Transboundary Aquifers in Karst - Source of Water Management and Political Problems
Case Study, SE Dinarides

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ABSTRACT

One of the most deeply karstified regions in the world is the area of the South-Eastern Dinarides situated between the Neretva River in the West, Kotor Bay in the East and the Adriatic Sea in the South-West. This area has the largest resources of natural fresh water in the Mediterranean region, and experiences the highest precipitation in Europe (up to 8,000 mm). Surface flows are rare and generally short-lived. Between 70% and 80% of water in this region flow through the well developed network of underground karst conduits. The subterranean karst is, also, world famous for the large number of different endemic species.

In this region, three countries (Croatia, Bosnia and Herzegovina, and Montenegro) now exist where a short time ago there was only one country, Yugoslavia. The transboundary relationships are sensitive and complex, and are further complicated by the existence of separate entities within Bosnia and Herzegovina. Infrastructure such as large hydropower systems, which previously served a single country, now needs to be shared between multiple interested partners. There are many examples where such engineering complexes now cross the newly defined international boundaries. The groundwater conditions are particularly complex. Main karst aquifers discharge from massive springs. In a few cases, serious problems have arisen as a result of aquifers crossing the new boundaries. In these cases, parts of catchment areas (and aquifers) do not fall into the same political entity as the springs. The main questions which have arisen are: who has the exclusive rights to use water potential for power production if the water occurs within a transboundary aquifer; how to control locations of concentrated infiltration into the transboundary aquifer to provide proper groundwater quality protection; how to control floods in closed karst depressions (karst poljes) if the boundary crosses the polje; and how to protect the environment, including underground endemic species, in the case of transboundary aquifer disturbance.

The groundwater resources of this region are excellent and have important potential for improved water usage, not only for local purposes. In the near future, this potential could be of significant interest to a large part of the greater Mediterranean region. The South-Eastern Dinaric karst region could potentially be declared a Mediterranean "Water Treasure". Presently, a large part of the water flows through underground channels or through power plant structures directly to the sea. Because of this, problems caused by transboundary aquifers have to be overcome and the entire region should be treated as a unique hydrogeological and hydrological entity. It is the only way to achieve optimal management and proper groundwater resource utilization.

Key words: transboundary aquifer, karst, South-Eastern Dinarides, hydro power, endemic species.

1. OBJECTIVE

The purpose of this article is to illustrate the very complex problem of transboundary aquifers located in the extremely karstified carbonates of the Dinaric Karst, with its deep and concentrated underground flows. Newly established state boundaries cross these aquifers. As a consequence, the main springs and parts of their catchment areas are divided and situated within different political units. The large hydropower system that exist in the region has a considerable influence on the underground water regime including the artificial transboundary transfer of a huge amount of water. The power system was constructed when the entire region was part of one state, hence, without transboundary concerns. Presently, questions appear regarding potential water power rights and the influence of transboundary aquifers on the environment (acceptable ecological flows, nature parks and endemic spices). Criteria for groundwater zoning to protect public supply, including proposals and restrictions which are acceptable for parties on both sides of boundaries are very important. However, very complex professional and (sometimes) political questions arise. Some of these questions are discussed in this article.

2. GENERAL HYDROGEOLOGICAL AND HYDROLOGICAL PROPERTIES OF THE REGION

The South-Eastern Dinarides situated between Neretva River on the West, Kotor Bay on the East and Adriatic Sea on the South-West is one of the most karstified regions in the world. The watershed between the Black Sea and Adriatic (Mediterranean) catchments is located along the mountain chain on the North (el. 1000 - 1300 m). In the recent past this region belonged to one country - Yugoslavia. Recently, region was separated between three countries (Croatia, Bosnia and Herzegovina and Montenegro). Bosnia and Herzegovina also consists, of two political entities.

The South-eastern Dinarides is the richest precipitation region in this part of Europe. Average annual precipitation varies from 1500 to 2500 mm/a, locally to more than 5000 mm/a. More than 70% of precipitation occurs during the wet season (October - March). Because this region is extremely karstified, surface flows are very rare. Infiltration exceeds 80%. Rain water percolates immediately through thousands of ponors (swallow holes) into the underground. The swallowing capacities of some individual ponors exceed 100 m^3/s. Only sinking rivers exist. Surface flows are temporary. Length of some underground flow systems is more than 30 km. Depth of underground flows is between 100 and 200 m, locally even deeper. Average velocity of underground flows range between 1 and 7 cm/s, sometimes between 20 and 30 cm/s. After heavy precipitation events, when aquifers are fully saturated, underground flows are much faster than during the dry period of year. Maximal registered fluctuation of groundwater levels exceed 300 m, up to 80 m/24 h. Discharges of underground flows are mostly concentrated at large karst springs. A common characteristic of these springs, whether permanent or temporary, is the strong dependence between precipitation and discharge. As a consequence, difference between minimum and maximum discharge is enormous (1 : 60, or more). The largest difference was registered at Bunica Spring, between 0.72 and 207 m^3/s. More than 150 m^3/s, average annually, are being discharged in the Adriatic Sea through only four huge permanent springs (Buna, Bunica, Bregava and Ombla) and few large but temporary springs at Kotor Bay.

