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WATER PROBLEMS CONNECTED WITH OIL SHALE MINING IN NORTH-EAST ESTONIA

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This paper presents a short overview about the discussion about the hydrogeological problems connected with oil shale exploration in NE Estonia. On the basis of the results of the solution to the hydrogeological model developed at Geological Survey of Estonia it was found that the proportion of unconfined groundwater in different open-cast mine fields accounts for 6–34% and precipitation water makes up 66–84% in the depleted area. Presently a unified groundwater model of Estonian–Russian border region comprising a 200×200-km area north from Lake Peipsi is being compiled under the initiative of French Geological Survey (BRGM).

Introduction

On 20 January 2006 a seminar to discuss the problems of North-East Estonian water resources was held in Tallinn University of Technology. The need for such a discussion was caused by the exaggeration of the negative effect of oil shale mining and use in an analytical overview published in December by Gavrilova et al. [1]. The authors of the overview stated that the aim of the publication was to give the first complete overview also to lay persons about the world's only power engineering based on oil shale and the problems involved.

After the overview was published, all scientists who have studied problems of oil shale mining and use agreed that the overview had a number of shortcomings:

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- The overview does not include any new information, being a selective review of data published earlier to mention nothing but the gross efficiency of oil shale-based power generation – 12–15% [2].
- The overview focuses on negative phenomena whereas little attention is paid to measures improving the environment and the positive effect of the oil shale industry on the environment such as increased cultivation value of land, improved quality of water supply [3, 4].
- The overview does not include any constructive proposals; the alternatives mentioned (dispersed, renewable and solar energy) have all been considered in recent national development programs.

Member of Academy D. Kaljo acted as the moderator of the discussion. Among the participants were professors R. Vilu and L. Vallner, the authors of [1]; Head of the Hydrogeology Department of Estonian Geological Survey R. Perens; Professor E. Reinsalu from the Department of Mining of Tallinn University of Technology; and Dr. E. Puura, Deputy Director of the Institute of Technology of University of Tartu.

The most important standpoints presented at the discussion by R. Vilu and L. Vallner were as follows:

- The groundwater circulation of Ida-Virumaa produces water with undesirable impurities, which make the water practically unsuitable for drinking
- The only aquifer system that has been well protected in Ida-Virumaa so far – Cambrian–Vendian (Gdov) – is overexploited, its quality does not meet requirements for drinking water
- Mineralization level of Cambrian–Vendian water is in places too high and it contains radionucleids, being therefore unsuitable for use as drinking water without dilution
- Closure and drowning of mines complicate the situation
- The status of groundwater (as a whole) in Ida-Virumaa does not meet the sustainability criteria of the EU Water Framework Directive, and it is obviously impossible to prove that the water supply of the towns in Ida-Virumaa can be solved on the basis of groundwater

Although, to some extent, these statements had already considered the criticism, a lively discussion developed at the seminar. The following problems were the most important ones discussed:

1. Direct dewatering of the mining area
2. Lowering of the groundwater level in the drainage cone formed
3. Deterioration of the quality of groundwater and drained water
4. Impact of the water reservoirs formed in the exhausted mining areas on the groundwater and surface water regime

Summary of the discussion

Environmental problems in North-East Estonia, which are mainly connected with the exploitation of the Estonian oil shale basin, date from the first decades of the 20th century. A favorable geographical location, variegated natural resources such as oil shale, Dictyonema argillite, raw material for lime production and building materials enabled to build up a strong energy basis and an industrial complex based on it. Economic activity in this region has been based on oil shale. Over the times more than a billion tons of oil shale has been excavated from an area of 430 km^2 of this basin; both surface and underground mining at depths up to 70 m have been practised. Mining has brought about numerous environmental problems, which became especially serious at the end of the 1980s.

Over the decades scientists have developed various concepts to mitigate environmental problems connected with mining, and these have been partly also used in practice. Thus, large amounts of materials concerning changes in the natural and man-made environment due to oil shale mining in North-East Estonia [3–6] have been published. The importance of these publications is wider than just solution of problems connected with the Estonian oil shale basin.

Oil shale mining is accompanied by lowering of the water level and discharge of mine water into bodies of surface water. The total amount of drained water is formed from precipitation water, surface water, subsoil water (unconfined groundwater) and confined groundwater, and mine water is actually a part of the natural cycle of water; the components of the balance of water pumped out from open-casts and underground mines differ significantly.

In the southern part of the Estonia mine and Narva open-cast (Fig. 1) the Keila-Kukruse aquifer is confined (layers that are well isolated from recharge by precipitation) [7]. To calculate the balance of mine water inflow, results of groundwater monitoring as well as hydrogeological modeling were used. The hydrogeological model used was developed by the hydrogeologists Savitski and Savva from the Geological Survey of Estonia for the central part of the Estonian oil shale field and Aidu open-cast [8]. In the case of Narva open-cast, which consists of Viivikonna, Sirgala and Narva open-cast fields, analytical solutions based on hydrodynamic equations were used to estimate the groundwater component.

