REGULATION AND UTILIZATION OF FLOOD WATER OF KARST POLJE – EXAMPLE OF GATAČKO POLJE, EASTERN HERZEGOVINA

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Abstract: In general, karst is known as extreme environment for construction of large structures. The average precipitation of karst poljes at Dinaric region of the Eastern Herzegovina for a wet year is about 2450 mm. Daily precipitation can be more than 250 mm. Due to prevailing underground drainage and limited dewatering capacity of ponors the floods are frequent. Only agricultural land is in the karst poljes, which remain flooded from 150 to 250 days in average per year. The population remains low as these difficult living conditions have driven people out of this region for many decades. Possibilities for socio-economic developments are poor. One of these poljes the Gatačko Polje is situated at the highest elevation of the Eastern Herzegovina. Uneven water regime of polje is typical for regions with deep and high developed karst. Sometimes floods are disastrous particularly for infrastructure. To change inconvenient natural water regime a few possible options are analyzed.
In article are presented, in very general, properties of natural regime of the Gatačko Polje, including some hydrological and hydrogeological specificities. Many decades behind two mutually coupled questions were analyzed: possibility to transfer the part water from the Gatačko Polje catchment to be used at the Multipurpose Hydrosystem Trebišnjica for power production, irrigation, water supply and other secondary benefits, and at the same time, to protect infrastructure, particularly to prevent disastrous effect on the Thermal Power Plant.

Key words: Karst polje, ponor, flood protection, management of reservoirs, Mušnica River

GENERAL SETTINGS

The drainage area of the Gatačko polje belongs to the uppermost cascade of the large Trebišnjica catchment area. This area is situated between the drainage basins of the Neretva, Drina and Zeta rivers. The Neogene sedimentation trench of the Gatačko Polje has been developed along the steep dislocations that follow Dinaric direction and transverse fractures. New tectonic movement had a pivotal role in predisposing and developing the karstification process. The capacity of karst corrosion and erosion abruptly increased with the rising of the northern tectonic blocks. As consequence of these processes the surface river net was disorganized, and underground drainage system has been developed.

The Gatačko Polje lost the surface drainage, particularly in direction of west, toward the Zalomka River. At the level of the Gatačko polje two independent infiltration zones have been formed under the influence of these two erosion bases (Milanović P, 2006). Evolution of this part of the karst aquifer moved in two directions, eastward toward the Piva Spring and southward toward the Trebišnjica Springs. The most concentrated infiltration zones were created along the south-east border of the Malo Gatačko Polje. The preferential sinking zone and groundwater flow was predisposed by the most important transverse fault zone of north-south direction between the Malo Gatačko Polje and the Cerničko Polje. The huge swallow-hole zone with massive swallowing capacity Jasikovac and Vranjača has been developed.

Total surface of Gatačko Polje is about 37.6 km^2, and its elevation is between 936 and 950 m a.s.l. It consists of two geomorphologicaly and hydrogeologicaly interconnected units: Gatačko Polje itself (31.83 km^2) and Malo Gatačko Polje (5.77 km^2), Fig. 1. Average annual precipitation is 1756 mm, with minimal annual values of 918 mm and maximal 2513 mm. The main stream of the Gatačko Polje is the Mušnica River, formed from three streams Vrba, Ulinjski and Jasenički stream. Its main tributaries are Gračanica and Gojkovića (Žarovića) stream. The Mušnica River flows through Gatačko Polje to Malo Gatačko Polje where it sinks in numerous ponors from Srđevići Ponor to Šabanov Ponor and the sinking zones Jasikovac/Vranjača (Fig. 2). Further, water flows as groundwater to Trebišnjica springs.

