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CHANGES IN MINE DEWATERING AFTER THE CLOSURE OF EXHAUSTED OIL SHALE MINES

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Oil shale mining in Estonia has been restructured to meet the contemporary economic and consumer requirements. Several old mines have been closed and are at present filled with water. An extensive technogenic groundwater body has formed inside the earth, influencing the drainage of the deeper, still working mines. In order to determine the exact proportions of precipitation, groundwater and water of closed mines in the water pumped out of mines, the corresponding relations were established and mathematical model was developed. It was found that the water from abandoned mines formed a large proportion of the water pumped out. As the water of closed mines comes mostly from precipitation, the dewatering of working mines has turned more dependent on precipitation as well.

Introduction

Estonian mines abound in water since the oil shale bed lies quite close to the surface and directly in the aquifer. Moreover, the area of mine fields is large and the deposit is water permeable, therefore also large amounts of precipitation penetrate into the mines. Mine dewatering has been one of the first priorities during the entire oil shale mining period. Nevertheless, despite much experience gained in this field, not all problems could be foreseen, and several critical situations occurred during spring tides in the 1960s, in the most intensive oil shale mining period.

Reliable forecast of the water inflow into mines has been essential in at least three occasions: during the construction of *Estonia* mine in the 1960s, during the planning of large *Kuremäe*, *Permisküla* and *Uus-Kiviõli* mines in the 1980s (which have not been built up to now), and recently during the closure of exhausted mines. The technical problems connected with the closure of mines are solved now, but the long-term impact of water-filled mines on the environment and working mines needs still to be elucidated.

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The latter problem may become topical when new mines are planned to be developed in the near vicinity of the water-filled mines.

