Hydrogeology of the western part of the Drava Basin in Croatia

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1. Introduction

The increasing demand for water that can be used for drinking, agriculture and industrial purposes was noted as an incentive to produce hydrogeological maps in the middle of the last century. Hydrogeological maps were considered as useful basic documents for the rational planning of groundwater resources. The compilation of hydrogeological maps at various scales and for various purposes commenced in 1940, and many countries have been covered by hydrogeological maps since that time (Struckmeier & Margat, 1995).

A hydrogeological map represents a complex system of water and rocks and describes their properties and interrelations (Struckmeier & Margat, 1995). This type of map also gives information regarding groundwater and any relevant aquifer systems. Sets of isolines, such as those pertaining to the depth of the covering aquitard, the base of an aquifer or the aquifer thickness, can illustrate the three-dimensional characteristics of a groundwater system. Three-dimensional mapping can: (1) aid in studies involving groundwater abstraction, protection and remediation; (2) assist with the development of policies surrounding land use and nutrient management and (3) help to better understand the interaction between surface and groundwater systems (Bajc & Newton, 2007). The water table or piezometric surface contours provide information on the direction of groundwater flow, groundwater stress as well as type and possibly a more defined location of hydraulic boundary conditions. A good hydrogeological map includes a careful analysis and interpretation of the existing data and a careful review of the relevant areal information, which includes topographical maps, hydrographical maps and geological maps. The subsurface three-dimensional geology is the architectural framework containing aquifers. Therefore, the good and real delineation provides better evaluation of the aquifer characteristics and groundwater status.

As a rule, the main elements within the graphical representation of a hydrogeological map are the title, which expresses the theme and scale of the map, the authorship, the main map and any additional maps (e.g. topographic and thematic information maps). Other major elements include cross-sections, legend entries, the date of map publication, the place of issue, the copyright and a proper bibliographic citation. A detailed description of making hydrogeological maps was given in a guidebook (Struckmeier & Margat, 1995). Numerous engagements of experts within two international scientific bodies, the International Association of Hydrogeologists (IAH) and the International Association of Hydrological Sciences (IAHS), and experts from the United Nations Educational, Scientific and Cultural Organization (UNESCO) preceded the preparation of this guidebook. The preparation and construction of hydrogeological maps for former Yugoslavia and Croatia were considered by Šarin (1978, 1984, 1987, 1988, 1989) and Šarin and Urhiva (1977) as well as by Biondić et al. (1997), Brkić, Čakarun, Kuhta, Mraz, and Singer (1998) and Slšković, Šarin, Brkić, and Singer (1999).
The hydrogeological map of the western part of the Drava Basin in northern Croatia is presented in this paper. This map was constructed on the basis of investigations that were conducted for the purpose of defining the water supplies of the Koprivnica and Đurđevac areas. The study area belongs to the central part of the Drava Basin that is situated in the SW part of the Pannonian Basin (Figure 1). It is situated in the Koprivnica-Križevci County. The northern boundary of the study area is delineated by the Drava River and the state border between Croatia and Hungary, while the southern boundary is defined by the Bilogora Mts., the western boundary is formed by the Mura Basin and the eastern part of the Drava Basin is located along the eastern boundary of the Koprivnica-Križevci County. This region is a markedly lowland area with altitudes of approximately 140–110 m a.s.l. The climate in this part of Croatia is moderate continental with a mean annual temperature of approximately 10°C. The mean total annual rainfall is approximately 840 mm.

The geological structures of the Drava Basin were formed during the Neogene and the Quaternary. The Periadriatic-Drava fault of the Dinaric strike (Prelogović et al., 1998), which is the regional southern boundary of the basin (Figure 1), played a major role in their formation. The authors believe that the fault is curved in the area between Varaždin and Virovitica due to the position and rotation of the Kalnik and Ivanščica Mts. (Figure 1) and Bilogora Mt. (in Figure 1). The upthrown block, which is known as Legrad prag, separates the Mura Basin from the Drava Basin. It is formed along the Ludbreg-Nagykánizsa fault, and together with the Drava fault represents the most important structure in this area (Duč & Urumović, 2007). On the Hungarian side of the Drava Basin, two basement uplifts are of interest (Figure 1): the Inke-Iharosberény high and the Görgeteg-Babócsa high (Saftić, Velić, Sztein, Juhász, & Ivković, 2003).

