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THE IMPACT OF INFILTRATION DAM ON THE GROUNDWATER REGIME IN THE KURTNA LANDSCAPE RESERVE AREA

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The area of Kurtna Landscape Reserve is situated between oil shale mines. This area is an important part of the Estonia deposit, and the located mining conditions there are good. Narva surface mine pumps groundwater from the area of Kurtna Lakes. It is able to minimize the influence of surface mining. Testing of mining technology and hydrogeological modelling show that mine front may be closed for stopping water flow instead of leaving an open trench by the border of the area of the lakes. According to modeling, hydraulic conductivity of the dam must remain 0.1 m/d to avoid sinking of water level in the lakes, and filtration basins must be supplied with water in an amount of 7000 m^3/d as yearly average. As the result, the landscape will be reclaimed, overall look and shape will be smoothed. Abandoned fields of peat milling will be reclaimed, and their fires will be avoided.

Introduction

The influence of the power and mining industry on Kurtna Lakes located in the centre of the oil shale mining area in North-East Estonia has been a discussion object for the last fifteen years. Oil shale mines surround the area of Kurtna Lakes. There are 40 lakes in a 30-km^2 area above a 70-m deep buried valley [1]. Two mines – Estonia and Narva – exert the greatest influence on this. Both mines pump out water from the area and lead it back to the lakes or rivers in the same area. The question is how much the mining influences protected lakes and species. Besides Narva surface mine neighbouring the lakes has claimed the permission to pump groundwater from the lake area (see Fig. 1). Surface mining was stopped at a distance of 2 km from the protected area since the problem had not been solved, thus the mining company asked independent research groups to perform corresponding analyses and to test the mining technology used in this area.

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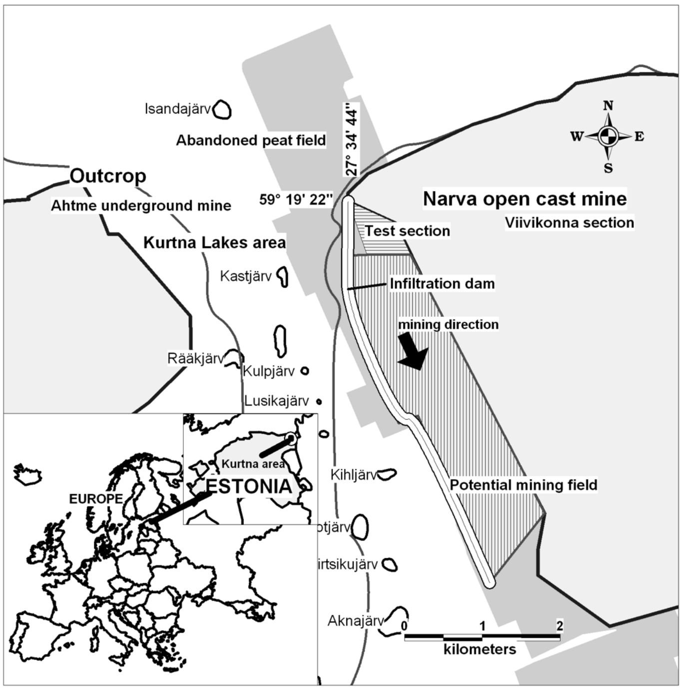


Fig. 1. Location of the Kurtna Landscape Reserve, mining section and infiltration dam

There are two main reasons for mining oil shale in the area. The first reason is oil shale resource. Local reserves represent an important part of the Estonia Oil Shale Deposit [2]. Energy rating of oil shale is one of the best among the potential mining areas reaching 44 GJ/m^2, and depth is relatively low (10 to 15 m) compared to 22 m in the rest part of the surface mining area [3, 4]. This resource is of great economical importance because when mined, total costs of mining will remain stable. On the other hand, pressure on mining oil shale in unsuitable areas will become actual in the future [5]. From these aspects, the application for mining permit is reasoned.