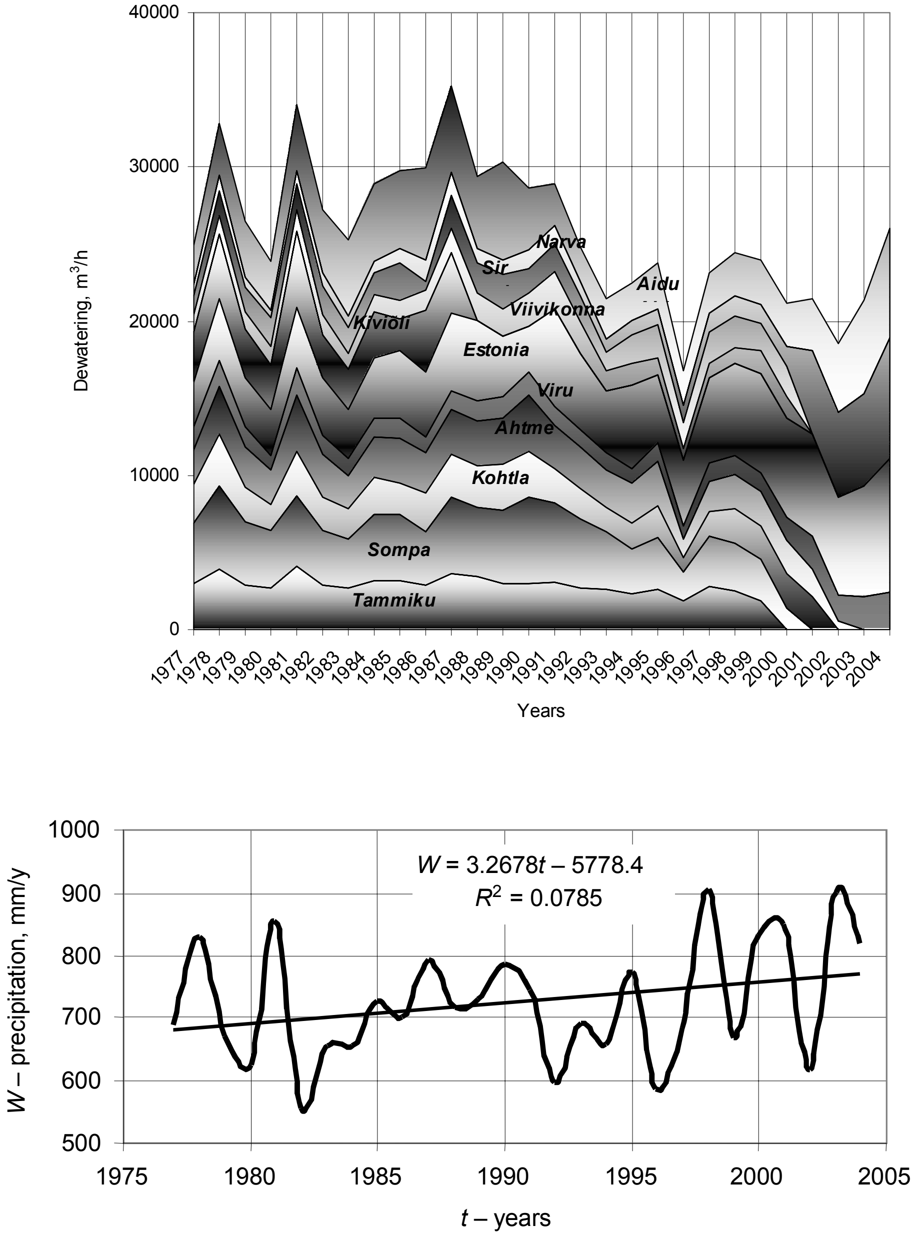


Fig. 1. The amounts of water pumped out of mines in different years (above) and annual precipitation according to data of Jõhvi meteorological station (below)

Present Situation

The following most essential changes in mine dewatering have taken place in the years 1994–2004:

- The amount of the water pumped out has been taken under control – measurements are more precise and the amount of recirculating water has been reduced.
- A technogenic water body has formed in closed mines.
- Views about environmental conservation have become more realistic, among mining enterprisers as well as environment protectors.

Statistical data show that the mine water pumping decreased notably at the beginning of the 1990s (Fig. 1) for the following reasons. First, the Government of Estonia imposed a charge on dewatering, due to which water measurements became more exact. Earlier, the amount of water was measured indirectly, on the basis of the electrical power consumed by pumps, but now direct measurements have been implemented everywhere. Owing to the charges levied on the water discharged from pumping stations, effective means have been taken for the reduction of the quantity of recirculating water. Second, the development of mining works has slowed down since the usage of oil shale has decreased.

Forecast of Mine Water Amounts

The amount of water penetrating into oil shale mines depends mostly on natural factors: hydraulic conductivity and piezometric head of aquifers, the amount and seasonal variation of precipitation, air temperature and its fluctuations, character of the aquitards and their position within the overlying rock. Technological factors, particularly roof handling, either holding or caving, are important as well. Both the natural and technological factors are indistinct, and therefore their occurrence and quantitative parameters cannot be uniquely determined. Owing to the multitude of factors, in most cases the pumping rates found by classical calculation methods do not coincide with the real values. The computer modeling applied worldwide has not given satisfactory results in Estonia either, mainly because of uneven hydraulic conductivity and anisotropy of the technogenic rock massive.

In world mining practice, in the conditions of the generally more distinct hydrogeological regime, problems are resolved by combining several methods, but mainly still empirically and based on analogy. Domanova [1, 2] tried to use similar principles in the design of *Kuremäe*, *Uus-Kiviõli* and *Permisküla* mines. Her work resulted in a valuable database, but empirical relations derived from the dewatering data available at that time did not prove adequate during later control.

Origin of the Water Pumped out of Mines

Mine pumping is considered abstraction of water from aquifers [3]. In reality, mine water consists not only of groundwater, but also of precipitation, particularly during spring tides. It contains also recirculating water, since part of the water pumped out infiltrates immediately back into the mine through the mined-out area and karst fissures. Because of precipitation and water recirculation, in Estonia a lower charge has been imposed on mine water than on other groundwater consumers.

