SUSTAINABLE GROUNDWATER MONITORING SYSTEM OF EAST-VIRU COUNTY, ESTONIA

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Partners:
University of Tartu, Estonia
Tallinn Technical University, Estonia
Geological Survey of Estonia

Authors
R. Perens; V. Savva; M. Truu; S. Jaštšuk
Geological Survey of Estonia

Establishment of the monitoring system for mining area water levels and sulphate contamination monitoring gaps

(Final report)

2011

1. Introduction

Establishment of the monitoring system for mining area water levels and sulphate contamination monitoring gaps was by project implementation plan (PIP) planned to implement in cooperation with Norwegian Geotechnical Institute (NGI). Unfortunately NGI on August 21, 2009 declared that it would not be participating in the project. The hydrogeological department of Geological Survey of Estonia (EGK) has the appropriate staff and skills to run the project.

The text of the report is compiled by Rein Perens. In the composition of databases, tables and figures participated hydrogeologists Valeri Savva, Leonid Savitski, Nadežda Kivit, Natalija Boldõreva, Merle Truu and Svetlana Jaštšuk, geologists Mati Lelgus and Helle Perens and technical workers Tiina Parm and Kaja Zavitskaja.

2. Overall Objective

The overall objective of the project is to assist in achieving in largest possible extent good qualitative and quantitative status of groundwater, maintain sufficient groundwater resource. One of the objectives is to increase the frequency of groundwater quantitative and qualitative monitoring by automating relevant measurements, thus improving monitoring quality and reliability of environmental information.

3. Background information

The assessment and control of groundwater quantity and quality have to be supported by representative and reliable monitoring data. As an EU Member State, Estonia is developing a new groundwater monitoring system that will correspond to the EU regulations and takes into account recommendations of the international networks. At the same time, the new system has to correspond to the continuous rapid changes, mainly characteristic to oil shale mining areas of East-Viru County. Sustainable groundwater monitoring system has to correspond to the local and regional needs in order to ensure the availability and quality of the groundwater resource, and to give input into regional planning.

Groundwater monitoring is largely a national responsibility, but while groundwater does not follow administrative borders, monitoring has to be conceived at local, regional, national and international levels. This is exactly the principle of the Water Framework Directive, the new Groundwater Protection Directive, as well as the Environmental Monitoring Act of Estonia.

Currently there are 86 monitoring wells in East-Viru basic groundwater monitoring network, in groundwater bodies influenced by oil shale mining (Figure 1). Till this project the measurements were carried out by EGK observers manually. Manual measurements set limits to

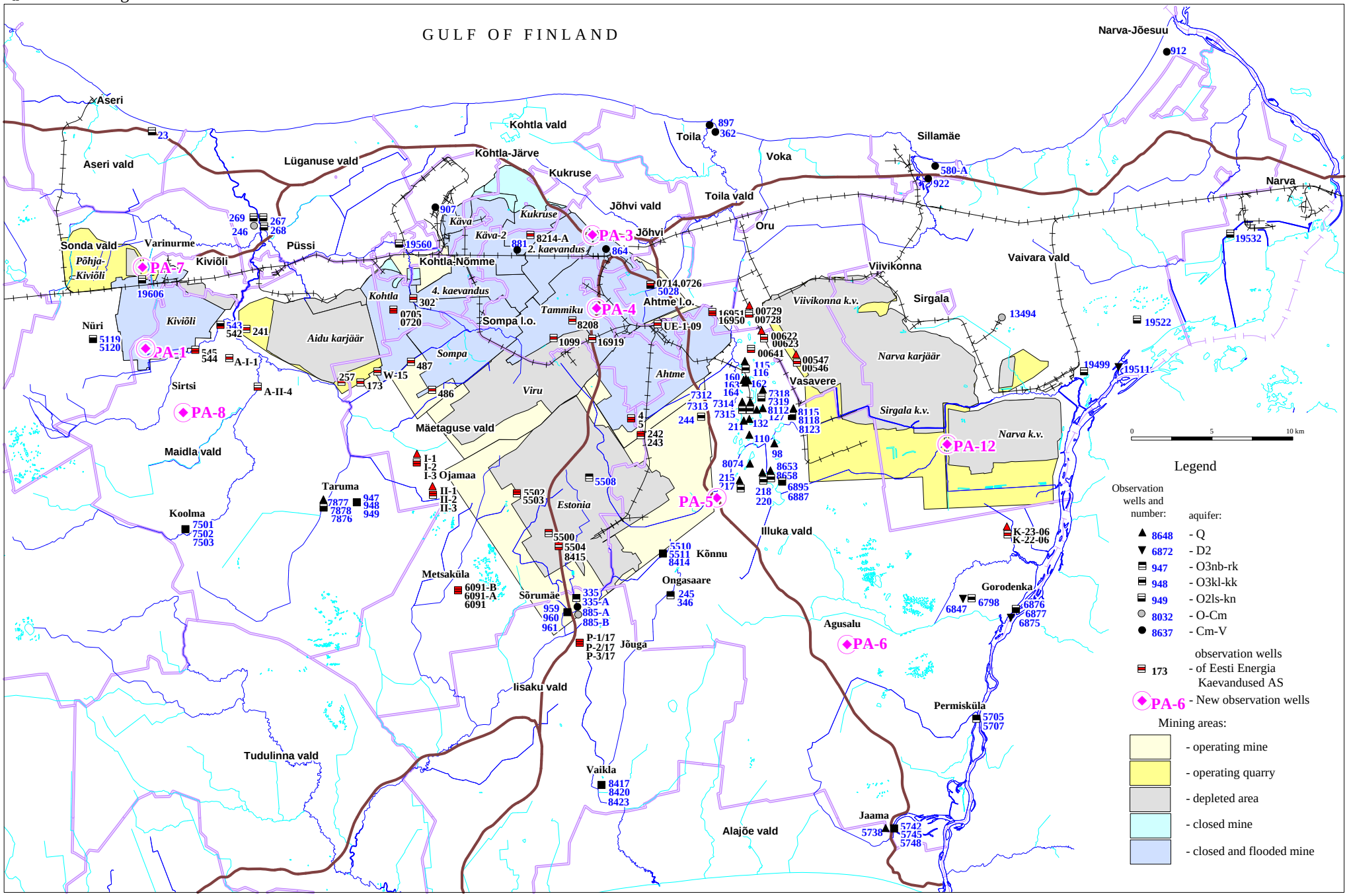

Figure 1. Distribution of monitoring wells of East-Viru county.

