HYDRO-POWER AND GROUNDWATER IN KARST

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INTRODUCTION

The region of Eastern Herzegovina is an area endowed with the highest precipitation in Europe. The average precipitation for a dry year is about 1250 mm and for a wet year about 2450 mm. This region borders the Orjen Mountain area, which has an average annual precipitation of more than 5000 mm. Additionally, this region is one of the most karstified areas in the world; surface flows are very rare; and distribution of precipitation is uneven during the year. About 70% of precipitation occurs during the wet season and 70-80% of rain water immediately percolates deep into the underground. Temporarily flooded karst poljes (flat-floored geographic depressions)), ephemeral rivers, numerous caves, and deep underground flows characterize this karst region. The main watercourse in the whole region is the Trebišnjica River, the largest sinking river in Europe. Since time immemorial, the people of this area have coped with two kinds of misfortune: flood and drought. It is a paradox. In spite of enormous precipitation in the wintertime, during the summer period, there is no water for fundamental human necessities. In remote villages, people still use rain water collected during the winter. When collected rainwater was insufficient, villagers used to walk hours to take water from karst shafts in the deep underground (nowadays the water is transported by cisterns). Only agricultural land is in the karst poljes, surrounded by desertous bare rocks. However, the poljes remain flooded for an average annual period of 150 to 250 days. Therefore, sowing and harvest are not determined by man, but by water. In a matter of a few days, floods change into drought and vice versa. As a consequence, for centuries, people have emigrated from this region in search of a better life.

EXISTING POLITICAL STATUS

Eastern Herzegovina is situated in the region of the South-Eastern Dinarides, between the Neretva River on the West ((Neretva River flows through Bosnia and Herzegovina and Croatia).), Montenegro on the East and Croatia (Dubrovnik littoral belt) on the South-West It is one of the most karstified regions in the world. The region belongs to the Adriatic catchment and the watershed with Black Sea catchment and goes along a mountain chain in the North (el. 1000 - 1300 m). The region of Eastern Herzegovina, including the coastal belt (Dubrovnik littoral), covers an area of about 7,500 km^2 and ranges in elevation from about 1500 m to sea level.In the recent past, the broader region, including Bosnia and Herzegovina Croatia and Montenegro, belonged to Yugoslavia, nowadays these are independent countries. Bosnia and Herzegovina (BiH) consists of two political entities: the Republic of Srpska and the Federation of BiH, whereas the largest part of Trebišnjica River basin is located in Republic of Srpska.

DEMOGRAPHY AND NATURAL CONDITIONS

The population of the Eastern Herzegovina between 1921 and 2006 (estimation) varied from 73,575 and 105,254 people. The population density per km^2 has remained very low: 1921 (25); 1931 (29); 1948 (23);

1961 (21); 1981 (20); 1991 (20) and 2006 (22). Two world wars and the last civil war in Yugoslavia had a great influence on demography in region.

The percentage of population engaged in agriculture was 92% in 1895; 87% in 1931; 72% in 1952; 52% in 1971; and 26% in 1981.

About 24,690 hectares in karst poljes are potentially arable lands. A large portion of this land is temporarily flooded and currently not cultivated. Pastures and natural meadows are also cultivated, composing 40% of the total area but with very low crop yields

Eastern Herzegovina, Trebišnjica Hydrosystem

SURFACE FLOWS AND KEY SPRINGS

Four sinking rivers and one permanent river are the only surface water flows. Trebišnjica River (the largest European sinking river) is the longest one with a total length of 90 km, of which only 28 km is

permanent. The Trebišnjica Springs are at elevation of 325m and the ponor (sinkhole) Ponikva at the end of Popovo Polje (the end of Trebišnjica River surface flow) at elevation of 220 m. The maximum Trebišnjica flow in Popovo polje is over a 300 m^3/s. The Zalomka River flow is active 213 days per year, on average. Maximum flow in middle section of river is 122 m^3/s and at the end section (ponor Biograd – Nevesinjsko Polje, elevation 800 m) is 440 m^3/s. The total length of Bregava River is 33 km. This flow exists only in the wet season. In the dry season, only the middle section is active. This section is 12 km long and located in the Stolac urban area. The Mušnica River in Gatačko Polje sinks entirely along the southern perimeter of the Malo Gatačko Polje (elevation 924 – 940 m). The only permanent flow, although relatively short, is in the Buna River (left branch of the Neretva River) at an elevation of 30 – 35 m above sea level.

Hence, the Trebišnjica, Mušnica and Zalomka Rivers do not have a surface connection with lower erosion base levels of the Neretva River and the Adriatic Coast. Yet, the connections are made through the network of underground karst channels.

The main karst aquifers in this region discharge through huge springs. The five most prominent springs in Eastern Herzegovina are: Trebišnjica (Q = 0.8 – 219 m^3/s); Buna (Q = 2.9 – 380.0 m^3/s); Bunica (Q = 0.72 – 207 m^3/s); Bregava (Q = 0.4 – 59 m^3/s); and Ombla (Q = 3 – 150 m^3/s). The Buna, Bunica and Bregava Springs belong to the Neretva River catchment area and the Trebišnjica and Ombla Springs to the Trebišnjica catchment.