As the proportions of both groundwater and precipitation are significant for the forecast of mine dewatering, the present paper tries to assess their ratio. The amount of the water pumped out of the mine is taken as a basis for the analysis and its relationship with precipitation in the same area is clarified.

In order to reduce the influence of seasonal variation, the annual amounts of precipitation and dewatering are used. As mentioned above, only the dewatering data of the years 1994–2004 can be considered reliable.

The premise of the study is that the water pumped out of the mine during some period of time consists of three parts: precipitation that has reached the mine in the same period, the water originating from aquifers, and recirculating water. Thus, the proportion of precipitation water in the pumped out water depends on the amount of precipitation (unlike that of groundwater-derived and recirculating water).

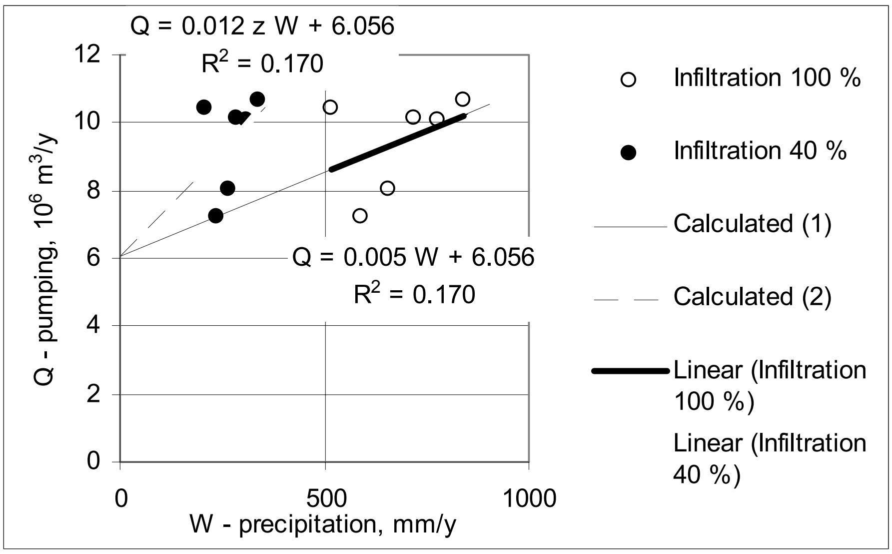


Fig. 2. Example of the use of the empirical-analytical method for estimating the amount and components of the water pumped out of *Viru* mine

The water amounts depending or not depending on precipitation can be determined on the basis of measurement data of several years, using methods of mathematical statistics. This is an extremely simplified way, but as seen below, the results are logical and explicable. The amounts of precipitation and water pumped out of mines are plotted on the graph in Fig. 2.

With some uncertainty, linear relation between these parameters can be noticed:

$$Q = 0.005W + 6.056\ 10^6\ (\mathrm{m}^3/\mathrm{y}) \qquad (1)$$

where Q is the amount of water pumped out in a year, million m^3/y;
W is annual precipitation, mm/y.

The correlation range is $R^2 = 0.17$, which corresponds to the correlation coefficient $r = (R^2)^{0.5} = 0.41$.

The empirical coefficient 0.005 million m^3/mm obtained from initial data indicates that in *Viru* mine 1 mm of precipitation would provide 5 thousand m^3 of water in a year. The other empirical coefficient 6.056 million m^3 expresses the annual quantity of water not depending on precipitation – the water derived from aquifers and recirculating water, which, unfortunately, cannot be treated separately by the present method.

Actually, not all of the precipitation infiltrates into the earth and reaches pumping stations of mines. Most of it evaporates in summer or flows away during thaws in winter and early spring. Evaporation in forest area is estimated to be roughly 25–35%, but less in fields and grasslands. Data on unreclaimed mine areas are not available. The proportion of the water infiltrating into the underground mine is impossible to measure, but it has been estimated to account for 20–60%. It depends on evaporation, which, in turn, is related to seasonal variation in precipitation and air temperature.

