Challenges in transboundary karst water resources management

Sharing Data and Information
Ognjen Bonacci
Faculty of Civil Engineering and Architecture, University of Split
21000 Split, Matice hrvatske 15, Croatia
obonacci@gradst.hr

The aim of water management is to satisfy water demands. This represents simple and pleasant task when the quantity and quality of the available water resources are satisfactory. As we are witnesses of and active participation in a global water crisis one of the critical issues of the 21st century will undoubtedly be the sustainable management of international water bodies. Sustainable management and development is an umbrella concept, which until now has not been put into practice enough efficiently. It has many dimensions with various definitions, depending on the professional background of the investigator. To obtain a harmonious, reliable and sustainable development, it is necessary to take the complex, interactive, technical, social, economic, environmental and cultural aspects of water resources management into account in decision-making. In the case of the transboundary karst water resources management it is especially hard and dubious task. First of all sustainable development needs to response to global pressure on karst water resources. It should safeguard quantity and quality of vulnerable karst water resources with its valuable habitats and endangered, very often endemic, surface and especially underground species. The necessity of identifying a karst water system as a whole is becoming more significant, due to fact that karst terrains have been more densely populated recently which has resulted in greater demands for water.

The goal of the paper is to point out specific characteristics of karst water circulation, which make a lot of difficulties in karst water resources management, and at the same time represent the main and real reason for possible conflict when they are internationally shared. The karst system shows extreme heterogeneity and variability of geologic, morphologic, hydrogeologic, hydrologic, hydraulic, ecological and other parameters in time and space. Such a complex system needs interdisciplinary approach. It is highly important to understand the interaction of groundwater and surface water in karst and their influence on surface and underground biological processes (Bonacci et al. 2008).

Karst terrains are typified by a wide range of closed and few open surface depressions, a well-developed underground drainage system, and strong interaction between circulation of surface water and groundwater. Karstification is primarily a geological characteristic important for water circulation and storage. This is a continuous process governed by natural and man-made interventions (Bonacci 1987). Generally it is greatest at the surface and decrease with the depth of a karst massif. Water circulation over and throughout karst terrains significantly differs from that in other types of terrain. The main reason is rapid rates of infiltrations and the influence of the solutionally enlarged underground aquifer, clearly distinguishing it from porous aquifer and other types of fractured aquifers, Karst aquifers are generally continuous (Bonacci and Roje-Bonacci 2000). However, numerous underground karst features strongly influence the continuity of karst aquifer, and commonly it does not function as a simple continuum within a catchment.

Conditions for water circulation and storage in karstified medium are strongly dependent on space and time scales being considered, especially in the deep and morphologically complex vadose zone. This zone and underlying phreatic karst aquifer are two-component system in which the major part of storage is in the form of true groundwater in narrow fissures and matrix, where diffuse or laminar flow prevails. On the other hand, the majority of the water is transmitted through the karst underground by quick or turbulent flow in solutionally enlarged conduits. The interaction between these two types of flow is significant and permanent, and strongly depends of prevailing hydrological conditions (low, medium or high waters).

One of the root causes of problems of karst waters management are impossibility and/or difficulty in catchment boundaries and areas definition, as well as their changes in time and space. The determination of the catchment boundaries and the catchment area is the starting point in all hydrological analyses and one of the essential data which serve as a basis for water resources management. For water circulation in karst, this classical and relatively simple hydrological problem (in other more homogenous types of terrain) represents extremely complex, sometimes unsolvable task. The differences between the topographic and hydrologic catchments in karst terrain are, as a rule, so large that data about the topographic catchment are useless in water management practice. Very often the position of the karst catchment boundaries depends upon the groundwater levels which strongly and sharply change in time. In some situations at very high groundwater levels (caused by heavy rainfall and during karst flash floods) generally fossil and inactive underground karst conduits are activated, causing the redistribution of the catchment areas, i.e. overflow from one to other catchment (Bonacci et al. 2006). Special problem represents determination of the catchment area of the poljes in karst due to fact that a given polje is only part of a wider system. It represents a subsystem in the process of surface, subsurface and underground water flow through the karst massif.

