Future Groundwater Resources at Risk (Proceedings of the Helsinki Conference, June 1994).
IAHS Publ. no. 222, 1994.

Effect of gravel extraction on groundwater

TUOMO HATVA
National Board of Waters and the Environment PO Box 250, SF-00101 Helsinki, Finland

Abstract Gravel extraction causes changes in seepwater and groundwater quality as well as in the elevation of the groundwater table and its variation. Acid rain flushes the soil, increasing the quantity of dissolved salts and seepwater and groundwater quality variations. The composition of water in groundwater ponds varies in the same way as that of surface water, seasonally. The great variations in the quality of pond water increase the variations in groundwater quality. Gravel extraction increases the pollution risk of groundwater and may cause difficulties in the treatment of the water abstracted from a groundwater intake. Post-extraction maintenance is recommended.

GENERAL

Most of Finland's groundwater resources suited for water supply purposes are in the same glaciofluvial deposits that are used for extracting sand and gravel for building purposes. Gravel extraction affects the groundwater and increases its pollution risk. This has created a set of problems the solving of which requires information about necessary groundwater protection measures.

The effect of gravel extraction on groundwater was monitored during five years at 30 groundwater areas where gravel extraction had terminated or was still practised. Water samples were taken four times a year from a total of 86 sampling sites consisting of observation pipes, wells, springs and groundwater ponds in gravel pits. In addition, seepwater investigations were made at 52 lysimeters. The number of samples taken was 4000 and the number of different analyses carried out on them varied between 35 and 40.

The purpose of the studies was to investigate the effect of gravel extraction on groundwater quality and quantity, pollution risk and on the use of groundwater, its usability and the need to protect it. On the basis of these studies and investigations new guidelines have been drawn up concerning groundwater protection, planning of gravel extraction as well as the post-extraction maintenance and use of the areas.

EFFECT OF GRAVEL EXTRACTION ON GROUNDWATER

Quality of seepwater

The composition of acidic rainwater that contains little dissolved salts changes as it seeps down through the podsol and the underlying ground to form groundwater. When the podsol is removed in connection with gravel extraction the number of biochemical reactions in seepwater is reduced significantly.

The composition of seepwater in intact soil (natural seepwater) is clearly different from that of seepwater in an uncovered gravel stratum (Figs 1 and 2). Under an exposed gravel surface the values and concentrations of the main parameters describing the seepwater (conductivity, hardness, bicarbonate, nitrate, sulphate, chloride, silicon acid and calcium) are distinctly higher than in natural state. When a surface layer similar to the natural podsol layer was made on top of the uncovered gravel, the quality of the seepwater that percolated through the layer bore a close resemblance to that of natural seepwater (Sandborg, 1993).

The acidity of seepwater increased during the five-year monitoring period both in natural groundwater areas and in exposed groundwater areas. The pH of natural seepwater decreased by 0.3 and that of seepwater in an exposed groundwater area by 0.5 units. The pH of groundwater in an intact, uncovered, groundwater area also went down relatively quickly and was of the same order of magnitude as the decrease in the pH of natural seepwater.

The thickness of that part of the podsol, which can be distinguished by its colour is only about 0.3-0.5 m, while the total podsol zone where chemical changes in seepwater quality take place is at least 2 m thick. (Sandborg, 1993).

Groundwater quantity and the groundwater table

When trees, other vegetation and podsol are removed at a gravel extraction site, evapotranspiration diminishes and groundwater formation increases. At gravel extraction sites groundwater amounts to 60-70% of the precipitation, when at natural groundwater areas it amounts to about 50-60% (Sandborg, 1993; Lemmelä, 1990).

Small evapotranspiration and quick melting of snow accumulated in gravel pits increase groundwater formation. As a result groundwater table in extensive gravel extraction sites is quickly elevated in spring to exceptional levels (Fig. 3).

Groundwater quality

Groundwater extraction above the groundwater table As a result of the removal of surface soil and gravel extraction above the groundwater level the quality changes in seepwater under the exposed gravel surface are also reflected in the groundwater quality (Table 1 and Fig. 4).