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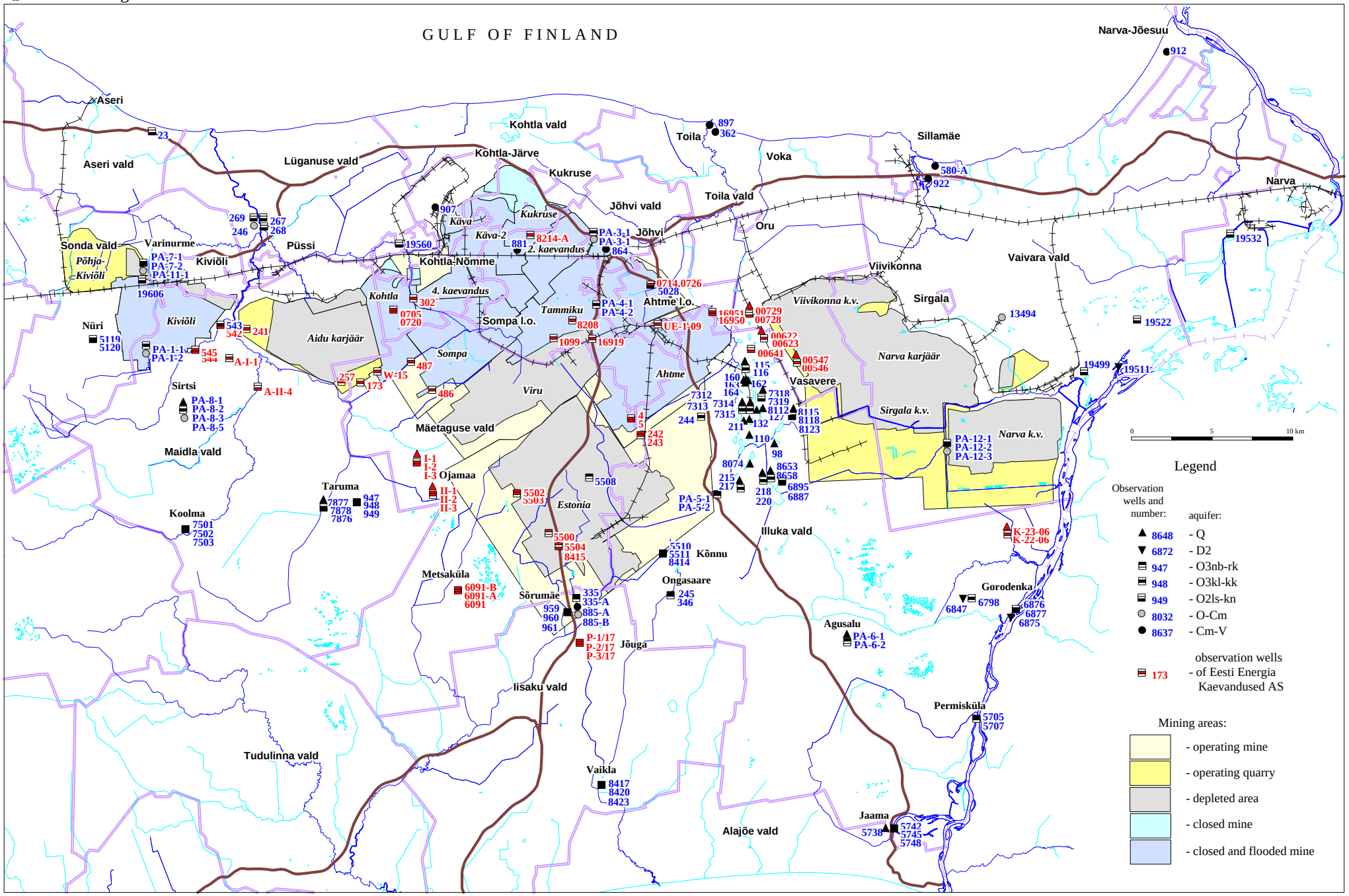

Figure 1A. Distribution of monitoring wells of East-Viru county by observed aquifers.

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monitoring frequency with respect to transport and labour costs etc. Thus, though current monitoring network is in large numbers the frequency of quantitative and chemical monitoring are insufficient (Table 1). In some areas the influence of quarries and mines dewatering and influence of exhausted and flooded mines to status of groundwater needed to evaluate in more details. Current activity should fill this gap.

Improved monitoring system are needed to provide information not only on groundwater quantity and quality in the light of its use as a drinking water resource, but also for the evaluation of its environmental quality.

The existing groundwater monitoring network hardly provides early warnings for pollution, so a network is needed to enhance the efficiency of monitoring the pollution loads, particularly in oil shale mining areas.

4. Monitoring of sulphate contamination of groundwater and gaps in monitoring system

During mining the water level drowning and increasing aeration zone cause intensive pyrite oxidation, which is the biggest groundwater pollution problem associated with underground mining. After mine closure the water level rising and pyrite oxidation decrease. The most noticeable change will take place in the sulphate content.

The 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 the oxidation of pyrite occurring in Ordovician rocks the water pumped out from mines contains large amounts of sulphates. Their concentration is up to 500 mg/l (Erg, 2005; Perens et al., 2006). Sulphates are easy to analyze and therefore good indicators for the description of the movement of mine waters. Sulphates are a potential threat to the environment as in a strongly anaerobic environment the release of toxic hydrogen sulphide may occur.

Long-term research conducted in the neighboring Kurtna Natura 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 sulphates in through-flowing lakes has increased tens of times (Punning et al., 1994).

There is also evidence that the decreasing amount of pumping-out mine water has a negative influence on the quality of the water of some rivers due to the decreasing of water in them (Punning et al., 1997).

After mines are closed, step-by-step restoration of natural conditions of the groundwater filling the mines starts – sulphates are carried out, the effect of air oxygen on the mineable seams

that used be drained disappears. As a result, the oxidation of pyrite diminishes and the mineral content of the water pumped out decreases. Quality studies of closed Kiviõli mine water have shown that in about five years after the closure of a mine the content of sulphates decreases below the maximum permitted level in drinking water, what is 250 mg/l (Figure 2). Changes of chemical composition of closed Kiviõli oil shale mine showed also, that there is good correlation between concentration of sulphates and total hardness and dry residue (mineralization) (Figure 2). Thus the installation of automatic divers for measures the electric conductivity of water would help to fulfill the caps we have in monitoring of sulphate contamination. A change in conductivity can indicate for instance, a change in flow or increasing or decreasing contamination or mineralization.

In recent years, in the area of oil shale mines, the chemical composition of groundwater has been rather stable. The content of SO_4 in groundwater has been 2 times higher in spring than during the remaining seasons of the year. It can be caused by dissolution of pyrites in oxygen – abundant water in spring (Erg, 2005). The water washes the already oxidizing pyrite products out of the limestone and the sulphate content in groundwater will increase. The sulphate may distribute in a lateral direction over the large territory (Figure 3). Closing and flooding of underground mines has changed also the groundwater forming conditions in the Lasnamäe–Kunda aquifer and sulphate content with it (Figure 4).

The gaps in data are connected with insufficient data about seasonal changes of groundwater quality especially changes of sulphate content in groundwater.

