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Mining under Kalina and Selisoo Bogs

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Abstract. **Continuous developing of Estonian power engineering on the basis of oil shale requires ever taking into use of new exploration fields. When the reserve of Estonia mine is depleted, mining of the exploration field of Seli has to be started. But that field is located under the Selisoo bog which is defined as a region of the Natura 2000 network and is planned become a nature preserve. Conservationists are interested for what extent oil shale mining under the Selisoo bog and in its immediate nearness will spoil the natural water regime of the bog. To clear up the environmental impact are carried through several investigations in the Selisoo bog. As a result of modeling is proposed a perceptible lowering of water table in peat layer.**

At the same time we have a positive experience on mining under bogs and water bodies, some kilometers to the north from the Selisoo bog. In Viru mine situated under the Kalina bog there is oil shale mining practically finished for today, but the Kalina bog exists as before, also the Lake Kalina in this bog.

The aim of this research is to compare the geological and hydrogeological parameters of the Selisoo and Kalina bogs, clearing up the essential factors owing to which the mining in district of the Selisoo bog could exert a larger influence on environment than under the Kalina bog. In this paper are some measures for diminishing of the environmental impact brought on.

Keywords **– underground mining, bog, water level, precipitations, water-resistance.**

I INTRODUCTION

Observable Selisoo bog lies in Northeastern Estonia in oil shale area beside of working Estonia mine. About 10 km to the north is located the lake Kalina surrounded by a bog of the same name (Fig. 1). Under that bog the reserve is depleted already. In the Estonia mine mining activities are approaching the bog Selisoo to the west. But Selisoo is defined as a region of the Natura 2000 network**Error! Reference source not found.** and it is planned become a nature preserve [4][4]. The aim of intended nature preserve is to protect different birds and valuable natural habitats – humus alimentary lakes and lakelets, bogs and bog forests.

Therefore all measures to prevent or reduce to a minimum changes in the natural state of Selisoo need to be carefully considered. Above all it is essential that the present water conditions will not be spoiled and biotope of that place will remain.

The reserves of Seli exploration field are validated in 01.04.1998. Only in first block the productivity is over 35 GJ/m^2 what meets the requirements of proved resource. The area of proved reserve is 1964.20 ha. 248 ha of planned nature preserve remains above the Estonia mine.

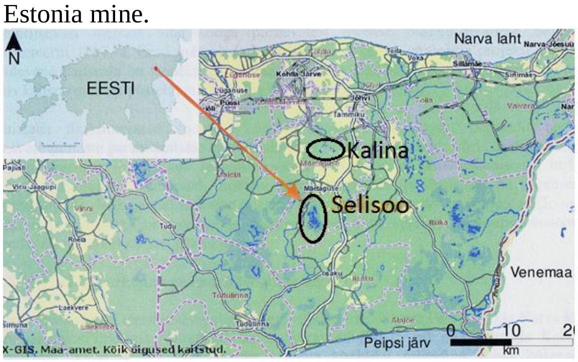

Fig. 1. Location of Kalina and Selisoo bogs [2].

II GEOLOGICAL CONDITIONS

For preservation of peatlands and water bodies in mined areas is essential the good water-resistance of sediments. In table I there is presented two geological cross-sections of observation wells in comparison [6][6]. The geology of sediments is investigated also just on shore of the Lake Kalina (borehole 1 in fig. 8) [7][7], where the thickness of little-decomposed peat was measured 1.72 m. Under peat was found 0.45 m of lake mud (gyttja) and 2.1 m clay with gravel and pebbles, containing 1 – 6 cm thick bands of sand. Sandy loam is laying in southern part of Lake Kalina, elsewhere is fine sand [7].

TABLE I
GEOLOGICAL CROSS-SECTIONS

Kalina			Selisoo		
85 0.5 km in the southeastern of the lake			233 0.8 km in the western of Selisoo		
Geol. index	Description of layer	Thick-ness, m	Geol. index	Description of layer	Thick-ness, m
QIV	Peat	3	gQIII	Sandy loam	4.5
lgQIII	Varigrained sand	1.5	O2-3nb	Fissured dolostone	9.6
O2jh-kl	Fissured dolostone	25	O2rk	Fissured dolostone	9.2
O2id	Compact limestone	7.87	O2on	Clayey limestone	3.3
O2kk	Dolostone	0.01	O2kl	Limestone	8.05
O2kk	argilliit	0.62	O2jh	Clayey limestone	10.45
O2kk	Dolomitic limestone	6.86	O2id	Clayey limestone	7.9
O2kk	Oil shale	5.53	O2kk	Oil shale	13.7
	Depth of oil shale	44.86		Depth of oil shale	53

The Quaternary cover under the Selisoo bog is 1 – 7 m thick; it is the thickest in the west of the bog above the esker of Mäetaguse and the thinnest in the northern part of bog [2].