The Drava Basin is filled with Neogene and Quaternary sediments. The maximum depth to the pre-Miocene deposits in the Drava Basin is approximately 6500 m (Pavelić, 2001). The older Quaternary boundary (Lower Pleistocene-Middle Pleistocene) is defined by the conditional E-log marker Q′, which represents the most distinctive lithostatigraphic boundary that can be tracked as a regional discontinuity of depositional conditions (Urumović, Hernitz, Šimon, & Velić, 1976). Above this marker, coarse-grained sediments of gravel and sand are observed, while the underlying sediments are composed of silt and clay. At the Legrad prag geological structure, the Q′ marker lies at a maximum depth of 30–40 m, while it resides at a depth of approximately 300 m towards the east of the structure and at a depth of maximum 150 m towards the west of the structure. The groundwater that accumulates in the sandy and gravelly aquifers above the Q′ marker is the main water supply source for the whole region.

2. Data and methods

2.1. Data collection and analysis

Data consisting of approximately 400 boreholes and wells were collected and analysed within this research. Borehole and site investigation data were collected from different sources, but most of them were from the database of the Croatian Geological Survey as well as from geotechnical and civil engineering companies. Accurate spatial coordinates of all boreholes are known. The latter datasets were stored in the database of the Croatian Geological Survey.

Measurements of the water stages of the watercourses (the Drava River and other channels and streams) and of groundwater levels in the piezometers have been collected by the State Meteorological and Hydrological Services (DHMZ) as part of a national monitoring network. In addition to the piezometers, a relatively large number of dug wells have been included in the national monitoring network. The dug wells are mostly located in the southern area of the Drava Basin. Manual measurements of the groundwater levels in the dug wells are usually carried out every 3–4 days, while limnigraphs are installed in many of the piezometers for the automatic recording of groundwater data. Limnigraphs are also installed at the gauging stations of the watercourses for the automatic recording of the water stages.

Groundwater levels taken from 25 locations within the national monitoring network and from piezometers at the pumping sites were analysed in detail for the period 2008–2012. During that period, two groundwater conditions were selected and analysed: hydrological conditions of low water levels and hydrological conditions of high water levels. In both these conditions, the groundwater flows from the southwest to the northeast and the Drava River is the discharge for the groundwater. Small streams and drainage channels in the Drava Basin have the same function, and some of them periodically dry up during low water conditions.

The main source of groundwater recharge is the infiltration of precipitation. Groundwater discharge occurs primarily through the watercourses and evapotranspiration and, to a much lesser extent, through pumping. Groundwater exploitation amounts to less than 10% of the average groundwater recharge (Brkić, Larva, Marković, & Briški, 2014).

2.2. Map design

The borehole and well data, for which there is an adequate range, facilitate descriptions of the geometry and characteristics of the Quaternary aquifer, respectively, and allow an estimation of the elements of the conceptual hydrogeological model in the Drava River Valley. The geological structure of the study area is presented most completely in the Basic Geological Map of the
Republic of Croatia at a scale of 1:100,000 for the Đurđevac sheet and in the accompanying guidebook (Hečić, 1986, 1987), as well as in the Basic Geological Map of the Republic of Croatia at a scale of 1:300,000 (Croatian Geological Survey, 2009). The aquifer is of Quaternary age (Main Map) and is composed of gravel and sand with silt and clay interlayers and lenses. The aquifer is composed of two permeable gravel and sand layers, which are divided by a semipermeable silty and clayey layer that is somewhere between a silty and sandy deposit. In some places, this semipermeable layer is missing. The upper aquifer layer is composed of coarse-grained gravel and sand, and the lower part has a higher amount of finer-grained sediments. The average hydraulic conductivity \( K \) of the aquifer was determined on the basis of pumping tests of the wells and varied from 50 to 200 m/day (Main Map). Along the southern boundary of the Drava Basin, the hydraulic conductivity has the lowest values (approximately 50 m/day). The aquifer transmissivity represents a product of the average hydraulic conductivity of the aquifer and its thickness. The aquifer is thinnest within the Legrad prag geological structure, where the transmissivity value is estimated at less than 3000 m\(^2\)/day. The thickness of the aquifer increases to 150 m to the west of the Legrad prag structure, while to the east of this structure, the aquifer thickness reaches 300 m. To the west and east of the Legrad prag structure, the transmissivity is more than 3000 m\(^2\)/day.

The groundwater level equipotential lines were produced based on these measurements and, as previously stated, selected groundwater levels. Water stages from the gauge stations on the watercourses were also used. The groundwater level equipotential lines were produced using the triangular interpolation method. However, due to the inadequate distribution of locations with measured water level data, an automatic interpolation without an interpretative intervention was not possible. After this procedure, the layer was digitized in ArcGIS.

