Water Balance of the Selisoo Bog and its Changes Caused by Underground Mining

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I. INTRODUCTION

Continuous developing of Estonian power engineering on the basis of oil shale requires ever taking into use of new exploration fields. The productive bed close to ground surface and containing more organic substance is already exhausted and deeper oil shale beds with more complicated mining conditions need to be taken in use.

In the mine Estonia mining activities are approaching the bog Selisoo to the west (Fig. 1). When the reserve of Estonia mine is mining of the exploration field of Seli has to be started. But Selisoo is defined as a region of the Natura 2000 network [3] and it is planned become a nature preserve [17]. The aim of intended nature preserve is to protect birds like wood grouse, horned grebe, plover, crane, black grouse, wood sandpiper, willow grouse, whimbrel and greenshank, also valuable natural habitats – humus alimentary lakes and lakelets, bogs and bog forests.

Fig. 1. Selisoo and its surrounding.

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 aim of present investigation is

- To give a review of present state of Selisoo;
- To propose conditions for preserving the bog;
- To calculate the possible influence of mining on water conditions of Selisoo.

II. THE SELI EXPLORATION FIELD AND MINING TECHNOLOGY

The Seli exploration field is located in the middle of the Estonian oil shale basin. Inside the field there is a part of Muraka bog nature preserve 1738.2 ha (Fig. 2). Reserves are calculated in four blocks on area of 87 km$^2$. Proved reserve was at 01.04.1998 56 mil t and submarginal mineral resource 192 mil t [7]. Into oil shale reserve are belonging oil shale layers F1, E, D, C, B, A', and A. The medium thickness of productive bed is 2.5 m and the medium heat value 7.33 MJ/kg. Oil yield is 18 – 20%. Productivity of the first block oil shale is over 35 GJ/m$^2$ and of the second, third and fourth blocks 31 – 34 GJ/m$^2$. Initially the proved reserve was bigger but the Muraka bog nature preserve was extended in 1997. In the nature preserve the mineral resource is submarginal.

Fig. 2. The Seli exploration field.

At present room-and-pillar mining technology is in use in Estonian oil shale mines. For breaking the minerals there are made also blasting operations where an advance of face by single blasting is 4.0 m. Taking into account these conditions
it is necessary to use for calculating of column pillars with square cross-section a suitable cubic equation 0.

A pillar that has to stand eternally must not have creeping of rocks. Creeping will take place if assurance factor \( n_t < 2.3 \). Therefore, we take in our calculations \( n_t = 2.3 \) in order to avoid creeping. The extent of blasting influence depends on the quantity of explosive charge. When blasting with a long advance of face (4 m), the summary depth of breaking of room walls is 1 m, but in case of shorter (2.1 m) shot holes it would be 0.6 m. The dimension of pillar is influenced also by the height of roof. In case of higher (3.8 m) roof it is necessary to have larger pillars than in case of lower roof (2.8 m). Except of pillars’ strength very essential is the diminishing of oil shale losses. The aim is that mining losses would not exceed 40%.

### TABLE I

<table>
<thead>
<tr>
<th>Roof height ( h ), m</th>
<th>Pillars breaking extent ( q ), m</th>
<th>Pillar side length ( x ), m</th>
<th>Mining depth ( H ), m</th>
<th>Mining losses, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8</td>
<td>0.6</td>
<td>9.6</td>
<td>60</td>
<td>33.4</td>
</tr>
<tr>
<td>3.8</td>
<td>0.6</td>
<td>10.8</td>
<td>60</td>
<td>36.8</td>
</tr>
<tr>
<td>2.8</td>
<td>1.0</td>
<td>10.3</td>
<td>60</td>
<td>35.4</td>
</tr>
<tr>
<td>3.8</td>
<td>1.0</td>
<td>11.5</td>
<td>60</td>
<td>38.6</td>
</tr>
<tr>
<td>2.8</td>
<td>0.6</td>
<td>11.6</td>
<td>80</td>
<td>38.9</td>
</tr>
<tr>
<td>3.8</td>
<td>1.0</td>
<td>12.3</td>
<td>80</td>
<td>40.6</td>
</tr>
<tr>
<td>3.8</td>
<td>1.0</td>
<td>13.9</td>
<td>80</td>
<td>44.2</td>
</tr>
</tbody>
</table>

As it appears in table 1 the best variant of room-and-pillar mining would be blasting with shorter advance of face and using of lower roof. When the oil shale bed goes down to 80 m, for avoiding the excessive losses large explosive charges and higher roof cannot be used.

