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Upconing of saline water from the crystalline basement into the Cambrian–Vendian aquifer system on the Kopli Peninsula, northern Estonia

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Abstract. The Cambrian–Vendian aquifer system is the most exploited groundwater resource in northern Estonia. As a result, the extensive use of groundwater has caused changes in the direction and velocity of groundwater flow in the Tallinn area. A groundwater flow and transport model of the Kopli Peninsula was built to investigate the upconing of saline water from an underlying layer, due to overexploitation of groundwater. A transient flow model was run in different flow regimes, using the pumping and water head data from the years 1946–2007. The vertical conductivity of crystalline rocks and the lower portion of Cambrian–Vendian rocks was found to be of the greatest importance for the range and shape of upconing phenomena. The results of the current study show that the range of the upconing process is dependent on the depth of the well screen interval. Therefore the results of many previous studies can be biased by the leaking of water from the underlying crystalline basement. The results also suggest that leakage from an underlying layer can be minimized by changing the screen depth of production wells.

Key words: Cambrian–Vendian aquifer system, upconing, groundwater modelling.

INTRODUCTION

The Cambrian–Vendian aquifer system (CVAS) is the principal and the most dependable source for the public water supply in North Estonia (Vallner & Savitskaja 1997; Savitskaja 1999). As a result of abstraction, lateral and rising groundwater flows have accelerated the transport of connate brackish water from the deeper portion of the aquifer system and underlying crystalline basement, as well as seawater intrusion towards coastal groundwater intakes (Yezhova et al. 1996; Mokrik 1997; Vallner & Savitskaja 1997; Savitski 2001).

In 2001 the *Hydrogeochemical Atlas of Estonia* was published (Perens et al. 2001). On the basis of 13 000 water samples collected from various aquifers during the last 50 years major constituents and chemical types of groundwater were mapped in that study. Samples from both monitoring wells and production wells were used. Several high Na^{+}, Cl^{-} and TDS anomalies were indentified in the CVAS on the northern coast of Estonia.

Production wells are often the primary source of temporal and spatial water quality and hydraulic head data, which are used to estimate the origin, mixing patterns and movement of groundwater and to calibrate and verify groundwater flow and solute transport models (Mayo 2010). It has frequently been assumed that wells provide a simple average of the vertical distribution of solutes adjacent to the well screen (Corcho Alvarado et al. 2009). Many studies concern the vertical and spatial heterogeneity of aquifers, thus several sampling protocols have been worked out (Hardy et al. 1989; Barcelona et al. 1994; Boylan 2004). Multilevel sampling devices are often used for monitoring wells (Einarson & Cherry 2002). Long-screen wells are also known to generate a sampling bias due to the vertical heterogeneity of the aquifer (Corcho Alvarado et al. 2009; Mayo 2010).

Previous studies have revealed a high content of trace elements in the CVAS (Karro & Marandi 2003; Marandi et al. 2004; Marandi 2007). Most of them treat the groundwater from the crystalline basement as one possible source of anomalies, as data from deeper wells indicate a higher content of e.g. Ba. Higher Ba concentrations have generally been associated with deeper well penetration during the mapping in the CVAS in North Estonia (Karro & Marandi 2003).

The study of the CVAS in the Tallinn area, Estonia, showed that high consumption of groundwater can cause an up to threefold increase in TDS in extracted groundwater (Karro et al. 2004; Marandi 2007). Hydrogeochemical investigations carried out in that region in 2004 allowed of the conclusion that the heavily depleted oxygen isotope composition and low ^{14}C concentrations of the groundwater of the CVAS point to a long residence time of groundwater. Thus, according to the results of isotope analysis, detectable intrusion of modern seawater into the aquifer system has not occurred yet (Karro et al. 2004).

In many aquifers fresh water overlies denser, more saline water, and the saltwater–freshwater interface moves vertically upwards in response to pumping from a well in the freshwater zone. Under some conditions a stable cone in the interface will develop at some depth below the bottom of the well, and the well will still discharge fresh water. Under other conditions the cone will be unstable and the interface will rise abruptly to the bottom of the well in a cusp-like form, causing the discharge to become saline (Hamza 2006). Therefore, the upconing phenomenon is studied in many freshwater aquifers overlying a layer of saline water. Local rise in saline water can occur when the freshwater aquifer system is exploited by fully or partially penetrating wells. Under certain conditions salt water can reach the bottom of the well and cause the discharge to become more saline (Chandler & McWhorter 1975; Todd 1980; Sufi et al. 1998; Zhou et al. 2005; Hamza 2006).

So far most investigations have treated the CVAS as a confined system between two aquitards. Leakage from the overlying Cambrian clays (Cm_1ln) and from the underlying crystalline basement has been neglected (Yezhova et al. 1996; Perens et al. 2001). These investigations treat the wells as fully penetrating, and as such, groundwater flow to the well is assumed to be horizontal only (Fig. 1A). However, Vallner (2003) expressed a different standpoint. He completed a digital groundwater model of Estonia, where an imaginary surface at a depth of 100 m beneath the upper surface of the crystalline basement acts as an impermeable bottom boundary for the entire overlying water-bearing formation (Fig. 1B). This conception can explain the results of Karro & Marandi (2003), Marandi et al. (2004) and Marandi (2007), leading to the conclusion that groundwater pumping induces upconing fluxes from the crystalline basement.