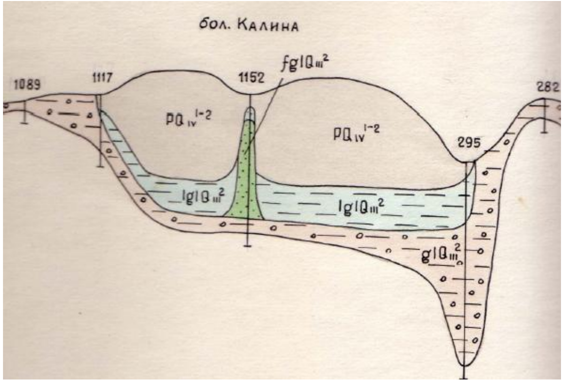

Fig. 2. Profile of Kalina bog, Quaternary deposits [13][13].

On the ground of figures 2 and 3 the both bogs are lying on a layer of silt, under what is till. Under Selisoo the silt contains 30% of pelite and 15% clay particle, which are not remarked under Kalina bog. A mound bounding the southeastern part of Selisoo is lying simply on bedrock and consists almost of pure sand, is dangerous because of large water permeability. By presence of gradient the ground water of Qaternary can move horizontally along more sandy layers in the direction of relief downfall [2].

A. Jointing

Fissured regions and crush belts are essentially facilitating the moving of water in rocks. About 5 km to the northeast from Selisoo is 50 km long and 0.5 – 2 km wide Ahtme crush belt and in the southeast 30 km long and 2 – 5 km wide Viivikonna crush belt [9]. The dislocation of Ahtme is about 800 m from Lake Kalina. The jointing belts of bedrock ranging along Mäetaguse and Metsküla eskers which width is about 150 m remain to the north from Selisoo [10]. In Viru mine the drainage of roof rocks has been largely influenced by an extensive karst belt ranging 420 m to the west of Lake Kalina along an entry on a scale of 250 m [12].

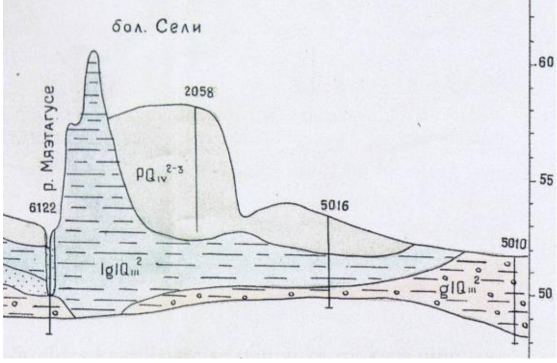

Fig. 3. Profile of Selisoo, Quaternary deposits [13].

III HYDROGEOLOGY

The Ordovician aquifer system immediately under the Quaternary deposits is formed by varying layers of limestone and dolomite. As a rule their hydraulic conductivities are irregular areally and also in profile. Joint belts spreading laterally are mostly 1 – 2 m thick [30][30]. Jointing and karst decrease with depth. The filtration rate of upper 20 m is 10 – 50 m/d, in depth of 20 – 50 m mostly 5 – 8 m/d and in depth of 50 – 100 m only 1 – 2 m/d [11][8]. Water flows downwards along vertical joints. The drain from workings neighboring karst forms 20 – 25% of whole drain [28]. In case of rare occurrence of joints we can consider filtration rate of limestones $1*10^{-3}$ m/d.

Nabala-Rakvere aquifer is separated from Keila-Kukruse aquifer by Oandu local aquitard consisting of clayey limestones and marl [14] (Fig. 4).

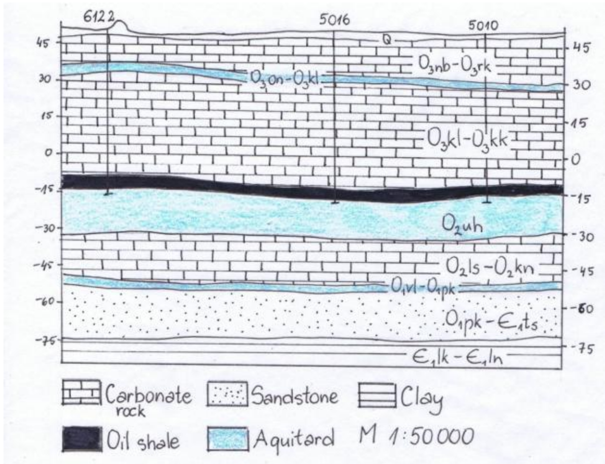

Fig. 4. Profile of Selisoo , bedrock.

