Planning of Mavropigi and Kardia Mines Depressurization Systems by Three Dimensional Groundwater Flow Numerical Modeling

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ABSTRACT

Mavropigi and Kardia lignite mines, located on western margins of South lignite bearing Ptolemais basin (NW Macedonia, Greece), have an annual lignite production of $15*10^6$ tones available, to provide it as partial contribution to the 3000 MW Power Plants' Electric System.

The confined loose water bearing formations under lignite seams, in fact can be extremely dangerous as water may enter the excavation area, after piping or heaving the mine bottom and benches.

In present paper there is an effort to simulate in three dimensions the underneath lignite seams aquifer's groundwater flow into the loose Neogene sediment's porous media ,only to confront heaving and piping effects. The model has developed in order to implement a depressurization water well's system of appropriate magnitude and other dewatering of mine measures or acts to be dimensioned.

The studied part of this aquifer was simulated in two layers of 1086 nodes each one, which lie in a square grid with a distance of 300 m between them. The simulation was performed on FREEWAT MODFLOW-2005 application in cooperation with Q-GIS open source that held all geological and hydrological information. The results of 3 stress periods model running revealed that is feasible the decompression of the aquifer under approximately 1500 m^3/h average pumping rate in both mines. The afterwards decompression, dewatering of free aquifer is not included to present investigation, because the appropriate ground water lowering to ensure slope stability is not geotechnical investigated yet.

The possibility of an artificial recharge on the decompressed aquifer is prospected to be simulated in future by the same numerical model. Thus it will be a further future investigation, going to the right direction of regional water resources rational management.

1 INTRODUCTION

In the region of South lignite bearing basin of Ptolemais (Macedonia, NW Greece) (Fig. 1), Public Power Corporation of Greece has developed a great mining activity in order to provide adequate lignite quantities to 3000 MW Power Plants.

Mavropigi and Kardia (Southwest field) mines (Fig. 2.) are two of the exploitation fields in which Ptolemais lignite bearing basin has been divided. The known lignite deposits of both fields rises up to $360*10^6$ tn lignite with $15*10^6$ tones average annual production.

Water inflow in the mining area creates slope stability problems, makes it difficult to operate and can even jeopardize the safety of the work [1, 2]. The loose water bearing formations under lignite seams, in fact can be extremely dangerous as they are likely to be under pressure (confined) and thus water may enter the excavation area after piping (groundwater vertical upwards flow through veins or faults filled with permeable porous material etc.) or heaving the mine bottom and benches.

Mavropigi and Kardia open pits are located on western margins of South lignite bearing Ptolemais basin, on Askion mountain's foothills. The up till now review of hydrogeological studies on the mine's area existing aquifers, clusters 3 group of aquifers. In this modeling case study the simulation was oriented only in the under lignite aquiferous system that was confirmed in area of Mavropigi mine [3] and in area of Kardia Southwestern Ptolemais Mine Field [4]. These under lignite aquifers are very significant for Mavropigi and Kardia mines' operations integrity causing potential piping and heaving inrushes' problems.

The under pressure aquifer of Mavropigi-Kardia (Northwestern Greece) strip mine projects is located on western margins of South lignite bearing Ptolemais basin next to Askion Mountain.

This aquatic system is under pressure, cause upon its roof is covered by impermeable formations consisting by lignite and clay marl seams (Figure 3). It is extended almost in whole Komanos horst region from Askion foothill till Vermion foothills, covering 92,5 km^2 with average thickness of 260 m, and keeping reserves of water exceeding $1,6*10^9$ m^3 [3].

Figure 1. Region of research. South lignite bearing basin of Ptolemais (Macedonia, NW Greece)

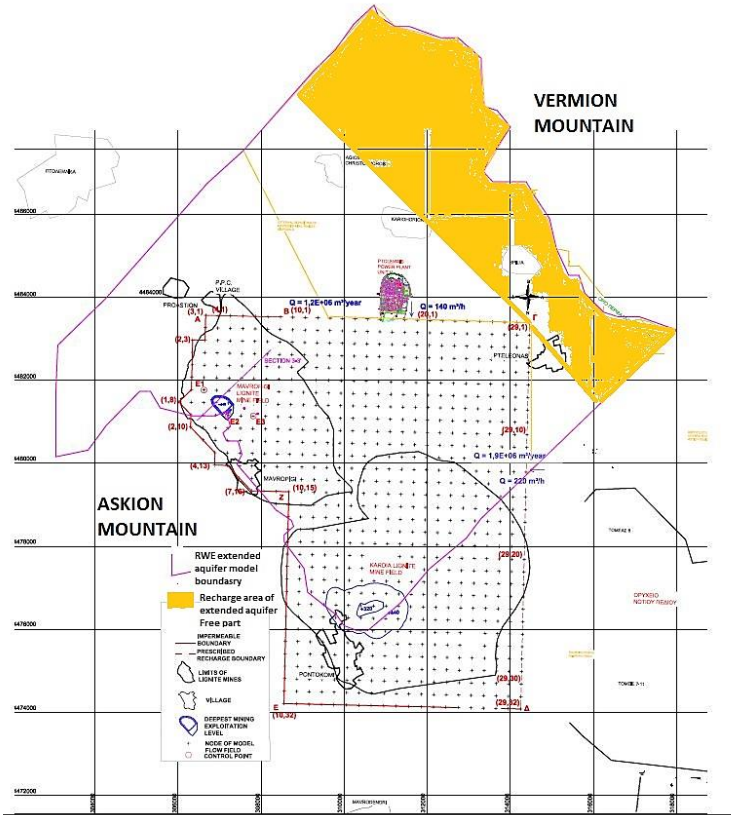

Figure 2. Mavropigi and Kardia mines layout. Water wells location map. Boundary conditions of model's layers I, II

