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Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater quantity in the Zagreb aquifer**

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INTRODUCTION

The Zagreb aquifer is built of saturated gravel and sand deposits stretching in NW-SE direction along the Sava River at the City of Zagreb territory. The aquifer is about 30 km long, from 10 to 15 km wide, and between 5 and 10 meters thick on average in the western parts to about hundred meters thick in the eastern parts of the aquifer system.

The Zagreb aquifer is located between Mt. Medvednica at the north and Vukomeričke Gorice hills range at the south (Fig. 1). The Sava River divides the aquifer into the left and right valley.

The Zagreb aquifer is of unconfined type. Considering hydraulic aspects, its boundaries are: impermeable boundary at the north, inflow boundary at the west, inflow boundary at the south, and outflow boundary at the east. Generally, the groundwater flows in W-E/SE direction.

The municipal water supply relies on groundwater from the aquifer which is abstracted at six currently operating wellfields shown in Fig. 1. During longer dry periods, smaller well fields which are usually not used by the water supply system are put into operation.

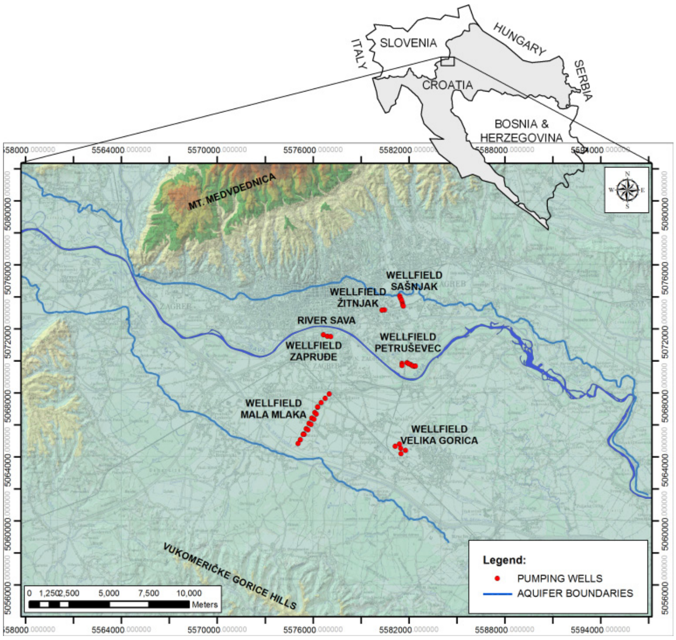

Figure 1. Location of the Zagreb aquifer.

The quantity of groundwater for the City of Zagreb territory is estimated from measurements of groundwater table carried out at 500 piezometers and aquifer geometry. The groundwater table measurements are carried out by the Croatian Meteorological and Hydrological Service and municipal utility Watersupply and Sewage Company.

GROUNDWATER QUANTITY ANALYSIS

The aquifer is generally recharged by (1) infiltration from the Sava River, (2) infiltration of precipitation; (3) infiltration from leaking water supply and sewage networks; (4) inflow along the western boundary from the neighbouring Samobor aquifer; and (5) inflow along the southern boundary from the Vukomeričke Gorice area.

The Sava riverbed cuts into the gravel and sand deposits of the aquifer. An analysis of the equipotential maps determined that during high water levels the Sava recharges the aquifer along its entire course at the Zagreb territory, and during medium and low waters aquifer drainage is noticed in some parts of the river course, which has unfavorable impact on the groundwater table and, consequently, on water quantity available during the dry periods. Comparison of the Sava and groundwater hydrographs with data recorded at the piezometers in the immediate vicinity of the river Sava shows very strong relation between the Sava water levels and groundwater table.

The analysis of the groundwater table fluctuations measured since 1950 indicates an average groundwater drawdown at the entire aquifer area of 1-2 m every 10 years for the last forty years (Fig. 2). The reasons for the groundwater drawdown could mostly be attributed to (1) deepening of the Sava riverbed caused mostly by construction of the hydropower plant reservoirs on the Sava upstream from Zagreb and gravel mining in the riverbed, (2) increase in groundwater abstraction for the City of Zagreb water supply, and (3) construction of dikes along the Sava River to prevent random flooding of the floodplain, and consequently potential inflow of water from the flooded areas into the aquifer. Total quantity of water pumped at the Zagreb well fields increased from 3300 l/s in 1983 to about 4700 l/s nowadays. This means that the water pumping rates have been continually increasing by about 700 l/s every 10 years. The increase in pumping rates quantity is caused not only by increased growth of the city and its population, but also by aging water supply network the losses from which, according to the Watersupply and Sewage Company (2003), amount to 40%.