The main aim of this research was to analyse and model the process of the upconing of saline water into the CVAS in northwestern Estonia and to compare the results with isotope-based studies carried out in 2004 (Karro et al. 2004). Another aim was to investigate the influence of hydrogeological parameters on the upconing process and to assess the optimum position of a well screen, in order to provide input parameters for regional studies in the future.

This paper presents a quantitative analysis of the upconing of saline water into the CVAS on the Kopli Peninsula in northwestern Estonia by using the modern methods of groundwater flow and transport simulation. The applicability of these methods is tested in real-world conditions where the source data are insufficient. The impact of hydrogeological parameters on the upconing process and the optimum position of a well screen and the pumping rate for an efficient freshwater supply are determined. Recommendations for groundwater monitoring and interpretation are provided. The results of this study should contribute to an optimum development of the CVAS in northern Estonia.

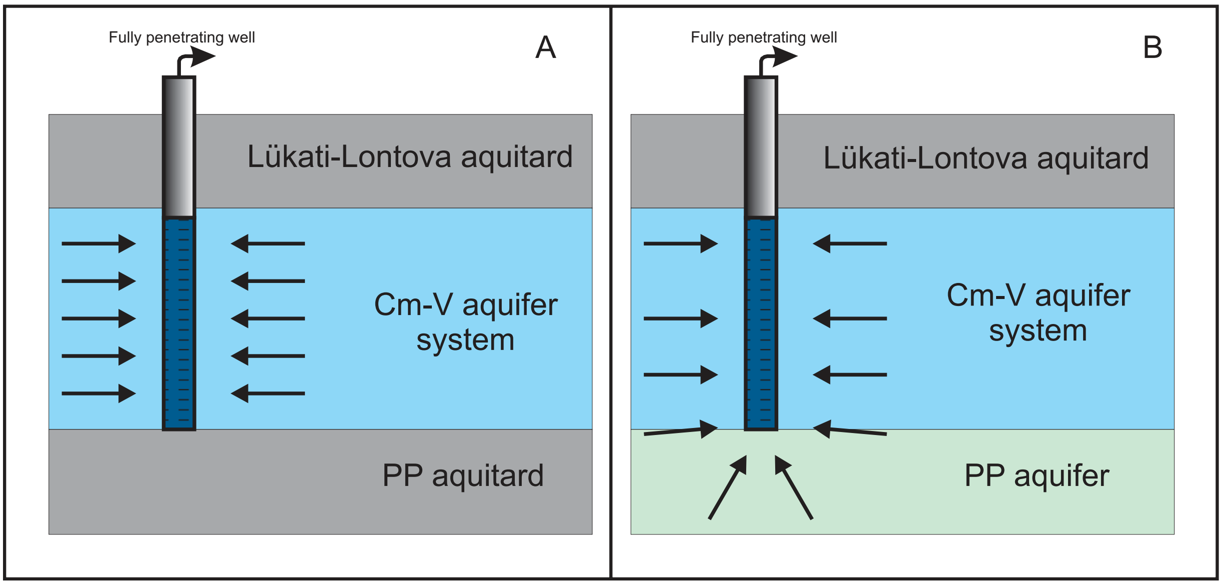

Fig. 1. Fully penetrating well in the Cambrian–Vendian aquifer system. Groundwater inflow to the well: (A) considering the PP layer as an aquitard, (B) considering the PP layer as an aquifer.

STUDY AREA

Estonia is situated in the northwestern part of the East European Platform. Structurally, its sedimentary beds, lying on the southern slope of the Baltic Shield, are inclined southwards at about 3–4 m per kilometre. The Lower Proterozoic crystalline basement is overlain by Upper Proterozoic (Ediacaran) and Palaeozoic (Cambrian, Ordovician, Silurian and Devonian) sedimentary rocks covered by Quaternary deposits (Fig. 2).

The crystalline basement is approximately 130 m deep in the Kopli area. It consists of granites and is overlain by a weathered layer composed of up to 10 m thick illite-smectite clays. The thickness and continuity of clays is not consistent and therefore their effect on permeability is unknown, but is expected to be variable.

The weathered layer of the basement is overlain by Ediacaran silt- and sandstones forming the CVAS with a total thickness varying from 70 to 90 m. In eastern Estonia the CVAS includes the upper, Voronka aquifer (V_2vr), the lower, Gdov aquifer (V_2gd), and the intermediate clayey Kotlin aquitard (V_2kt). In western Estonia, where the Kopli Peninsula is located, the Kotlin clays are thin and not continuous and do not form an aquitard between the Voronka and Gdov aquifers.

In the study area the Voronka aquifer consists of quartzose sandstone and siltstone and the conductivity of rocks (*K*) ranges from about 0.6 to 12.5 m/d. Transmissivity ranges from 100 to 150 m^2/d. The Gdov aquifer comprises mixed-grained sand- and siltstone and the conductivity of water-bearing rocks is 0.5 to 9.2 m/d, while the transmissivity is about 300 m^2/d (Perens & Vallner 1997).