Anthropogenic intervention, especially constructions of dams and reservoirs as well as inter-basin water transfers through long tunnels and pipelines can introduce instantaneous and distinct change in catchment areas

and boundaries. In karst terrains those processes very often are uncontrolled, and results in hazardous consequences (Bonacci 2004). Natural and anthropogenic changes in karst regions frequently cause redistribution in karst catchments, which strongly, suddenly and dangerously affect processes of water circulation at the local and regional scale. Generally these changes are unforeseeable, unexpected and with hazardous consequences. The benefit resulting in one area was frequently smaller than damage caused in another area. Occurrence of landslides, floods, collapses of dolines, regional water redistribution, drying up of karst springs and open watercourses, can be caused. By this way in case of transboundary shared karst surface water and groundwater it can be trigger for serious international conflicts.

Interactions between surface and subsurface in karst are very strong. Water circulation in karst systems shows the extreme heterogeneity and variability of hydrogeologic, hydrologic, hydraulic, ecological and other parameters in time and space. Karst systems are some of most complex and difficult to decipher. Karst water resources, because of their unique hydrologic and ecologic characteristics, are extremely susceptible to contamination. The surface and especially subterranean environment in karst provide a range of habitats with very different chemical and biological processes. Karst ecosystems are sensitive to environmental changes. The importance of maintaining biological diversity goes far beyond mere protection of endangered species and beautiful landscape. It is necessary to obtain a thorough understanding of how aquatic and terrestrial ecosystems functions and interact in very complex, vulnerable and in time and space extremely dynamic karst systems (Bonacci et al. 2008). All previously mentioned imperatively requires that ecological aspects of transboundary karst water resources management should be treated much more carefully than in case of other types of terrains.

In cases of karst surface water and groundwater management, water crises are increasingly serious all over the world. Few examples of internationally shared karst water resources (the Ohrid and Prespa Lakes, the Cetina River catchment and the Trebišnjica River catchment) are given.

Lakes Ohrid and Prespa are located in the Balkan Peninsula, with Lake Ohrid shared by Macedonia and Albania, and Lake Prespa by Macedonia, Albania and Greece (Popovska and Bonacci 2007). From the hydrological and hydrogeological points of view the lakes are extremely interesting water bodies, but they have not been fully investigated up to now. The main reason for the lack of investigation is partly due to very complex runoff processes in karst underground of their catchments and partly to the fact that lakes' basin is shared among three countries. The lakes are the largest tectonic lakes in Europe. Because of its biodiversity and unique cultural heritage, Lake Ohrid is a resource of tremendous local and international significance. UNESCO declared it a World Heritage Site in 1980. Lake Prespa does not have surface outflow. The waters from it outflow through karst underground massif into Lake Ohrid. Therefore, from the hydrological as well as transboundary water management aspect, both lakes cannot be analysed separately. The lakes are influenced by permanent and strong natural changes that are poorly monitored, but also by uncoordinated, uncontrolled and mainly dangerous anthropogenic impacts. Coordinated water resources management between the three countries has not been established up to now.

Because of karst environment particularities it should be developed original methods and approaches in transboundary karst water resources management. For the sustainable development and the protection of such ecologically, and economically valuable karst transboundary water resources, it is very important to establish prerequisites for the definition of a reliable water balance. This will provide conditions for integrated and sustainable management of transboundary water resources and avoid potential conflicts related to water use. This is the only way to prevent an ecological catastrophe, which is a real treat manly to Lake Prespa which water level decreased 7.8 m in 1963-1995 period.