Since Estonian main oil shale-fired power plant has been renovated, and new boilers require oil shale of a more stable quality than the former ones, the need for oil shale mining remains actual for at least 25 years, which corresponds to the resource in current minefields [6]. New power units operate applying a new, fluidised-bed technology that guarantees less impact on the environment. Total resources of oil shale in the Estonia deposit guarantee operating of power plants for 60 years [2, 5].

Due to low oil shale quality in the most part of the deposit and additional environmental restrictions, the quantity of mineable oil shale is not as great as it seems. Compared to 50% total loss of oil shale resource in the case of underground room-and-pillar mining, the loss in open cast mines reaches 30% [7]. The losses are due to differences in official and actual resources and oil shale remaining in supporting, protective and barrier pillars. As for the usage of resources, surface mines are more valuable [8]. The main problems concerning mining fields are related to mining conditions and environmental restrictions. Surface mining is reaching depth limit, while underground mining is confronted by low quality of oil shale, bad roof conditions and environmental restrictions [4, 9]. For these reasons continuation of mining in the section neighbouring the area of Kurtna Landscape Reserve is advisable. Mining in the test section should be performed under continuous monitoring for calibrating dynamic modelling with groundwater software.

Influence of oil shale mining on the area of Kurtna Landscape Reserve

The influence of mining on the lakes has been investigated from the hydrogeological aspect, recommending the usage of infiltration basins and regulation of water flow [10–14]. Water chemistry has been investigated proceeding from the effect of oil shale mining on sulphate content of water [15]. The influence on the landscape and plants has been studied by analysing plant species and mining waste [16–19]. The set of water wells and lakes in the water monitoring program has been set to analyse changes in ecological situation. Unfortunately, it has not given a clear answer to the question about the influence of mining on the groundwater flow in the area. The reason for that has probably been complexity of situations and lack of an interested party who would evaluate all the aspects concerning this region.

The closest lakes (Kastjärv, Aknajärv, Jaala, Kihljärv, Nootjärv, Valgejärv and Virtsiku) are located in a distance 1.5 to 3 km from the front of Narva surface mine. Data of observation wells show that the level has not been remarkably changed due to surface mining operation during the last five years. All these lakes are located in the area of boggy, glaciolacustrine and -fluvial deposits. Drawdown of groundwater has been formed due to an intensive consumption of groundwater at the water intake in the central part of the Vasavere buried valley. Quaternary aquifer is an unconfined water-bearing stratum. The values of porosity and permeability of Quaternary aquifer depend to a large extent upon the degree of sand cementation. Consequently, these values are generally expected to be much higher for the central part of the valley than for the slopes. A study of the samples shows that porosity values exceeding 33% are common for the central part, whereas those less than 20% are usual for the southern part of the valley. Similarly, intergranular permeabilities average 2500–2700 $m^3\,d^{-1}m^{-2}$ in the central part and drop to 10–50 $m^3\,d^{-1}m^{-2}$ at the border of the valley [20]. Seasonal factors, changing flow and various forms of recharge may all produce fluctuations in the water level of about 1 m.

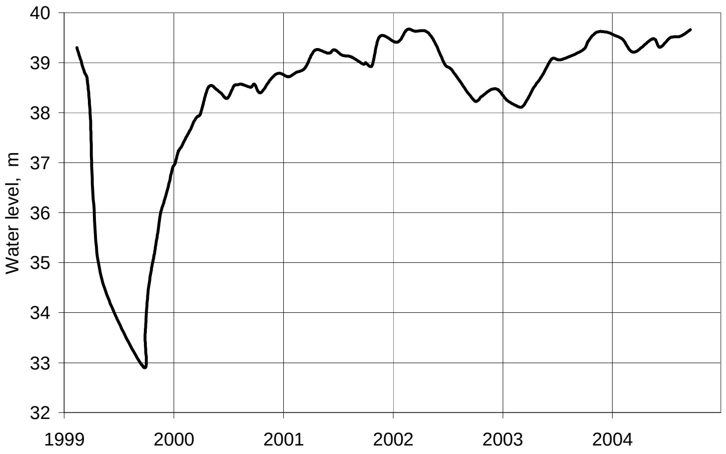


Fig. 2. Sinking of water level shows sand inflow to the trench and quick normalisation of the state after closing the flow. Water wells B 6-1 ja B 6-2 are located between Lake Kastjärv and the dam