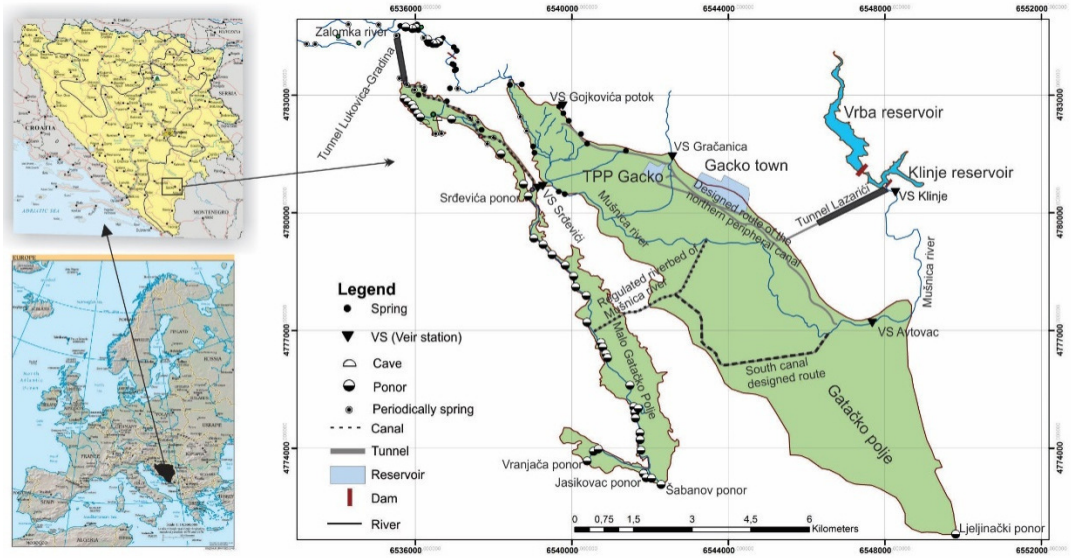

Fig. 1. Geographical position and schematic map of wider area of Gatačko Polje with main hydrotechnical constructions

There are 6 gauging stations in the Gatačko Polje with average annual flow values calculated for monitored data: VS Vrba (1949-1975) - 0.92 m^3/s, VS Klinje (calculated on the base of correlation with VS Vrba and VS Avtovac) 3.11 m^3/s, VS Avtovac (1962-1982) - 4.514 m^3/s, VS Gračanica (1947-1995) - 1.746 m^3/s, VS Gojkovića Most (1975-2001) – 0.415 m^3/s, VS Srđevići (1947-2014) - 8.06 m^3/s.

Natural regimes of water flows in the Gatačko Polje have been slightly changed after 1898, when Klinje Dam was built to provide water for irrigation. It has a water storage reservoir of only $1.73 \cdot 10^6$ m^3, with regular water level 1027 m a.s.l. Significant change of the water regimes in the Gatačko Polje have been registered after 1982, when dam Vrba was built, for the needs of technical water supplying for Thermal Power Plant Gacko (TPP Gacko). It is located upstream from the Klinje reservoir. Volume of water storage reservoir is $14.6 \cdot 10^6$ m^3, and regular water level 1062.5 m a.s.l. Reservoirs Vrba and Klinje works together - water from the Vrba reservoir is complementing the Klinje reservoir, from which water flows through the 6150 m long pipeline. First section of pipeline is constructed in the tunnel Lazarići (2920 m), and remaining part is realized as underground pipeline to the TPP Gacko.

PONORS AND PONOR ZONES IN GATAČKO POLJE

Natural dewatering of Gatačko Polje is possible only through the ponors and underground flows. The largest amount of water disappears through number of ponors developed along the contact impervious sediments/limestone, between the Srdjevići Ponor and the last one the Šabanov Ponor at the lowest, south/west section of Malo Gatačko Polje. The total recharge capacity, in the case of maximum flood, is approximately 160 m^3/s (Fig. 2).

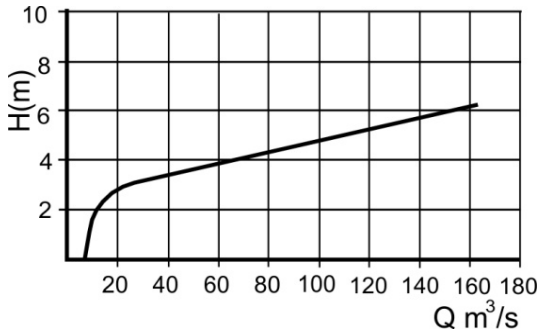

Fig. 2. Gatačko Polje. Summarized capacity of ponors in Malo Gatačko Polje, based on data at Srdjevići weir.

The largest infiltration zone developed along the southern perimeter of the Malo Gatačko Polje is ponor zone Jasikovac/Vranjača (Fig. 3). This ponor zone consists of number of huge shafts at elevation between 920 - 935 m. The total capacity of that zone is probably more than 60% of the total capacity of the Malo Gatačko Polje. The closest hydrologic station to this ponor zone is at the same time the

lowest point, Šabanov Ponor at Malo Kulsko Polje, 924.90 m a.s.l. (personal communication Supić R, 2016). It is about 4 m lower than elevation of the closest Mušnica river bottom (929.03 m). Between Mušnica River bed and Jasikovica/Vranjača ponor zone is natural ridge at least 5 m higher (approximate elevation 925 m) than Mušnica river bed and about 9 m higher than Šabanov ponor.