In different mines the amount of water infiltrating into the earth depends on the mining method (surface or underground mining) and mining system (room-and-pillar or longface mining in underground mines and opencast or strip mining in surface mines). The amount of precipitation reaching the mine is largely affected by aquitards in the mine field: Quaternary sediments, but also relative aquitard of Oandu age in the southern part of the deposit.

Thus, all further calculations are based on three infiltration coefficient values between 0.2 and 0.4 (20–40%). For example the calculations presented in Fig. 2 use the infiltration coefficient $z = 0.4$, assuming that on average 40% of precipitation reaches pumping stations. For that case another relation was obtained:

$$Q = 0.012(zW) + 6.056\ (\text{million m}^3/\text{y}) \qquad (2)$$

The result is mathematically trivial: the component 6.056 million m^3/y not depending on precipitation is not affected by the amounts of precipitation reaching the mines, and the coefficient depending on precipitation is, in the limits of rounding accuracy, the same as in Equation (1), divided by the infiltration coefficient:

$$0.005/0.4 = 0.012 \text{ (million m}^3\text{/mm)}$$

Attempts to establish the linear relation between the precipitation and mine water pumping have been made also earlier. However, for example, in [4] the constant term of the equation is negative for all mines. This would mean that pumping from mines stops if precipitation is low and the ground becomes water absorbing if precipitation is very low. In other words, in that case groundwater would not be pumped out of mines at all. Obviously, dewatering data available at that time were unreliable. The negative constant term may have been obtained if the amount of dewatering was shown larger namely in a precipitation-rich year. This could also have happened if the quantity of water was measured not in the pumping-station but in a more distant water body containing also surface water. It is also possible that earlier, when most of the water was produced by shallow mines, the relation between the infiltrated precipitation and total precipitation was progressive (nonlinear). For instance, if the infiltration coefficient is proportional to the amount of precipitation, the relation between the pumping volume and precipitation could be as follows:

$$Q = (aW)W + b = aW^2 + b \tag{3}$$

where aW is the infiltration coefficient depending on precipitation;

b is the quantity of water not depending on precipitation.

Analysis of the statistical dewatering data of the earlier period (up to 1980) using Equation (3) yields a positive constant term, which is fully logical. In the analysis of more recent data (years 1994–2004) Equations (1) and (3) show no great differences.

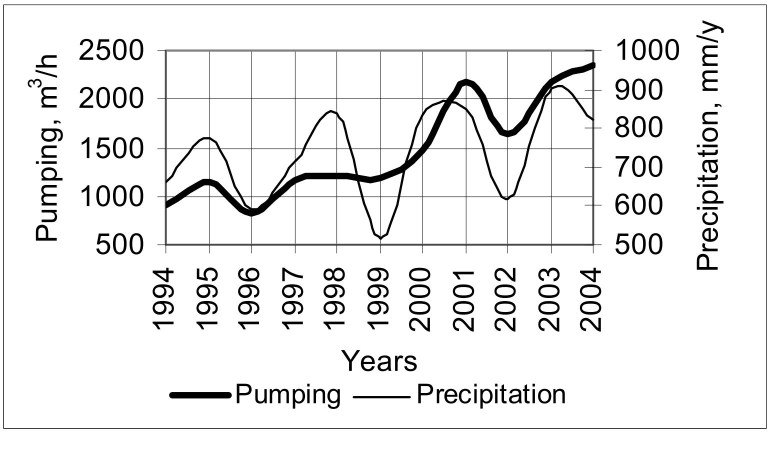
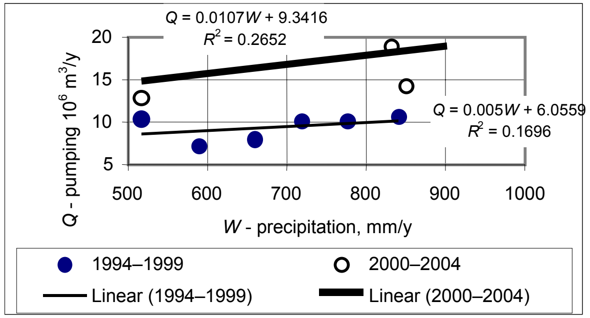