Fig. 3. Technogenic valley formed after sand flow into the trench in March 1999

Water table of L. Valgejärv lowered 2 m in 1984, caused by water usage for stopping peat fires. For the year 1996, water level was normalised again. Only one remarkable event happened in 1999 when sand basement of the peat field flew into mining trench (see Fig. 2, 3). This happened because the spoil was piled on ice, and when ice melted sand spoil became unstable. The water-table diagram shows that original water level was restored quickly after closing sand inflow.

Mining technology

The influence of Narva surface mine at the east side of the lakes’ area could be minimised. First, the mine front can be closed for stopping water flow instead of leaving an open trench in the border the area of lakes. Second, the overburden material that is used for closing the trench can be piled in such a way that it has lower permeability than soil in the nature. Besides, a part of that area is covered with abandoned fields of peat milling. Thickness of the residual peat layer reaches up to 3 m being a good material for decreasing permeability of the final dam material. For testing these assumptions, a test section was planned and designed by Mining Department of Tallinn University of Technology in 1997. The purpose was to test whether the filtration dam will decrease the sinking of water level in the area. Test mining in this section started in 1998. The idea originated from dam-piling experiences in the same mine where a dam has been piled with careful dumping and mixing of overburden material (see Fig. 4). This resulted in accumulation of water behind the dam, a water body now called Lake Vesiloo named after the designer of the dam. Water level in the upper lake has remained stable for 45 years, which proves permeability of piled overburden material consisting of limestone, clayey sand and peat.

For evaluating the influence of mining on a larger area, a modflow-groundwater model was set up by independent company AS Maves in co-operation with Mining Department of Tallinn University of Technology [19]. The model is supported by continuous monitoring of water wells and mine-dewatering data.

For closing the existing open trench, placement of mine front and stripping technology were changed. The direction of mine front had to be changed by 45 or 90 degrees (see Fig. 5). This could enable building of an infiltration barrier between the lakes and the mine at the end of the trench where only a 30-m-wide pit would be temporarily opened for water infiltration.

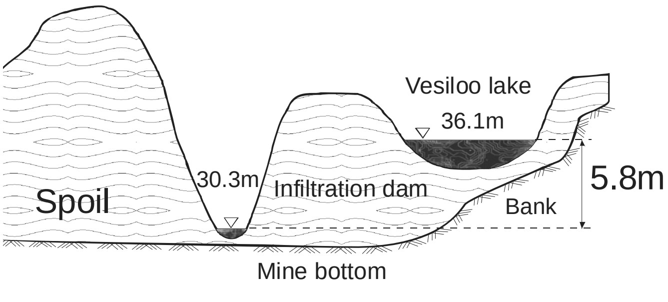


Fig. 4. Cross-section of infiltration dam in the mined-out area of Viivikonna section. Water level in Lake Vesiloo has remained 6 m higher from water level in lower lake for 45 years