Because the swallowing capacity of the Šabanov Ponor is small, it becomes "suffocate" very fast and flood level in front of the ponor increases fast. When flood rise up to the level to overflow natural ridge the ponor zone Jasikovica/Vranjača becomes active.

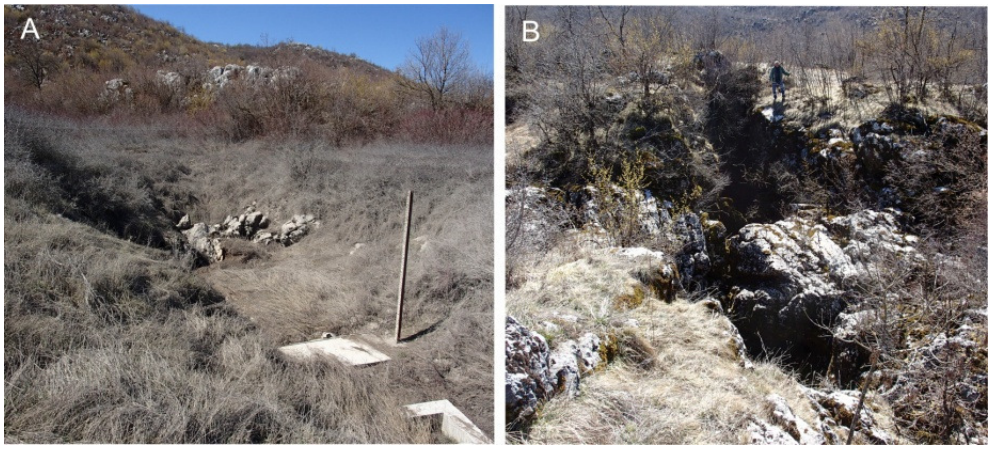

Fig. 3. Gatačko Polje. A. Šabanov ponor, B. One of Jasikovac ponors

According earlier opinion, the Srđevići Ponor has been declared as the largest ponor in the Malo Gatačko Polje. However, according the new findings this opinion needs to be revised. Usually, due to its prevailing hydrogeological function Srdjevići are declared as ponor. However, in the case of precipitation more than 100 mm/24 h at area of the Bjelasnica Mountain and abrupt saturation of aquifer Srdjević becomes estavelle until piezometric line is higher than surface water.

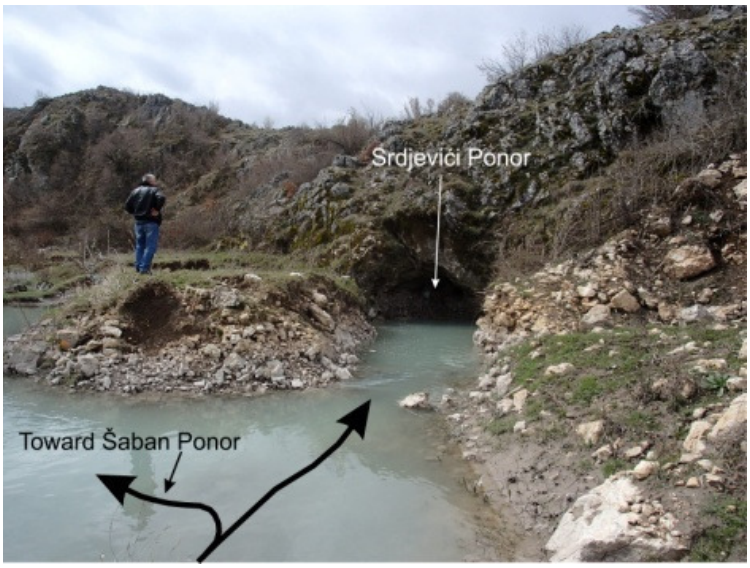

Fig.4. Gatačko Polje. Mušnica River. Branch toward the Srdjevići Ponor

Only a small area of the south-eastern part of Gatačko Polje belongs to the Piva River catchment area. Negligible amount of water (less than 5%) sinks into the Ljeljinački Ponor and flows toward the Piva Spring (Fig. 1).