The CVAS thins out northwards offshore, and pinches out about 20 km from the coast. On the Kopli Peninsula the CVAS is covered by 70 m thick Cambrian clays that form the laterally continuous Lükati–Lontova aquitard (Cm_1lk–Cm_1ln). The aquitard has a strong isolation capacity as its transversal conductivity is predominantly 10^{-8}–10^{-7} m/d in northern Estonia (Vallner 2003).

MODEL CONSTRUCTION

A groundwater flow and transport model of the Kopli Peninsula was built by using the Visual MODFLOW

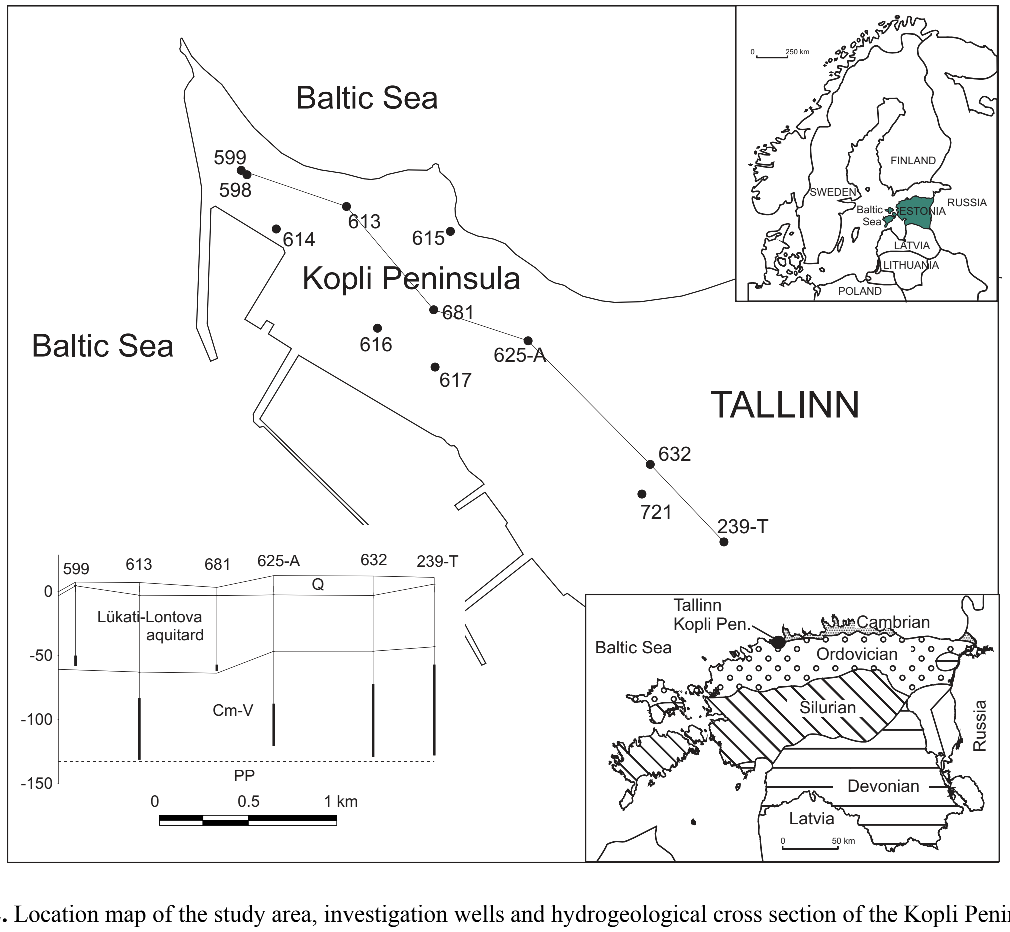

Fig. 2. Location map of the study area, investigation wells and hydrogeological cross section of the Kopli Peninsula.

2009.1 code to investigate the local upconing phenomenon. The study area was covered by a planar quadratic computational grid with the grid-square size of 250 m × 250 m (Fig. 3A). The grid of the local model contains 12 rows and columns, and 7 layers were generated to cover the cross section.

In the model the freshwater CVAS (model layers 3–5, Fig. 3B) is underlain by saline water in crystalline rocks (PP aquifer) (model layers 6 and 7) and is confined by the Lükati–Lontova aquitard (model layer 2). The thicknesses of the CVAS and PP aquifer in the Kopli area are approximately 75 and 110 m, respectively. The CVAS was divided into three modelling layers based on geology. Model layer 3 includes the Voronka aquifer. Layer 4 represents the Kotlin Formation having aquifer properties in the study area. Layer 5 coincides with the Gdov aquifer. A bed of Quaternary deposits with a thickness up to 5 m (model layer 1) was created above the Lükati–Lontova aquitard.

No chemical reactions were included in transport calculations, therefore, the TDS was assumed to behave conservatively. Background information from previous studies (Karro et al. 2004) was used to set the initial and boundary conditions. Additionally, results of chemical analyses from the State Groundwater Monitoring programme (Liiv et al. 2010) were employed.

The initial TDS content was 393 mg/L for the CVAS and 4587 mg/L for the PP aquifer. The TDS values were taken from the *State Groundwater Monitoring Database* (Liiv et al. 2010).