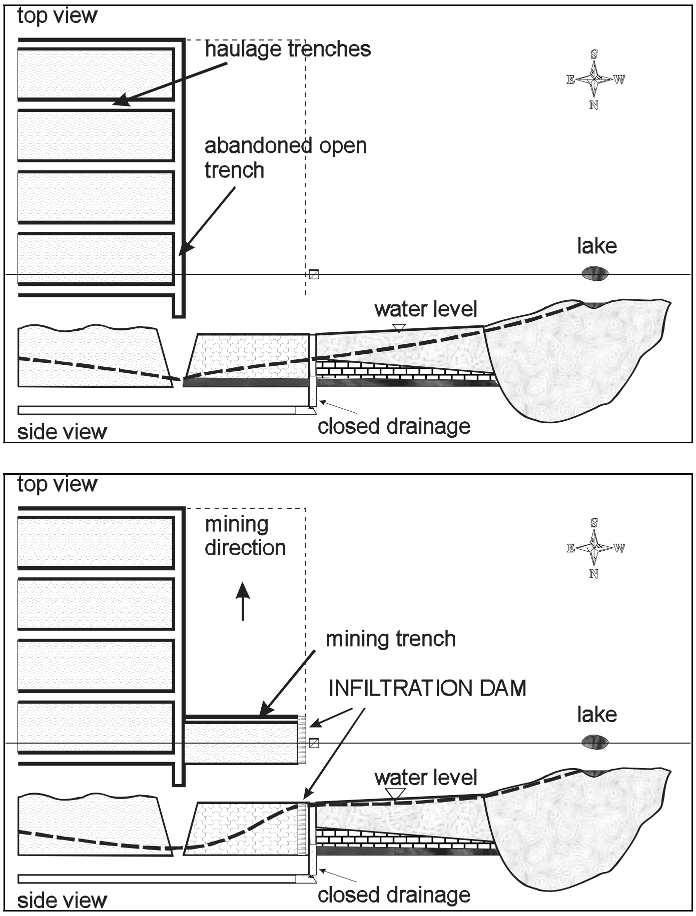


Fig. 5. Layout of water inflow to the mine applying old technology (above), new technology (below)

Dragline ES-10/70 is used for piling the dam. Ordinary selective piling of the overburden will be finished at 50 m from the border. Beginning from this point, the material will be disposed homogeneously. Different materials are dumped on top of each other. This should guarantee low permeability of the dam. Important is that the material be dumped from the maximum height of dumping position of the dragline and onto different locations. The width of the dam should be at least 25 m, and the high wall should be covered with a mixture of clayey material and peat. Stripping productivity in the section will be decreased by several factors. Dragline's cycle time increases because of hauling of the bucket to the maximum height of the dump, repositioning of the boom in every cycle, and careful monitoring of homogenisation of the spoil.

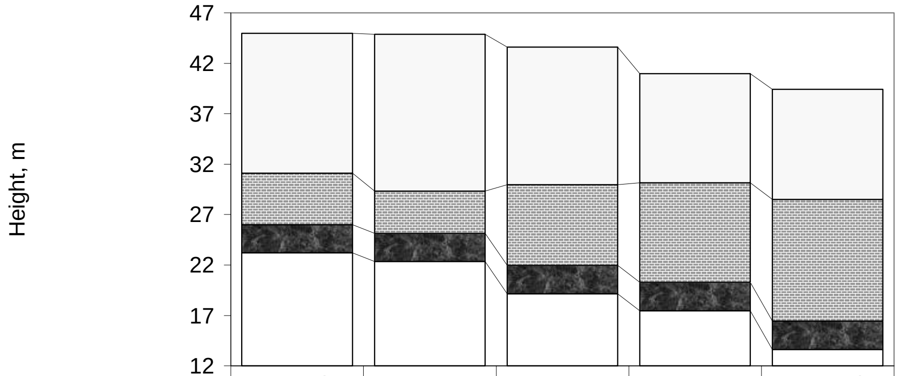
Besides, technology of seam extraction in the dam area is affected by many factors. Oil shale interlayer C/D has to be hauled away from the location of the dam because of its high swelling value (up to 200%). Hydraulic conductivity of this loose material could reach 1000 m/d. Alternatively, the seam has to be extracted non-selectively, leaving a 30-cm limestone layer in the output material. The overall productivity will decrease because the trench is short – 700 m, the optimum length being 1.5 km [21]. This concerns organising stripping, haulage and dam operations in a short section. Optimum length of the section was achieved by positioning the trench at 45 degrees instead of planned 90° in relation to the original North-South direction. (see Fig. 5)

The groundwater model was made on several assumptions. Groundwater discharge from the mine should be within certain limits to keep the decrease in the water level of the lakes below the agreed limits. According to the model, hydraulic conductivity of the dam material should not exceed 0.1 m/d. Besides, infiltration basins which are located between the mine front and the lakes should be fed with water in an amount of 7000 m^3/d for complementing soil water of the surroundings and keeping water level in the area stable.