GENERAL CONCLUSIONS

For the thermo-power structures flood waters are particularly risky. Fast concentration of flood waves is common in Dinaric karst region, with high maximal flows. Return period of flood water of 1% (once per 100 years) are estimated to be: VS Vrba - 123 m^3/s, VS Klinje - 264 m^3/s, VS Avtovac - 283 m^3/s, VS Gračanica - 131 m^3/s, VS Gojkovića Most - 49 m^3/s, VS Srđevići - 387 m^3/s.

Drainage capacities of ponors in the Malo Gatačko Polje are limited, with maximal swallowing capacities of approximately 160 m^3/s (Fig. 2). In the period of high water flows, when flows in Mušnica River is higher than swallowing capacities of the ponors, the Malo Gatačko Polje floods and acts as natural retention.

An example is the large flood occurred in 1975. Flow measured at the Srdjevići hydrologic station was app. 600 m^3/s. The flood wave provoked damages at the Klinje Dam (Fig. 5).

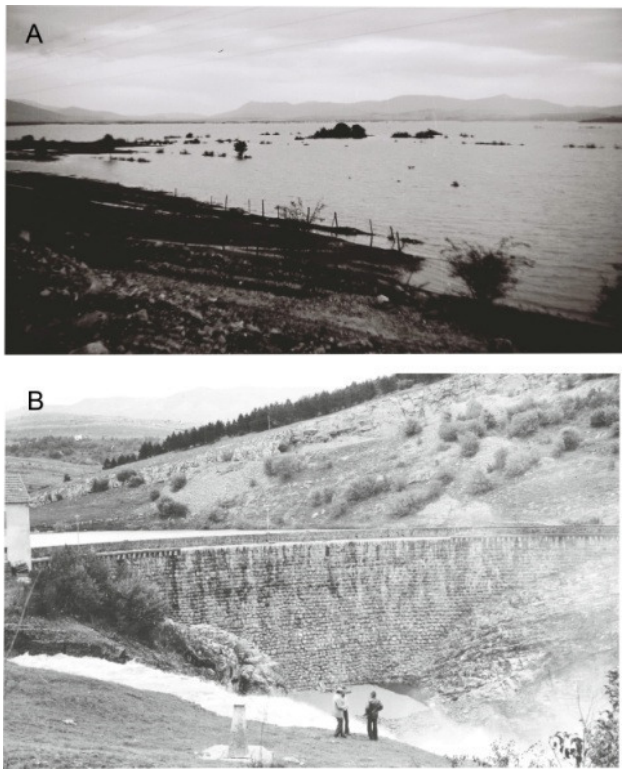

Fig. 5. A) Gatačko Polje. Flood 1975. B) Klinje dam, the day after flood 1975.

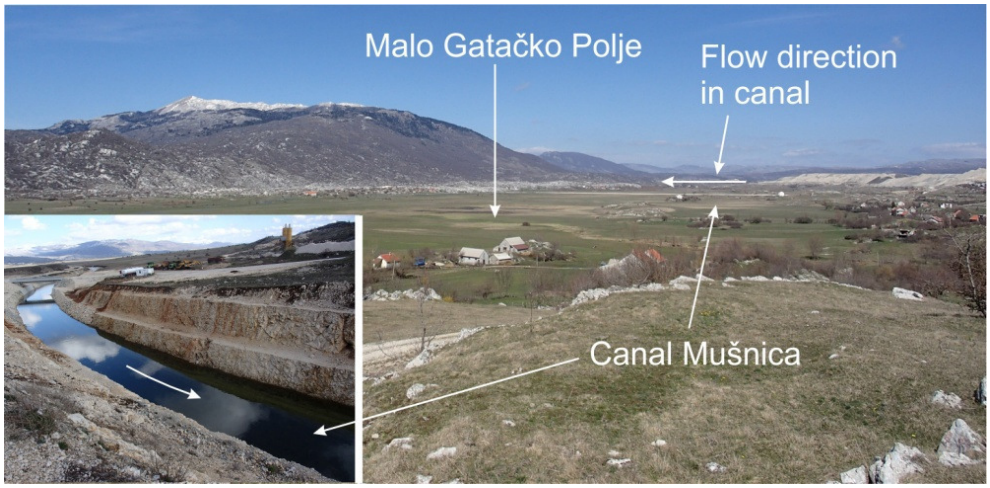

Fig. 6. Gatačko Polje. Re-routing canal of Mušnica river bed

After intensive rain of 280 mm in three days disastrous flood occurred in October 1998. (limnigraph Srdjevići – 498 m^3/s). Open coal mine was flooded

and heavily damaged. To prevent such events, different protection measures have already been undertaken: re-routing sections of the Mušnica River and defining the optimal management rules in flood periods for Vrba and Klinje reservoirs.

