasing trend due to climate change. According to scenario A2, the change in water requirements in the period 2011-2100 after the reference period (1971-2000) shows an increase at a rate of 1.6 mm/year.

5.2. RELIABILITY OF WATER SUPPLY FOR IRRIGATION UNDER EXISTING SYSTEM INFRASTRUCTURE

The analysis of possible water supply for the irrigation system was performed for the reference period (1971-2000) and for three future periods according to scenario A2. The calculation was performed with unregulated values of average monthly flows (at site Laktaši), for several reasons:

- Upstream from the considered site there are three dams and HPPs: Jajce I, Jajce II and Bočac and one barrier with gates in the profile of SHPP Bočac 2. Of all the listed facilities only the Bočac reservoir has significant useful volume (42.9×10^6 m^3), while other HPPs work as run of river HPPs, so they do not affect the change of water balance.
- The operational volume of the Bočac reservoir can perform weekly water balance, so there will be no significant balance changes in the flow on a monthly level.
- The main purpose of the Bočac reservoir is hydropower production, so it cannot be required to discharge water for the irrigation of areas located more than 60 km downstream.
- It is necessary to maintain the ecological flow (EF) in the watercourse downstream from the water intake for irrigation. A constant flow of 25% of average annual flow is required: $Q_{EF} = 0.25 \times Q_{av}$, where Q_{av} is the average annual flow determined for the reference period 1971-2000. The priority in meeting the needs is the ecosystem, i.e. the release of environmental flow. The irrigation system captures water only in cases when the flows in the Vrbas River are higher than QEF. The amount of taken water depends on the remaining available water quantities (Qriver - QEF) and it can vary between 0 and the required quantities. Balance analyses were performed under the assumption that water is taken from the river constantly, i.e. the system works 24 h/day.

For each analyzed year, the reliability of water supply (PV) was determined on the basis of the total annual amount of water that could not be delivered to the irrigation system - water deficits (V_{def}) and the total annual water needs (V_{total}): $P_V=(1-V_{def}/V_{total})\cdot 100$ (%)

In Figure 4 the percentage of water deficit in each year (the relation of water deficit to the total required amount of water for irrigation) is presented. It is obvious that water deficit increases towards the end of the century. In the near future, a significant deficit occurs in about 12 years, in the distant future (2041-2070) in 22 years, while at the end of the century a larger or smaller deficit occurs in almost every year. The volume of missing water also increases. A deficit of more than 50% of the required quantities occurs in 10 years in the distant future, and in 23 years at the end of the century.

Based on the performed analyses, the average ten-year values of reliability and changes (decrease) of these values in relation to the reference period were determined (Figure 5). The trend of decreasing is obvious, and it is especially pronounced in the second half of the century. It is the consequence of a decrease in available water quantities and increased flow variability due to which low-water periods are longer, and increase in water requirements for irrigation as a consequence of increased air temperature and reduced precipitation.

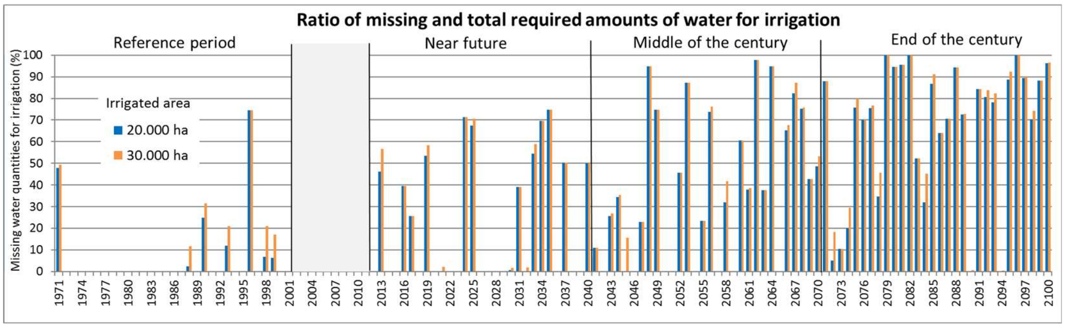

Figure 4. The ratio of missing and total required amounts of water for irrigation

The analysis of water supply reliability was performed for several different values of the irrigated area. Given that these are relative (percentage) values, reliability changes are similar for all analyzed areas, and average values in the analyzed time periods decrease from about 17% in the near future, to over 35% in the distant future, to 63-67% at the end of the century.