Fig. 3. Dependence of the amounts of water pumped out of *Viru* mine on precipitation and closure of neighboring mines: *Tammiku* in 2000, *Sompa* in 2001 and *Ahtme* in 2002

Table 1. **Dewatering Analysis Sheet. *Viru* Mine**



Mine	***Viru***								
Equation of trend	$Q = aW + b$								
	R^2	a	b						
	R-squared	Precipitation coefficient 10^6 m^3/mm	Groundwater and recirculation, 10^6 m^3/y						
Period 1994–1999	0.17	0.005	6.06						
2000–2004	0.27	0.011	9.34						
Precipitation, mm/y		W							
Infiltration, mm/y		$I =$	$z\ W$	1994–1999			2000–2004		
Infiltration range		z	0.2...0.4	0.4	0.3	0.2	0.4	0.3	0.2
Coefficient of infiltration 10^6 m^3/mm		$a \times z$		0.0020	0.0015	0.0010	0.0044	0.0033	0.0022
Pumping, average per period, 10^6 m^3/y		Q_{avg}		9.44	9.44	9.44	17.31	17.31	17.31
Precipitation, average per period, mm/y		W_{avg}		683	683	683	820	820	820
Groundwater and recirculation rate, %		q	b/Q_{avg}	0.64	0.64	0.64	0.54	0.54	0.54

Conclusion:
Before the closure of *Tammiku* mine the water pumped out of *Viru* mine was mainly (64%) groundwater.
After the closure of *Tammiku* and *Sompa* mines the water pumped out of *Viru* mine consisted of 54% groundwater and 46% rainwater.

The corresponding infiltration area	F	$1000(1 - q)Q_{avg}/zW_{avg}$	12.4	16.5	24.7	24.3	32.4	48.6
and its radius, km	r	$(F/\pi)^{0.5}$	2.0	2.3	2.8	2.8	3.2	3.9

Based on the empirical-analytical method, a respective calculation model has been developed. The results obtained for *Viru* mine for the periods of 1994–1999 and 2000–2004 are given in Table 1. The former period characterizes the work of the mine before, the latter after the closure of nearby *Tammiku* and *Sompa* mines, in 2000 and 2001, respectively. The change in the amount of the water pumped out can be seen in Fig. 3.

The data in Table 1 show that after the closure of the neighbouring mines, the water outlet from *Viru* mine increased mostly on account of precipitation. The increase started shortly after the closure of *Tammiku* mine in December 1999 and continued after the closure of *Sompa* mine in January 2001. Inflow of precipitation was somewhat inhibited by the dry summer and autumn of 2001, but it grew again in the extremely rainy summer of 2003. At the same time, the dependence of inflow on precipitation increased. While before the closure of *Tammiku* and *Sompa* mines one millimetre of precipitation produced 1500–2000 m^3 of mine water, then after the closure the respective amount was 3300–4400 m^3.

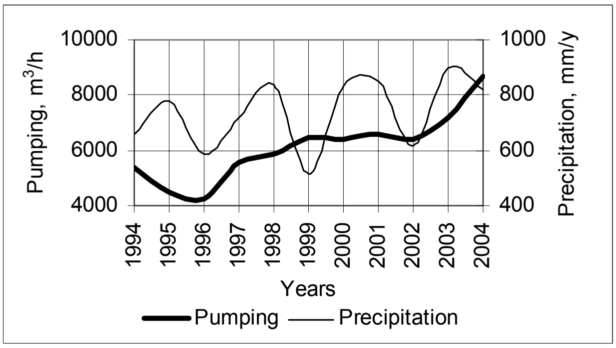


Fig. 4. Dependence of the amounts of water pumped out of *Estonia* mine on precipitation and closure of *Ahtme* mine in 2002

Similar calculations were performed for all mines (Fig. 4). For working mines two periods were considered – before and after the closure of the mines nearby. The data for the year 1999, when *Kohtla*, *Sompa* and *Tammiku* mines were still operating, were taken as a basis for the calculations and were compared with the data for 2004. In this way the proportions of precipitation and groundwater in mine water could be assessed and also some conclusions could be drawn about the proportion of recirculating water. The results of the analysis are presented in Table 2.