Effects of reservoirs to mitigate the flood waves are analyzed in detail in Dašić et al., 2016. The conclusions show that reservoirs, even are of small volume, can have considerable influence to mitigate huge water waves if management procedure is optimal.

Due to great importance of thermal-power potential situated in the Gatačko Polje, and need to be protected against floods, and to take advantage of considerable hydro-power potential the concept of water conveyance at two directions is developed.

To protect the thermal-power structures and facilities, the re-routing part of Mušnica in direction of the Malo Gatačko Polje has been already done (Study of water resources management, 2015). The re-routing canal crosses the limestone ridge to be connected with the Mušnica river bed in the Malo Gatačko Polje (Figures 1 and 6). However, influence of these structures on flood regime in the lower part of polje is not expected. To decrease the flood time of the Malo Gatačko Polje the connecting canal between river bed at elevation 929 m and ponor zone Jasikovac/Vranjača should be constructed. According this solution, the part of water belonging to the Gatačko Polje catchment will travel, mostly, as underground flows in direction of the Trebišnjica Springs.

As the water at elevation of about 1000 m a.s.l. contain a huge hydro-power potential, the concept of the Multipurpose Hydrosystem Trebišnjica System – Upper Horizons, includes transfer the part of flood waters from the Trebišnjica catchment into the Zalomka Reservoir. On this way each cubic meter of transferred water can be used for different purposes from elevation 1000 m to the sea level. According this concept the complex conveyance structure is foreseen (Fig. 7). This structure consists of pumping facilities in front of the Srdjevići Ponor; derivation canal along the Lukovice valley; and tunnel Lukovice – Gradina (Zalomka Reservoir).

To overcome difference of 22 m between the Srdjevići Ponor and canal entrance the pumping facilities are needed. Due to complex geological structure (reverse regional fault) the hydrogeological properties along the route of conveyance system was carefuly investigated (Study of detailed geological research for the main project needs of "Nevesinje" HPP, 2016). Number of ponors and caves were investigated. One of important problems is frequent floods of the Lukovice

valley. Protection of arable land against floods is one of secondary benefits of the conveyance system (Milanović S, 2015).

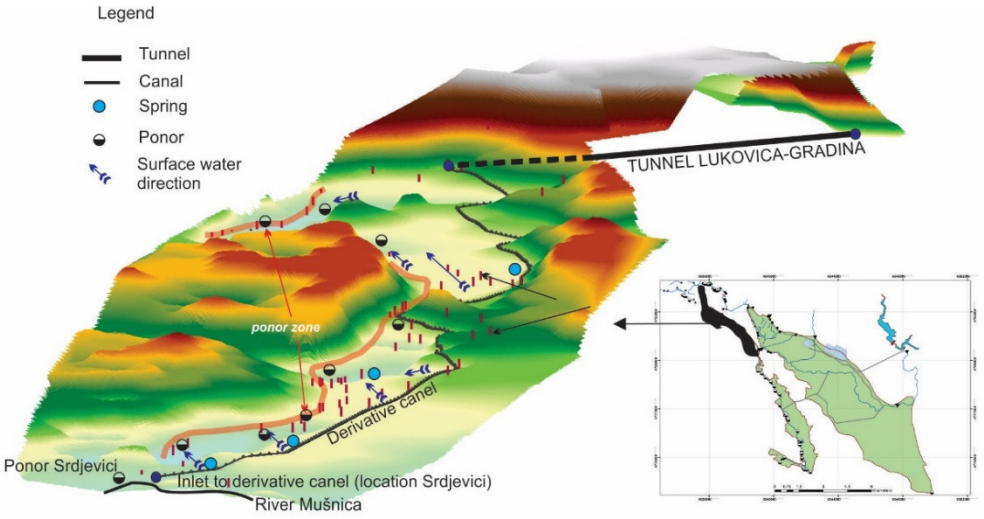

Fig. 7. Conveyance structures for water transfer from Gatačko Polje to the Gradina (Zalomka Reservoir)

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