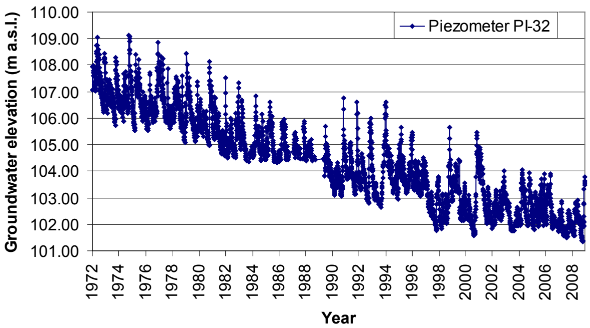

Figure 2. Typical hydrograph.

Continuous groundwater drawdown threatens the yields of well fields. During dry periods, the phreatic line decreases below the upper screen edge level in specific wells, which results in decrease in yield. For identification of relations between groundwater levels and positions of screen in wells, the hydrographs of the piezometers closest to the water wells were analyzed. The data on water tables in the pumping wells were not available.

Mala Mlaka wellfield consists of ten dug and eight drilled wells. During dry periods, groundwater tables in all dug wells and three drilled wells drops below the level of the upper screen edge. To illustrate the relations, one dug and one drilled well have been selected (Fig. 3 and 4).

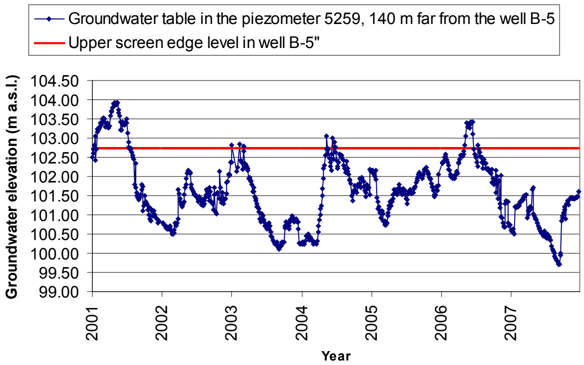

Figure 3. Mala Mlaka wellfield — comparison of the upper screen edge level in dug well B-5 and hydrograph for the piezometer 5259 placed at 140 m distance from the well.

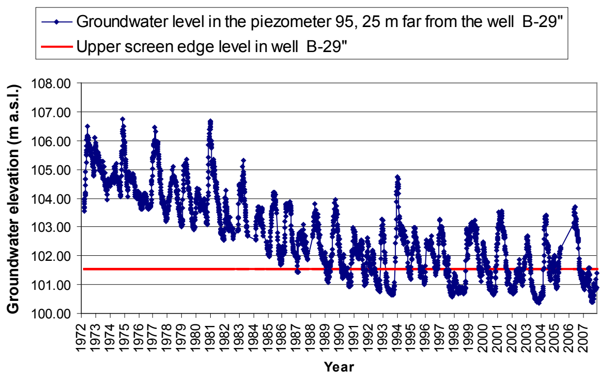

Figure 4. Mala Mlaka wellfield — comparison of the upper screen edge level in drilled well B-29 and hydrograph for the piezometer 95 placed at 25 m distance from the well.

Presently, groundwater table in only one of six wells at the Sašnjak wellfield and in two of three wells at the Zapruđe Well Field falls below the upper screen edge. Minimum groundwater tables at the Petruševec wellfield are between 2.7 and 8 m above the upper screen edge, depending on the screen position in individual wells. Minimum groundwater tables at the Velika Gorica wellfield are between 1.7 and 7.1 m above the upper screen edge, depending on the well, and the minimum tables at the Žitnjak wellfield exceed the upper screen edge level by more than 12 m. It should be stressed that the analysis was carried out using different water tables in piezometers rather than in wells, which means that the actual situation is even more unfavorable.