The piezo metric groundwater levels in the part aquifer's sector that include Mavropigi Kardia mines, ranges from 600 m a.s.l. in Mavropigi region till 570 m in Soulou river let region east of Kardia mine (Figure 4.). The main direction of flow in the region of Mavropigi – Kardia mines is North Northeast to South Southwest, revealing a mean gradient 2,5% in Southwest part of Mavropigi mine, 0,25% in Northeast part of Mavropigi mine and 1% in the region of Kardia mine [4] (Fig. 4.). The recharge of this narrow area under simulation is realized by lateral inflows of the large regional Komanos horst aquifer towards the model area (Fig.4).

A general review of the results deduced by analysis and interpretation of 28 wells pumping tests performance's data acquisition indicates a range of transmissivities between 10^{-4} and 10^{-2} m^2/sec [4].

2 METHODOLOGY

Main subject of a dewatering study is the determination of basic elements needed to plan depressurizing systems. The solution of such a problem requires the knowledge of hydrological, hydrogeological conditions, the hydraulic properties of aquifer that appear in the region of mine estimation, in combination with future mine's exploitation plans scheduled.

To be specific the engineers in cooperation with geologists have to determine the number, location and technical prescriptions of drainage wells in order to avoid under the lignite aquifer inrush risk on Mavropigi and Kardia mines. The solution is based usually on mathematical model simulation of groundwater flow results [4,5,6].

In these under pressure sub lignite horizons the water level in Mavropigi and Kardia mines central part is recorded approximately at 600 a.s.l., that means 160 m higher than the prescheduled deepest stand of Mavropigi exploitation bottom's elevation of +440 m a.s.l. [7] (Fig. 8., Fig. 11.) It also means that piezometry is 280 m higher than the prescheduled deepest stand of Kardia exploitation bottom's elevation of +320 m a.s.l [8] (Fig. 8., Fig. 11.).

It's absolute necessity of depressurizing the aquifer at least at a water level of 490 a.s.l. [6], in order to secure the deeper sector of Mavropigi mine against heaving and piping underseepage hazard. This sector will be exploited into the next decade [7].

There is also a need of 160 m lowering of pressure in the region of Kardia mine. The piezometry must be reached below the +440 a.s.l. at 1.1.2032, in order to secure Kardia mine's exploitation against heaving and piping under seepage hazard, into the period 2023-2042.

Additional to these withdraws must operate a dewatering well point system for the lowering of water table after decompression complete, in order to secure the mines from classical slope stability. These quantities are expected to be significant but didn't take into account in the present simulation .

In order to design the dewatering process we used as basic tool a mathematical model, based on the solution of differential equation that describes the time variant water flow in porous media all over field, expressed as follows:

$$\frac{\partial(kx*\frac{\partial h}{\partial x})}{\partial x}+\frac{\partial(ky*\frac{\partial h}{\partial y})}{\partial y}+\frac{\partial(kz*\frac{\partial h}{\partial z})}{\partial z}=S*\frac{\partial h}{\partial t}+Q \quad (1)$$

where: kx is the permeability in X direction
ky is the permeability in Y direction
kz is the permeability in Y direction ,
h is the piezo metric head or pressure in node
S is coefficient of storage,
Q is the inflow or outflow per unit area.

This is Boussinesq continuity equation, which governs groundwater flow and naturally satisfies the preservation of mass [9]. This equation was also incorporated by McDonald et al to the first 3D MODFLOW models [10]. The system of partial derivative equations, that governs non-permanent three dimensional water flow in non - homogeneous and non-isotropic aquifer has been solved with finite difference method of slice successive over relaxation technique.

The studied part of this aquifer was simulated in two confined layers in early stages that in late stages become unconfined convertible layers [5, 14] with 1086 nodes each one. The layer I consists mainly by green fine to medium sandy with clay. The layer II consists mainly by gravel layers with sand. The nodes lie in a square grid with a distance of 300 m between them. FREEWAT Mudflow's application undertook the solution of equations' system in cooperation with Q-GIS open source [15, 16, 5], that held all geological and hydrological information.

The FREEWAT platform is based on open source solutions to perform an integrated coupling between the QGIS desktop software, surface and subsurface model engines, mostly based on fully distributed and numerically-based codes developed by the USGS [6,13], and other software applications, and the SpatiaLite spatial database[13].