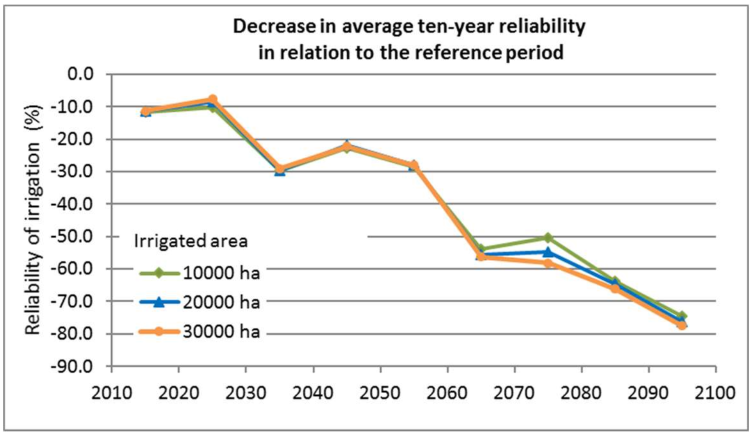

Figure 5. Decrease in average ten-year reliability in relation to the reference period (1971-2000)

Of particular concern is the increasing number of months during which it is not possible to deliver any amount of water for irrigation, as the flows in the river are lower than the environmental flow ($Q_{river} < Q_{EF}$). At the end of the century (2071-2100), there will be years in which water delivery will not be possible during the entire irrigation period.

Described analyses were performed with average monthly flow values. The situation would be even more unfavorable if the analyses were performed with daily flow values. Such analyses were not performed for the entire considered period, but the calculation was performed for several years from each of the three considered periods and the results show that water supply reliability is lower (0 - 20%) in relation to the values obtained with average monthly values. The decrease in reliability increases towards the end of the century.

5.3. RELIABILITY OF WATER SUPPLY FOR IRRIGATION WITH PLANNED MULTIPURPOSE WATER STORAGE RESERVOIRS ON THE VRBANJA RIVER

As shown in the previous section, the reliability of water supply for irrigation will be significantly reduced in future periods, and this reduction will be particularly pronounced in the second half of the century. Reliable irrigation, in such conditions, can be achieved only if there are reservoirs, which can be used to redistribute water over time. Considering the location of irrigated areas, the impact of reservoir Čelinac (with active volume of 43×10^6 m^3) will be analyzed.

Figure 6 show the water deficit in each year in relation to the total required amount of water for irrigation. There is a significant reduction in the amount of deficit water for irrigation compared to the situation without reservoirs. The existence of only this one reservoir (planned are two more reservoirs in the upstream part of Vrbanja river), enables very reliable irrigation of the planned areas at the Lijevče polje site. It is possible to irrigate a net area of about 20,000 ha, which means that water deficits in the near and distant future would occur very rarely, and the missing quantities would be relatively small (mostly up to 10% of the required quantities). Deficits greater than 20% would occur only at the end of the century (1971-2000) in just 6 years. Irrigation of larger areas would affect the more frequent occurrence of deficits. Unlike the situation without reservoirs, in this case deficits higher than 50% would occur relatively rarely (only in 7 years) at the end of the century.

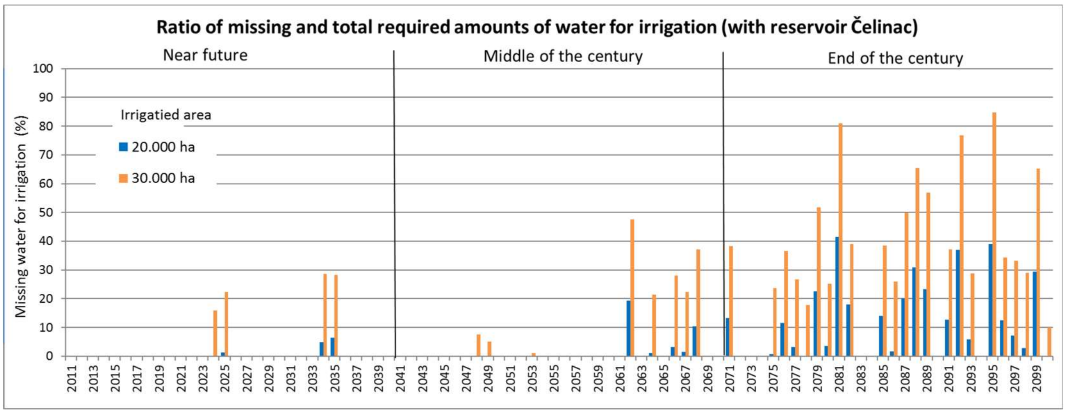

Figure 6. The ratio of missing and total required quantities of water for irrigation in conditions with the reservoir Čelinac

With the inclusion of the Grabovica reservoir, irrigation of an area of about 20,000 ha would be practically without water deficits, except in a few driest years at the end of the century. Irrigation of larger areas (up to 30,000 ha) would be almost without a deficit in the near and distant future, while deficits would occur only at the end of the century, but it would not exceed 50% of the required amount of water.