Water stored at highly elevated reservoirs influence the water regime in springs at lower elevations. During construction of the first phase of Trebisnjica Hydrosystem project, karst aquifers were starved of about 4 billion cubic meters of water annually as a result of surface water re-routing through a number of tunnels, reservoirs, bored channels for power production and due to the plugging of many swallow holes (ponors). Resolving water resource conflicts between power plant owners (from one side of the border) and spring consumers (on the other side of the border) required common sense and an understanding of the karst systems involved. To prevent conflict issues, 8 years before the project became operational, a total of 120 springs that could potentially be affected by the Hydrosystem were cataloged, and carefully monitored, along a 100 km length of the Adriatic Sea coast, and along 50 km of the eastern border of Neretva River valley.

Changes of underground and surface water regimes locally have, also, a very distinct negative effect on the fauna of subterranean karst. Realization for the need to increase environmental protection appears as a very important issue. Ecological and environmental protection is more difficult when deterioration of an aquifer is unexpected, occurs rapidly, the source of problem is located some distance from the impacted area, and on the other side of an international border.

The karst environment is unusually sensitive to any change in natural conditions because its reactions to such disturbances are fast and often drastic. For such complex natural hydrogeologic conditions, newly established state boundaries additionally complicate the situation by provoking a number of very important professional and political questions.

3. SIMPLIFIED MODEL OF TRANSBOUNDARY AQUIFERS IN KARST

As it was stated above, hydrogeological properties of karst are quite different than for nonkarstified rock masses. The term transbounday aquifer in karst does not mean only zones located close to both sides of a state boundary - borderland zone. In many cases transboundary problems appear as a consequence of water sinking into ponors located far from the state boundary i.e. close to watersheds with other catchments, at distances of 10, 20 or 30 km from the borderland. As a result, the entire catchment area can be declared as potentially dangerous for groundwater regime and properties of water within borderland areas. In general the transboundary problem in karst appears at any case where the border is located between the recharging zone inside the catchment area and areas of discharge along the erosion base levels (sea coast and deep valleys).

Two simplified models of transboundary aquifers (better say transboundary concentrated flows) are presented in figures 1 and 2. A number of expensive investigation works have to be done to define exact connections between sinking and discharging points. Particularly complicated is knowing the location of the main channels and monitoring of groundwater regime and water quality in the borderland. The groundwater regime in the dry period of the year (flows with free surface) is quite different from that of the wet period of year. After periods of heavy precipitation, karst aquifers are fully saturated and water within the main channels is under pressure (hydraulic system under pressure). The groundwater regime is very dynamic and permanently changes in space and time. Within some parts of an aquifer, bifurcation of the regime can occur further complicating the hydrogeological model.

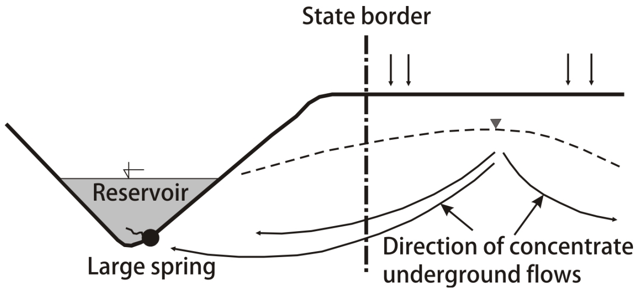


Fig. 1 Transboundary flow crossing state border.

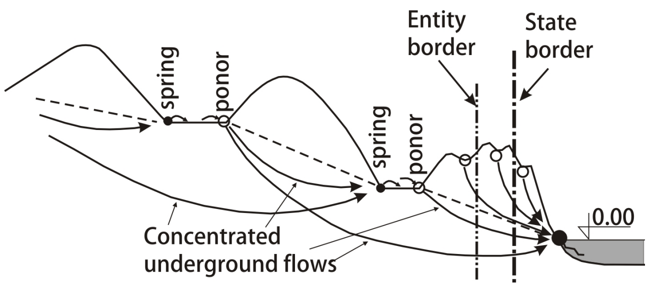


Fig. 2 Transboundary flows crossing entity and state border.