Figures 5 and 6 show the proportions of precipitation and groundwater (together with recirculating water) in the water pumped out of underground mines and opencasts in 1999.

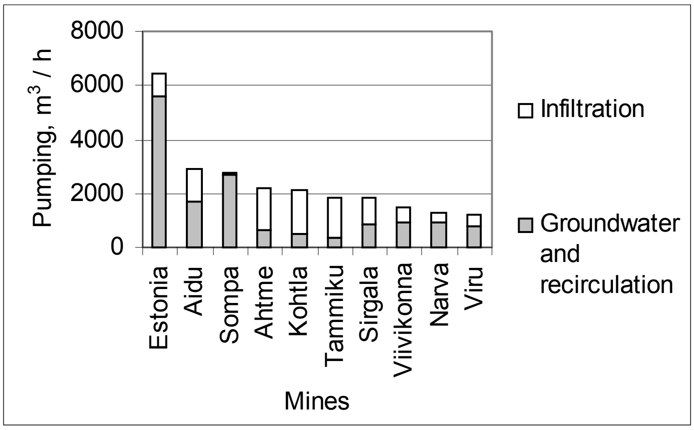


Fig. 5. The proportions of infiltrating precipitation and groundwater plus recirculating water in the water pumped out of mines. The mines are ordered according to the water amounts pumped out in 1999

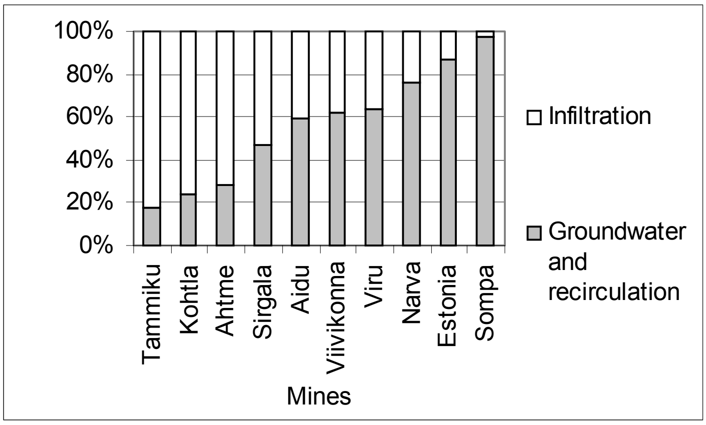


Fig. 6. The proportions of infiltrating precipitation and groundwater plus recirculating water in the water pumped out of mines in 1999. The mines are ordered according to dependence on precipitation

Table 2. **The Origin of the Water Pumped out of Mines and Its Changes**

Mine	1999				2004				Changes 2004/1999, %		
	Pumping, m^3/h	Ground-water and recircu-lation rate, %	Ground-water and recirculating water, m^3/h	Infiltration, m^3/h	Pumping, m^3/h	Ground-water and recircu-lation rate, %	Ground-water and recirculating water, m^3/h	Infiltration, m^3/h	Pumping, m^3/h	Ground-water and recirculating water, m^3/h	Infiltration
Ahtme	2181	0.28	611	1570							
Aidu	2885	0.59	1702	1183	7031	0.1	703	6328	244	41	535
Estonia	6464	0.87	5624	840	8667	0.54	4680	3987	134	83	474
Kohtla	2144	0.24	515	1629							
Narva	1240	0.76	942	298	2082	0.76	1582	500	168	168	168
Sirgala	1824	0.47	857	967	3702	0.47	1740	1962	203	203	203
Sompa	2754	0.97	2671	83							
Tammiku	1847	0.18	332	1515							
Viivikonna	1461	0.62	906	555	2131	0.62	1321	810	146	146	146
Viru	1192	0.64	763	429	2356	0.54	1272	1084	198	167	253
Total m^3/h	23992	0.62	14923	9069	25969	0.44	11299	14670	108	76	162
10^6 m^3/y	210		131	79	227		99	129			
Precipitation, mm/y	670				820				122		