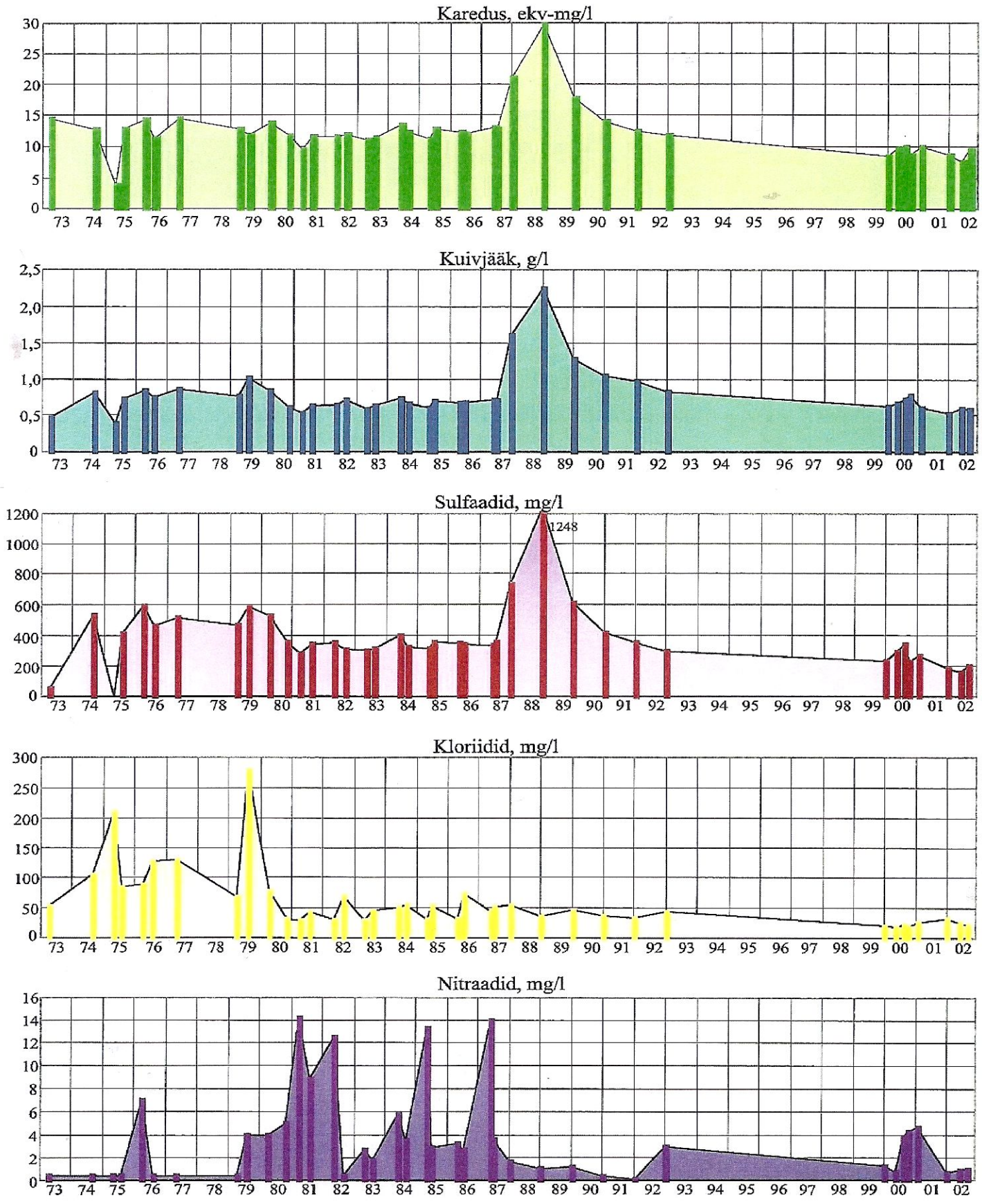
To solve the problems connected with sulphate contamination and to fulfill sulphate contamination monitoring gaps is possible only by establishment of the new automatic monitoring network with measuring and registration of groundwater level, groundwater temperature and conductivity.

5. Main tasks of the monitoring system

The activity:

1) Reviews the existing situation and elaborates the groundwater monitoring network for mining area with drilling of new wells, where groundwater measurements must be automated;

2) Develops the existing groundwater monitoring system – installs automatic monitoring devices (divers, loggers) into wells of representative locations in order to give early warning signals to avoid deterioration of status of a groundwater.



Joonis 2. Kiviõli kaevandusest ärajuhitava vee keemilise koostise muutused.
Figure 2. Changes of chemical composition of closed Kiviõli oil shale mine.

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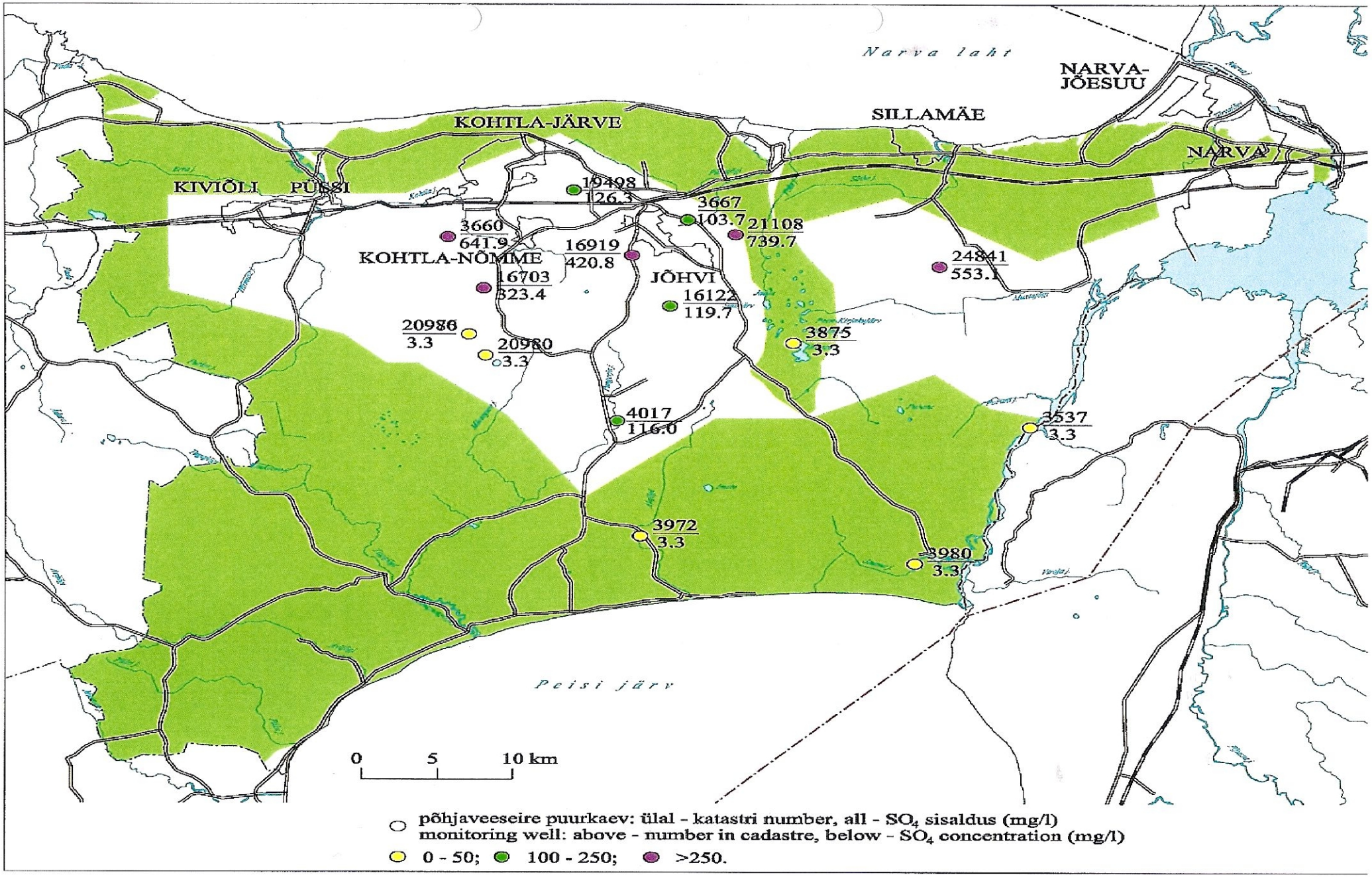
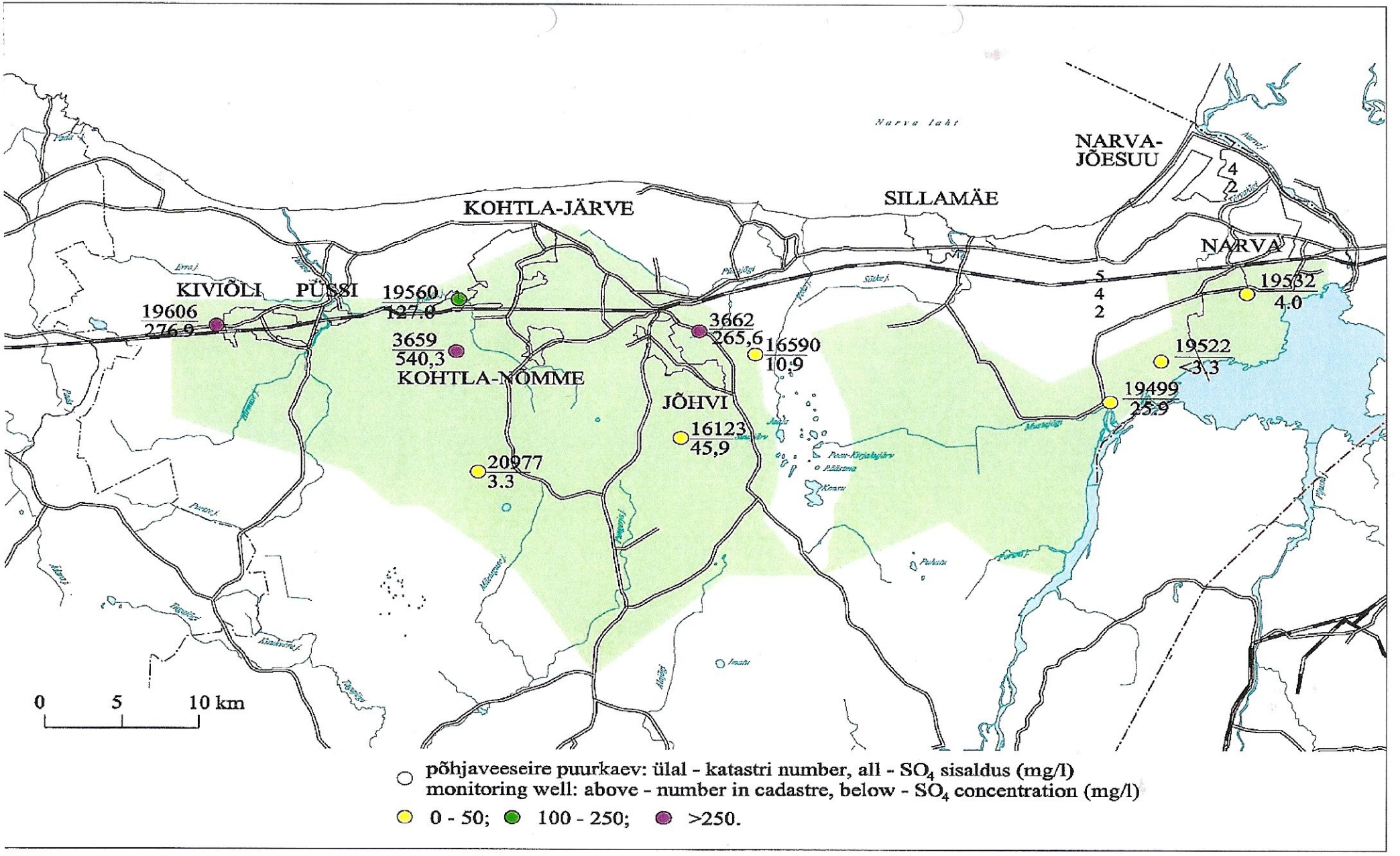