When the process of evaluating and predicting groundwater flow was started, these data were transformed into files that the core program of MODFLOW2005 could read [6,14].

Simulating Mavropigi mine aquifer part three types of boundaries conditions are settled (Fig. 4, Fig. 5):

Impermeable boundaries
Prescribed recharge boundary
Prescribed heads boundary

Impermeable boundary type is considered in nodes where no flux passes through this boundary.

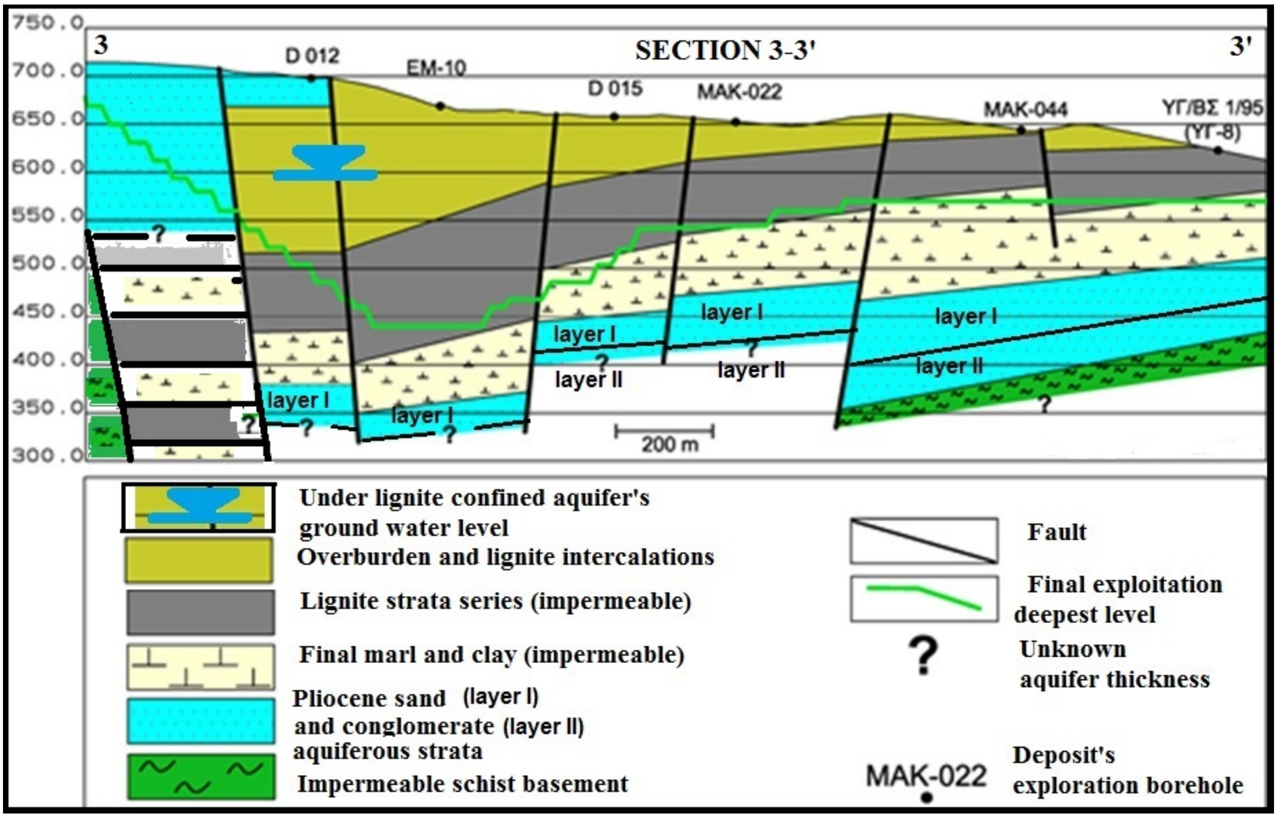

Figure 3. Two layers groundwater model

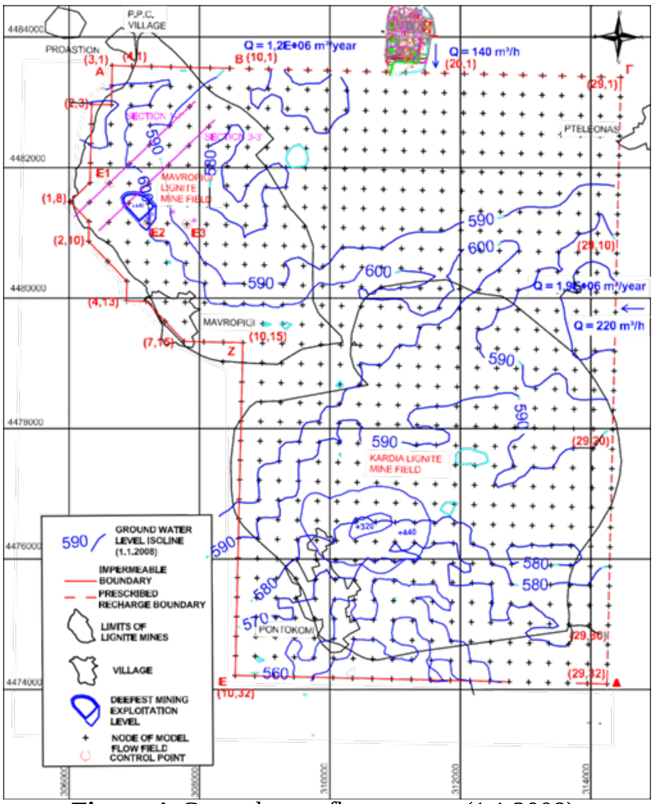

Figure 4. Groundwater flow pattern (1.1.2008).
Piezo metric equipotential lines in 1.1.2008