Nabala-Rakvere aquifer is absent under Kalina bog. There are existing Keila-Jõhvi and Idavere-Kukruse aquifers separated from each other with bands of metabentonites [15] Local aquitard in upper part of Idavere stage can consist up to 11 metabentonite bands with thickness of 1 – 5 cm [16]. Relatively water-resistant interlayers are found also in aquifers. Practice shows that in limestone above mine is water and there is possible to ground also wells [2]. It is possible, if from sides flows enough water and at the same time vertical drain is small.

IV HYDROLOGY OF PEAT LANDS

In mires there are natural conditions for gathering and preservation of water. Both Kalina and Selisoo bog have under peat layers a mineral bottom of concave shape what has caused formation of wetland. The water of peat deposit has free surface, its depth of bedding is 0.2–0.5 m from ground in natural conditions and 1.0–1.5 m in dewatered areas. The range of water table changes yearly 0.2–0.5 m [8]. Fens feed on ground water, bogs on precipitations.

B. Kalina Bog

The area of Kalina bog is 2819 ha, from which peat extraction area covers 1239 ha [17]. Peat is produced from year 1963 to 1991. The area of abandoned peat extraction area is 107.50 ha at present [3]. The table of surface water was in October 2006 in average 1 m [3] in drainage ditches below ground surface. In autumn 2011the water table reached ground surface (Fig. 5).

Little-decomposed peat of abandoned peat extraction area has the medium thickness 0.9 m and the medium decomposition rate 17 %, well decomposed peat accordingly 1.0 m and 26 % [17]. The layer of lake mud is found on 23.8 ha in surroundings of Lake Kalina. Its thickness is about 0.5 m. Under the influence of draining in the middle part of mire the bog with stunted pines is replaced with pine bog. In places there is found hollows and treeless bog. In the northeastern part of mire water table has lowered owing to oil shale mining [8].

Fig. 5. Abandoned peat extraction field in Kalina bog (photo of J. Olikainen 2011).

C. Selisoo Bog

The area is located on slope of Jõhvi upland what is favoring the pouring of water towards the mire. The esker of Mäetaguse bounding the mire from west and on southeastern boundary located bank are hindering the runoff of water and are very essential from the standpoint of development of mire [2].

The area of bog is 2051 ha, from what eutrophic mire covers 734 ha, mesotrophic mire 359 ha and mire 958 ha [4][24]. It is typical mire with a convex surface and very rich of bog-pools. Fen is located mostly in the northern part of the mire [8], transition bog in the eastern part.

People have influenced Selisoo by drainage ditches grounded in years 1950. – 1970. Whole mire of Selisoo is bordered with ditches and fen and transition bog are practically dewatered in the whole extent [2]. In marginal areas of Selisoo the water table is in average 1 m from ground surface [5].

At present, the state of Selisoo is near to the natural. Resting upon observation of this autumn wood drainage ditches are grown over with peat moss in extent of 70% and therefore the water runoff in ditches is minimal or absent at all. Also, the former small peat harvesting fields are grown over. The water table is at a depth of 0.1 – 0.2 m in the whole area of abandoned peat fields what has created optimal conditions for regeneration of peat [25][25].

The maximum thickness of peat is 6.5 m in the mire, mesotrophical and fen peat at the outskirts is 1.0 m thick in average [8]. Filtration rates of peat of Selisoo are measured in two peat profiles $0.1 - 1*10^{-4}$ m/d [5]. In the north and middle part there is a sporadic deposit of lake mud (gyttja) which serves as a moderate aquitard [11].

In spring the largest[8] runoff was in the northern part of Selisoo and the smallest in the western part [2]. In fall runoff from the southern part exceeded the runoff from the northern part quite essentially. We can say that discharge in southern ditches is more influenced by precipitation than in northern ditches. Northern ditches gather their water rather from forest and get supplement also from groundwater what adds the stability to discharge**Error! Reference source not found.**.