Real depths of production wells (Table 1) were used, therefore the depth and the screened interval vary from fully penetrating wells to partially penetrating wells with short screen intervals in the CVAS. During the modelling process several pumping rates were assigned to pumping wells according to data given in Table 1.

A Dirichlet flow boundary was applied to cells bordering the domain of the local model. The values for boundary conditions for the local model were derived from the profoundly calibrated regional model of Estonia (Vallner 2003) covered by a planar quadratic computational grid of 1000 m × 1000 m. The layers of the regional model include all main aquifers and aquitards from ground surface to as low as the impermeable part of the crystalline basement on the whole territory of Estonia. The time-dependent head and concentration values as boundary conditions were given to bordering cells of the local model on the basis of simulation results for the same cells obtained by running the regional model. The MT3DMS and SEAWAT-2000 engines were used for transport simulations.

RUN AND CALIBRATION OF THE MODEL

A transient flow model was run in different flow regimes. During the runs the model was calibrated by a trial and error method, where the results of modelled water heads were compared with the measured ones. The observed values from pumping wells 625-A and

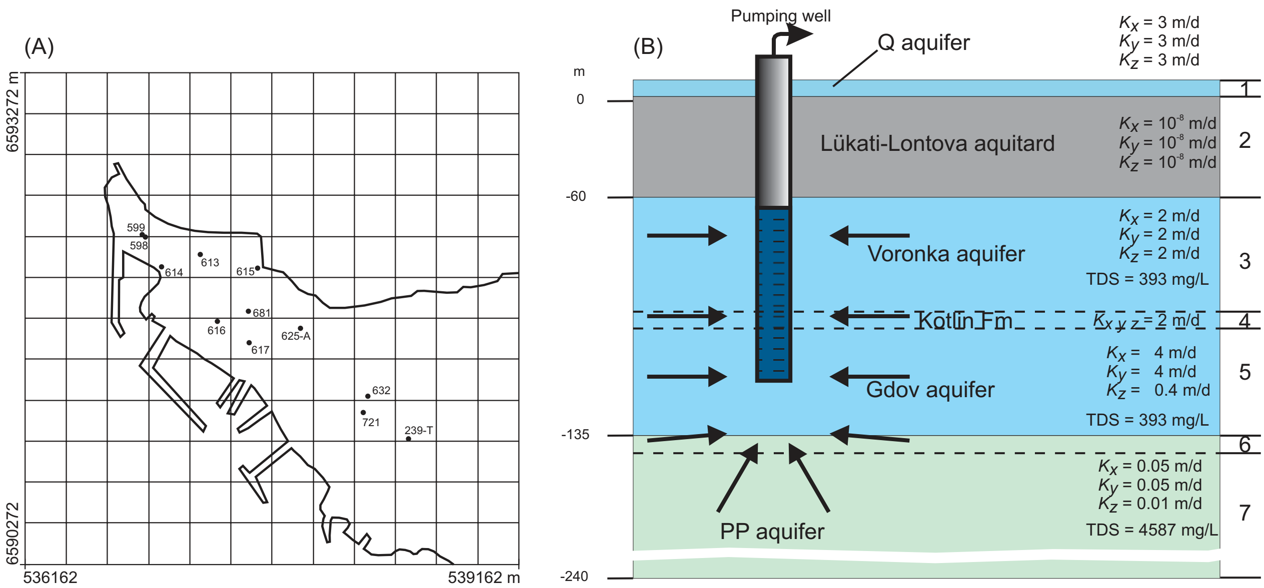

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Fig. 3. Conceptual model of the upconing of salt water due to pumping of the CVAS. (A) Layout of the horizontal grid of the model. (B) Conceptual cross section of the area and numbers of vertical grid layers on the right side. K_x, K_y, lateral conductivity; K_z, transversal conductivity.

Table 1. Yearly averaged pumping rates (m^3/d) of wells and the interval of the well screen (m b.s.l.)

Start time	End time	Pumping wells												Total
		239-T	598	599	613	614	615	616	617	625-A	632	681	721	
1946	1948	666	40	12	579	688	382	498	1035	1311	960	5	1155	7331
1948	1965	666	40	12	579	688	382	498	115	823	631	5	471	4910
1965	1973	695	40	12	935	971	259	437	316	815	738	5	737	5960
1973	1976	721	40	12	456	631	423	377	348	707	721	5	719	5160
1976	1991	489	40	12	878	529	60	500	0	667	558	5	0	3738
1991	1996	464	40	12	368	458	71	368	0	317	458	5	0	2561
1996	1999	0	40	12	48	320	135	174	0	0	0	5	0	734
1999	2007	0	23	1	18	100	0	175	0	0	0	114	0	431
Well screen interval		68–138	97–107	52–60	90–138	76–133	82–140	94–136	61–133	101–133	83–139	60–66	59–130	

632 were used. After each run the water conductivity of water-bearing rocks was corrected manually in order to get the best fit between the modelled and measured results. The results of calibration are given in Fig. 4. A 99% correlation was achieved after calibration of the groundwater flow model.