All waters of Eastern Herzegovina discharge into the Adriatic Sea through 120 permanent or temporary springs. A large amount of water discharges into the Adriatic Sea as submarine springs. A general hydrologic property of all these springs is great fluctuation in discharge volumes.

In all those cases, the parts of catchment areas (and associated aquifers) are not contained in the same political boundaries as the springs. The five largest springs are situated as follows: Trebišnjica Spring in BiH, Republic of Serpska; Ombla Spring in Croatia; and Buna, Bunica and Bregava Springs in BiH, Federation of BiH.

WATER BALANCE

An abundance of water during the autumn and winter (floods) and almost total lack of water (drought) during the crop-growing period is a key hydrological property of eastern Herzegovina. The wettest month is November with average precipitation of 300 mm. The maximum observed daily precipitation is close to 300 mm with a maximum rain intensity of 4 mm/minute. The total available water balance in the region of the Eastern Herzegovina is at average about 145.0 m^3/s and the total volume of water is over 4.5 billion m^3 of water. However, these waters are only those which are in very complex karst hydrogeology appear on the surface and can be controlled by common hydrological measurements. It is a known fact that there are considerable quantities of underground waters which have not been included in the above balance since they have been insufficiently investigated so far. In natural conditions, these waters amount to more than 200 m^3/s annually.

GROUNDWATER REGIME

The karstified rock mass of Eastern Herzegovina is characterized by an uneven distribution of porosity. Large-scale porosity of channels and caverns also has an uneven distribution. These karst features are

often concentrated in certain zones or across stratigraphic layers The deeper parts of the underground drainage network are dominated by individual conduits that convey water toward the baseflow channels. The highest intensity of karstification is in the part of the karst aquifer with the largest storage capacity and that is within the zone of water table fluctuation. These areas are of potential for for engineering interventions to control underground regimeand to use this water for power production or other applications (water supply, irrigation, industry).

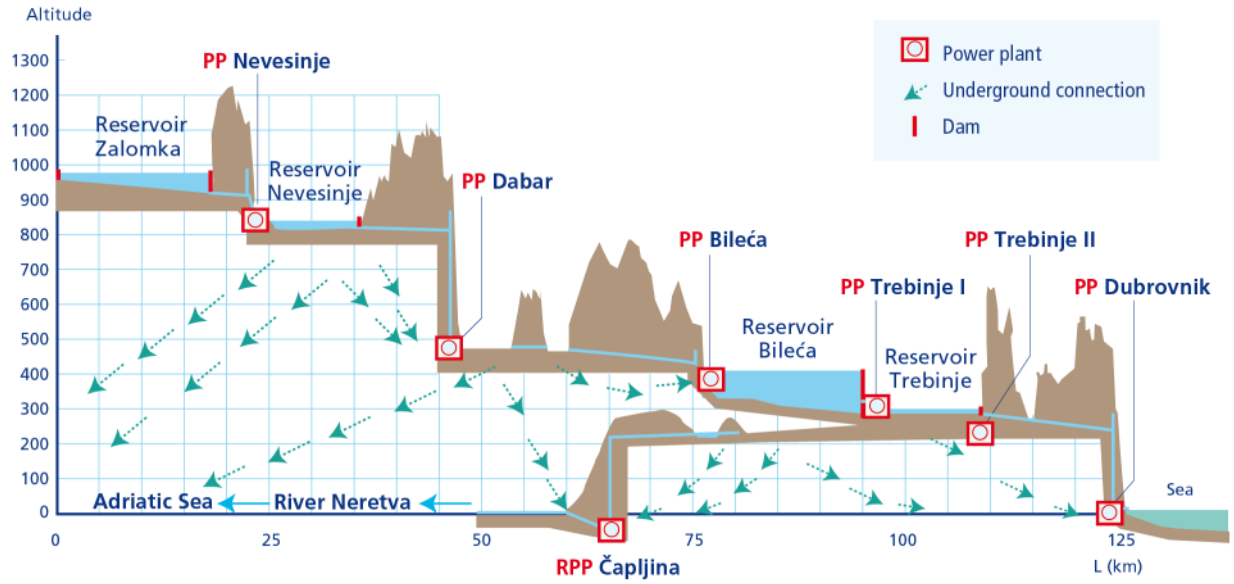
These aquifers react quickly to high precipitation (after 4 to 10 hours). The water table sometimes rises 90 m in only 10 hours. Fluctuations of the water table are very fast with high amplitudes, in some cases more than 300 m. Average underground flow velocities vary widely from 0.002 to 55.2 cm/s. The majority of karst flows are turbulent flows under pressure through rough conduits. This hydraulic property is very important for groundwater use as source for renewal hydropower energy.