Joonis 3. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi seirekaevude põhjavee SO_4 sisaldus 2008. a. (Keila-Kukruse veekiht)

Figure 3. Distribution of SO_4 concentration in ground water of monitoring wells of Ordovician Ida-Viru Oil Shale Basin GWB in 2008. (Keila-Kukruse aquifer)



Joonis 4. Ordoviitsiumi Ida-Viru põlevkivibasseini põhjaveekogumi Lasnamäe-Kunda veekihi põhjavee SO_4 sisaldus 2008.a.

Figure 4. Distribution of SO_4 concentration in grounddwater of monitoring wells of Ida-Viru Oil Shale Basin GWB in 2008 (Lasnamäe-Kunda aquifer)

6. Establishment of the new monitoring stations

The current monitoring stations are established on regions with different geological and hydrogeological conditions and different amount of groundwater discharge because at mining activities.

In the frame of current activity by EGK were selected suitable places for drilling of new monitoring wells (Table 2 1). Ministry of Environment signed contracts with land-owners and organized tender for drilling. The location of new monitoring wells is presented in Figure 1, the data of wells in Table 3 and in the wells reports (Appendix 2).

All together 9 new monitoring stations with 20 wells were drilled and installed with loggers for water level, temperature and conductivity measurements (Table 3). Additionally 4 Barologgers were installed in order to correct the water level measurement results with respect to air pressure.

7. Main results

As result of this activity environmental information on groundwater as the important water resource will be more reliable, enabling and early warning on deterioration of groundwater quality and quantity. Therefore local municipalities and environmental authorities can plan and take measures to protect this valuable water resource. More precise information on groundwater quality and quantity fluctuations assists in more effective water resource management – it will be used in issuing environmental permits and assessing groundwater resources.

Figure 4. Location of monitoring wells PA-1-1 (26249) and PA-1-2 (26250).

Figure 5. Location of monitoring wells PA-3-1 (26251) and PA-3-2 (26252).

Figure 6. Location of monitoring wells PA-4-1 (26253) and PA-4-2 (26254).

Figure 7. Location of monitoring wells PA-5-1 (26255) and PA-5-2 (26256).

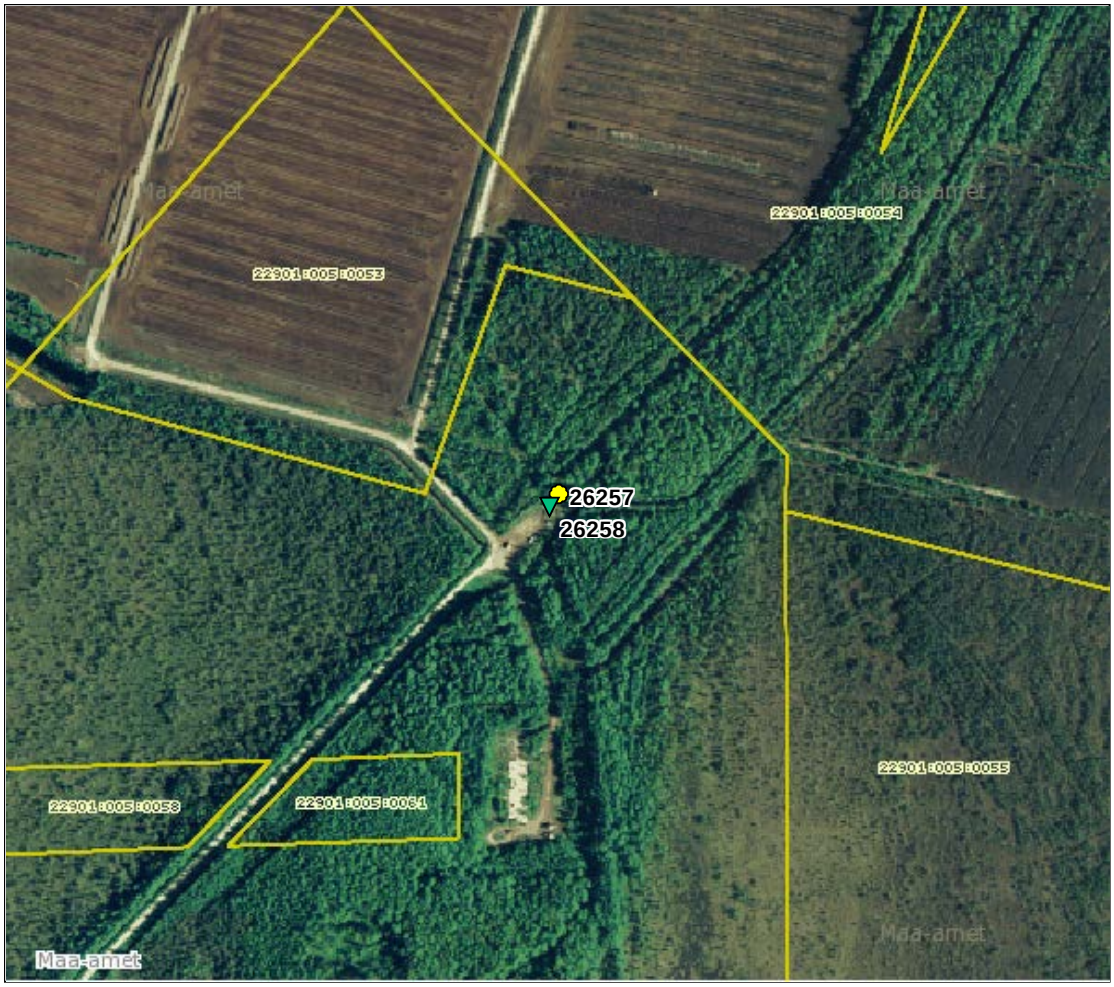


Figure 8. Location of monitoring wells PA-6-1 (26257) and PA-6-2 (26258).