The calibrated flow model was then used as a basis for transport model calculations and calibration. The transport model was separately calibrated according to measurements from observation wells 613, 614 and 632 in the years 1991, 1996 and 2007 in the Kopli area (Table 2). The reasons for choosing these observation wells and calibration years were (1) data availability, (2) data match with calibration years of the groundwater flow model and (3) ability to assess the effect of differential pumping rates on changes in TDS. According to the monitoring data, average annual concentrations were calculated (TDS observed in Table 2) and compared with modelled results during the calibration process (Table 3). Note that the original module for concentration calibration provided by Visual MODFLOW was not suitable for calculations because observation wells were screened over several model layers (layers 3–6, Table 3, Fig. 3). Therefore, every screened model cell was assigned as a budget zone in order to calculate the amount of water removed by the well. On the basis of the average water concentration in a cell ('c' in Table 3) and water outflow from the cell ('q' in Table 3), average TDS contents (TDS modelled in Table 3) in the water pumped from each well were calculated. The calibration results show good correlation between the observed and

Table 2. Monitoring data for calibration calculations

Well No.	Date	TDS
613	21.03.1991	1112.5
613	30.10.1991	1166.5
613	10.12.1991	1266.5
613	25.09.1996	1383.5
613	22.03.2007	994.5
613	4.09.2007	1076.0
614	21.03.1991	833.5
614	30.10.1991	791.5
614	10.12.1991	951.0
614	3.07.1996	879.0
614	25.09.1996	835.5
614	22.03.2007	993.0
614	4.09.2007	900.5
632	13.02.1991	1106.0
632	29.10.1991	1230.0
632	10.12.1991	1558.5
632	3.07.1996	1208.0
632	25.09.1996	1214.5

modelled concentrations and the error is mostly less than 10%. Larger differences could be observed only in well 613 in 1996, where the error between the observed and measured results was 21%. This can be explained by the fact that only one measurement from 1996 was available for the calibration calculations.

RESULTS AND DISCUSSION

The calibrated model was used to simulate the possible effect of the screen depth interval on upconing. The first important results, however, were derived during the calibration process.

During calibration the critical parameters that rule the upconing process were gained in the Kopli Peninsula in the Tallinn area. Vertical conductivity of the crystalline basement and the lower portion of the CVAS was found to be of the greatest importance for the range and shape of the upconing phenomena. As stated before, the calibration of the model was performed in two steps. At first the model was calibrated against pumping rates and water heads. The second calibration was done to achieve the corresponding water salinity in the water pumped out of the wells. During the transport model calibration the conductivities of the lower portion of the CVAS and the crystalline basement were corrected compared to the calibration results of the flow model.

It is important that the results were satisfactory already with the conductivities assigned during the flow model calibration and the correlation between the measured and modelled results remained at the same level after a change during the transport model calibration, where the vertical conductivity of the Gdov aquifer (model layer 5) and the PP aquifer (model layers 6 and 7) had to be reduced 10 and 5 times (0.4 and 0.01 m/d, respectively) compared to lateral conductivity (Table 4) in order to be consistent with the observed concentration values. Thus, the parameters which affect the transport of salts may be offset when only the flow model is calibrated during the modelling process. However, in many cases only groundwater flow models are used to prove available resources for consumption, although the quality is of similar importance in estimating the available groundwater sources. So the results of the current study suggest building and calibration of both the flow and the transport model if there is a danger of change in salinity due to pumping. This study also showed that the difference in vertical and lateral conductivities must be considered in future investigations or in regional models for transport calculations for upconing phenomena of the CVAS in North Estonia (Table 4).

As a next step different screen interval depths were used in order to assess the effect of the screen depth on the range of the upconing saline water. The maximum screen depth used as a starting scenario was 130 m b.s.l., and then, the bottom of the screens was raised in 10 m steps up to 100 m in order to simulate variation in partial penetration of wells. Rock properties, initial conditions, water salinity and pumping rates were identical for all scenarios. Pumping rates for 1991 were used for calculations during all scenarios and initial salinity was 393 mg/L for the CVAS and 4587 mg/L for the PP aquifer.

Figure 5 represents the range of upconing saline water with a maximum screen depth of 130 m (A) and 100 m (B). The upper picture indicates the situation where most of the wells are fully penetrating and the lower picture represents the situation where wells are mostly completed in the upper one-third of the aquifer system.

No health-based guideline value for TDS has been proposed for drinking water (WHO 2004), but water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/L. The high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipes, heaters, boilers and household appliances. Therefore the 1000 mg/L salinity isoline was chosen for comparison of the range of upconing saline water.

According to our analysis, fully penetrating wells or wells that are completed in the lower one-third of the aquifer cause little changes in saline upconing. However, as the screened area reaches close to the interface between fresh and salty water, the lower portion of the screen captures water of high salinity. As a result, most of the pumping wells produce higher salinity water, as shown above during the calibration calculations (Table 3).

The 1000 mg/L TDS contour line represents the range of upconing saline water. It is shown to steepen as the screen becomes less penetrating. Reduction in the screen depth results in water being captured predominantly by lateral inflow. In this case only the wells situated in the centre of the depression cone (well 613, Figs 5B, 6) are predicted to capture higher salinity water within the lower portion of the screen.