The longest underground flow is 34 km between Gatačko polje and Trebišnjica springs. The largest elevation difference between sinking point (ponor) and discharge point (spring) is 764 m (ponor Biograd in Nevesinjsko polje and Bunica Spring), and between Gatačko polje and Trebišnjica springs (520 m).

HYDRO-ENERGY POTENTIAL

Water is the most important renewable natural resources in Eastern Herzegovina, thus the economic and social development of the region depends on its optimal utilization. Morphologically closed and stepwise karst depressions (karst poljes) make optimal use of huge water potential from the elevation of 1000 m to the sea level. Hydropower was the initial cause of the construction of the Trebišnjica Multipurpose Hydrosystem, but all structures have been designed in such a manner that can be used for other needs: water supply, food production; industry; fish farming; recreation; prevention of deforestation and number of secondary benefits. Water and electrical power are currently the only major export products and provide necessary funds for the regional development.

Situated in the area of Eastern Herzegovina, the Trebišnjica Hydrosystem is a project consisting of seven dams, six artificial reservoirs, six tunnels, and four channels. The ultimate aim of the Hydrosystem is to provide multi-purpose use of water resources from an elevation of 900 m to the sea level. Construction of the Trebišnjica Hydrosystem started in 1959, but still is not completed. A part of the Hydrosystem, between elevation 400 m and sea level is already operational. The installed power capacity of four already operational power plants (Trebinje I, Trebinje II, Dubrovnik and Čapljina) is 820 Mw and power production in an average wet year is 2723 Gwh. As a consequence, the Trebinje is the only settlement in the Eastern Herzegovina with a constant positive population growth . Finalization of part of the Trebišnjica Hydrosystem between elevation 400 m and 1000 m still is pending. In this area the population growth is constantly negative. According to the project, three new power plants (Nevesinje, Dabar and Bileća) with installed power of 251 Mw and power production of 672 Gwh should initiate faster development of Nevesinje, Berković, Stolac and Bileća counties. After many years of delay because of the civil war, the construction will continue soon.



Longitudinal profile of Trebišnjica Hydrosystem, with directions of groundwater flow

Upon full completion, the natural regime of surface and groundwater will be completely changed at both local and regional scales. The key aim is to prevent water sinking and to keep part of the water at surface as much as possible. To achieve this goal, the optimal use of regional water resources is necessary, i.e. the Hydrosystem requires the transfer of 30% of water from the catchments of the Buna, Bunica and Bregava springs (Neretva River catchment) to the direction of the already operational part of the Hydrosystem (Trebišnjica River catchment). To keep water at the surface, as much as possible, redistribution of water potential and re-routing of surface and underground flows was key prerequisite for optimal system operation.

An important issue for the future is how to keep the balance between the necessity for regional development and the preservation of the unpredictable and complex ecological system of Eastern Herzegovina. Also, despite the fact that a huge amount of available water is be stored at the surface in the reservoirs -, and transported from an elevation of 900 m through tunnels and channels to be eventually discharged into the sea -, a large amount of water (a few billion m^3) remains underground without being utilised. able to be effectively used for power production.

In some cases only unconventional underground structures (underground dams and water collecting galleries) make optimal use of these waters possible. Of course, geological structure is a key prerequisite for successful design. One of the interesting projects is Ombla underground dam and reservoir, near Dubrovnik (Croatia). The water used in this project belongs entirely to the Eastern Herzegovina catchment area and cannot be used for power production by applying any conventional means. Construction of the underground dam is the only solution.

The main karst channel of the Trebišnjica Spring permanently discharges between two and a few hundred cubic meters of water into the Bileća Reservoir (located in in the entity of Republic of Srpska). Hence there is a considerable hydropower potential exactly in spring location but a feasibility of its

utilisation is questionable with the current energy prices and the technology. Nevertheless, the waters of Trebišnjica Spring recharge the Bileća Reservoir built for hydropower production further downstream. The reservoir is also used for recreation and fishery, providing example of multipurpose use of karst waters in the region.

It is obvious that Eastern Herzegovina and the nearby region of Kotor Bay (Montenegro) are the most important water resource areas in this part of the Europe and the Mediterranean. In the near future, because of the global water shortage, importance of this water will quickly increase. This region will serve as the most important "water treasure" for surrounding parts of the Mediterranean. The estimated average annual water potential in this region (except water already used for power production), from elevation 1800 m to the sea level, is approximately Qav/a = 300 m^3/s of excellent quality water.

Presently, only one part of the huge water potential is used for power production and negligibly for water supply and irrigation. Almost all this water is eventually lost into the sea. Surrounding Mediterranean regions, and especially the African coast, has a constant shortage of water resources. .

The region of Eastern Herzegovina is presently dissected by state borders and integrated management of the water resources has become very complex. With increasing water demands, optimal (and therefore integrated) management of water resources in the whole region becomes necessity. Importance of Eastern Herzegovina region in terms of water availability extends far beyond its borders. Accordingly, the regional water management, including water quality protection and continuous monitoring should be a common effort of all stakeholders in the region.