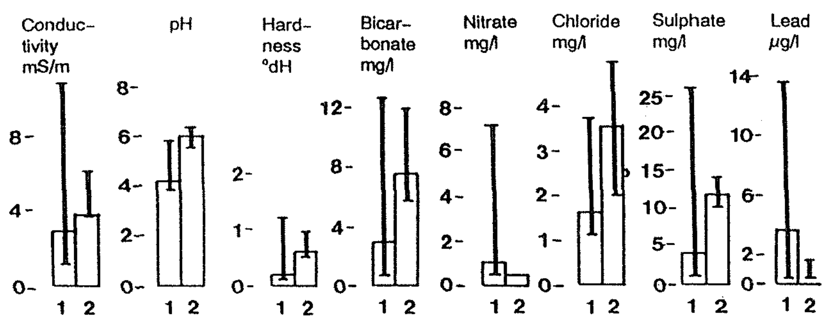

Fig. 1 The quality of rainwater (1) and natural seepwater at the depth of 2.5 m from ground surface; median, minimum and maximum values (Sandborg, 1993).

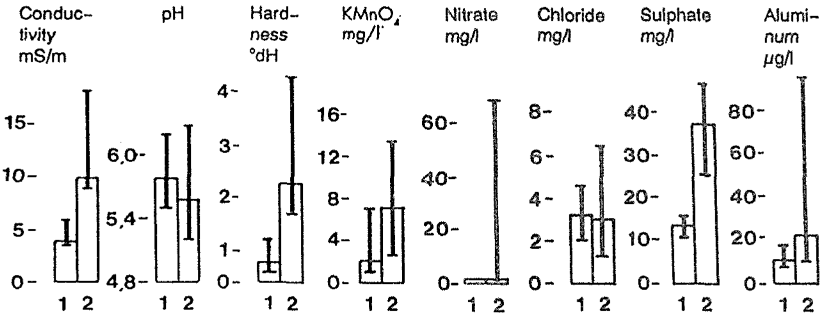

Fig. 2 The quality of natural seepwater i.e. seepwater in intact soil (1) and under an uncovered gravel surface (2) at the depth of 2.5 m from the ground surface; median, minimum and maximum values (Sandborg, 1993).

At gravel extraction sites electrical conductivity and hardness as well as the concentrations of carbon dioxide, nitrate, sulphate and chloride are distinctly higher than at the intact (natural) areas of the same esker range. Groundwater at gravel extraction sites in Southern Finland showed signs of acidification. The risk of acidification of groundwater can be said to increase with increasing gravel extraction (Hyyppä & Penttinen, 1993).

Variations in groundwater quality at gravel extraction sites are greater than at natural groundwater areas. The stability of groundwater quality is impaired as a result of gravel extraction. Water quality changes can be felt at the water intake. In all the cases studied, however, the groundwater quality met the requirements and targets set for drinking water, with the exception of organic matter which in some places exceeded the target value. This was caused by water from bogs being introduced into the gravel extraction site from outside the aquifer (Hyyppä & Penttinen, 1993).

Gravel extraction below the groundwater table In areas where availability of gravel above the groundwater table has been insufficient gravel extraction has often been extended below the groundwater table. Groundwater ponds have then been formed in gravel pits. Their number is highest in southwestern and western Finland. These ponds

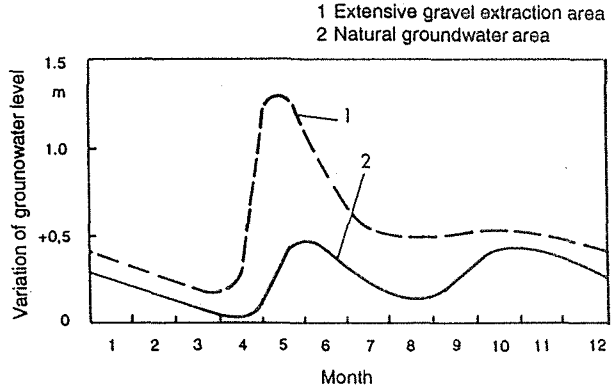

Fig. 3 Schematic drawing of variations in groundwater table at intact (natural) groundwater areas and extensive gravel extraction sites. (Hatva *et al.*, 1993a; Soveri & Ahlberg, 1989).