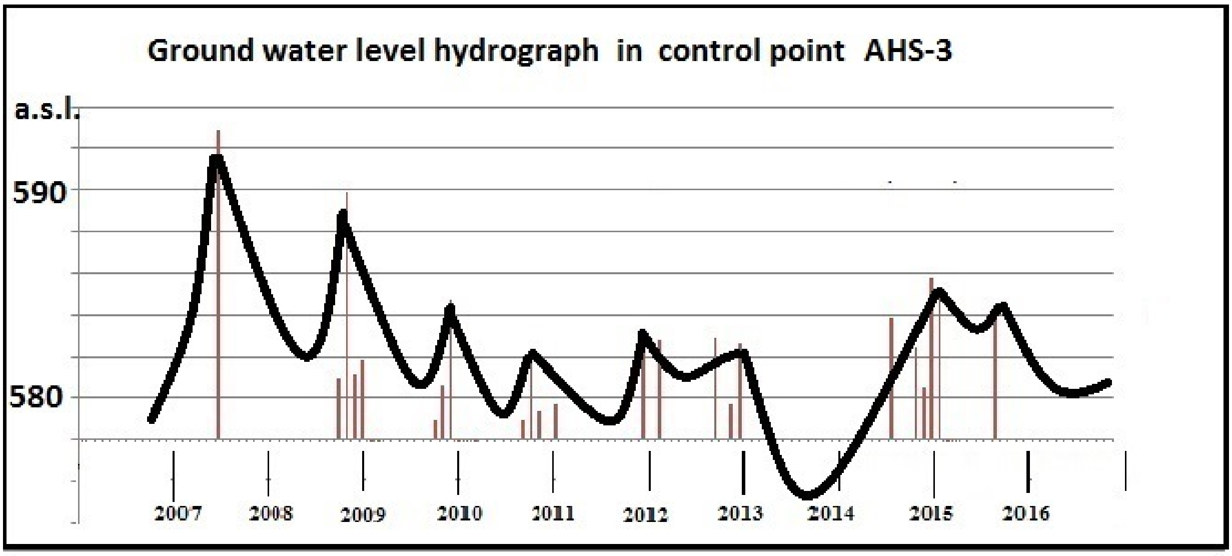

Figure 5. Prescribed head boundary fluctuation

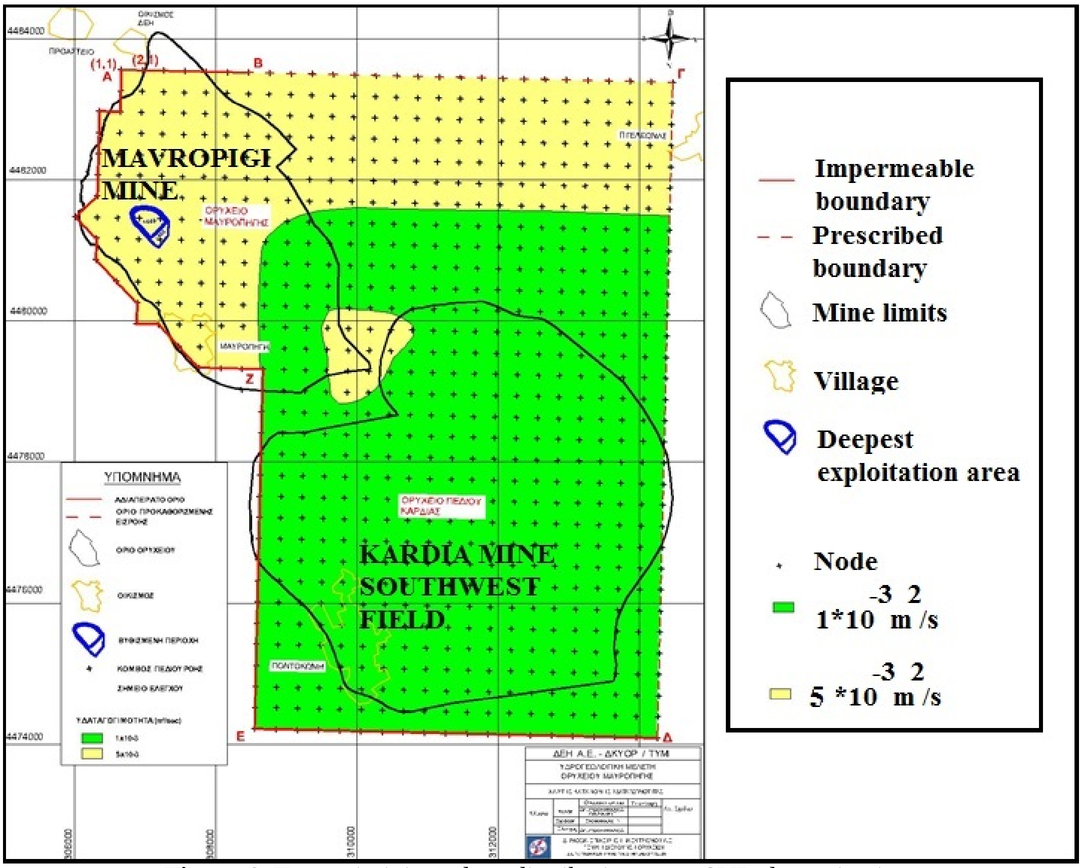

Figure 6. Transmissivity values distribution map. SVD determination.

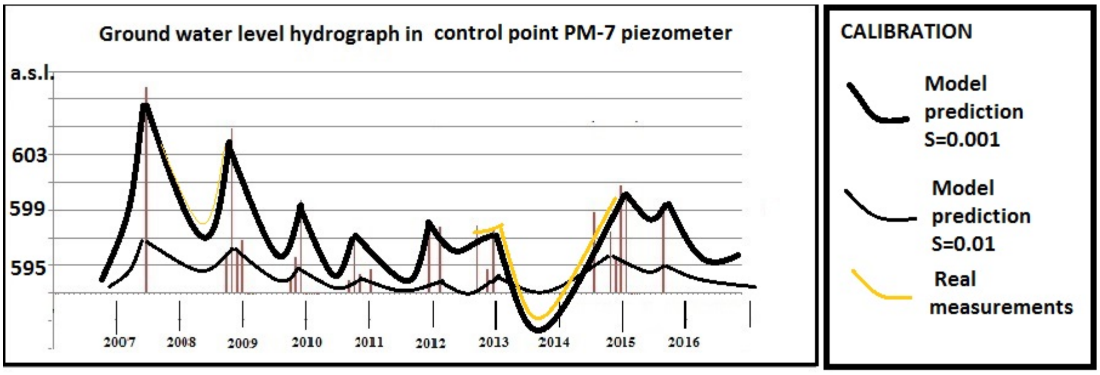

Figure 7. Storage coefficient inverse modelling determination

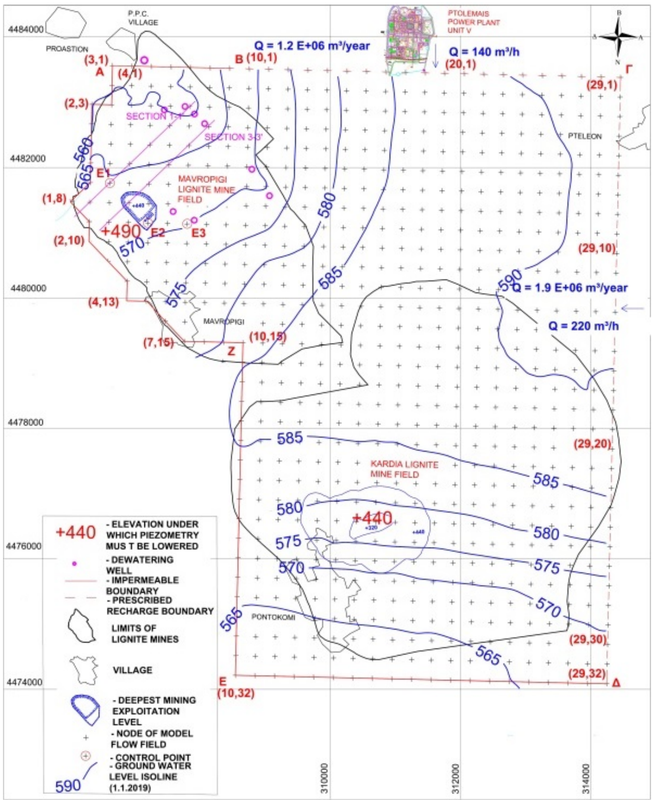

Figure 8. Prediction of groundwater flow pattern 1.1.2019. Piezo metric equipotential lines in 1.1.2019

The boundary conditions of the model were selected according to geological and hydro geological conditions of the Mavropigi mine area.

The borders between consolidated sediments schists of Askion and unconsolidated sediments of South lignite bearing Ptolemais basin were treated in West side of model net as impermeable boundary. Such a type of boundary was installed at a small part of Southeast to Northwest direction fault that separates Komanos horst from internal Ptolemais basin. In South end of model net a part of fault that separates Kardia mine from South lignite bearing Ptolemais basin is considered as impermeable.

During calibration by inverse modeling the prescribed constant head fluctuation (Fig. 5) in line ΒΓ was introduced. This flunctuation is the outcome of unsaturated zone water balance in the north east unconfined part (Fig. 6) of the hole aquifer.