The Quaternary aquifer is mostly overlain by semipermeable sediments that were formed during the Upper Pleistocene and Holocene. The thickness of the covering deposits was defined using a Kriging interpolation method. In the most of the study area, the thickness of the covering deposits is less than 5 m and is often missing. Along the southern boundary of the Drava Basin, its thickness increases and reaches more than 20 m in some places. The lithological composition of the upper part of the covering deposits is displayed based on the soil data for the first 4 m of the overlying layer depth and consists primarily of sand with silt and clay in different ratios. The average content of sand amounts to approximately 65%, the maximum content of which reaches 95% at some locations. The data were collected from the Faculty of Agriculture of the University of Zagreb (Vidaček et al., 2003). The thickness and composition of the covering deposits are shown on the second map.

### 2.3. 2D Cross-section construction

Cross-sections were identified using the lithological data from the boreholes. The borehole data were exported and processed within an Excel spreadsheet. Every point contained \( X \), \( Y \), and \( Z \) coordinates and the depth of the covering deposits, depth to the semipermeable layer between the first and the second aquifer, as well as the depth to the second aquifer and its bottom.

Thirty-three borehole records were selected for the construction of lithological profiles throughout the study area. The boreholes that are located within the Drava River Basin were used for a longitudinal lithological profile, while a series of boreholes situated perpendicularly to the valley direction were grouped to display cross-sections of the valley. Two longitudinal and three transverse profiles are shown on the map.

### 2.4. 3D Aquifer System Model Construction

A 3D aquifer system model of the investigated area was built using Visual MODFLOW Flex 4.0 software. The model consists of five layers, which were delineated...
using data from 280 boreholes. Only 40 boreholes reached the aquifer system bottom. The first layer represents the deposits overlying the aquifer. The aquifer system is represented by two permeable layers and one layer of the semipermeable silty and clayey deposits between them. The fifth layer represents the aquifer bottom. The borehole data were imported into Visual MODFLOW Flex and interpolated into surfaces with a Kriging interpolation method. For the areas lacking borehole data, the depths to the layers were estimated on the basis of the hydrogeological profiles. A DEM (digital elevation model) was used to create the ground surface, which was used to define the model layers in conjunction with the five surfaces interpolated from Excel. The model boundaries and topology data (i.e. rivers and settlements) were imported as shapefiles from ArcGIS software. There are five 3D profiles and one overall view shown on the map. 3D profiles are accompanied by small maps that show the view of the profile and its orientation in space.

3. Conclusions

The hydrogeological map of the western part of the Drava Basin provides detailed insight into the groundwater resources of the study area. This work was focused on the vertical and horizontal delineation of the regional Quaternary alluvial aquifer system and on the direction of groundwater flow.

The hydrogeological characteristics of the aquifer are the products of tectonic activity and the depositional environments of the sediments within the valley. The groundwater flows from the valley margins towards the Drava River. The main source of groundwater recharge is the infiltration of precipitation. Groundwater discharge occurs primarily through the watercourses and evapotranspiration and, to a much lesser extent, through pumping. Groundwater exploitation amounts to less than 10% of the average groundwater recharge.

Such a conceptualization of the aquifer system can serve as the physical and hydraulic basis for a future numerical evaluation of the regional hydrogeological system.

Software

Both the hydrogeological map and the covering deposits' thickness and lithological map were made using ESRI ArcGIS 10 and ArcMap 10.2.1. CorelDraw X8 was used for the 2D cross-sections. The 3D aquifer system model was built in Visual MODFLOW Flex 4.0. The final map was made in Inkscape 0.92.