For maintaining the unspoiled natural state first of all it is needful to guarantee the persistence of ground surface, in order to avoid subsidence or collapse that can cause ground surface cracks and spoil the normal water conditions of Selisoo.

III. SELISOO

Selisoo is bordered by the eastern part of the extensive Muraka bog. The extent of Selisoo from north to south is 7.4 km and from west to east 3.7 km. The area is 2051 ha, from what eutrophic mire covers 734 ha, mesotrophic mire 359 ha and mire 958 ha [2][5]. It is a typical mire with a convex surface and very rich of bog-pools (Fig. 3; Fig. 6). 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 [9]. In the north and middle part there is a sporadic deposit of lake mud (gyttja) under the peat deposit, which serves as a moderate aquitard [12]. The Quaternary cover under the 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. Fairly Quaternary deposits under the bog are thinner (<3 m).

At present, the state of Selisoo is near to the natural. Resting upon observation of this autumn wood drainage ditches excavated about 50 years ago 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 [8].

Selisoo is mainly recharged from precipitations. On the ground of data of Jõhvi weather station the annual rainfall here is in average 753 mm. Vaporization is 460 mm in year [14]. Consequently, the increase of precipitation water is about 290 mm what flows by ditches in rivers during water-rich seasons.

Owing to the general southerly downfall of relief Selisoo is drained southward by draining ditches in the Milloja river. Smaller fluvial water bodies that are formerly drained eastward are directed to ditches what also carry their water in Milloja that in its turn flows in the river Roostojä. The relict lake of Seli is located in southern part of the bog, in addition there are several 3 m deep bog-pools within the mire massif. Southeast from Selisoo, there is a big artificial lake – the Milloja sedimentation basin of the Estonia mine. The draining ditch marking the north boundary of Selisoo directs its water gathered mostly from the southern slope of Jõhvi upland in river of Mäetaguse.

The Ordovician aquifer system immediately under the Quaternary deposits is formed by varying layers of limestone and dolomite, which abundance of water and hydraulic conductivity depend on jointing and karst. As a rule they are irregular areally and also in profile. Joint belts spreading laterally are mostly 1 – 2 m thick [11]. 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 [12].

In the observable region of Ordovician water system, there are distinguished Nabala-Rakvere, Keila-Kukruse and...
Lasnamäe-Kunda aquifers separated from each other with local aquitards [15], (Fig. 4, Fig. 6). Ordovician aquifer system is recharged from overlying Quaternary aquifer and groundwater drain coming from Pandivere upland. Nabala-Rakvere aquifer is an essential influencer of water flowing into Estonia and Viru mines. Keila-Kukruse aquifer is represented by fissured and occasionally karstified dolomitized limestone. The saturated zone in Selisoo region is ca 30 m thick, in the region of working mines the water table is lowered until to aquifers base.

First of all the Keila-Kukruse aquifer is dewatered by mining. From Nabala-Rakvere aquifer, the water reaches mine through the Oandu relative aquitard what is represented by clayey limestone and marl or by local fissures and boreholes and ventilating holes.

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.

Several groundwater observation wells are drilled near to Selisoo (Fig. 5). 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 to 1986 accordingly 10 and 7 m. It is not known exactly what causes such a lowering of water table above Oandu aquitard. Probably it is caused by boreholes and shafts. Water table of the observing well 5503 located in the mining district has lowered 34 m.

