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Karstification, Caves and Karst Aquifers on the Adriatic Islands (Croatia)

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This article deals with the Adriatic karst island aquifers especially from the point of view of karstification and how karst phenomena influence the accumulation of groundwater, its movements inside the system and its outflow. Flow through karst channels has been separated from flow through fractures within the rock mass regarding the scale of study. Although it is usually understood that groundwater flow in karst aquifers is usually turbulent, it has been shown that this phenomenon should also be taken into consideration regarding the scale. Turbulent flows are present in karst channels, but on most islands the majority of flow is happening through the network of fractures and joints within the rock mass, and that flow is predominantly laminar proven by statistic processing of step-drawdown pumping test. It has been shown how extensive and systematical research of karst aquifers must cover both phenomena. The most significant method of karst channel flows research as well as for disintegrated fault zones tracing is pointed out. On the other hand, while rock mass behaves according to the Darcy's law to a certain extent, hydraulic parameters can be used for description of such an aquifer. Still, in karst terrains all hydraulic values should be taken only as approximations.

Based on all known findings it is possible to conclude that karstification processes are very important for hydrogeologic research on the Adriatic islands. In order to understand those processes, besides the karstification process, it is also important to know about the changes in sea level during recent geologic past – especially in Holocene. Karst phenomena from earlier karstification phases also exist and participate in the whole hydrogeologic setting, but because of the latter processes, they don't have the significance of recent ones which are still hydrogeologically active.
Due to karstification and the presence of dissolution cavities, channels, and speleological objects, a very heterogeneous rock mass was created. Groundwater flow in such environment must be studied in two ways: a part of water flows through karst channels or at least tectonically predetermined fracture zones while another part flows through the network of fractures within the rock mass itself. Bigger presence of speleological objects, karst springs, submarine springs, estavelles or ponors, indicates that the majority of flow happens through dissolution channels. On the other hand when there are no such objects or very few of them, it is right to assume that the majority of flow happens within the rock mass. According to that follows the knowledge about scale effects (fig. 5). In regional scale attention should be directed on flow through karst channels and fracture zones. Tracer tests results are the most important in such cases. However when the well's surroundings or borehole's surroundings are analyzed, then we talk about local or subregional scale, and in that case hydraulic parameters of rock mass and well should be calculated. Based on 12 available tracing experiments 24 underground connections have been determined with average apparent velocity of 1.09 cm/s. The results clearly indicate the fact that when tracing was performed in natural karst environment apparent velocities are higher and vice versa. Such data indicates that tracings for sanitary protection of a part of a terrain should be done from a real karst object, even if it's a fracture zone. Tracing from a borehole regularly gives significantly lower apparent velocities. The average velocity for natural connections was 1.42 cm/s; and for those from artificial objects it was 0.45 cm/s.
On most Adriatic islands, especially smaller ones, there has been no significant preferential groundwater flows established, which means that majority of flow happens within rock mass/aquifer. Such aquifer is to some extent subjected to general laws of groundwater flow, so even if the terrain is karstified, aquifer and well parameters should be calculated. Still, at every moment one should be aware of basic karst terrain properties, and the results should be seen only as approximate, as an order of magnitude. In that way 18 step-drawdown pumping tests results from islands wells and boreholes were analyzed. Special attention was directed to analysis of laminar and

turbulent flow ratio. Generally it is thought that predominant conditions in karst are turbulent flow, but they are disputed to a certain extent. At discharge rate of 1 l/s most of flow is regularly laminar, and average share of laminar flow is almost 70%. Still, by increasing discharge rate to 10 l/s the situation changes. Now turbulent flow is predominant, while a part of laminar flow drops to some 30%. It is possible to state that natural flow without pumping is mostly laminar and it validates the assumption that calculating hydraulic parameters of rock mass according to Darcy law is justified. Still, the probability that boreholes will match hydrogeologically active karst channel with distinctive turbulent flow is relatively low.