On the basis of the initial assessment, the average TDS of the water pumped out of the wells with different depths of the screen interval was calculated. The results of calculations proved that the TDS in pumped water was decreasing with the decreasing depth of the well screen range in wells 614 and 615, but was increasing in well 615 (Fig. 6).

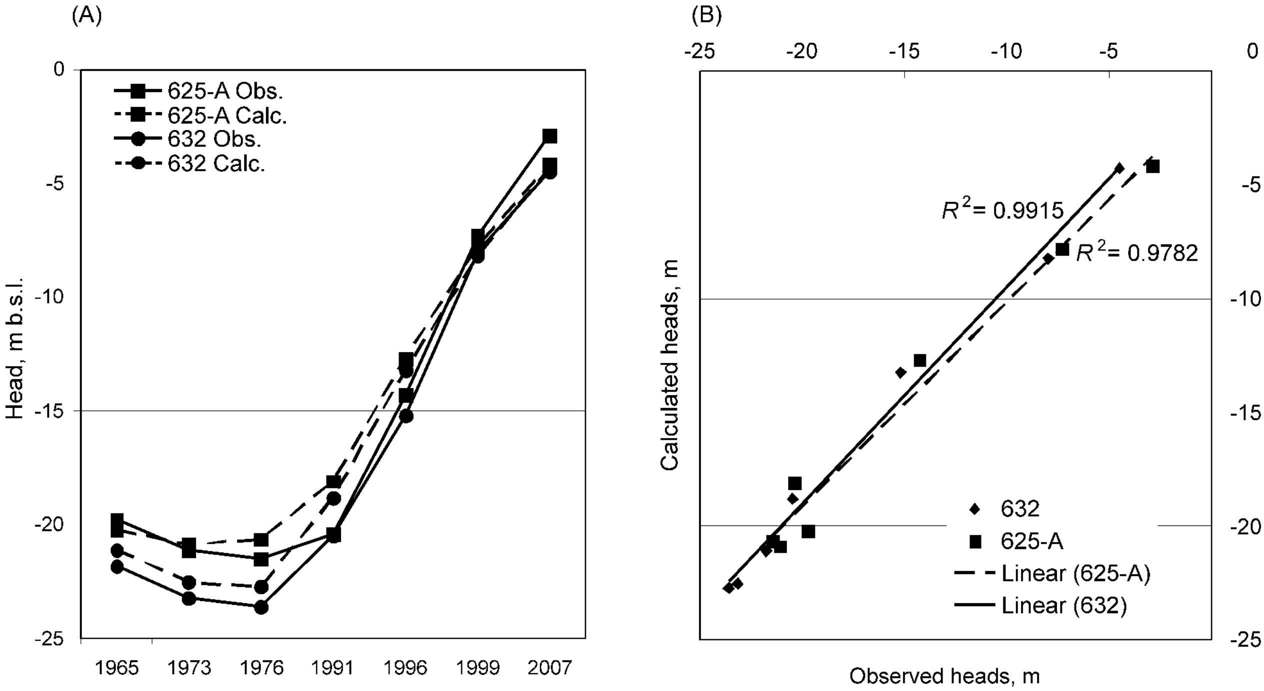

Fig. 4. The results of calibrations. (A) Observed and calculated heads during the calibration years. (B) Correlation between the observed and calculated values.

Table 3. Calibration results of the Kopli area groundwater transport model in wells 613, 614 and 632 for years 1991, 1996 and 2007

		1991			1996			2007	
		613	614	632	613	614	632	613	614
Layer 3	q, m^3/d	100.6	232.6	212.0	100.6	232.6	212.0	100.6	232.6
	c, mg/L	403.8	404.1	415.9	402.5	404.2	416.4	401.4	403.6
Layer 4	q, m^3/d	48.2	42.2	70.3	48.2	42.2	70.3	48.2	42.2
	c, mg/L	447.4	486.7	524.0	436.3	478.4	520.3	458.9	467.7
Layer 5	q, m^3/d	417.5	413.2	655.8	417.5	413.2	655.8	417.5	413.2
	c, mg/L	1250.4	1220.8	1469.8	1225.3	1204.4	1470.8	1288.8	1166.4
Layer 6	q, m^3/d	12.7	0.0	21.9	12.7	0.0	21.9	12.7	0.0
	c, mg/L	4587.0	4587.0	4587.0	4587.0	4587.0	4587.0	4587.0	4587.0
TDS modelled, mg/L		1109.6	899.7	1238.9	1090.4	889.4	1239.5	1137.8	865.7
TDS measured, mg/L		1181.8	858.7	1298.2	1383.5	857.3	1211.3	1035.0	947.0
Error, mg/L		–72.2	41.0	–59.2	–293.1	32.1	28.2	102.8	–81.3
Error, %		–6.1	4.8	–4.6	**–21.2**	3.7	2.3	9.9	–8.6

c, average water concentration in a cell; q, water outflow from the cell.