Figure 9. Location of monitoring wells PA-7-1 (26266), PA-7-2 (26267) and PA-11-1 (26268).

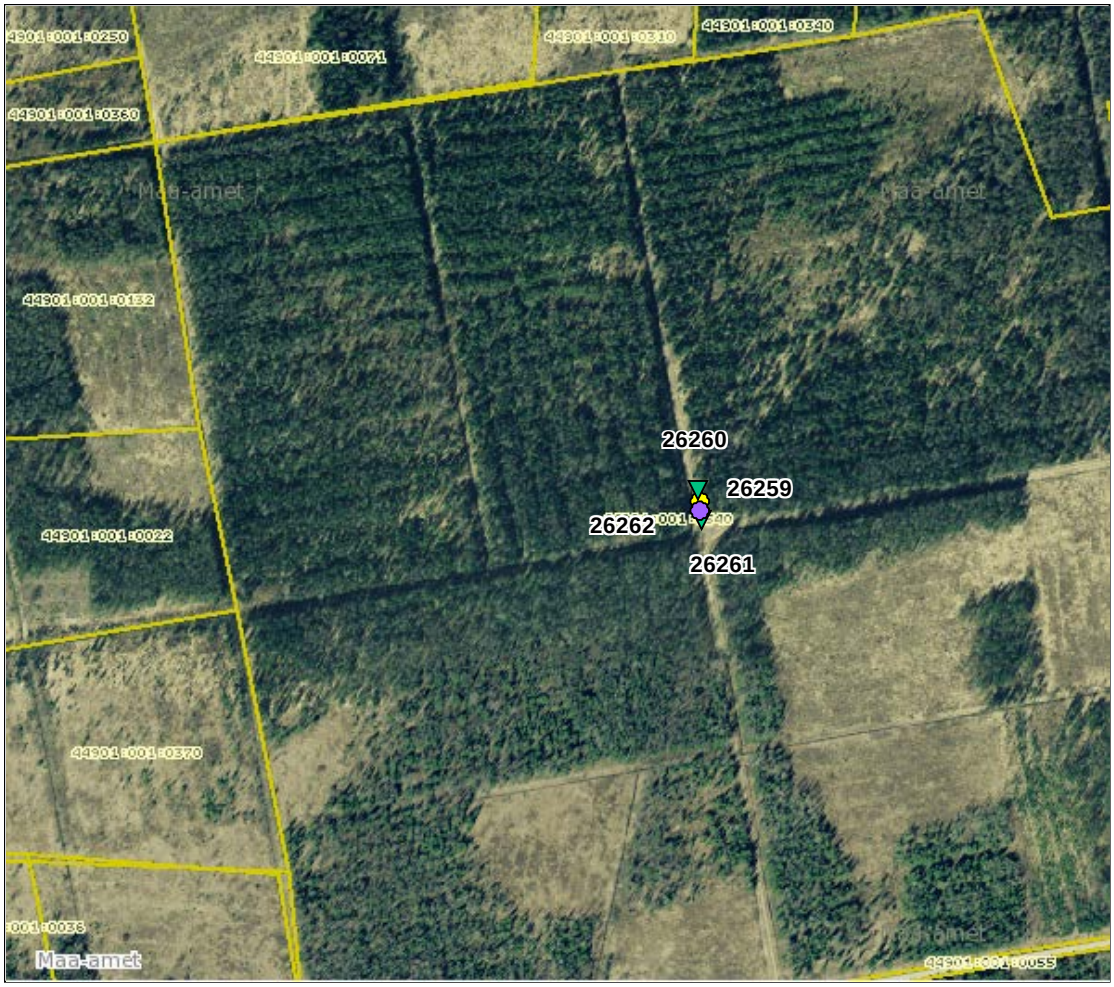


Figure 10. Location of monitoring wells PA-8-1 (26259), PA-8-2 (26260), PA-8-3 (26261) and PA-8-5 (26262).

Figure 11. Location of monitoring wells PA-12-1 (26263), PA-12-2 (26264) and PA-12-3 (26265).

Table 1. List of existing monitoring wells for installation of divers

No in cadastre	Address	Aquifer	Existing monitoring		Diver
			water level	chemical monito-ring	
01 Cambrian–Vendian Gdov GWB					
2438	Sompa	V_2gd	2		C; B
2464	Toila kalavastuvõtupunkt	V_2gd		+	C
02 Cambrian–Vendian Voronka GWB					
2088	Narva-Jõesuu, Raja t – Vambola t	V_2vr	12	+	C
2198	Sillamäe veevärk, 4. pumbamaja	V_2vr	12	+	C
4018	Sõrumäe k	V_2vr	12		C
2478	Toila 9-kl kool	V_2vr		+	C
04 Ordovician–Cambrian GWB					
4019	Sõrumäe k	O-Cm	12	+	A
19016	Ida-Viru mk, Lüganuse al-k	O-Cm	60	+	A
05 Ordovician East-Viru GWB					
19028	Kõrkküla	O_2ls–O_{2-1}kn	60	+	A
3971	Vaikla (Nurme k)	O_2ls–O_{2-1}kn	12		A
3974	Vaikla (Nurme k)	O_3nb–rk	12		A
3972	Vaikla (Nurme k)	O_3kl–kk	12	+	A
3277	Ahtme kaevandusväli, Kurtna järvest 0,3 km kirdesse	O_2id–O_3kk	12		A
3280	Ahtme kaevandusväli, Kurtna järvest 0,3 km kirdesse	O_2id–O_3kk	12		A
3281	Ahtme kaevandusväli, veehaardel, Kurtna järvest 1,05 km kirdesse	O_2ls–O_{2-1}kn	12		A
3538	Gorodenka k	O_2ls–O_{2-1}kn	12		A
3525	Gorodenka k	O_3kk	12		A
3979	Jaama k	O_2ls–O_{2-1}kn	12		A
3981	Jaama k	O_3nb–rk	12		A
3980	Jaama k	O_3kl–kk	12	+	A
3289	Kaevandusväli 14 (Konsu järve ääres)	O_2ls–O_{2-1}kn	60		A
3537	Kaevandusväli 14, Gorodenka k	O_3kl–kk	12	+	A
3862	Konsu järve ääres	O_2id–O_3kk	60		A
3872	Konsu järve ääres	O_2id–O_3kk	60		A
13701	Konsu järve ääres	O_2id–O_3kk	60		A
3875	Konsu järve ääres	O_{2i}d–O_3kk	60	+	A
3988	Permisküla	O_2id–O_3kk	12		A
4014	Permisküla	O_3nb–rk	12		A
5069	Vasavere ürgorg, Pannjärvest 60 m lõuna poole	O_2id–O_3kk	12		A
3398	Vasavere, Valgejärve ääres	O_3kk	60		A
3396	Vasavere, algejärve ääres	O_2ls–O_{2-1}kn	60		A
19026	Lohusuu, Separa k	O_3prg	12		A
3651	Lohusuu, Separa k	O_3prg	12		A
3650	Lohusuu, Separa k	O_3prg	12		A
3646	Lüganuse al-k	O_{2-1}kn	60		A