By inverse modeling subroutine UCODE 2014 runs, the spatial transmissivity distribution that is depicted on figure 6 was defined and then the transmissivities were introduced (expressed as permeability's input data) to the mathematical model MODFLOW. The inverse modeling involved Singular Value Decomposition SVD technique.

As far as it concerns a storage coefficient the value of approximately 0.001 fitted the real groundwater level fluctuation with model results, after sensitivity analysis and calibration procedure. The compliance between ground water level fluctuation and appropriate storage coefficient (Fig. 7) involved weighted linear regression [20].

In late stages, while layers become unconfined a value of S equal to 0.07 is set to layer I and S equal to 0.10 is set to layer II.

The initial conditions at 1.1.2019 (Fig. 8.) of the groundwater simulation were settled as the results of a 10 year stress period (2008-2019) mean values [11,13] of recharges and out charges simulation near the date of the drainage initialization period (1.1.2019).

This simulation was carried out on an annual basis for a period of 25 years (until 2032) and aims at estimating the water inflows into the mining site during the study period, as well as planning the best possible drainage measures to be implemented, in order for the exploitation's works to continue without problems inside the mine.

For this purpose, several alternative drainage scenarios (with different pumping rates, different number of wells drilled, etc.) were investigated and simulated and the optimum one is selected. In particular, the number, location and technical characteristics of the drainage boreholes to be constructed, in order to prevent the risk of groundwater inflow from the lignite deposit's subjacent aquifer into Mavropigi mine, are specified for each scenario.

The selected scenario has three stress periods (Fig. 12.). First stress period corresponds the up till 1.1.2023 (Fig. 5.) need of depressurization the deepest part of Mavropigi. Second stress period (2023-1.1.2032) is starting depressurization of Kardia in addition with Mavropigi. In third stress period (2032-2042) Mavropigi decompression terminates and begins water level recovery in the region. Kardia's decompression is continuing in third stress period.

3 RESULTS

The model results, in the worst case scenario, estimate inflows of 950 m^3/h in Mavropigi mine, while the best dewatering design scenario (among the tested ones) that can confront most effectively these inflows in a realistic and operationally applicable way, is based on 600 m^3/h of initial pumping peripheral the exploitation and an increase of 200 m3/h to the mine internal area corresponding to 10-20 additional wells to be drilled, equipped by pumps and operate for the next 4 years (2019-2023) into mine Mavropigi.

The groundwater flow pattern prediction for 1.1.2023 (Fig. 9.), that ensures geotechnical safety in Mavropigi, indicates inverse groundwater flow direction from South to North and duplication of hydraulic gradient. Despite the zero pumping rates in Kardia region during first stress period there is a worthwhile drawdown of 40 m in Southwest lignite Ptolemais Field, but not sufficient for geotechnical safety in Kardia.

After that first stress period (Fig. 12.), that involves no dewatering to Kardia mine, the next stress period (second period) continues for 10 more years following the same pumping rates mentioned in first stress period for Mavropigi mine. Additional to these the second stress period, that ensures at his end geotechnical safety for both mines, involves 1100 m3/h pumping rates into Kardia mine (2023-2032) coming from 10-20 additional wells in Southwest lignite of Ptolemais Field.

The groundwater flow pattern prediction for 1.1.2032 (Fig. 10.) indicates rein verse groundwater flow direction from North to South and duplication of hydraulic gradient in Kardia.

The third stress period (2032-2042) years, involves decompression pumping only in Kardia region, while in Mavropigi region is finally attenuate to no pumping (Fig. 12.). The zero pumping in Mavropigi results in a partial recovery of groundwater level in Mavropigi mine neighborhood as it reveals in groundwater flow pattern prediction for 1.1.2042 (Fig. 11.).

4 DISCUSSION

The results of the method are reliable and are confirmed by the current drainage practice applied in the Mavropigi mine. This methodology is a particularly effective and an operationally useful practice for drainage planning of lignite deposits that will be or are under exploitation.

The model results on the selected scenario are reliable, confirmed by the up till now following dewatering process and subjected in calibration and future revision of the dewatering process modeling.

By incorporating the vertical component of flow 3D FREEWAT platform's application MODFLOW model, gave us the capability of simulating two layers and two possible conditions (free and under pressure state transition) that can appeared in first layer. Thus the 3D solution can be considered more accurate in comparison with the two dimensional finite difference application [4].

There is a difference between the FREEWAT application and RE finite element model. In comparison with the results of the RE finite element model [1] that overestimated the dewatering measures involving the need of more than 60 wells in order to achieve the level of +440 m.

In its conceptual model RE uses unnecessary wells patterns that cover all region of exploitation, in contradiction with our model, that installs wells only aligned along lines that would remain stable for a long time, providing a sustainable well's operational life. Indeed, as open cast mine's operations due to strip mining's excavations creates a continuously modified in topography environment that threads damages to dewatering water wells or destroys them. In contrary with partial recovery of wells technique, it is more convenient and friendly to rest mining activities the depressurizing wells group to be aligned along lines that would remain stable for a long time, providing a sustainable well's operational life.