Results and Discussion

The Mines Closed in 1999–2003

For ***Ahtme*** **mine**, the proportion of groundwater in mine water was not large, accounting for 28% (together with recirculating water). As the mine is deep, this result was somewhat unexpected. Closer analysis, however, revealed several explanations for this phenomenon. First, the *Ahtme* mine field is bordered by tectonic fault zones on two sides. In the northwest, the mine field boundary coincides with the *Ahtme* fault zone, in the southeast, with a set of fault zones, termed as the Kurtna fault zone [5]. Second, mining works at Ahtme had resulted in the formation of an extensive groundwater drawdown cone which did not expand any more. Third, most of the groundwater in the southern part of the deposit was pumped out by the neighbouring *Estonia* mine. Fourth, the high proportion of precipitation in *Ahtme* mine water can be explained also by shallow eastern and northeastern parts of the mine field, absence of significant aquitards in the overburden and the occurrence of several karst zones in that area.

Kohtla and ***Tammiku*** **mines** were typical shallow mines in the central part of the lowering of the piezometric surface. The proportion of precipitation in mine water was about 80%. The remaining 20% consisted largely of recirculating water, particularly in *Kohtla* mine. The high proportion of precipitation could also be explained by the circumstance that both mines pumped out the predominantly precipitation-derived water originating from the closed mines in the north.

The water of ***Sompa*** **mine** showed very high percentages of ground- and recirculating water. This can partly be explained by the development of mining to the southwest, from where groundwater penetrated into the mine along karst fissures. However, a very high load on mine dewatering was caused by the infiltration of water from the Kohtla River bed back into the earth. According to indirect calculations, it accounted for half of the mine water. Now that *Sompa* mine is closed, the Kohtla River is dry in water-deficient periods.

Working Mines

The claim of ***Aidu opencast*** is characterized by very high hydraulic conductivity [2], but this was of no particular consequence in 1999. As usual with opencast mines, the proportions of groundwater and precipitation in mine water were 59 and 31%, respectively. The water outlet in 1999 was not very large because of the Savala buried valley acting as an aquiclude in the south and west and inhibiting groundwater inflow (Fig. 7). Dewatering of *Kohtla* mine lying in the east was still in progress in 1999. The situation changed abruptly after the closure of *Sompa* and *Kohtla* mines. The water accumulating in these eastern closed mines started to penetrate through the highly permeable barrier pillar between the *Kohtla* and *Aidu* mine fields.

Partly the *Kohtla* mine water started to flow into *Aidu* mine from the north, through long closed *Kohtla* opencast. The amount of the water pumped out of *Aidu* opencast increased more than twice and the proportion of precipitation in mine water increased more than five times.