3643	Lüganuse al-k	O_{2-1}kn	60		A
3648	Lüganuse al-k	O_2ls–O_{2-1}kn	60	+	A
2581	Kaevandusväli 12, Tarumaa k, Lipu talu	O_2id–O_3kk	60		A
2582	Kaevandusväli 12, Tarumaa k, Lipu talu	O_2ls–O_{2-1}kn	60		A
4021	Koolma k	O_3nb–rk	12		A
4023	Koolma k	O_2id–O_3kk	12		A
4022	Koolma k	O_2ls–O_{2-1}kn	12		A
06 Ordovician East-Viru Oil Shale Basin GWB					
4016	Sõrumäe k	O_3nb–rk	12	+	A
3198	Sõrumäe k	O_2ls–O_{2-1}kn	12		A
3197	Sõrumäe k	O_3kl–kk	12		A
3196	Sõrumäe k	O_3nb–rk	12		A
4017	Sõrumäe k	O_2kl–kk	12	+	A
3969	Kõnnu k	O_2ls–O_{2-1}kn	12		A
4012	Kõnnu k, kaevandusväli 9	O_3nb–rk	12		A
3008	Kõnnu k, kaevandusväli 9 (Ongassaare)	O_2id–O_3kk	12		A
3963	Kurtna mõis	O_2id–O_3kk	60		A
3964	Mäetaguse	O_3nb–rk	12		A
3966	Ongassaare k	O_2id–O_3kk	12		A
2595	Tarumaa k	O_2ls–O_{2-1}kn	60		A
2593	Tarumaa k, 4 km Ojamaa jõe vasakkaldast	O_3kl–kk	60		A
2594	Tarumaa k, 4 km Ojamaa jõe vasakkaldast	O_2rk	60		A
4015	Ridaküla	O_2rk	60		A
19532	Balti Elektrijaama territoorium	O	1	+	C
4010	Nüri k, kaevandusväli 13	O_2ls–O_{2-1}kn	12		A
4009	Nüri k, kaevandusväli 13	O_2id–O_3kk	12		A
19499	Eesti Elektrijaama territoorium	O_{2-1}	1	+	C
13 Vasavere GWB					
3367	Kurtna–Vasavere, Kirjakjärve lõunakaldal	fQIII	60		A
3263	Pannjärve karjäär (Vasavere veehaare)	fQIII	12	+	C; B
3873	Konsu järve ääres	fQIII	60	+	A

A – means always GW level
B – Baro-Diver
C – GW level + conductivity

Table 2. Establishment of the new monitoring stations for mining area water levels and sulphate contamination monitoring

Number of monitoring station on Figure 1	Task of monitoring station	No of well	Depth of well	Geological index of aquifer	Proposal for automatic loggers
PA-1	To evaluate influence of flooded Kiviõli mine to groundwater quality	PA-1-1	45 m	O_3id–kk	GW level + conductivity
		PA-1-2	105 m	O–Ca	GW level + conductivity
PA-3	To evaluate influence of flooded Tammiku mine to groundwater quality	PA-3-1	25 m	O_3id–kk	GW level + conductivity
		PA-3-2	70 m	O–Ca	GW level + conductivity
PA-4	To give early warning signals by Internet to avoid possible floods in Jõhvi Town	PA-4-1	20 m	O_3kl–jh	GW level + conductivity
		PA-4-2	45 m	O_3id–kk	GW level + conductivity
PA-5	To evaluate influence of Estonia mine dewatering to groundwater, including springs Kuremäe	PA-5-1	15 m	O_3nb–rk	GW level
		PA-5-2	75 m	O_3id–kk	GW level
PA-6	To evaluate influence of peat production to water regime of Puhatu Natura Reserve	PA-6-1	5 m	Q	GW level
		PA-6-2	30 m	O_3nb–rk	GW level
PA-7	To evaluate influence of Põhja-Kiviõli quarry dewatering to groundwater level and Kiviõli oil production enterprise to groundwater quality	PA-7-1	15 m	O_3kl–kk	GW level + conductivity
		PA-7-2	40 m	O_3ls–O_{1-2}kn	GW level + conductivity
PA-8	To evaluate influence of prospective Uus-Kiviõli mine to natural status of groundwater quality and quantity	PA-8-1	4 m	Q	GW level
		PA-8-2	25 m	O_3nb–rk	GW level
		PA-8-3	55 m	O_3id–kk	GW level + conductivity
		PA-8-5	105 m	O–Ca	GW level + conductivity
PA-11	To evaluate influence of Põhja-Kiviõli quarry and Kiviõli oil production enterprise to groundwater quality	PA-11-1	75 m	O–Ca	GW level + conductivity
PA-12	To evaluate influence of Narva quarries closure to status of groundwater level and quality	PA-12-1	30 m	O_3nr–kk	GW level
		PA-12-2	55 m	O_2ls–kn	GW level + conductivity
		PA-12-3	85 m	O–Ca	GW level + conductivity