For calculating the groundwater components of water balance Darcy’s formula is used

\[ Q = FkI, \]  

where \( Q \) is ground water discharge (m³/d), \( d \) is a 24-hour day, \( F \) is the square of current cross-section (m²), \( k \) is filtration rate of ground water (m/d) and \( I \) the gradient of hydraulic pressure.

\[ I = (H_1 - H_2)/L, \]

where \( H_1 \) and \( H_2 \) are hydraulic pressures in different cuts (m) distance between which is \( L \) (m).
For calculating of the groundwater outflow from bog $H_1=50$ m, $H_2=45$ m and $k=0.39$ m/d [5] what is the medial filtration rate of Quaternary deposits. In this manner the calculated outflow was 1160 m$^3$ in a year.

Even on heavily ditched peat production areas the water discharge is very small [10]. The volume of peat deposit of Selisoo is 50 mil m$^3$. Supposing that medium hygroscopicity of peat deposit is 85% then the whole amount of water being included in peat is 42.5 mil m$^3$. The water in the peat deposit is a very important characteristic what helps to prognosticate lowering of water table in bog in case of underground mining.

On the ground of described calculation was composed the Selisoo water balance of peat deposit what corresponds to medium natural water regime of last years in investigated region. After underground mining is started, water needs to be pumped out from workings. As a result, lowering of pressure in overlying groundwater layers is taking place. The quantity of water flowing into dewatered mine was calculated on the ground of vertical filtration formula [13].

$$Q = FKI,$$  

(1)

where

$$K = L/(L_1/k_1 + L_2/k_2 + ... + L_n/k_n)$$  

(3)

$K$ is medial vertical filtration rate of the system (m/d), $L$ is the whole thickness (m), $L_1$, $L_2$,...,$L_n$ mark thicknesses of single layers and $k_1$, $k_2$,...,$k_n$ vertical filtration rates of these layers (Table 2).

**TABLE II**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Composition of layer</th>
<th>Filtration rate, m/d</th>
<th>Thickness, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Peat</td>
<td>0.002 – 0.0002</td>
<td>4.5</td>
</tr>
<tr>
<td>L2</td>
<td>Terrigenous sediments</td>
<td>0.016</td>
<td>3</td>
</tr>
<tr>
<td>L3</td>
<td>Limestone of Nabala-Rakvere aquifer</td>
<td>1.0</td>
<td>17</td>
</tr>
<tr>
<td>L4</td>
<td>Marl and clayey limestone of Oandu aquitard</td>
<td>0.00001 [6]</td>
<td>2.3</td>
</tr>
<tr>
<td>L5</td>
<td>Limestone of Keila-Kukruse aquifer</td>
<td>0.5</td>
<td>41</td>
</tr>
</tbody>
</table>

Water balance in Selisoo is presented in table 3.

**TABLE III**

<table>
<thead>
<tr>
<th>Precipitation</th>
<th>Vaporization</th>
<th>Lateral ground-water inflow</th>
<th>Lateral ground-water outflow</th>
<th>Vertical water flow into mine</th>
<th>Subsoil water outflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.38</td>
<td>9.43</td>
<td>0.63</td>
<td>0.001</td>
<td>2.00</td>
<td>4.57</td>
</tr>
</tbody>
</table>
Based on observing data of well 5500 (Fig. 5) we can see that water table has lowered there about 0.68 m every year. If to suppose that the same situation will repeat in Selisoo, the question is, when will we see water table lowering in bog? On the ground of calculations during the first four years the water balance in Selisoo remains positive although outflow of subsoil water decreases. Only fifth year we can observe water table lowering by 5 cm. The depression cone ought to shape up within about 14 years. After this time the water table in bog has lowered by 70 cm.

IV. CONCLUSIONS

- Present state of Selisoo is near to the natural. The water regime in the bog is keeping its balance.
- Although the amount of water flowing into planned underground mine is quite big, thanks to the ability of peat to bind with it water the bog does not necessarily dry out to an essential extent.
- To prevent peat water decrease by building dams before draining ditches.
- The sustainability of biotope has to be predicted by biologists on the ground of supposed water regime.
- Water table fluctuations need to be followed and runoff in ditches measured.
- Geophysical investigations would help to determine more precisely the filtration parameters of overburden above the mine.
- 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.
- Avoid fissured and karstified zones at establishing of workings.

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REFERENCES