Figure 7 presents the security of water supply in cases when there are no reservoirs (dashed lines), and with Čelinac reservoir. It can be seen that reliability of providing water for irrigation is considerably increased if Čelinac reservoir is in use. The reliability of water delivery for 20,000 ha would amount to over 80%, which is a satisfactory value for that user (irrigation). The same area could be irrigated completely reliably in the case of the Čelinac and Grabovica reservoirs.

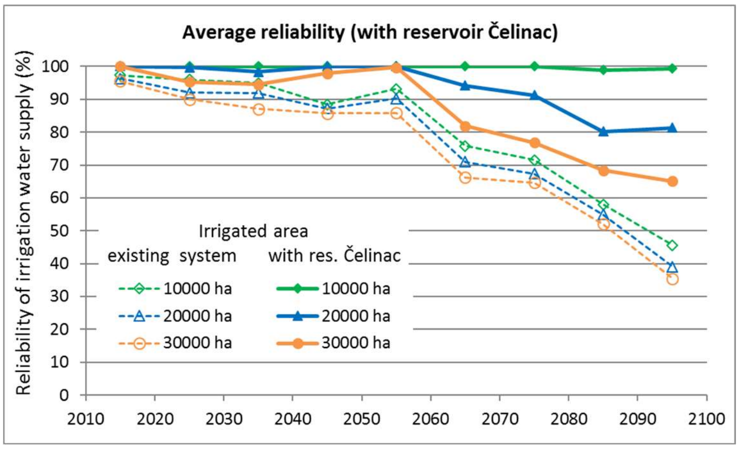

Figure 7. Average ten-year reliability of irrigation water supply

In the case of construction of all three reservoirs Čelinac, Grabovica and Šiprage, the required amount of water for irrigation would be fully provided, even for the largest irrigation area of 30,000 ha.

It should be noted that the analyzes were performed under the assumption of irrigation as a priority user in relation to energy. The performed analyzes do not consider other roles of the planned multipurpose reservoirs at Vrbanja River, such as the reduction of flood waves in the downstream area, especially in the city of Banja Luka. Hydrological analyzes have shown that in the future, in the conditions of climate change, an increase in high water flows can be expected (for return period of 100 years, scenario A2, average increase is about 15% in the near and distant future, and up to 35 % at the end of the century). Considering that river Vrbanja has the characteristics of a torrent flow, with a very short time of flood waves concentration and large flows (peaks), transformation of flood waves in the reservoirs would significantly reduce the risk of floods in the downstream area. Performed analyzes gives only approximate values of the impact of reservoirs on increasing the security of water supply for irrigation purposes. More accurate values could be obtained by more detailed analysis of the needs of all users, with the optimization of the operation of reservoirs.

6. CONCLUSION

In the context of climate change and the increasing variability of water regimes, the significance of reservoirs is heightened. They play a crucial role in providing required water quantities by balancing water throughout the year and actively mitigating flood waves. To optimize the use of the reservoirs' active volume, improved reservoir management is necessary.

A reservoir management model, aiming to minimize flow in downstream urban areas, was applied to the Bočac reservoir. The potential for mitigating flood wave were analyzed for different initial water levels in the reservoir (representing preemptive reservoir volume). The results indicate that these models can be effectively utilized, especially when coupled with hydrologic models that simulate flood event hydrograph, enabling preempting of the reservoir. In the case study, predicting the flood wave two days in advance and implementing optimal management measures significantly delayed and reduced the flood peak in Banja Luka.

The planned Čelinac reservoir in the downstream part of the Vrbanja River would further reduce flooding in Banja Luka. This reservoir would retain a portion of the highly unfavorable Vrbanja River flood wave, characterized by steep flow increases and high peaks. Additionally, the multi-purpose nature of this reservoir would provide necessary water quantities for irrigation.

One area under consideration for agricultural expansion and irrigation system construction in Republika Srpska is located in the Vrbas River basin, particularly in its downstream region. As a result of climate change the demand for irrigation water increases in time. The analysis indicates a significant reduction in the reliability of irrigation water supply, which will worsen by the end of the century. Therefore, the construction of reservoirs on Vrbanja River, especially the Čelinac reservoir, would increase the irrigation water supply reliability.

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