Table 3. List of the locations and constructions of new monitoring wells

Number of well in cadastre	Number by project	Location	Protection zone, m	Depth, m	Aquifer	Elevation a.s.l., m	Constuction			Coordinates	
							Diameter of drilling	Casing	Casing isolation	X	Y
26249	PA-1-1	Maidla parish, Soonurme village, Sonda forestry 16 (44901:001:0610)	10	45	O2kk-id	57	Ø152mm - 0-20m; Ø108mm - 20-45m	Ø125mm - +0,3-20m; Ø108mm - no casing 20-45m	cement 0-19m	6579195	665672
26250	PA-1-2	Maidla parish, Soonurme village, Sonda forestry 16 (44901:001:0610)	10	105	O1pk-C1ts	57	Ø152mm - 0-75m; Ø108mm - 75-105m	Ø125mm - +0,5-75m; Ø108mm - no casing 75-105m	cement 0-74m	6579185	665674
26251	PA-3-1	Jõhvi parish, Edise village, area between Künka estate and Tallinn-Narva road	10	25	O3id-kk	57	Ø152mm - 0-5m; Ø108mm - 5-25m	Ø125mm - +0,3-5m; Ø108mm - no casing 5-25m	cement 0-4m	6586098	693231
26252	PA-3-2	Jõhvi parish, Edise village, area between Künka estate and Tallinn-Narva road	10	70	O1pk-C1ts	57	Ø152mm - 0-40m; Ø108mm - 40-70m	Ø125mm - +0,3-40m; Ø108mm - no casing 40-70m	cement 0-39m	6586102	693241
26253	PA-4-1	Jõhvi parish, Puru village, Lennuväli estate (25201:003:0123)	10	20	O3kl-jh	73	Ø152mm - 0-5m; Ø108mm - 5-20m	Ø125mm - +0,3-5m; Ø108mm - no casing 5-20m	cement 0-4m	6581670	693347
26254	PA-4-2	Jõhvi parish, Puru village, Lennuväli estate (25201:003:0123)	10	45	O3id-kk	73	Ø152mm - 0-25m; Ø108mm - 25-45m	Ø125mm - +0,3-25m; Ø108mm - no casing 25-45m	cement 0-24m	6581659	693347
26255	PA-5-1	Illuka parish, Edivere village, Koke estate (22901:003:0101)	10	15	O3nb-rk	53	Ø152mm - 0-5m; Ø108mm - 5-15m	Ø125mm - +0,3-5m; Ø108mm - no casing 5-15m	cement 0-4m	6569947	700899
26256	PA-5-2	Illuka parish, Edivere village, Koke estate (22901:003:0101)	10	70	O3id-kk	53	Ø152mm - 0-25m; Ø108mm - 25-70m	Ø125mm - +0,3-25m; Ø108mm - no casing 25-70m	cement 0-24m	6569954	700908
26257	PA-6-1	Illuka parish, Agusalu village (EHAK kood 1103)	10	5	gQIII	38	Ø178mm - 0-5m	Ø125mm - +0,3-1m; Ø125mm - slit filter 1-5m	cement 0-0,5m; sandfilling behind the filter 0,5-5m	6560854	708887
26258	PA-6-2	Illuka parish, Agusalu village (EHAK kood 1103)	10	30	O3nb-rk	38	Ø152mm - 0-8m; Ø108mm - 8-30m	Ø125mm - +0,3-8m; Ø108mm - no casing 8-30m	cement 0-7m	6560854	708898
26259	PA-8-1	Maidla parish, Sirtsi village, Maidla forestry 14 (44901:001:0540)	10	4	gQIII	56	Ø178mm - 0-4m	Ø125mm - +0,4-1m; Ø125mm - slit filter 1-4m	cement 0-0,5m; sandfilling behind the filter 0,5-4m	6575171	667983
26260	PA-8-2	Maidla parish, Sirtsi village, Maidla forestry 14 (44901:001:0540)	10	20	O3kl-jh	56	Ø152mm - 0-5m; Ø108mm - 5-20m	Ø125mm - +0,5-5m; Ø108mm - no casing 5-20m	cement 0-5m	6575182	667982
26261	PA-8-3	Maidla parish, Sirtsi village, Maidla forestry 14 (44901:001:0540)	10	55	O3id-kk	56	Ø152mm - 0-30m; Ø108mm - 30-55m	Ø125mm - +0,5-30m; Ø108mm - no casing 30-55m	cement 0-30m	6575193	667981
26262	PA-8-5	Maidla parish, Sirtsi village, Maidla forestry 14 (44901:001:0540)	10	105	O1pk-C1ts	56	Ø152mm - 0-75m; Ø108mm - 75-105m	Ø125mm - +0,5-75m; Ø108mm - no casing 75-105m	cement 0-75m	6575204	667979
26263	PA-9-1	Vaivara parish, Mustanina village, AS Narva Karjäär lands 3, (85101:011:0034)	10	25	O3nr-rk	30	Ø152mm - 0-10m; Ø108mm - 10-25m	Ø125mm - +0,3-10m; Ø108mm - no casing 10-25m	cement 0-10m	6574047	715137
26264	PA-9-2	Vaivara parish, Mustanina village, AS Narva Karjäär lands 3, (85101:011:0034)	10	55	O2ls-kn	30	Ø152mm - 0-30m; Ø108mm - 30-55m	Ø125mm - +0,3-30m; Ø108mm - no casing 30-55m	cement 0-30m	6574056	715143
26265	PA-9-3	Vaivara parish, Mustanina village, AS Narva Karjäär lands 3, (85101:011:0034)	10	80	O1pk-C1ts	30	Ø152mm - 0-55m; Ø108mm - 55-80m	Ø125mm - +0,3-55m; Ø108mm - no casing 55-80m	cement 0-54m	6574046	715148
26266	PA-7-1	Sonda parish, Varinurme village, Sonda forestry 6 (75101:003:0297)	10	15	O3kl-kk	53	Ø152mm - 0-3m; Ø108mm - 3-15m	Ø125mm - +0,5-3m; Ø108mm - no casing 3-15m	cement 0-2m	6584264	665498
26267	PA-7-2	Sonda parish, Varinurme village, Sonda forestry 6 (75101:003:0297)	10	40	O3ls-O1-2kn	53	Ø152mm - 0-20m; Ø108mm - 20-40m	Ø125mm - +0,5-20m; Ø108mm - no casing 20-40m	cement 0-19m	6584284	665498
26268	PA-11-1	Sonda parish, Varinurme village, Sonda forestry 6 (75101:003:0297)	10	65	O1pk-C1ts	53	Ø152mm - 0-65m	Ø110mm - +0,5-45m; Ø110mm - slit filter 45-65m	cement 0-44m; sandfilling behind the filter 44-65m	6584274	665503

Appendix 1

List of monitoring wells of basic monitoring network in groundwater bodies influenced by oil shale mining

Vasavere GWB (13)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
3209	133	1961-1994	
3228	212		1972-1998
3231	213		1972-2002
3245	3245		2007-2010
3263	160	1981-2010	1994-2010
3264	162	1981-2010	1994-2006
3265	163	1981-2010	
3266	164	1981-2010	1994-2006
3270	7304	1973-2002	
3273	7308	1973-1976	
3278	7312	1973-2010	1995-1995
3279	7314	1973-2010	1996-1997
3282	7318	1973-2010	
3287	6863	1970-1992	
3366	89	1963-1994	
3367	98	1960-2010	
3368	101	1960-2000	
3369	103	1961-1991	
3372	110	1959-2010	
3374	151		1993-1993
3375	152	1968-1981	1961-1972
3376	153	1968-1975	
3377	155	1968-1973	
3385	8074	1976-2010	
3400	8115	1976-2010	
3401	8134	1976-2002	
3404	8139	1976-2002	
3860	7306	1973-1983	
3861	8653	1984-2010	
3870	215	1978-2010	
3873	218	1979-2010	1995-2010
3876	211	1961-2010	
4713	8648		1994-1994
5070	115	1994-2010	1995-2006
5077	127	1991-2010	
5078	128	1995-2005	
13733	132	1991-2010	
19243	135		1961-1963
19255	224	1978-1991	
19571	8112	1998-2010	

Middle-Lower Devonian GWB (10)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
3462	323		1965-1989
3524	6847	1969-2010	
3533	6872	1970-1998	1970-1995
3536	6875	1969-2010	1996-2006
19231	57		1960-1962
19511	19511		2007-2010

Ordovician East-Viru Oil-Shale Basin GWB (6)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
2585	6091	1968-2003	
2586	6091-A	1968-2003	
2587	6091-B	1968-2005	
2588	6091-C	1968-2003	
2589	6258	1969-1994	1969-1994
2590	6258-A	1967-1994	1968-1974
2591	6258-B	1967-1994	1970-1994
2592	6258-C	1967-1994	1968-1991
2593	948	1967-2010	1968-1997
2594	947	1967-2010	1968-1997
2595	949	1967-2010	1968-1997
2598	950	1967-1994	
2984	1-G	1961-1992	
2985	64-G	1968-1978	1966-1969
2986	84	1959-1972	1961-1971
2987	85	1959-1972	
2988	232	1968-1982	1967-1993
2989	233	1968-1982	
2990	234	1968-1978	1966-1991
2991	235	1968-1982	
2994	392	1968-1989	
2995	393	1968-1988	
2996	394	1968-1981	
2998	952	1967-1975	
3001	809	1968-1974	
3002	976	1969-1994	
3003	3746	1962-1972	
3004	3888	1962-1977	
3005	5500	1972-2003	
3006	5501	1972-1986	
3007	5065	1968-1974	
3008	5510	1972-2010	
3009	7158	1970-1980	
3018	8206	1974-1983	
3020	8210	1974-1983	
3022	8208	1974-1983	
3023	8207	1974-1983	
3196	959	1969-2010	
3197	960	1965-2010	
3198	961	1969-2010	

3215	142	1968-1973	
3260	3743	1968-1981	
3293	6889	1970-1993	
3294	6890	1970-1993	
3295	6891	1970-1993	
3439	330	1964-2004	
3440	334	1968-1981	
3441	332	1968-1981	
3452	58	1967-1994	
3452	58-A	1962-1994	
3452	58-B	1968-1994	
3452	58-G	1962-1994	
3455	72	1963-1992	
3456	70	1968-1978	1960-1976
3457	71	1968-1984	1960-1984
3458	73	1960-2005	2004-2004
3463	66	1962-1997	
3642	1-B	1980-1992	
3655	5002	1987-1999	
3656	5003	1987-1999	
3659	5005	1987-1999	
3660	5004	1987-1999	
3662	5028		2007-2010
3663	5017	1995-1995	
3664	5018	1995-1995	
3732	542	1988-1991	1989-1993
3733	543	1988-1991	1989-1993
3734	544	1988-1991	1989-1991
3735	545	1988-1991	1989-1991
3736	546	1988-1991	
3737	547	1988-1993	
3738	548	1988-1991	1989-1991
3739	549	1988-1991	1989-1991
3952	249	1980-1999	
3955	253	1980-1999	
3957	255	1980-1999	
3958	238	1975-1992	
3959	239	1975-1990	
3960	241	1975-1998	1996-1997
3961	242	1975-1992	
3962	243	1975-1992	
3963	244	1975-2010	
3964	245	1975-2010	
3965	340	1975-1991	
3966	346	1975-2010	
3969	8414	1978-2010	
3970	1-A	1980-1992	
3992	75	1960-2004	
3993	274	1981-1982	1983-1983
3994	274-A	1981-1982	
3996	275	1981-1984	1983-1983
3997	275-A	1981-1984	
3999	276	1981-1984	
4000	276-A	1981-1984	
4003	5502	1972-2003	1984-1997
4004	5503	1972-2003	