4. QUESTIONS APPEAR

Before new state boundaries were established, the concentrated infiltration points and springs were located entirely within one country. Boundaries between republics had no role or posed no serious obstacle. Problem of defining exclusive rights to underground water was not a very important task. Water needs for power production and water supply were analyzed as part of integral projects on the bases of their hydrogeological and hydrological properties. Competent boundaries only were the natural boundaries that defined the physical limits of watersheds. Projects were focused on multipurpose utility to obtain the greatest water potential for development of the entire region.

Immediately after new boundaries were established (boundaries between republics became state boundaries, see figure 3) a number of very important questions appeared that need to be solved. Newly established regulations for each country were not harmonized. Criteria for determining the environmental protection, as well as, regulatory procedures that are applicable for nonkarst regions are generally not suitable for karst terrains. Velocities of concentrated underground flows in karst are a basic problem. In some cases (dry period) velocity of labeled tracer is 1.13 cm/s, however for the saturated aquifer case (wet period) velocity increase up to 7.53 cm/s.

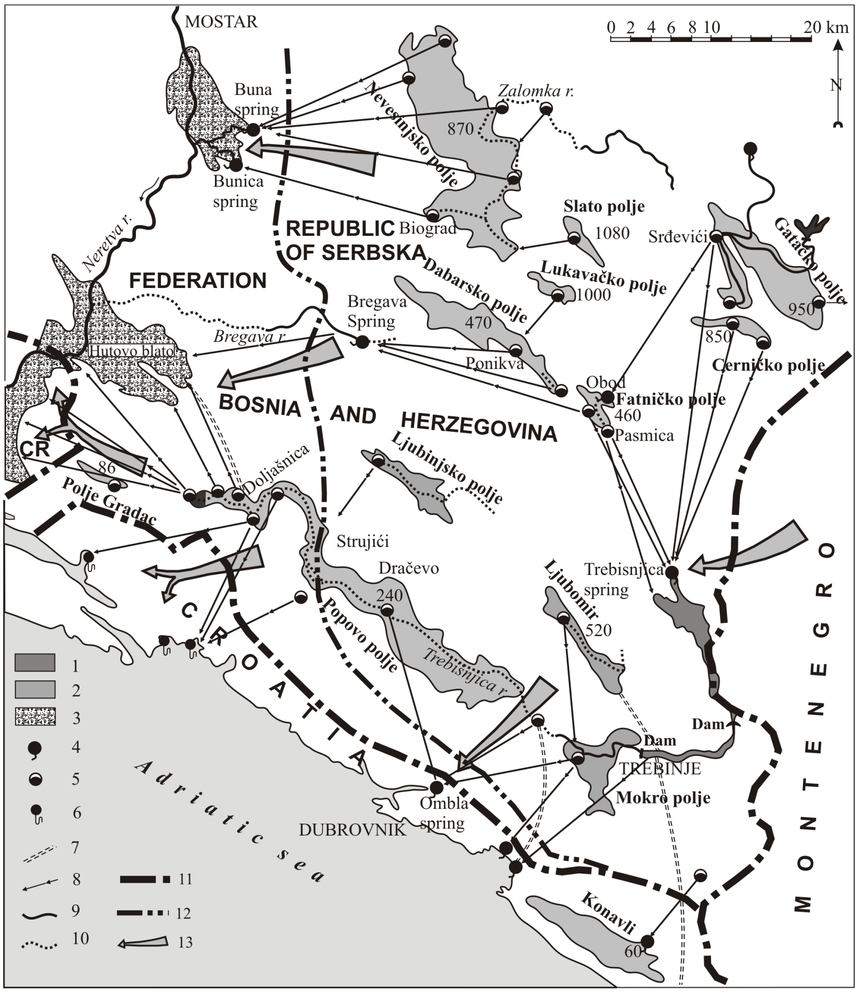
4.1. Example 1

One of the largest spring zones in the entire region are Trebisnjica Springs that discharge between 2 and >300 m^3/s. Majority of its catchment area presently is situated on one side of the border (in Bosnia and Herzegovina) but a minor part of its catchment is situated on the other side of the border (in Montenegro). However, the part of catchment area in Montenegro has not been exactly determined. Due to construction of the 123 m high dam and reservoir in Herzegovina, this spring zone was exposed to a water head of 75 m. The newly established state border locally enter along a small part of the reservoir. The average discharge of the spring has been estimated at 80 m^3/s. This part of the aquifer can be determined as a transboundary aquifer. The problem of transboundary flows did not exist when this was included in one state. Immediately after the new state border had been established, question of exclusive rights of spring water appeared. Groundwater governed by rights in one state now crosses the border and discharges at the springs in the other state. Request for rights for part of this discharging water because part of its cattchment is located on the other side of border for power production is a topic of very tough negotiations.