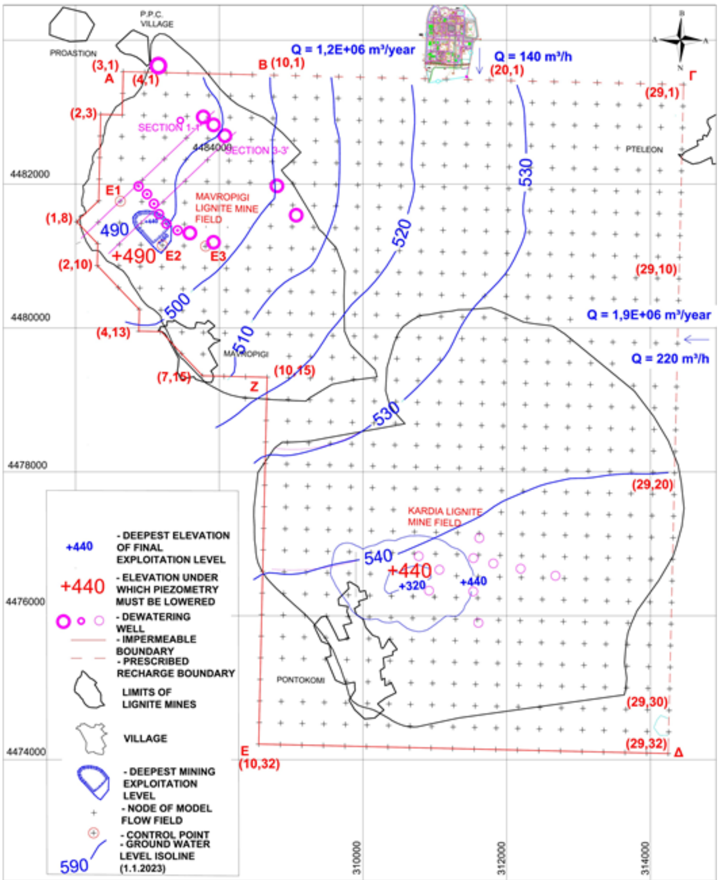

Figure 9. Prediction of groundwater flow pattern in 1.1.2023. Piezo metric equipotential lines in 1.1.2023

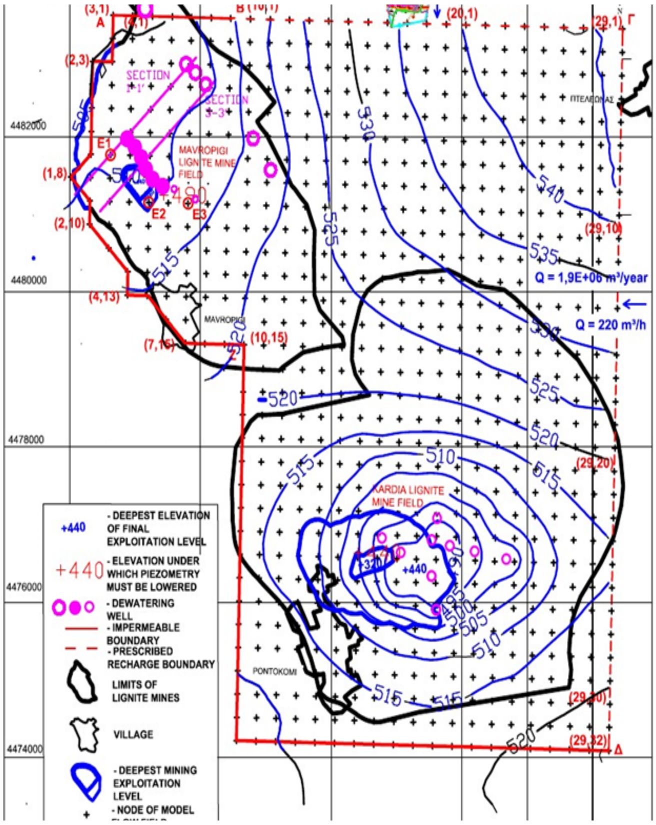

Figure 10. Prediction of groundwater flow pattern 1.1.2032. Piezo metric equipotential lines in 1.1.2032

In addition to this in the RE's flow conceptual model incorporate both decompression stage and dewatering of the remain free water table till dry, meaning lowering of aquifer till level +440 a.sl. In the present conceptual model a geotechnical study of heaving and piping risk (according to US standards of safety [19]), that precede the groundwater flow model. This geotechnical study, concludes that the safety maximum decompression ground water level in Kardia is +440 and in Mavropigi +490, meaning 50m higher than lower bottom excavations' levels.