D. Precipitations

The increase of amount of precipitation induces the rise of water level and herewith larger vaporization and runoff [18]. In years rich of water the surface of bog can rise 10 – 15 cm [19]. The arching of bog surface betters runoff and stops its further rise. By deep water level the runoff practically is absent. In the time of drought water level sinks the less the deeper it is. The preservation of bogs through the millenniums, as in the time of favorable as unfavorable climate periods give evidence of reliability of these natural systems. In case of sufficient amount of moisture peat mosses are accumulators of water consisting water over 90 % of their mass. As in Estonia the amount of precipitations exceeds vaporization the mires areas would expand also nowadays. For preventing it there are digged border ditches in mires [18][18].

We have about 650 – 750 mm precipitations yearly in Estonia and 470 – 480 mm vaporization. 250 – 270 mm flows away by rivers. In clayey areas the existence of plentiful nutrient salts prevents the expanding of bogs. The best conditions for formation of bogs are in areas where on clays lying sand layer prevents and unifies runoff of water. The evaporation ability of bogs is 20 – 25 mm yearly smaller than in fens.

The natural moisture content of well decomposed peat can be 500 % and for weakly decomposed peat 3000 % [20][20]. A rise or fall in water level of 10 mm is equivalent to a water gain or loss of 1 mm [21].

Evaporation measurements showed that the average summer daily evaporation above mire vegetation was about 1.5 mm. It is about 3 times less than from a mineral soil with non-limiting soil moisture content [21].

In periods abounding on water a part of hollows will form to pools [18]. In waterless climate periods a part of pool have begun to grow over. The water permeability of bog was in depth of 1.5 m 10 times and in depth of 1.0 3.3 times smaller than in depth of 0.5 m [22][22]. Only the first 10 cm of peat are able to drain off big amounts of water accompanied with rainfalls.

E. Water Conductivity of Peat

The higher is the degree of decomposition the smaller is its water conductivity. It depends also on compressibility and type of peat. In case of equal degree of decomposition the permeability of bog peats is 35 times smaller than fen peats [23]. In saturated peat difficulties between horizontal and vertical water conductivity are usually small. The results of water conductivity experiments showed that the main part of water exchange is taking place in extent of 1.5 m of upper part of peat.

F. Mines Influence

In natural conditions the range of yearly water level is up to 2 m, in spoiled conditions 8 m and yet more [1]. Very great amount of snow melting water reaches from ground surface by means of shafts, technical bore holes and karst joints right into mine [6]. About 90 – 96% of mine water comes via roofs. The coefficients of storage are dependently of season 3.2 – 63.2 m^3/t in lower northern mines and 2.6 – 7 m^3/t in deeper southern mines [15].

In figure 6 are represented hydroisohypses of upper Nabala-Rakvere aquifer before oil shale mining. The natural water level is the highest on Ahtme uplift and lowers in the direction of Lake Peipus. In figure 7 are represented hydroisohypses of same area when Ahtme, Viru and Estonia mines were working already. The water level of Nabala-Rakvere aquifer has lowered about 10 m, Keila-Kukruse 20 – 25 m and Lasnamä-Kunda 35 m. During 6 years the water table has raised in closed Ahtme mine 21.5 m.

The bale up of mine water influences above all the aquifer lying immediately on exploitation seam and the aquifer lying about 15 m deeper from it. In consequence of mining the pressure level of Ordovician–Cambrian water complex has also lowered about 20 m [14].

In the district of the Estonia mine, the radius of drawdown cone is 6 – 7 m, at the same time in Nabala-Rakvere aquifer only 1 km. The radius of drawdown cone in Lasnamäe-Kunda aquifer is 25 km [2].

Several groundwater observation wells (Fig. 9; 10) show that the water tables in Nabala-Rakvere aquifer remained stable in observing wells of Sõrumäe and Metsküla. In wells 5500 and 5504 located in the Estonia mining district the free surface of Nabala-Rakvere aquifer has lowered from year 1972 to1986 accordingly 10 and 7 m. In wells of Kalina water table has also lowered about 10 m.

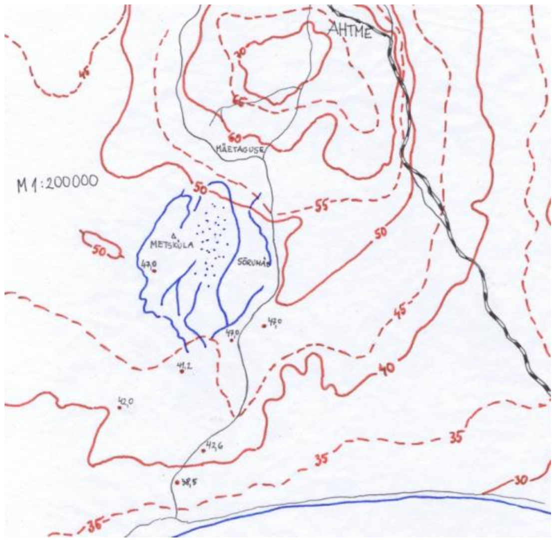

Fig. 6. The hydroisohypses of Nabala-Rakvere aquifer in 1961 [13].

