Subsidence measurements – marshland subsiding owing to pumping the groundwater

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Abstract: The Ljubljana marsh is a perspective drinking water source for the Ljubljana City. In the future 500 l/s of groundwater is planed to pump which should stress the lower Pleistocene aquifer. As a consequence because of the groundwater exploitation the subsidence is exposed.

Key words: Pleistocen aquifer, drinking water, groundwater exploitation, subsidence.

Introduction

The discussion about the connection between the groundwater pumping and the land subsidence is presented, since it is known for the long time that the defined parts of the Ljubljana marshland subside or lower with regard to surroundings.

The lithological data from the boreholes (drilled all over the Marshland in the past) and the geophysical investigations indicate that the marshland area is a basin with the stone bedrock that is cut to several smaller basins and hallows. In the southern part the bedrock consists from the Triassic dolomite and limestone and in the northern part from the Permocarbonic schist's. The basin is filled up with the lacustrine, marshy and fluvial sediments. The peat, the peat mud and the lacustrine grey silty carbonate clay called "polžarica", partly on the brown sandy clay and the sandy silt, are the most frequent sediments on the surface. The polžarica has the structure like a honeycomb and contains 70-75 % of water and 60 % of limestone grains. All these specify its characteristics and sensitivity on the pore pressure lowering (Mencej, 1988/1989).

Below the silty and clayey sediments the thick gravel layers are present and the groundwater is under the pressure. Those gravel sandy aquifers are the continuation of gravel fans of rivers that flow from the mountains to the marshy plain. The gravel aquifer is not uniform through the height; the lacustrine and marshy layers interrupt it.

The impermeable and low permeable clay and silt layers, which cover the upper part of the marshland, prevent or limit the precipitation percolation to the deeper layers. In some places the percolation is impossible because the groundwater piezometric pressure of the gravel aquifer is below the one of the marshy layers.

Scientific paper

In the period from Pliocene to Pleistocene the Ljubljana filed and Ljubljana marshland basins became to sink. The tectonic movements are still active in present days, which the frequent earthquake shocks warn us.

The following reasons for the marshland subsidence could be added to the abovementioned ones:
- sinking of the Quaternary sediments bedrock; estimation: 1-2 mm/year;
- natural consolidation of the Quaternary lake sediments; estimation: 1,3 mm/year;
- draining of the marshland, hydrotechnical interventions, loading the surface with additional weight due to road and building constructions;
- groundwater exploitation.

In the first step the water work Brest was planed to exploit the groundwater from the unconfined Holocene aquifer. Even the extensive investigations were realised, the exceptive quantity of groundwater was not achieved. Therefore the water work sanitation was carried out and two deep wells were drilled for the groundwater exploitation from the upper artesian Pleistocene aquifer and the lower Pleistocene sub artesian aquifer. In 2001 the total exploitation volume of water work Brest was 150 l/s; 80 l/s was pumped from the deep well A1gl, which has the screen mostly in the lower Pleistocene aquifer.

RESULTS AND DISCUSSION

In 1985 the subsidence analyses were done. On the base of laboratory analyses of geotechnical parameters of the marshland sediments the subsidence calculation were performed considering the different horizons, which could influence the artesian pressure inside the gravel aquifer. The results confirm assumptions that the upper 20 m thick stratum is not uniform, but the stratified soil is present.

The City of Ljubljana and its surrounding are situated on the earthquake active area, so the systematic geodetic measurements, established in 1962, were necessarily. The vertical and horizontal movements along tectonic joints have been detected. If the measurements are repeated in defined time intervals, the data about the surface subsidence could be obtained on the observation area (KOLER, 2002).

In the Ljubljana marshland the measured subsidence is considerable in two areas. The first area is the confluence of the Iščica and Ljubljanica rivers, where the subsidence is in the range between 15 and 20 mm/year. The second centre of the intensive subsidence is the area where the villages Lipe and Črna vas are situated. The subsidence is in the range between 5 and 10 mm/year in this area (VODOPIVEC, 2002).