The area of the mines flooded and becoming filled with water is presently over 220 km^2, the volume of water in these mines is more than 170 mln m^3. On the basis of the results of the solution to the hydrogeological model developed at the Geological Survey of Estonia, and also Department of Mining TTU it was found that the inflow from closed flooded mines to the Viru mine amounts to 26 000 m^3 a day or 45% of the total inflow, and the inflow of unconfined groundwater makes up 55% (Table 1).

Although the Estonia mine is located at a much greater depth than the Viru mine, the long-term dynamics of the inflow to the latter mine also shows a rather great dependence on weather conditions. This is evidenced by the factor of irregularity of the monthly inflow, which fluctuates in the range 2.0–3.3.

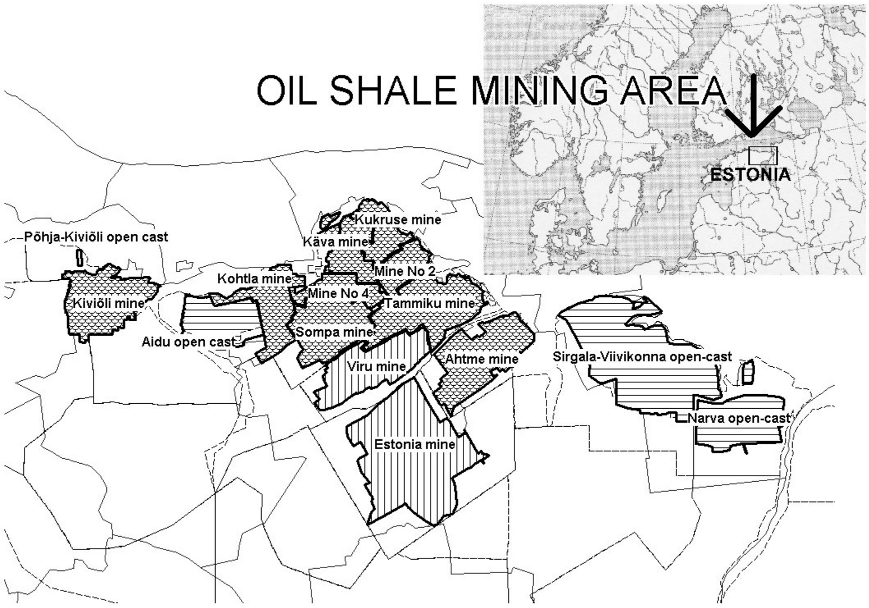

Fig. 1. Underground and surface mines of the Estonia oil shale deposit

In the Estonian oil shale field the operating units are presently Aidu open-cast mine and its Vanaküla mining field; Narva open-cast mine, which consists of Narva, Sirgala and Viivikonna open-cast fields and Põhja-Kiviõli open-cast mine (Fig. 1). Calculations of the components of the inflow balance of open-cast mine fields are presented in Table 1. It can be seen that

Table 1. **Distribution of water pumped out from underground and open-cast oil shale mines, %**

Mine	Groundwater, %			Inflow from flooded mines	Water infiltrating back from outflow canals	Precipitation water	Water drained in 2004, m^3/d
	Unconfined	Confined	Total				
Viru underground mine	55	–	55	45	–	–	56,543
Estonia underground mine	47	26	73	20	7	–	208,018
Total underground mines	**51**	**13**	**64**	**32.5**	**3.5**	**–**	**264,561**
Narva open-cast mine, Narva department	10	10	20	–	–	80	55,032
Sirgala department	6	10	16	–	–	84	83,765
Viivikonna department	34	–	34	–	–	66	51,144
Aidu open-cast mine	27	–	27	54	–	19	168,736
Total open-cast mines	**19.25**	**5**	**24.25**	**13.5**	**-**	**62.25**	**358,677**

confined groundwater makes up 10% of the total inflow, the proportion of unconfined groundwater in different open-cast mine fields accounts for 6–34%, and precipitation water makes up 66–84% in the depleted area.

An important problem is prognostication of hydrological processes after the depletion of mineable seams and shutting down of mines. In connection with the shutting down of four depleted mines (Kohtla, Sompa, Tammiku and Ahtme) in 2000–2004 a large technogenic underground body of water was formed in the mining area. The water in the area filtrates from one mine to another and feeds the waters of operating mines. As the closed mines are fed by precipitation, the proportion of confined groundwater in the mine water has fallen to a fifth by today.