Dam material consists of silty fine-grained sand whose modulus of hydraulic conductivity $k = 0.1–0.8$ m/d depending on density and compaction index of the material, and the content of clay particles. Provided that the test section was piled according to the design, the modulus of hydraulic conductivity of the material in this section could be in limits $k = 0.1–0.2$ m/d. In addition, the overburden contains moraine ($k = 0.01–0.05$ m/d), fine-grained sand ($k = 0.5–2$ m/d) and loose broken limestone ($k = 100$ m/d). Spoil material dumped conventionally is characterised by $k = 0.5–50$ m/d. It is assumed, basing on the experience gained from the test section, that fine material will fill spaces in coarse material decreasing permeability of the bank dam. The given solution will not work with drains that could form in the case of piling C/D layer, or with open dewatering tunnels under oil shale bed. The influence of mining on water level and quality of lake water near the test section is unnoticeable that proves the suitability of the technology. However, the conditions will become more complicated in southern direction (see Fig. 6).

There are peat, sand and moraine layers in the cross section of the Quaternary sediments and Ordovician limestone in hard overburden, causing high permeability of the spoil. An increase in the thickness of limestone seam in southern direction causes most of the dumping problems in dam building. Additional amounts of sand have to be scraped from aside, probably rehandling the overburden, and, in addition, compactors should be used for achieving proper modules of hydraulic conductivity.

Dam piling was modelled applying the geometric model that is used for determining the ultimate pit depth for draglines [9]. The model yields figures about suitability of draglines, need for rehandling and additional scraping, and also differences in the final height of the ground (see Figures 7 and 8). The test section has shown that it is difficult both organisationally and technologically to establish all these parameters. For evaluating the effectiveness of the dam in the southern part, several tests on density, compression and permeability of the spoil material have to be performed and compared with data obtained using the hydrogeological model.



	1-North	2	3	4	5- South
☐ Soft overburden	13.9	15.5	13.6	10.8	10.9
▨ Hard overburden	5.1	4.2	8.0	9.9	12.1
■ Oil shale seam	2.8	2.8	2.8	2.8	2.8
☐ Bottom layer	23.2	22.3	19.2	17.5	13.6

Fig. 6. Thickness of limestone overburden increases in southern direction causing dumping difficulties for draglines and higher hydraulic conductivity of overburden material

Fig. 7. Pit at the end of the trench before 1997. Limestone pile on the bottom of the trench forms under spoil drainage channels

If the technology of dumped spoil fails, the compactors on the spoil and a geomembran barrier on the bank wall made using contour blasting, or a clay barrier must be applied.

