*Full Paper*

# THE IMPACT OF SAND OPEN PIT "JAKOVAČKA KUMŠA" ON GROUNDWATER IN A PART OF BELGRADE SOURCE

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**Abstract:** The need for quality underground drinking water is always current. On the other hand, industrial development, which is unavoidable in modern societies, as time passes, is beginning to threaten the sources of groundwater. It is sometimes impossible to find a compromise between these two important factors of human development and sometimes it is possible, with specific measures that reduce the effect of possible impact on the quality and quantity of groundwater to an acceptable one. The role of detailed hydrogeological research and hydrogeologists in solving problems of preventive protection of groundwater sources is of great importance. One such problem was successfully resolved on a part of Belgrade water source in the zone of Jakovo (Municipality of Surčin) where the sand open pit "Jakovačka Kumša" is located.
**Keywords:** preventive protection, groundwater, water supply, water source of Belgrade

## INTRODUCTION

Public enterprise "Surčin" from Surčin, in order to provide their own high-quality raw material of sand, which would be used for construction and reconstruction of roads, wastewater network and other civil engineering objects in the municipality, launched activities to determine the possibility of finding this material on the location "Jakovačka Kumša".

In the area near the location where the exploitation of sand is planned, there are several tapping objects used for Belgrade water supply – four Ranney wells and nine tubular wells.

The location which is planned for exploitation of sand, is in the inner zone of sanitary protection (zone II), in a part of the existing water source in Belgrade. Also, due to the need for additional quantities of water, Belgrade waterworks have already initiated activities to develop technical documentation for the opening of a new infiltration type water source in the location "Zidine" which is close by.

For this reason, the problem of preventative protection of groundwater in this part of Belgrade source in the mentioned zone must be given proper and adequate attention.

## GOAL

The aim of the research was to determine the possible impact of the sand open pit "Jakovačka Kumša" – Jakovo on a part of the existing groundwater source. It was necessary to determine the possible increase in vulnerability of groundwater due to the removal of the overlying layer of captured aquifer and to define the conditions of exploitation, in order to maintain the quality and quantity of groundwater. It was also necessary to simulate a possible scenario in which the accidental pollution comes to the aquifer, in order to determine the reaction time.

## GENERAL CHARACTERISTICS OF RESEARCH AREA AND APPLIED METHODS

Research area is located 30 km southwest of Belgrade (Fig. 1). It covers about 16 ha, while the wider research area covers an area of about 320 ha.

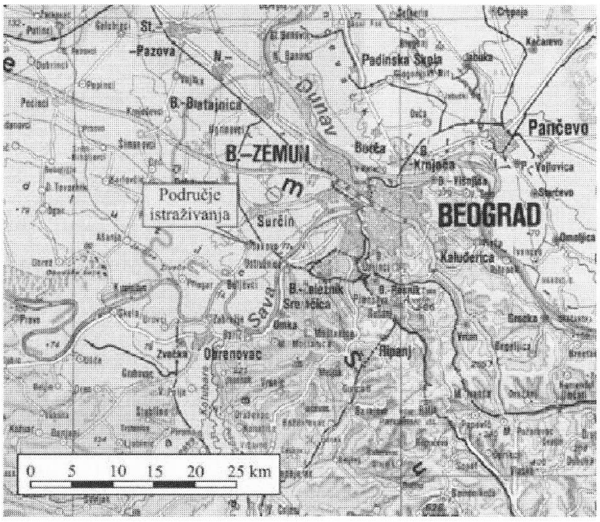


*Figure: 1: The geographical position of the research area*

Based on the data obtained from boreholes, from a geological aspect the presence of deposits of Pleistocene and Holocene age was detected. Within this zone it is possible to single out deposits of marsh and alluvial origin. They consist of sands and alevrits (b), gravel, sand and clayey sands (a) and sands and alevrite sands (ap).

Based on the geological structure of the terrain, the represented lithostratigraphic units and their structure type of porosity, as well as hydrodynamic conditions, within the research area it is possible to single out: intergranular high hydraulic conductivity aquifer formed in the sandy-gravel sediments, intergranular lower conductivity aquifer formed in the yellow and fine grained sands and alevrite sands, and areas of little or no significant groundwater (Fig. 2, Tab.1).