A heated discussion developed regarding the quality of the water pumped out from the mines and its impact on the environment. Mining activities have a direct influence on groundwater quality due to the use of machinery (blasting, fuel and oil residues, etc.). Kinetics of oxidation reaction changes significantly as a result of grinding rocks and access of air oxygen due to the lowering of the water level. Because of oxidation of pyrite occurring in Ordovician rocks the water pumped out from mines contains large amounts of sulfates; their concentration is up to 500 mg/l. Sulfates are easy to analyze and therefore good indicators for the description of the movement of mine waters. Sulfates are a potential threat to the environment as in a strongly anaerobic environment the release of toxic hydrogen sulfide may occur. Long-term research conducted in the neighboring Kurtna Nature Reserve, where on the basis of some lakes systems for directing pumped-out mine water have been established, shows that compared to 1937 the concentration of sulfates in through-flowing lakes has increased tens of times [5]. At the same time in the nearby closed lakes where the oxygen-poor hypolimnion formed under the influence of thermal stratification should create a potential environment for the formation of sulfides, no infiltration of sulfates has occurred. Investigations of the bottom sediments of through-flowing Lake Nõmmejärv (to which mine water is discharged after primary sedimentation) showed that the discharge of mine waters beginning from the 1970s has dramatically altered the state of Lake Nõmmejärv ecosystem, recorded by the composition of sediments [8]. Huge amounts of suspended mineral matter, incorporated by these waters, have caused a rapid decrease of organic matter in sediments and increased the input of elements typical of oil shale (Ce, Hf, La, Sc, Yb). Diatom communities have also altered, the abundance of epiphytic species reflects an intensive influx of mineral matter. According to diatoms there is also evidence of increased phosphate and macroelements in the water. Beginning from the early 1980s the state of the lakes seems to have improved. This conclusion is made on the basis of decreasing concentration of metals in surface layers, also the diatom communities tend to slightly change towards their pre-industrial state. It should be noted that the colder and relatively oxygen-rich mine water has had a positive effect on the status of some water bodies retarding the influence of anoxic conditions prevailing in the hypolimnion. There is also evidence that the decreasing amount of pumped-out mine water has a negative influence on the quality of the water of some rivers due to the decreasing amount of water in them [9].

Another set of complicated problems in this region is connected with power engineering and chemical industry. Compared to mine water, the substances leaching out of the production residues of these sectors affect the environment more seriously. Although in the region long-term geochemical investigations have been carried out, it is often impossible to distinguish the effect of mine waters on ecosystems as a large number of other factors are involved, especially intensive deposition of fly ash emitted by the power plants into the atmosphere in the 1970s–1980s.

After mines are closed, step-by-step restoration of natural conditions of the groundwater filling the mines starts – sulfates are carried out, the effect of air oxygen on the mineable seams that used to be drained disappears. As a result, oxidation of pyrite diminishes, and the mineral content of the water pumped out decreases. Quality studies of mine water have shown that in about five years after the closure of a mine the content of sulfates and iron decreases below the maximum permitted level in drinking water. The highest permitted content of iron in first-class drinking water is 0.2 mg/l and that of sulfates 250 mg/l [10].

During the presentations and the following lively discussion a number of problems were raised that are especially topical in connection with the objectives set by the Water Framework Directive 2000/60/EC.

One of the topics discussed is the harmony of estimating the proved groundwater reserves in North-East Estonia with the European Union Water Framework Directive. The Cambrian–Vendian aquifer system is the main source of supplying inhabitants of Ida-Virumaa with water. The largest withdrawal of water from this complex occurred in 1991 when the total withdrawal was over 60,000 m^3/d. As a result of the intensive use, in the 1990s the potentiometric surface sank deeper than 50 m below sea level in the area of Kohtla-Järve–Jõhvi, and an extensive drawdown cone was formed. As in the Gulf of Finland the aquifers lie below the Quaternary deposits, there exists the danger that brackish sea water may some time intrude into aquifers.

Conclusions

Presently no deterioration of the groundwater quality can be observed. As compared to the early 1990s, the withdrawal of groundwater has decreased over three times (in 2004, 17,065 m^3/d), and therefore also the potentiometric surface has continuously risen. In connection with new requirements to the quality of drinking water, in 2005 the Geological Survey of Estonia recalculated the groundwater reserves of the Cambrian–Vendian aquifer system [8]. The forecasts based on the hydrodynamic model show that during the prognostication time (until 2035) no intrusion of salty water will occur. Of course, in parallel with water consumption it is necessary to continuously monitor the quantitative and chemical status of groundwater so that measures could be taken if any negative trends were observed. As the Cambrian–Vendian aquifer system has been declared a transboundary groundwater body, improved co-operation with Russia in monitoring its status and using its water reserves is necessary. Presently a unified ground-water model of Estonian–Russian border areas is being compiled under the initiative of the French Geological Survey (BRGM), which comprises a 200×200 km area north from Lake Peipsi.

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