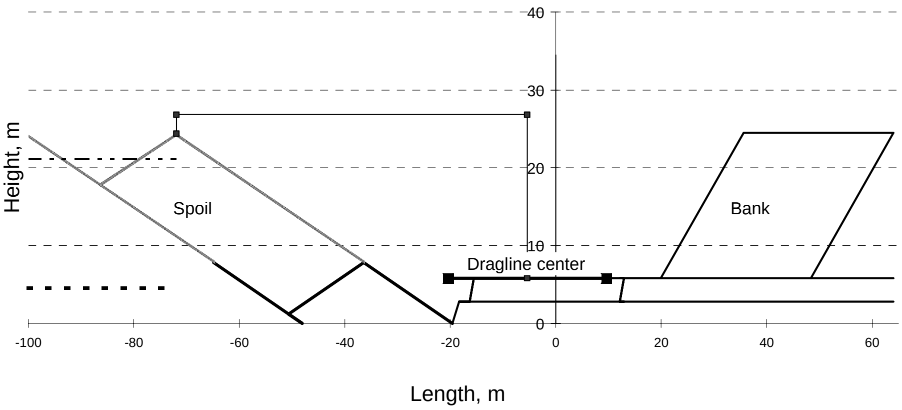


Fig. 8. Pit layout and modelling of surface height using geometrical model

Different materials and constructions are widely used to reduce hydraulic permeability at exploitation of mines, quarries and waste depositories. Depending on purposes, the barriers, dams, sheet piles or cut-off walls of different permeability could be constructed. In Estonia, hydraulic barriers are designed and constructed around Sillamäe Radioactive Waste Depository (bentonite slurry cut-off wall) and Tallinn old municipal landfill (vinyl sheet-pile wall). Watertight clay barriers are widely used in construction of new landfills.

Vertical slurry cut-off walls

Slurry cut-off walls are vertical walls constructed by excavating a trench and simultaneously filling the trench with a bentonite slurry. The bentonite slurry forms a thin (typically ≤3 mm) filter cake of low hydraulic conductivity (<10-8 cm/s) on both sides of the trench. The filter cake minimises slurry loss from the trench, stabilises native soil on the side walls of the trench, and provides a plane for slurry stabilisation in the excavated trench. The bentonite slurry contains typically 4% to 7% (w/w) sodium bentonite mixed with water.

Three main types of slurry walls, used to locate polluted groundwater, are soil-bentonite (SB) walls, cement-bentonite (CB) walls, and composite slurry walls (CSW). Soil-bentonite slurry walls are constructed by displacing bentonite slurry in the excavated trench by backfilling with a mixture of bentonite slurry and excavated trench spoils. Cement-bentonite (CB) walls are constructed by using a mixture of cement and bentonite slurry to maintain the stability of the excavated trench; i.e. no backfill materials are required. Therefore, CB walls are typically constructed in the case when suitable backfill materials are not available. Composite slurry walls (CSW) are constructed simply by inserting a geomembrane into the slurry in the trench.

Alternative passive barriers

Aside from slurry cut-off walls, other passive vertical barriers include walls constructed using deep soil mixing or jet grouting using chemical grouts (e.g., silicates, resins, and polymers), grout curtains, and sheet-pile walls. Although these technologies are used extensively in more traditional geotechnical engineering applications, such as dams and construction excavations, none of these technologies have been used extensively as passive containment barriers for remediation of contaminated land.

A comparison of the construction costs for the vertical barriers shows that the costs associated with used material of alternative barriers is typically greater and the construction rates lower than for the more traditional SB and CB slurry walls.

Biobarriers

The concept of using bacteria to form biofilm barriers, or biobarriers, in otherwise highly permeable media (e.g., sands) through plugging or fouling the massif to reduce the migration of contaminant plumes has recently gained attention. Reductions in hydraulic conductivity from one to three orders of magnitude have been reported for a variety of porous media using many types of bacteria and different treatment methods, including stimulation of indigenous bacteria (biostimulation) and injection of full-size living and dead bacteria as well as ultramicrobacteria (bioaugmentation). A significant additional research must be performed before biobarriers can be used routinely for practical application.

Conclusions

In the test section of the Estonia deposit near Kurtna Lakes the influence of mining on the water level in lakes is low. The technology of dam construction has been proved. However, geological and geotechnical conditions will be more complicated southwards. According to modelling, hydraulic conductivity of the dam must remain 0.1 m/d to avoid sinking of water level in the lakes, and filtration basins must be supplied with water in an amount of 7000 m^3/d as yearly average. After oil shale mining east of the area of Kurtna Lakes the area will be recovered as

- landscape will be reclaimed, overall look and shape will be smoothed
- abandoned fields of peat milling will be reclaimed and their fires avoided.

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