All measurements give the information about the moving and the subsidence of the whole package, the bedrock and sediments. However, for determining the subsidence portion due to the groundwater exploitation, we need the data about the subsidence in the marshland sediments, where the influence of the artesian and sub artesian groundwater is present.

Because of that, the levelling net of six floating and six depth measure points was restored to observe the eventual surface subsidence because of the groundwater abstraction. The depth points were stabilized on the boundary between the silty clay and the clayey gravel in the depth from 7 to 10 m. The surface floating points were built below the surface. The height variations between two points indicate the eventual subsidence inside the silty clay layer. From December 1999, when the measurements were established, till June 2003 twenty measurements were done. On floating points the subsidence was detected in dry periods, while in wet periods the lifting was observed. On depth points the lifting was present at the beginning of dry periods, but in the cases of long dry periods the subsidence was detected. The common subsidence inside the silty layer was between -0,1482 m to +0,0022 m on the floating points and between -0,09 m to +0,09 m on the depth points. All those indicate that the sediment behaves like a sponge that contracts in dry periods and stretches in wet periods (Vodopivec, 2003).

The deciding factor for most activities and events on the Ljubljana marshland is the groundwater level. For the future drinking water supply from the water work Brest with the volume of 500 l/s the groundwater level in the lower Pleistocene aquifer is one of the most important factors. Therefore for decades the groundwater level have been measured two times per months in piezometers with the screen in the upper and lower Pleistocene aquifer. To find out more precise correlation between the subsidence and the hydrological state, two piezometers, OP-1 and P-19, were equipped with the continuously groundwater level data logger.

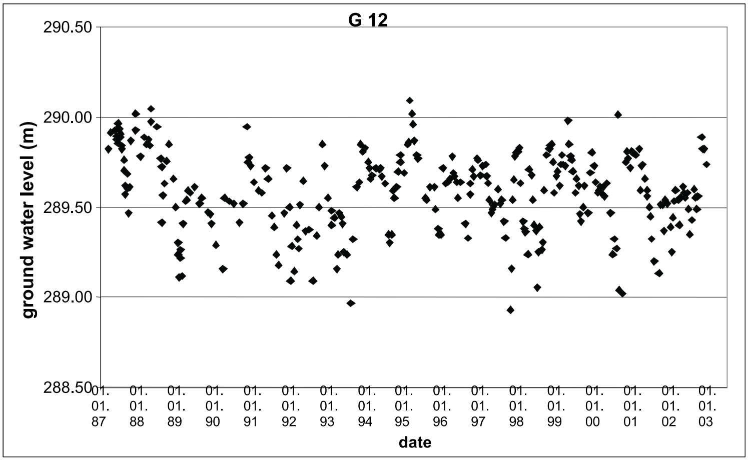

Figure 1. Groundwater level oscillation in the lower Pleistocene aquifer

The produced data were applied for subsidence calculations on the theoretical base (Veselič, 2000).

CONCLUSIONS

The subsidence of the Ljubljana marshland due to the groundwater exploitation is the result of two time dependent processes:

1. decreasing groundwater level in aquifers
2. consolidation and subsidence developing in the low permeable and impermeable layers

Both processes are relatively slow dependent dynamic processes. The land subsidence due to the groundwater exploitation from confined aquifers could delay for years or even decades after the groundwater exploitation. In the same time, the water leakage from subsiding layers could effectively retain the groundwater level decreasing (VESELIČ, 2000).

The results of analyses of the long-term groundwater level decreasing due to the groundwater pumping from the lower Pleistocene aquifer with the discharge of 150 l/s demonstrated that

- the groundwater level decreasing in the upper Pleistocene aquifer should not exceed 2, 5 m even after 20 years (in general it is smaller than 2 m), and
- the groundwater level decreasing in the lower Pleistocene aquifer should not reach 10 m even after 10 years.

The subsidence velocity analyses for the single layer indicate that the groundwater level decreasing due to the earlier groundwater exploitation is between 0,122 and 0,142 m. When the well A2gl will be included to the system, the subsidence between 0,274 and 0,0336 m could be expected in 50 years (VESELIČ, 2000).

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