Fig. 7. Hydroisohypses in year 1987 [26]. Green line – Nabala-Rakvere aquifer, blue line – Keila-Kukruse aquifer, red line – Lasnamäe-Kunda aquifer.

G. Investigations in surroundings of Lake Kalina

Research (05.1982-04.1985 a.) ascertained that water levels in Keila-Jõhvi and Keila-Idavere aquifers were lowered in comparison with static level 10 and 20 m [12]. Consequently the detachment of Quaternary aquifer from bedrock's aquifer was 10 – 25 m. Lake water can infiltrate to bedrock through the Quaternary deposits. Clear signs of leaking of mire or lake water into mine are heightened moisture, smell of hydrogen sulphide, heightened oxidation and content of NH4+ion, what was observed in entries opening the karst zone about a half kilometer away from the lake. Runoff was found as from horizontal as vertical joints and under the anchors. Discharges of runoff were 0.04 – 0.14 m^3 per hour. Measuring of lake water levels since May 1982 till August 1983 showed that the volume of lake (40000 m^3) practically didn't change. It was in 1969 the same.

Observations began again in March-April 1995 when mining operations were approached to the lake at the distance of 70 – 80 m [7]. During 11 years water level of the lake had risen 20 – 30 cm, water level of Keila-Kukruse aquifer remained practically changeless and water level of Idavere-Kukruse lowered 15 m.

In space of time 03.95 – 07.96 when excavating took place directly under the lake, only seasonal fluctuations of water tables were ascertained.

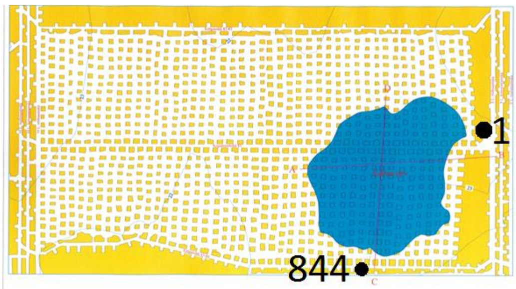

Fig. 8. Lake Kalina and the pillars in underground area.

When about a quarter of area under lake was excavated, an observation was carried through at 05.12.95 in the mine. The roof under lake was practically dry except some few moist places. Water appearance was noticed in the anomalous fissured part of an entry. From a passing energy borehole nr 844 (Fig. 8) located 35 m in the southwest of the lake the water was flowing in 4 trickles with total discharge of 0.2 l/s.

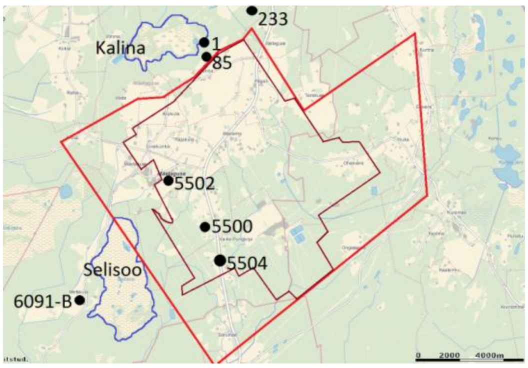

Fig. 9. The claim and depleted area of Estonia mine. Observation wells.

V Results

The influence of mining on mires water regime depends on horizontal and vertical water conductivity of limestone of the region. In surroundings of Selisoo upper Nabala-Rakvere aquifer ought to have been preserved by Oandu aquitard which water conductivity is very small - 10^{-5} m/d [30]. According to other data water conductivity of this aquitard is 0.0003 – 0.0004 m/d [2]. Nobody has specially determined water conductivities of bedrock limestone for this research.

Existing data are very different. It is not possible to determine equable water conductivity for a layer because it varies areally and also in profile.