4.2. Example 2

At the western border of the region, along the Neretva River valley, the largest springs are Buna (2.95 - 380 m^3/s), Bunica (0.75 - 207 m^3/s) and Bregava spring (0.45 - 58.7 m^3/s). Buna and Bunica springs including their entire catchment area are situated in one country (Bosnia and Herzegovina), however, both springs are situated in one political entity but almost their entire catchment area is located within another political entity (approximately 90%) . By construction of the large hydropower system, part of spring waters would be re-routed in the direction of the already operational part of hydro-system. Bunica Spring (el. 36 m) is directly connected with Biograd ponor at el. 800 m and distance 20 km. Underground flows cross the entity border at depths of 600 - 700 m. The entire Zalomka River sinks into the Biograd ponor (about 110 m^3/s at maximum). During summer time this river does not exist. The river bed is totally dry. However, minimal flow of Bunica Spring also depends on catchment by its own aquifer (not only due to sinking water in Biograd ponor).

Consequences of water re-routing on the regime of the Buna Spring is negligible in periods of minimal as well as in maximal discharge. Discharge of the Bunica Spring however, is considerably disturbed but only during periods of high discharge. For discharges less than 4 m^3/s, influence of any man-made structure within catchment area is not possible. This is confirmed by two independent mathematical models.



Legend
1.Resevoir; 2. Karst polje;
3.Alluvial deposits; 4.Large spring:
5.Large ponor; 6.Submarine spring;
7.Fault zone; 8.Underground connections;
9.River flow; 10.Temporary river;
11.State boundary; 12.Entity boundary;
13.Main directions of underground flows.

Fig. 3 SE Dinarides. Boundaries between Bosnia and Herzegovina, Croatia and Montenegro.

4.3. Example 3

Protection zones for public water supply in karst cannot be based on the same criteria as for nonkarstic aquifers. The important difference between karst aquifers and aquifers in intergranular or low permeable rocks is a consequently shorter contact of the contaminant with the rock matrix because of the fast circulation through karst conduits. Contaminated water masses quickly spread through the karst aquifer, that is, the time available for autopurification process is very short.

All waters discharging at a number of springs near the sea coast (Croatia) are derived from sinking water through thousands of ponors in Bosnia and Herzegovina. When this transboundary aquifer is fully saturated, the groundwater needs about 70 hours to travel a distance of 16 to 18 km, from sinking to discharging point. If the aquifer is not completely saturated (dry period), underground flows are 2 to 3 times slower. For both cases, underground water flows are very fast when compared to non karst aquifers.

Zoning concepts on both sides of state borders are based on the same parameters: groundwater velocity, groundwater residence time and distance between source of pollution and intake structure. However, an important question appears. Is it possible to apply a general rule for zoning (i.e., same rules for all hydrogeological formations) or do karst aquifers need separated rules adjusted to the specific hydrogeological and hydrological properties of karstified rock masses? It is sure that in karst the parameter of groundwater velocity cannot be applied automatically. Also, optimal zoning concept in karst depends on many other factors: saturation of aquifer, necessary time of water replacement, locations of ponors and their swallowing capacities, protective measures at sinking zones, discharge capacity and similar other concerns. In many cases the zone of immediate protection, requiring very severe protection and restrictions, crosses state borders and encompasses large areas on the other side of the border. Because of this, proposed criteria should be applied with flexibility and should allow for changes to be made when local hydrogeological conditions require it.

Crucial question in this particular example is how to harmonize optimal criteria and how to monitor efficiency of accepted criteria on the other side of border. Trust between both parties, professional approach and verification are the only possible way to provide efficient protection of transboundary aquifers.

5. IMPORTANCE OF WATER POTENTIAL OF SE DINARIDES

It is obvious that the Eastern Herzegovina and Kotor Bay areas are the most important water resource area of this part of Europe. In the near future, because of the global water shortage importance of this water will increase. This region will serve as a source of "water treasure" for surrounding parts of the Mediterranean. The estimated average annual discharge potential of the entire region, from elevation 1800 m to the sea coast, is Qav = 300 m^3/s of excellent quality water.

Presently only one part of this enormous water potential is used for power production and negligibly for water supply or irrigation. Almost all this water is lost into the sea. Surrounding Mediterranean regions, including the African coast suffer because their needs for water are much higher than their own surface and underground water potential.

As previously stated, this region is presently dissected by state borders and optimal management with huge water potential has become very complicated. However, rapidly increasing water shortages impose the necessity for acceptance of the entire region as one unique water resource. Importance of this region is much beyond its border. Because of its potential, water quality has to be under severe control. Proposals for regional water quality protection, monitoring and optimal water management have to be important goals of all parties in region.

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