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Disclosure statement

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References

Bajić, A. F., & Newton, M. J. (2007). Mapping the subsurface of water resource region, Ontario, Canada; An improved framework of Quaternary geology for hydrogeological applications. Journal of Maps, 3(1), 219–230.
Biondić, B., Dukarić, F., Goatti, V., Hinić, V., Lukić, O., Singer, D., & Biondić, R. (1997). Osnovna hidrogeološka karta RH 1:100.000. List Rijeka [Basic hydrogeological map of the Republic of Croatia, scale 1:100,000, Sheet Rijeka – in Croatian]. Zagreb: Croatian Geological Survey.
Brkić, Ž., Čakarun, I., Kuhta, M., Mraz, V., & Singer, D. (1998). Osnovna hidrogeološka karta RH 1:100.000. List Zagreb [Basic hydrogeological map of the Republic of Croatia, scale 1:100,000, Sheet Zagreb – in Croatian]. Zagreb: Croatian Geological Survey.
Brkić, Ž., Larva, O., Marković, T., & Briški, M. (2014). Hidrogeološka studija u svrhu definiranja eksploatacijskih zaliha podzemne vode na području Koprivnica – Đurđevac [Hydrogeological study for the definition of the exploitation groundwater resources in the area of Koprivnica – Đurđevac]. Zagreb: Croatian Geological Survey (Unpublished report).
Croatian Geological Survey. (2009). Geološka karta Republike Hrvatske 1:300.000 [Geological Map of the Republic of Croatia at a scale 1:300,000 – in Croatian]. Zagreb: Croatian Geological Survey.
Duć, Ž. & Urumović, K. (2007). Influence of legrad threshold structure on hydrogeological characteristics in koprivnica area. Rudarsko-geološko-naftni Zbornik, 19, 1–10.
Hecimović, I. (1986). Osnovna geološka karta SFRJ 1:100.000. List Đurđevac L33–71 [Basic geological map of SFRY, scale 1:100,000, Sheet Đurđevac L33–71 – in Croatian]. Belgrade: Federal Geological Survey.
Hecimović, I. (1987). Osnovna geološka karta SFRJ 1:100.000. Tumač za list Đurđevac L33–71 [Basic geological map of SFRY, scale 1:100,000, Guidebook of the geological map of the Đurđevac sheet – in Croatian]. Belgrade: Federal Geological Survey, 39 p.
Pavelić, D. (2001). Tectonostratigraphic model for the North Croatian and North Bosnian sector of the Miocene Pannonian Basin system. Basin Research, 13, 359–376.
Prelogović, E., Saftić, B., Kuk, V., Velić, J., Dragaš, M., & Lučić, D. (1998). Tectonic activity in the Croatian part of the Pannonian basin. Tectonophysics, 297, 283–293.

Saftić, B., Velić, J., Sztanó, O., Juhász, G., & Ivković, Ž. (2003). Tertiary subsurface facies, source rocks and hydrocarbon reservoirs in the SW part of the Pannonian Basin (northern Croatia and south-western Hungary). Geologia Croatica, 56/1, 101–122. doi: 10.4154/232.

Šarin, A. (1978). Purpose and contents of the hydrogeological map of Croatia, scale 1:200.000. Geoloski Vjesnik, 30/2, 385–409.

Šarin, A. (1984). Upute za izradu Osnovne hidrogeološke karte SFR Jugoslavije, 1:100.000 [Instructions for the preparation of the Basic Hydrogeological Map of SFR Yugoslavia, 1:100.000] – in Croatian]. Belgrade: Federal Geological Survey, 124 p.

Šarin, A. (1987). On the cartography of groundwater pollution hazards in the Dinaric Karst of Croatia (Vol. 19, part 2, pp. 331–338). Memoires, International Association of Hydrogeologists, Congress of Karlovy Vary, Prague.

Šarin, A. (1988). An analysis of trends in the hydrogeologic cartography of karstic terrains (Vol. 21, part 2, pp. 1242–1249). Memoires, International Association of Hydrogeologists, Congress of Guilin, Beijing.

Šarin, A. (1989). What is a hydrogeologic map and for what does it serve? (pp. 31–40). Memoires, International Symposium on hydrogeological maps as tools for economic and social development. International Association of Hydrogeologists, Hannover, FRG.

Šarin, A., & Urhiva, H. (1977). Cartographic novelty in a hydrogeologic map of Croatia (Vol. 18, part 1, pp. 29–38). Memoires, International Association of Hydrogeologists, Birmingham.

Slišković, I., Šarin, A., Brkić, Ž, & Singer, D. (1999). Osnovna hidrogeološka karta RH 1:100.000. List Ivanić Grad [Basic hydrogeological map of the Republic of Croatia, scale 1:100.000, Sheet Ivanić Grad – in Croatian]. Zagreb: Croatian Geological Survey.

Struckmeier, W. F., & Margat, J. (1995). Hydrogeological Maps. A Guide and a Standard Legend (Vol. 17, 177p). Hannover: International Association of Hydrogeologists.

Urumović, K., Hernitz, Z., Šimon, J., & Velić, J. (1976). O propusnom mediju kvartarnih, te gornjo i srednjo pliocenskih naslaga sjeverne Hrvatske [About permeable medium of the Quaternary, Upper and Middle Pliocene’s deposits in the northern Croatian – in Croatian] (Vol. 2, pp. 395–410). Zbornik radova 4. jug. simp. o hidrogeol. i inž. geol., knjiga.

Vidaček, Ž, Bogunović, M., Husnjak, S., Sraka, M., Bensa, A., & Petosić, D. (2003). Hidrogeološka karta Republike Hrvatske 1:300.000. Vodno područje slivova Drave i Dunava [Hydrogeological map of the Republic of Croatia, Drava and Dunav River Basin – in Croatian]. University of Zagreb Faculty of Agriculture (Unpublished report).