Based on a recession analysis, it was concluded that Petruševec, Velika Gorica and Žitnjak wellfields will be available for pumping during the future twenty odd years provided the groundwater table drawdown trend does not change (Posavec, 2006; Posavec et al., 2006).

Analysis of the minimum groundwater levels and Zagreb aquifer geometry for the period 1976-2006 determined gradual decrease in water volume (Fig. 5). Summary data for the period 1976-2006 indicate a decrease by approximately 4%.

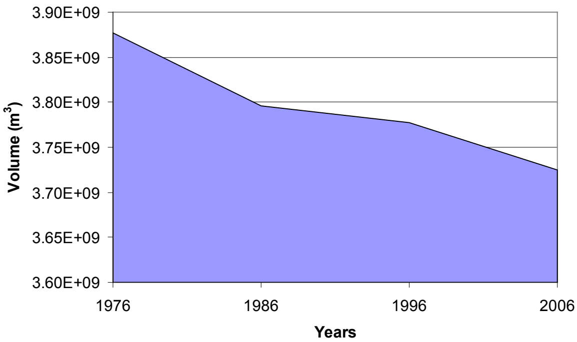

Figure 5. Groundwater volume below minimum annual groundwater tables.

Annual recharge of the aquifer is determined as the water volume between minimum and maximum annual groundwater tables. An analysis of the water surfaces at minimum and maximum groundwater tables for the period 1996–2006 determined that the annual recharge show no strong trend, which is understandable since they depend on annual precipitation.

Comparison of annual recharge of the aquifer with average annual pumping rates at the Zagreb well fields during the period 1996–2006 indicates that the pumping rates exceed the recharge (Fig. 6). This means that the part of abstracted groundwater which exceeds recharge is taken from unreplenishable reserves, which results in decrease of reserves in time and "overpumping" of the Zagreb aquifer.

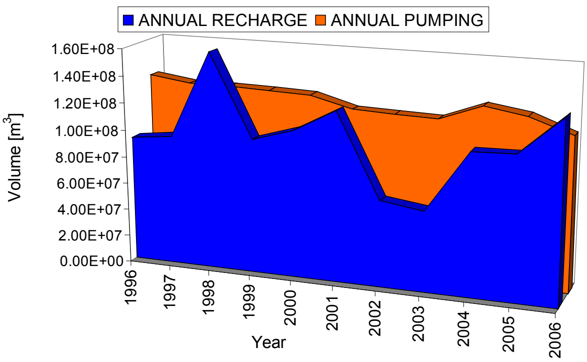

Figure 6. Comparison of the recharge and the pumping.

CONCLUSION

The analysis of groundwater table data collected for the Zagreb aquifer indicates an average groundwater drawdown 1–2 m every 10 years since 1950. Reasons for the groundwater drawdown include: (1) deepening of the Sava riverbed caused mostly by construction of the hydropower plant reservoirs on the Sava upstream from Zagreb and gravel mining in the riverbed, (2) increase in groundwater abstraction for the City of Zagreb water supply, and (3) construction of dikes along the Sava River to prevent random flooding of the floodplain, and consequently potential inflow of water from the flooded areas into the aquifer.

During dry periods, groundwater table falls under the upper screen edge level in the wells at the Mala Mlaka, Zapruđe and Sašnjak Well Fields, which decreases their yields. The upper screen edge levels in the wells at the Petruševec, Žitnjak and Velika Gorica wellfields are several meters below minimum groundwater table, on average, which shall enable unobstructed pumping during the future twenty odd years provided the groundwater drawdown trends do not change.

Total annual pumping rates for all Zagreb well fields exceed the annual groundwater replenishment rates, which mean that the Zagreb aquifer is "overpumped". The part of the pumped quantity that exceeds the replenishable reserves is made up from unreplenishable reserves. The permanent reserve volume was 3.88 km^3 in 1976, and 3.72 km^3 in 2006, therefore it decreased by 4% in thirty years.

To conclude: total groundwater quantity in the Zagreb aquifer is comparatively abundant, however presence of a negative groundwater table trends and excessive pumping from the aquifer ask for caution, which means quality monitoring and systematic analysis and interpretation of the monitoring results. This ensures realistic inputs for an optimum management of water as a strategic Croatian resource.

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