The Cetina River in southern Croatia and western Bosnia-Herzegovina has been regulated for hydroelectric power generation since 1910s. Its catchment area is estimated to cover about 4000 km^2 although the precise hydrological catchment area and boundaries are not known. From Bosnia-Herzegovina region of the Cetina River catchment water flows to the Croatian part of its catchment only through karst underground connections. The analyses showed that operation of five hydroelectric power plants (HEPP-s) caused changes in the hydrological regime throughout the most part of the total length of the Cetina River course which is completely situated in Croatia, while the about two third of its catchment is in Bosnia-Herzegovina (Bonacci 2003; Bonacci and Roje-Bonacci 2003). It should be noted that nowadays existing transboundary hydrotechnical system were built in former Yugoslavia. The Cetina River catchment is a typical example of an unclear relationship between water in open karst stream flow, many abundant karst springs and karst groundwater in transboundary shared karst catchment. However, even though more systematic work within the management of transboundary karst water resources of the Cetina River catchment between Croatia and Bosnia-Herzegovina hasn't started yet, it is positive that booth sides left the discussions for better times.

The Trebišnjica River catchment is internationally shared between Croatia and Bosnia-Herzegovina. Complex hydrotechnical system has been constructed on its catchment. This area is part of deep and bare Dinaric karst (Bonacci 1987; 2003; 2004; Milanović 2004). In former Yugoslavia on the Trebišnjica River catchment has been built complex hydrotechnical system. There are strong karst underground connections between the Trebišnjica River and the Ombla karst spring, which supply town of Dubrovnik with high quality water, as well

as many other karst springs around the Adriatic Sea cost in Croatia. Croatia has plan to build the HEPP Ombla (Bonacci 1995), which will exclusively use groundwater from the Ombla Spring aquifer while Bosnia-Herzegovina wishes to transfer water through a tunnel from the Fatničko Polje to Bileća Reservoir (Makropoulos et al. 2008). Consequences of these holds in transboundary karst aquifer will change hydrological and hydrogeological regime and by this way could open serious problems in water management between two neighbouring countries which shared the Trebišnjica River catchment.

Because of the fact that appearance, storage and circulation of water in karstified areas is significantly different from other more homogenous and isotropic terrains, transboundary karst water management should developed original methods and approaches based on continuous monitoring of many different climatological, hydrological, ecological and many others parameters. A first and essential step is to create the aquifer characteristics, the catchment areas and parameters of their water budget. It should be based on detailed and continuous monitoring of many different climatological, hydrological, geophysical, ecological, chemical and many others parameters. Hydrology in close co-operation with other geosciences must report to the public the scientific issues that touch human interest. Limitation is that they cannot change environmental problems.

The objective of this paper is to point to the importance of well organised and based on data monitoring and experts co-operation, as the prerequisite for a more efficient transboundary water resources management based on the principles of sustainable development. Caution in seeding, preparation, and fulfilment of them should be extremely high.

Of paramount importance is to ensure a stable exchange of information and to create institutions and space where a public and open discussions among all partners will be conducted. These discussions should be based on reliable and objective expert's assessments (Bonacci 2000). In transboundary karst water resources this is especially complex task. We should not create the illusion that politicians and lawyers can be the main judges of disputes connected with the transboundary karst water resources management. Karst water related problems will be better and more efficiently solved if professional and scientific principles are fully recognised and not affected or influenced by daily politics (Bonacci 2003). The efficiency and reliability with which one can manage transboundary karst water resources depend, first of all, and to a large extent, on quality and quantity of the hydrological and hydrogeological information used in their planning and operation. Co-operation between hydrologists and hydrogeologists from countries involved in problem is the paramount prerequisite for understanding water resources dynamic in complex karst systems, and to avoid international conflict.

Main existing problem is that managers wish to implement projects quickly and at low cost while experts (in this case first of all hydrologists, hydrogeologists and environmentalists) would like greater attention to be given to the principles of sustainability and ecological compatibility. There is no doubt that new approaches should be found and used in transboundary karst water resources management in order to maximise the benefits to all peoples as well as environment of the planet Earth.

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