*Table 1: Model layers with appropriate lithological members of the hydrodynamic model*

| Model layers | Lithological layers | Elevation of layers (m.a.s.l.) |
|---|---|---|
| First less permeable layer | Complex of alevrite and yellow sandy overlying sediments with interlayers of clay | 68,22 - 57,30 |
| Second water bearing layer | Gray sands | 62,70 - 54,74 |
| Third water bearing layer | Water bearing sandy gravels | 58,55 - 37,24 |
| Layer of little or no significant groundwater | Clayey sediments | 37,24- |

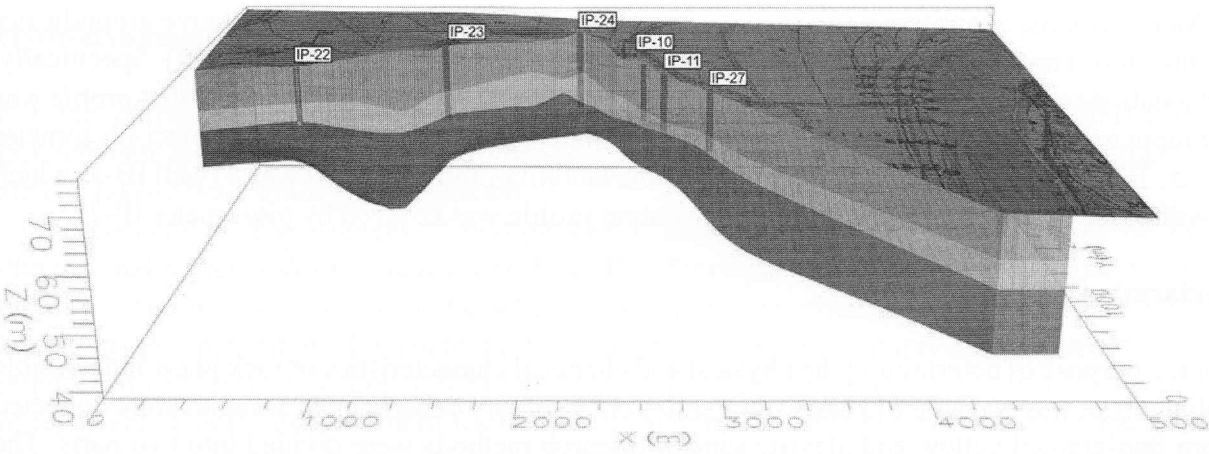


*Figure 2: 3D Hydrogeological cross-section of the terrain*

For the purposes of sand mine research 54 boreholes and one well were made (Milićević R. et all, 2009). Field surveys for hydrogeological purposes consisted of making 27 exploration boreholes (piezometers) which were used for defining geometric and seepage characteristics of the aquifer in the wider research area which was affected by the hydrodynamic model of groundwater flow. The position of exploratory boreholes is shown in Fig. 3 and 4. Samples of rock material were taken during the drilling from boreholes IP-5, IP-13, IP-15, IP-17, IP-9, IP-22 and IP-25 (3-4 per borehole) for the purpose of completing a grain-size analysis. On the basis of the grain-size analysis hydraulic conductivity of sands and gravels was calculated.

With the aim of determining the zero state of groundwater regime (water tables, quality and quantity of abstracted water) at objects of Belgrade waterworks and sand mine, monitoring of groundwater regime (quantity of abstracted water, water tables) was carried out in the period 12.02-10.05.2010. Dynamic of the monitoring was adapted to provide valid data for development of a hydrodynamic model of groundwater flow. In Fig. 3 and 4, the isolines of the maximum and minimum water tables are displayed.

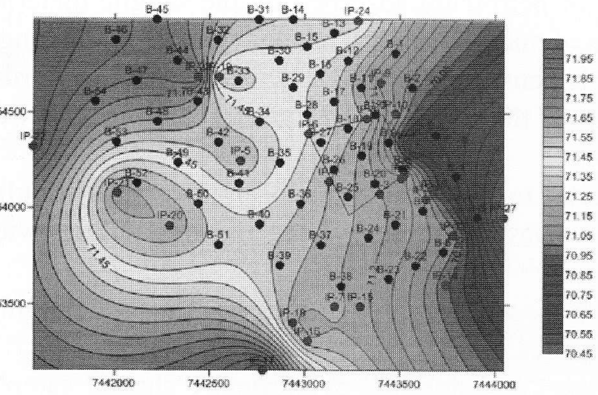

*Figure 3: Isolines of the maximum water tables*
*Legend: black-boreholes, blue-piezometers, rectangle-research area*