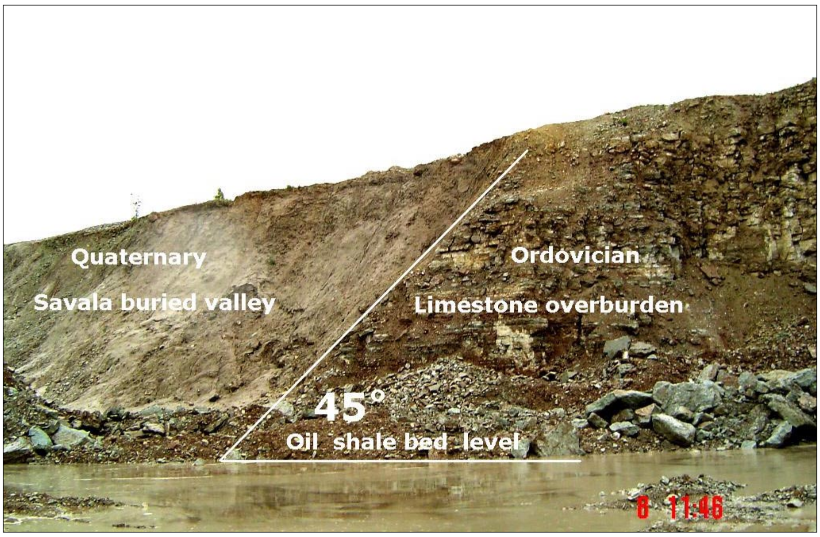


Fig. 7. Savala buried valley, exposed during mining works in *Aidu* opencast. The fine-grained clayey Quaternary sediments to the left form an aquiclude on the southern and western sides of the mine

***Estonia* mine** is located in the marginal area of the cone of depression of the Keila–Kukruse and Nabala–Rakvere aquifers, thus large amounts of water are pumped out. Another reason for intensive dewatering in 1999 was the development of mining works to the south, towards the undrained area. The mine is deep and the overburden includes the Oandu-age relative aquitard, therefore the contribution of precipitation to mine water was only 13% in 1999. The situation changed in 2004 with the start of influx from water-filled *Ahtme* mine in the northeast. The amount of the water pumped out of *Estonia* mine increased by 34% and the proportion of precipitation in mine water grew markedly. As mentioned above, *Ahtme* mine was relatively sensitive to precipitation, which also enhances the seasonal variation of the water quantities penetrating into Estonia mine.

Sirgala, Viivikonna and ***Narva*** mines are parts of the mining enterprise *Narva Karjäär*. In *Viivikonna* claim the proportions of groundwater and precipitation in mine water are 60 and 40%, respectively, which may be considered normal. In *Sirgala* the proportion of precipitation is higher, because precipitation water from the drainage network of the nearby Puhatu peat bog infiltrates into the mine. Somewhat lower percentage of precipitation in the water pumped out of *Narva* claim is due to the water infiltrating back from Mustajõe outlet.

***Viru* mine** is located in the centre of the groundwater drawdown area. In 1999, mine water was still pumped out in neighbouring *Tammiku* and *Sompa* mines. Inflow into *Viru* mine started to increase in 2000, and in 2004 the situation was similar to that in *Aidu* opencast – the pumping increased about twice and the proportion of precipitation in mine water grew over three times.

Conclusions

- A system of dewatering oil shale mines has been developed in Estonia, ensuring safe and high-quality mining in complicated local hydrogeological conditions.
- About 55% of the water pumped out of mines originates from precipitation. The remaining 45% comes from groundwater or consists of water recirculating in the dewatering system.
- The closure of exhausted mines increased about twice the amount of the water pumped out of operating *Aidu* opencast and *Viru* mine, whereas the proportion of precipitation in mine water grew markedly. A similar situation is likely to occur in Estonia mine because *Ahtme* mine is filled with water.

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REFERENCES

1. *Domanova, N., Reinsalu, E.* Analysis of hydrogeological conditions in Oktoobri opencast : Topic 0107, Stage HD No. 1, Estonian Branch of A. Skotchinski Institute of Mining Engineering. 1979 [in Russian].
2. *Domanova, N.* Formation and Forecast of Water Flowing into the Mine Workings Driven into Carbonate Rocks with Uneven Infiltration Properties: Candidate's thesis / A. Skotchinski Institute of Mining Engineering. 1986 [in Russian].
3. Regulation No. 160 (May 8, 2001) of the Government of Estonia "Charge Rates for Use of Water from a Water Body or Groundwater Aquifer".
4. *Savitski, L.* Formation of water inflow into mines of the Estonia oil shale deposit // Hydrogeological Problems in Estonia. Tallinn, 1980. P. 152–161 [in Russian, with Estonian summary].
5. *Vaher, R.* Tectonics of the Phosphorite-Oil Shale Area of Northeast Estonia: Candidate's thesis. 1982 [in Russian].

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