4005	5504	1974-2003	
4006	5506	1972-1986	
4007	5507	1972-2003	
4008	5118	1975-1999	
4009	5119	1975-2010	1995-1995
4010	5120	1975-2010	1995-1995
4011	5121	1975-1999	2007-2007
4012	5511	1972-2010	
4013	5512	1995-1995	
4015	5508	1972-2010	1995-1997
4016	335	1975-2010	1977-2010
4017	335-A	1975-2010	1977-2006
4030	228	1989-1994	
4032	74	1963-1992	
5066	118	1995-1995	
5067	117	1995-1995	
5072	120		1995-1997
12301	8415	1978-2003	
13703	61	1962-1994	
19233	63	1963-1963	
19234	67	1968-1974	
19239	76	1968-1992	
19240	87		1960-1964
19241	88		1960-1965
19242	110-2		1963-1966
19250	168	1968-1972	
19251	201	1968-1974	
19252	202		1965-1966
19253	284-2	1968-1974	1960-1966
19263	5509	1972-1980	
19264	5065-C	1968-1974	
19265	5065-B	1968-1974	
19266	7173	1970-1975	
19278	8416	1978-1986	
19498	8214-A	1975-1995	1983-2010
19499	19499		2007-2010
19522	19522		2007-2010
19532	19532		2007-2010
19560	19560		2007-2010
19606	19606		2007-2010
132007	123-P		1972-2002
132009	102-P		1972-1994
132011	104-P		1972-1994
132012	107-P		1973-2002
132013	138-P		1985-1994
132014	118-P		1985-1994
132015	119-P		1985-1994
132016	120-P		1985-2002

Ordovician East-Viru GWB (5)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
2425	240		1962-1975
2581	7878	1972-2010	
2582	7876	1972-2010	

3199	6168	1968-1996	
3200	6168-A	1968-1996	
3201	6168-B	1967-1996	
3216	143	1961-1978	1961-1972
3269	7305	1973-2002	
3271	7307	1973-1984	
3275	7311	1973-1979	
3277	7313	1973-2010	
3280	7315	1973-2010	1981-1996
3281	7319	1973-2010	1981-2003
3289	6887	1969-2010	
3396	8123	1977-2010	
3398	8118	1976-2010	
3477	6218	1967-2001	
3478	6218-B	1967-2001	
3479	6218-A	1967-2001	
3487	6864	1969-1992	
3488	6917	1970-1992	
3491	6886-D	1969-1982	
3525	6798	1969-2010	
3526	6766	1969-1995	
3534	6873	1969-1997	1970-1994
3535	6874	1969-1996	1970-1994
3537	6876	1969-2010	1995-2010
3538	6877	1969-2010	1996-1996
3641	6168-C	1967-1997	
3643	269	1981-2010	1981-1991
3646	268	1981-2010	
3648	267	1981-2010	1983-2010
3650	272	1980-2010	1981-1994
3651	271	1984-2010	1984-1999
3653	270	1998-1998	1981-1994
3862	8658	1986-2010	
3867	104		1961-1963
3871	216	1978-1999	
3872	217	1978-2010	
3874	219	1978-1994	
3875	220	1978-2010	1995-2010
3971	8423	1978-2010	1988-2006
3972	8420	1978-2010	1988-2010
3974	8417	1978-2010	1988-2006
3979	5748	1986-2010	2003-2006
3980	5745	1986-2010	2003-2010
3981	5742	1986-2010	2003-2006
3983	5709	1986-1997	2004-2004
3988	5707	1986-2010	2003-2006
4014	5705	1986-2010	2003-2006
4021	7501	1972-2010	
4022	7502	1972-2010	
4023	7503	1972-2010	
4024	7505	1972-1997	
4025	7545-B	1995-1995	
4026	7545	1995-1995	
4031	6218-C	1967-1998	
4715	8651	1984-1991	
4720	8641	1995-1995	

5069	116	1996-2010	1995-2006
5436	5436		2007-2007
13701	6895	1969-2010	
13704	3187	1961-2002	
19026	273	1981-2010	
19028	23	1947-2010	1961-2010
19235	68	1968-1974	
19244	140		1961-1963
19256	225	1978-1991	
19257	226	1978-1991	
19305	22	1964-1992	

Ordovician-Cambrian GWB (4)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
2254	557	1962-1982	1961-1992
2360	860	1962-1994	
2997	395	1973-1982	
3248	210		1982-1991
3253	8032-A		1979-1991
3254	312	1966-1992	
3402	8032	1977-2002	
3445	316	1968-1999	
3953	250	1980-1999	
3989	39	1963-1994	
3990	236	1968-1982	
4002	7545-C	1995-1995	
4019	885-B	1983-2010	1994-2010
4029	229	1989-1994	
4719	8642	1995-1995	
5166	131	1992-2010	
13494	13494		2007-2010
19016	246	1989-2008	1995-2010
19228	24	1963-1998	
19230	26	1960-1967	
19245	859	1968-1976	
19254	223	1978-1991	
19304	854-2		1961-1967

Appendix 2

List of monitoring wells of Cambrian-Vendian groundwater bodies

Cambrian-Vendian GWB (1+2)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
2145	852	2002-2002	1961-1977
2149	858		1961-1991
2190	852-A	1968-1978	
2281	866		1961-1964
2291	558	2000-2000	1965-1997
2315	556	1989-2000	
2476	897-B		1982-1991

Cambrian-Vendian Voronka GWB (2)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
2079	913-A	1979-1979	1973-1997
2083	912-A	2003-2003	1980-2003
2088	912	1979-2010	1996-2010
2090	913	1958-1982	1961-1995
2100	2100		2007-2007
2110	981	1973-1992	1973-1990
2119	2119		2007-2010
2179	358-A		1965-2006
2198	580-A	1973-2010	1972-2010
2262	864	1965-2010	1965-1979
2333	933		1973-1988
2470	879	1961-1999	1961-1997
2473	934	1973-1993	1973-1996
2478	362		1973-2006
2657	2657		2007-2010
2993	319		1989-1989
3195	885	1967-1978	
3403	8138	1976-2002	
3434	3434		2008-2010
4018	885-A	1983-2010	
4225	4225		2007-2010
13702	8637	1986-2000	
19403	311-A	1965-2004	

Cambrian-Vendian GWB (1)

No of well in cadastre	No of monitoring well	Groundwater level	Chemical composition
2084	913-B		1981-1989
2138	918		1978-1991
2141	916		1978-1993
2142	917		1979-2007
2182	907	1982-2010	

2207	922	2000-2010	1979-2010
2282	919		1977-1992
2383	820-A	1963-1994	1963-1995
2387	2387		2007-2010
2400	906	1957-2002	1961-2002
2438	881	1965-2006	
2464	897	1956-1994	1962-2010
2477	940-B		1975-1995
2632	865	1967-1995	1963-2002
3448	311	1965-2004	
9026	9026		2007-2010