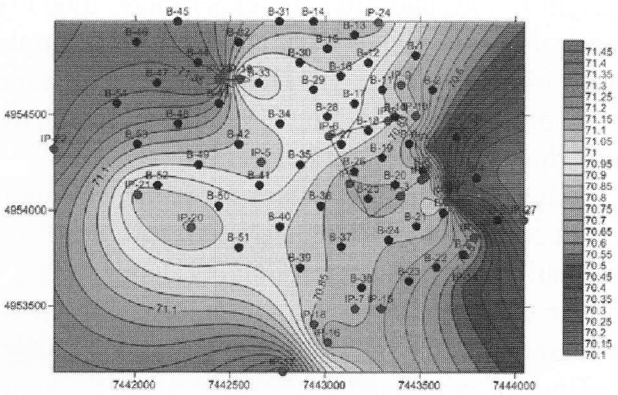

*Figure 4: Isolines of the minimum water tables*
*Legend: black-boreholes, blue-piezometers, rectangle-research area*

The laboratory part of the research included performing 27 grain-size analyses of samples of the rock material, to determine the lithological profile in the research area.

In order to determine the seepage characteristics of the aquifer, a pumping test was done on the well IB-1, while the water tables were also monitored at the piezometers IP-1, IP-2 and IP-3, which are located nearby.

Along with the quantitative observation, monitoring was carried out for qualitative groundwater regime, too. Three chemical analyses were carried out (objects IP-23, IB-1 and IP-27). Specifically, the locations of sampling objects were chosen so that they cover three profiles. The first profile was the input to the direction of groundwater flow (above the current mine) with the object-piezometer IP-23. The second was located directly below the landfill of the municipal waste (well IB-1) which is within the current mine, while the third - output profile was covered by piezometer IP-27.

**Performing experiments**

For the purpose of determining the physical and chemical characteristics of rock mass and possible pollutants, it was necessary to carry out a series of laboratory experiments. Samples were collected from fine-grained yellow and alevrite sands. Research methods were divided into two parts. The first part referred to the "undisturbed" samples, which relatively credibly reflect terrain conditions, and the other to the determination of characteristics of disturbed samples. With an adequate sampler (steel cylinder with a plastic cartridge) 10 "undisturbed" samples were taken from the mine. Also about 20 kg of material were taken as a disturbed sample from the same location.

In the experiments the seepage characteristics of the material were determined first. Since calculated data for various parameters already existed, these experiments were expected to confirm obtained values. Experiments were performed so that they simulated terrain conditions ("in situ").

Based on the analyses results of groundwater quality from monitoring objects, parameters with value above MAC were selected and they were used in the experiments performed under laboratory conditions. Only the review related to petroleum (D2) is given here because the possibility of its leaking during the breakdown of machines and trucks exists. Adsorption properties of sediments were determined and the time of penetration of petroleum through the individual samples was registered. Based on these values, it is possible to calculate the time of petroleum penetration to the groundwater, with the aim of determining the time of intervention.

The samples were treated in static and dynamic conditions. Static conditions were applied on disturbed samples. 16.3 kg of material were taken and filled with petroleum (D2) to complete saturation. After that, a complete decanting of the sample was done. Based on the difference in weight before and after the experiment, quantity of petroleum adsorbed by the sample material was calculated. Experiment consisted of 5 samples of material and calculated values were in range from 14.5 to 18.9 weight% depending on the sample density (Matić I. et all, 2011). In other words, 1 m3 of material weighing 1.5 tons (volume density of the sample is 1.5 kg/dm3) has the ability to adsorb from 145 to 189 l of petroleum (D2).

In dynamic conditions samples were firstly subjected to long-term water infiltration and hydraulic conductivity was determined again. After that, pure petroleum was filtrated under conditions with hydraulic gradients slightly higher than natural.

The obtained values of hydraulic conductivity were around 2.5 x10-6 m / s and they roughly correspond to the previously obtained laboratory values.

Time of petroleum (D2) penetration through the "undisturbed" cylindrically shaped sample (length 42 cm, diameter 9.2 cm) had an average value of 17-22 hours or about 38-50 hours for 1 m of overlying aquifer.

Understanding of the hydrogeological environment in the area of mine exploitation and in this case petroleum as the only likely potential pollutant of groundwater, is imperative to the timely undertaking of preventive measures to protect the water source.

## Hydrodynamic analysis

For the purpose of performing an analysis of the impact of alevrite sands exploitation on groundwater quality, a complex hydrodynamic analysis of the groundwater regime in the wider area of Jakovačka Kumša was conducted.