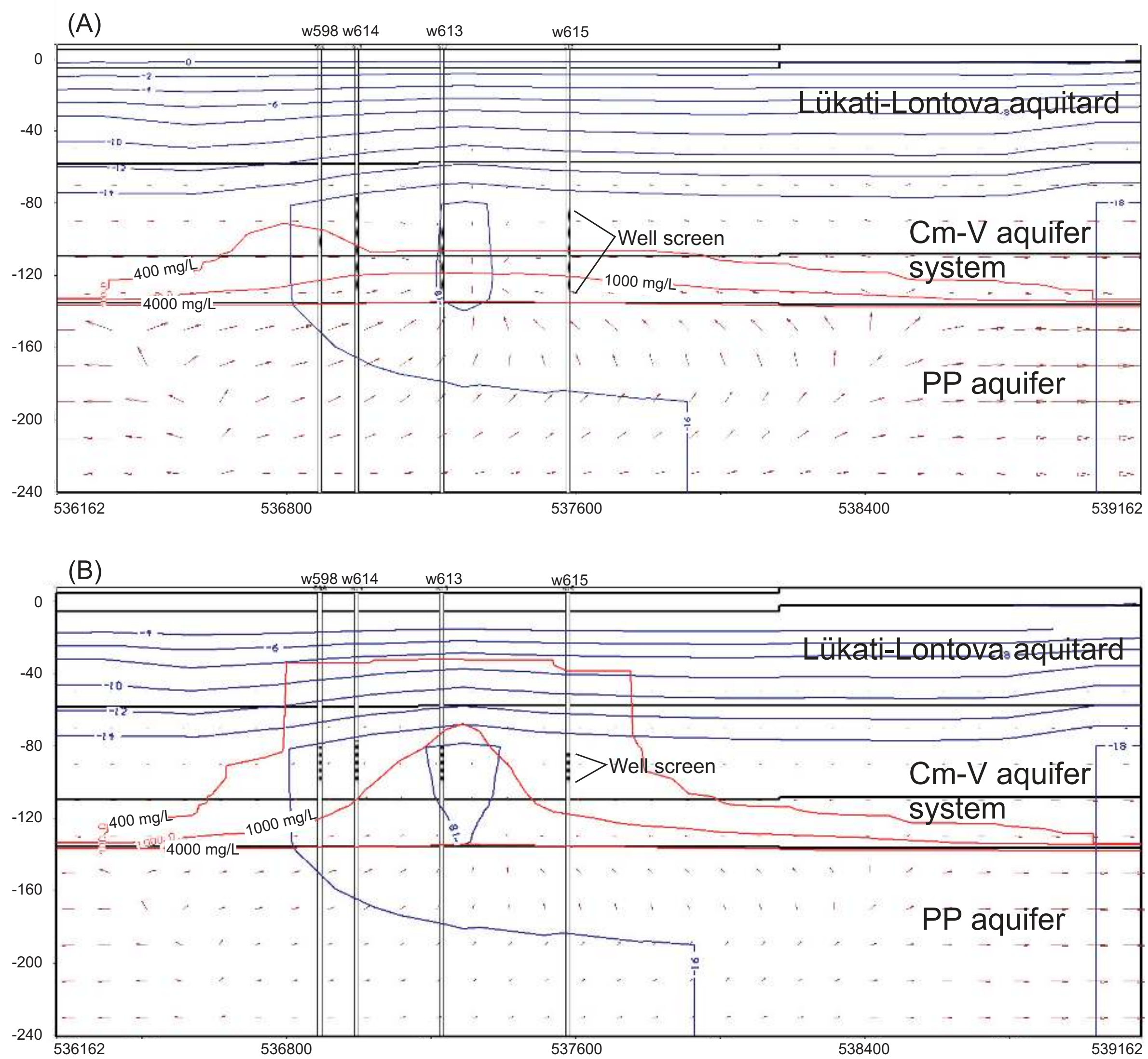

Fig. 5. The range of upconing salinity depending on the screen interval depth of the water consumption well. (A) A fully penetrating well reaching the lower part of the aquifer. (B) Screen interval between 80 and 100 m b.s.l. The screen range is indicated with a black area on well columns. Blue lines – head contours, red lines – contours of TDS concentration. Arrows indicate the velocity vectors scaled according to the magnitude of the groundwater flow velocity. The length interval of a vector equal to 1 mm in the figure corresponds to the flow velocity of 0.001 m/day.

Table 4. Conductivity (m/d) of the hydrogeological units modelled

Hydrogeological unit	Lateral conductivity $K_{x,y}$	Transversal conductivity K_z
Quaternary deposits	3	3
Lükati–Lontova aquitard	10^{-8}	10^{-8}
Voronka aquifer	2	2
Kotlin Formation	2	2
Gdov aquifer	4	0.4*
Lower Proterozoic basement	0.05	0.01*

* Specified by calibration of the Kopli model.