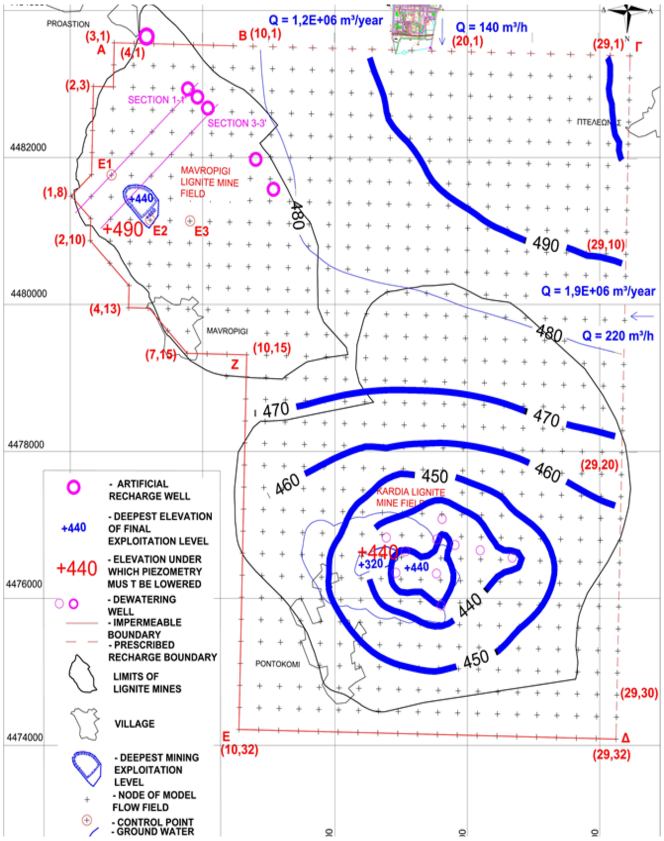

Figure 11. Prediction of groundwater flow pattern 1.1.2042. Piezo metric equipotential lines in 1.1.2042.

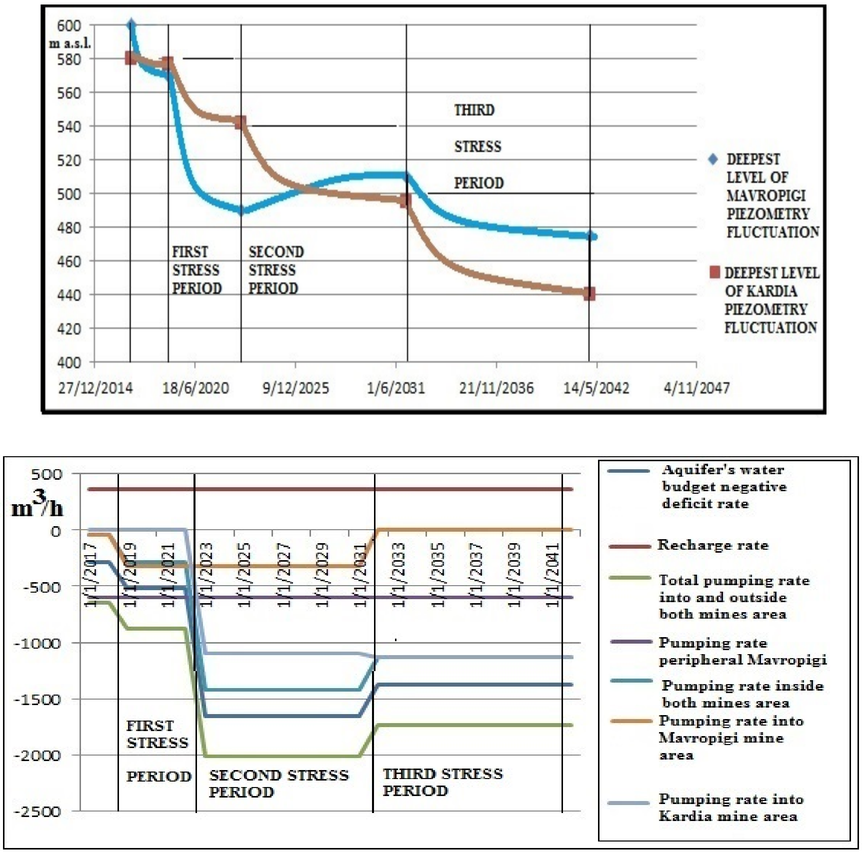

Figure 12. Subsurface hydrologic unit future water budget. Recharge and drainage withdraws rate. Ground water level piezometry prediction in deepest exploitation level of each mine

5 CONCLUSION

The results of 3 stress periods model running revealed that is feasible the decompression of the aquifer under approximately 1500 m^3/h average pumping rate in both mines. These results of MODFLOW can refeed Q-GIS data base [16] in a total holistic management of ground and surface waters of the area, that takes account also the demands of city, agriculture and industry in water.

After evaluated, by geotechnical slope stability investigation, the after decompression necessary a.s.l.of groundwater horizon, the future model's runs are called to calculate the appropriate well points discharge rates to reach this safety lowering water level.

It is suggested to proceed in investigation by modeling how likely is the implementation of artificial recharge of groundwater horizon in the region of peripheral Mavropigi dewatering wells feasible, during the third stress period, in order to compensate the environmental impacts of dewatering as fas as possible.

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