The concept of development of hydrodynamic model of the wider area is based on three-dimensional simulation of groundwater flow. The development of the model was started from the basic interpretation of input data, schematization of the porous medium, flow field and flow conditions so that the model could be formed and calibrated. Natural factors were the most important ones for the selection of the model's concept, such as type and geological characteristics of represented units, distribution of water bearing and impermeable layers, seepage characteristics of the porous medium, conditions, mechanism and regime of groundwater flow, as well as the desired goal within a task. In selecting the basic design features, a multilayer model was made, with the possibility of an automatic change of flow field, depending on flow conditions.

Calculations were conducted on the licensed Visual MODFLOW 2009.1, which is among the top world programs of its kind.

Basic matrix dimensions that covered the studied area were 5000 m x 3000 m, which encompasses the area of 15 km$^2$. Lateral discretization of the flow field in the wider research area was executed with a basic cell size of 50 m x 50 m, while the cell size in the zone of Jakovačka Kumša was 25 m x 25 m.

For the analysis of travel time of potential pollutants from the open pit to the source wells, a simulation of "ideal" particle movement (conservative, nonresponsive) or tracer was carried out. Particles were placed on the contour of the mine and one was placed in the center of the mine in the first layer of model.

Hydro dynamical model showed that it takes 35-39 months for the "ideal" particle to come from the open pit to the source wells for the capacity of 88.9 l/s. It was also concluded that all particles gravitate towards the well RB-65 as a result of the highest drawdown of the water table in this object, due to its location in the middle of the series and its highest capacity. For a capacity of 240 l/s, the situation is similar, except that the retention time of particles on their way from the open pit to the wells is 18-23 months. Fig. 5 and 6 show the analysis of "ideal" particle travel from the open pit to the source wells.

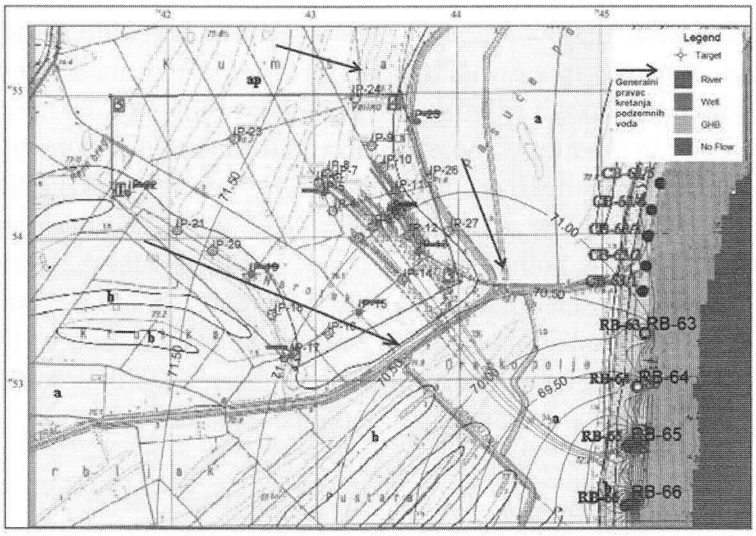


*Figure 5: Map of piezometric levels with travel time of "ideal" particle to the wells of Belgrade water source (in months) for its capacity of 88.9 l/s*

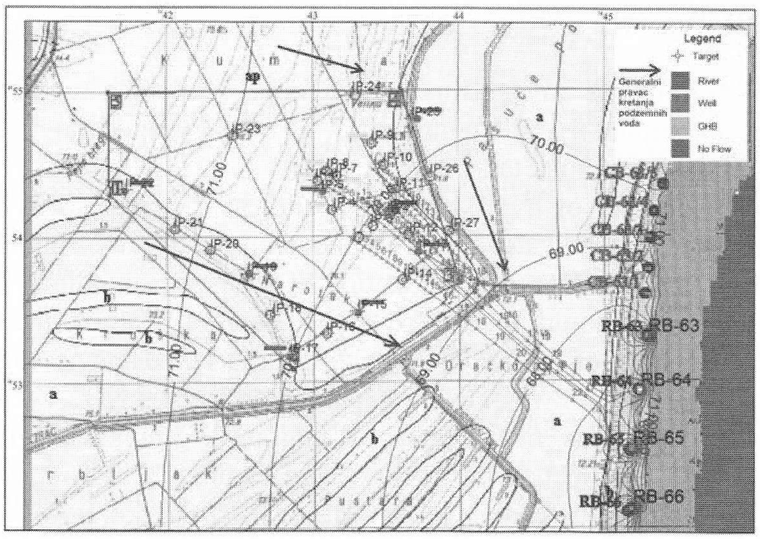


*Figure 6: Map of piezometric levels with travel time of "ideal" particle to the wells of Belgrade water source (in months) for its capacity of 240 l/s*

## RESULTS

Based on all previous and new researches, measures were determined that should be implemented for preventive groundwater protection.