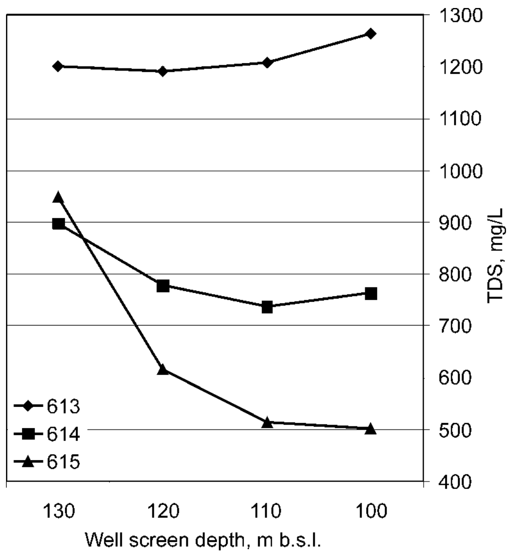

Fig. 6. Change in the TDS in the pumped water with different depths of the well screen interval.

The results of the current study, where the range of the upconing process is dependent on the depth of the well screen interval, suggest that in many cases the production of high-salinity groundwater by wells tapping the CVAS can be avoided by planning activities. It is an important issue for water management and needs a serious attention hereafter.

Several anomalies of hydrogeochemistry have earlier been identified by other researchers for the CVAS in northern Estonia (Perens et al. 2001). Our previous studies have also revealed high concentrations of trace elements/microconstituents in the CVAS (Karro & Marandi 2003; Marandi et al. 2004; Marandi 2007). Most of these studies consider groundwater from the crystalline basement as one possible source of anomalies (for example, data from deeper wells showed higher concentrations of Ba; Karro & Marandi 2003). Note that all of these studies used data from fully penetrating pumping wells that reach close to the PP aquifer system. Therefore it is highly possible that the water pumped out of such wells can also contain some portion of water from the PP aquifer, as suggested by the results of this study. Therefore, water consumption, the depth of the well screen interval and the possible upconing phenomena must take into account the spatial variations in the Cambrian–Vendian groundwater chemistry.

CONCLUSIONS

Large-scale local modelling of groundwater movement and solute transport in the Kopli Peninsula in the Tallinn area has provided information about critical parameters that rule the upconing phenomena. The vertical conductivity of the crystalline basement and the lower portion of the CVAS were found to be of the greatest importance for the range and shape of upconing phenomena. Although the conductive nature of the upper portion of crystalline rocks has been suggested by previous modelling works, this study shows that the vertical conductivity is required to decrease up to 10 times compared to lateral conductivity in order to explain the observed TDS changes in pumping wells. Such conductivities must be considered in future investigations or in regional models for transport calculations for upconing phenomena of the CVAS in North Estonia.

The modelling of the effects of different screen interval depths on the salinity of the water pumped out gave two major results:

1. Proper design of wells and planning of the distribution of wells in space may reduce or avoid the upconing of salty water from the underlying layer of the CVAS in Estonia. If wells capture the groundwater only from the upper part of the aquifer system, only the wells in the centre of the cone of depression will be affected by the upconing of saline water.
2. The results of many previous investigations dealing with the hydrochemistry of the CVAS in Estonia may be biased by the capture of water from the crystalline basement which contains higher salinity groundwater. These studies have indicated that high salinity and some trace elements have a positive correlation with the increasing well screen interval depth (Karro & Marandi 2003; Marandi et al. 2004; Marandi 2007). This study has established that fully penetrating wells with large screened intervals reaching the PP rocks may capture saline water from the underlying crystalline basement. The screen interval depth and capture zones of wells must be considered in future investigations of Cambrian–Vendian groundwater anomalies. Proper design of the well screen depth can often potentially avoid the contamination of groundwater and expensive treatment of drinking water.

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Soolaka vee ülestõmme aluskorrast Kambriumi-Vendi veeladestikku Põhja-Eestis Kopli poolsaarel

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Kambriumi-Vendi veeladestik on enim kasutatud põhjavee allikas Põhja-Eestis. Intensiivse ekspluateerimise tõttu on selles loodusliku seisundiga võrreldes oluliselt muutunud põhjavee liikumise suund ja kiirus. Tallinna piirkonnas on väljapumbatava vee soolsus kohati suurenenud kuni kolm korda. Väljapumpamisega tekitatud sooldumisprotsessi kvantitatiivseks iseloomustamiseks konstrueeriti käesoleva uurimistöö käigus Kopli poolsaare põhjavee mittestatsionaarne filtratsiooni- ja migratsioonimudel. Soolaka vee allikaks peeti paleoproterosoilist aluskorda. Mudel kalibreeriti põhjavee rõhu, pumpamise ja kvaliteedi andmete järgi, mis saadi 1946. kuni 2007. aastani tehtud mõõtmiste alusel. Modelleerimisarvutused tõestasid, et intensiivne väljapumpamine Kambriumi-Vendi veeladestikust kutsub esile soolaka vee ülestõmbe aluskorrast. Soolaka vee ruumiline levik oleneb kõige rohkem Kambriumi-Vendi veeladestiku alumiste kihtide ja aluskorra läbilaskvusest vertikaalsuunas. Puurkaevudest väljapumbatava vee soolsus sõltub samuti kaevude avatud osa vertikaalsest paigutusest. Kambriumi-Vendi veeladestikku tervenisti läbistavate puurkaevude vesi võib olla segunenud soolaka või soolase aluskorra veega ka teistes Eesti piirkondades. Soolase vee ülestõmmet on võimalik vältida või leevendada kaevude asukoha ja nende avatud osa sügavuse hoolika kavandamisega.