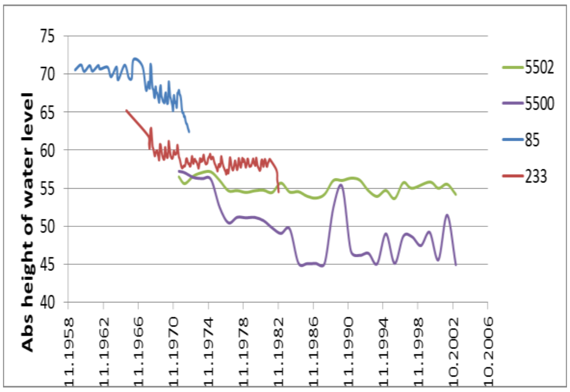

Fig. 10. Water levels in observation wells.

On the ground of data of observation wells the water table in the area of Estonia mine has lowered in upper aquifer up to 10 m. Similarly water level has lowered also in Kalina (figure).

Quarternary sediments are also not absolutely impermeable. The medial filtration rate in Selisoo is 0.39 m/d, whereas filtration rate of silt was $1*10^{-3}$ m/d and of sediments with higher clay containing $2*10^{-4}$ m/d [2]. In Kalina bog the medial filtration rate of Quaternary sediments was 1.4 m/d. Medial thickness of peat was 4.5 m in Selisoo and only 2.5 m in Kalina bog. The degree of decomposition of Kalina peat is a little higher [8]. In sum we can say that these bogs are similar by their geological conditions.

In 2012 hydrogeological modeling was carried through on an area of 16×27 km what covers Ratva bog, Selisoo and Estonia mine [5][5]. In the model there was used following filtration rates (table II). Water conductivities of carbonate rocks were partly determinated by means of fitting into working model.

TABLE II
Filtration Rates

Layer	Thickness, m	Vertical filtration rate, m/d	Horizontal filtration rate, m/d
Peat	1	0.01	0.1
Peat	up to 3.4	0.001	0.03
Peat	up to 2.2	0.0002	0.0007
Mineral soil		0.001 – 0.0005	
Nabala-Rakvere	25	0.005	40
Oandu	2.5 – 3.5	0.0003 – 0.0004	
Keila-Kukruse	45	0.01	1.2 - 7

For checking the trustworthiness of the model, calculated water tables were compared with levels measured in observation wells. If the difference was below 2 m, the result was considered good. In consequence of modeling was found out that in case of widening of Estonia mine under Selisoo water level in peat layer would lower more than 2 m, above all in southern part. Therefore an aquitard of clay or peat with water conductivity not higher than $1*10^{-5}$ m/d was considered an essential assumption. But netoinfiltration 200 mm yearly will also preserve the water level in conditions of maximal mining [5].

Also department of mining of TUT has made calculations about water level lowering in Selisoo [29]. On the ground of these results the water level in Selisoo would not lower during first 4 years after beginning of mining. Only the runoff by ditches will decrease. The depression cone ought to shape up within about 14 years. After this time the water table in bog has lowered by 70 cm.

VI CONCLUSIONS

The investigations have shown that an absolute water-resistance in case of underground mining is not possible to gain. In Estonian oil shale area the water-resistance of Quaternary and peat deposits is more essential than water-resistance of limestone. Lake Kalina is isolated from bedrock in addition to mineral sediments with a layer of gyttja up to 0.5 m thick. The filtration rate is predictably in size of $1*10^{-5}$ m/d [2]. Nevertheless nobody has determined exactly the water conductivity of that material. It is known that the layer of gyttja does not extend under the whole Kalina bog [3][17].

As regards the model there is considered the time factor not at all what makes the result quite questionable. Unfortunately whatever calculations about so large and variable geological massif are inexact. Better is to take into consideration practical experiences. Lake Kalina and the bog are preserved in spite of total underground mining (figure). Although the water level in border ditches is low, in bog there is found enough free water (Fig. 5). On the ground of investigations of year 1995 it is known that water was flowing into working 0.2 l/s. It makes 6307 m^3 yearly, as a result of which the lake had to be after 6 years practically empty. It is not happened owing to reliability of bogs in our climate where precipitations exceed vaporization. It is possible to increase the netoinfiltration in place of runoff.

Consequently the mining under Selisoo is possible without spoiling the water regime in bog in substance. It is needful to prevent peat water decrease by building dams before draining ditches. Water table fluctuations need to be followed and runoff in ditches measured. When building of ventilation roads and boring holes it is necessary to use only constructions isolating groundwater layers. Electricity and other communications have to be taken into mine underground. It is needful to avoid fissured and karstified zones at establishing of workings.

VII ACKNOWLEDGMENTS

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