It was determined that it is necessary to keep the protective layer of yellow and alevrite sands 3 meters thick. This buffer zone will be sufficient to prevent possible leakage of potential pollutants (especially D2), which was proven by laboratory experiments. Extremely high adsorbing capability of alevrite sands and relatively low penetration speed of petroleum through this environment leave enough time for possible intervention.

Hydro dynamical analysis showed that the travel time of the "ideal" tracer is in the order of 18-39 months depending on the capacity of the objects of Belgrade's water source, and that the travel time of particles of possible pollutants will be much slower depending on their adsorption as an additional benefit in terms of taking protection measures.

It is suggested to repair and reclaim the local "wild" municipal waste landfill located within the area of research.

In order to monitor the impact of the mine on the quantitative and qualitative characteristics of groundwater during and after the operation, it is necessary to schedule an adequate program of monitoring. The "zero" state of groundwater quality has been determined and selected parameters reflect the real situation in relation to existing and potential polluters. The measurements of water tables were conducted too. In the future, the monitoring of water tables at the monitoring objects at all sites should be done on a monthly basis, and as for the observation of qualitative features, they should be monitored at three profiles as before. In the case of possible accidents and the cases of increased concentrations of some pollutants, it is necessary to expand the network of monitoring objects. Monitoring of surface water channels, as the recipients, should be provided, too.

At the end of sand exploitation it is necessary to conduct reclamation of the open pit. At this location the exploitation of sand is going to last for many years, according to the opening stages of certain parts of the mine. A phased reclamation should be conducted as well.

## CONCLUSIONS

Hydrogeological studies of the assessment of impact of the designed sand open pit "Jakovačka Kumša"- Jakovo on groundwater, a part of Belgrade source, have clearly defined the conditions and measures to be observed by the future user of the specified research area in order to eliminate the possibility of its contamination.

Special measures to be implemented in the open pit zone are determined in such a way that it is necessary to keep the protective layer of alevrite and yellow sands, perform reclamation of the existing "wild" landfill, perform continuous monitoring of water tables (once a month at all sites), carry out continuous monitoring of groundwater quality in the three profiles on the already determined parameters and perform reclamation of the open pit after the ending of exploitation.

Research results have allowed prescription of measures on one hand, for the permanent protection of one part of Belgrade groundwater source, on the other for an undisturbed exploitation of sand in the mine "Jakovačka Kumsa" in Jakovo. This presents the basis for the dual-purpose use of the study area and its sustainable development.

### References


Filipović B., Vujasinović S. - The protection of groundwater, Faculty of Mining and Geology, Belgrade, 1982

Krešić N., Vujasinović S., Matić I. - Remediation of groundwater and geologic media, Faculty of Mining and Geology, Belgrade, 2006

Ložajić A., Matić I., Vujasinović S., Pušić M. - Hydrocarbon spills at the industrial zone of Pančevo, Yugoslavia - water resources impact, XI International Scientific Conference "Danube-Rever of Cooperation", Belgrade, 2000

Matić I., Vujasinović S., Minić G. - Ecogeological conditions of contaminated river deposits cleanup process near the water supply source of Belgrade, poster 33th International geological Congress, Oslo, 2008

Matić I., Polomčić D. - Study on assesment of impact of the projected open pit sand "Jakovačka Kumša" - Jakovo on existing and and projected groundwater source Zidine, Faculty of Mining and Geology, Faculty of Mining and Geology, Belgrade, 2011

Milićević R., Pavlović Z. - Study of reserves of building sand in the bed "Jakovačka Kumša" in the area of the village Jakovo, Municipality of Surčin, Belgrade, 2009

Vujasinović S. - Contamination and protection of groundwater, Faculty of Mining and Geology, Belgrade, 1988

Vujasinović S., Matić I., Ložajić A. - Hydrogeological problems of pollution and protection of water sources in Belgrade, Mining and Geology, Belgrade, 1999

Vujasinović S., Matić I. - Basics of hydroecogeology, Faculty of Mining and Geology, Belgrade, 2009