Table 1 Composition of rain and groundwater at intact (natural) groundwater areas and adjacent gravel extraction sites where extraction takes place above groundwater table (Hatva *et al.*, 1993; Järvinen & Vänni, 1990).

Parameter		Rainwater $n = 12$			Natural groundwater areas $n = 43\text{-}60$			Gravel extraction areas $n = 76\text{-}240$		
		Md	min	max	Md	min	max	Md	min	max
Temperature	°C				4.7	1.1	6.8	5.6	0.0	8.8
Acidity	pH	4.5	4.1	6.3	6.4	5.6	7.3	5.9	5.4	7.3
Conductivity	mS m^{-1}	4.0	2.0	9.0	6.0	3.0	9.0	7.0	4.0	19.0
Carbonic acid	mg l^{-1}				11.0	2.0	44.0	24.0	2.0	62.0
Bicarbonate	mg l^{-1}				25.0	15.0	38.0	20.0	8.0	45.0
Chloride	mg l^{-1}	1.0	1.0	3.5	2.0	1.0	7.0	3.0	2.0	37.0
Sulphate	mg l^{-1}	2.0	0.5	3.0	4.0	4.0	12.0	10.0	5.0	16.0
$KMnO_4$-consumption	mg l^{-1}				3.0	0.0	9.0	2.0	0.0	51.0
Hardness	°dH				1.0	0.5	1.5	1.0	0.5	3.0
Nitrate	mg l^{-1}	2.1	1.4	6.7	0.4	0.0	4.0	1.9	0.0	11.5

are in most cases small and shallow, their surface areas varying from a few hundred square metres to some hectares. The largest ponds resemble lakes, exceed 10 ha in surface area and are more than 10 m deep.

The basic chemical composition of the water in groundwater ponds is in most cases the same as that of the groundwater. The pond water, however, is exposed to weather and immediate impacts of the physiological functions of organisms which explain the great seasonal variations in the quality of the pond water. The range of variations can be as great as in surface waters (Table 2).

The properties of individual ponds are to a great extent affected, besides the composition of groundwater, by the size and depth of the pond, its location in the groundwater area, the organisms living in the pond and the immediate surroundings (Fig. 5). Small ponds are often eutrophic and there are great variations in its water quality. Also surface runoff e.g. of bog waters from the immediate vicinity affects the water quality and increases variation. Deep large ponds located in the groundwater flow field are often oligotrophic and their water quality is stable (Hyyppä & Penttinen, 1993).

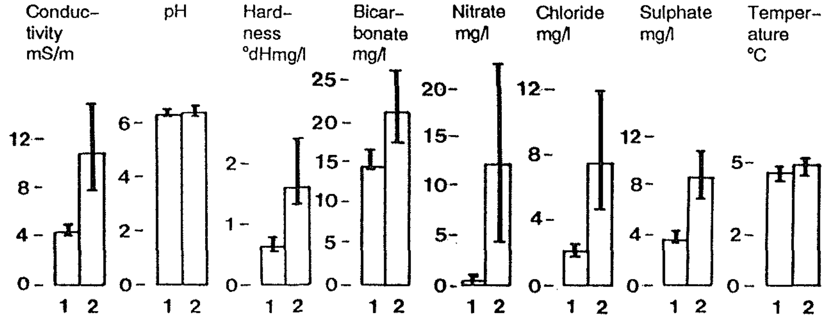

Fig. 4 The quality of groundwater in natural (1) and gravel extraction area (2) situated on the same groundwater area. High nitrate values may be a result of dumping of wastes in gravel pit; median, minimum and maximum values (Hatva *et al.*, 1993a).

Table 2 Water quality values in spring and summer in groundwater ponds formed in gravel pits (Hyyppä & Penttinen, 1993).

Parameter	Unit	Summer: min	Summer: Md	Summer: max	Winter: min	Winter: Md	Winter: max
Conductivity	mS m^{-1}	1.5	4.9	19.8	2.8	7.3	23.6
Acidity	pH	6.5	7.2	8.9	5.9	7.4	7.1
Hardness	°dH	0.2	0.7	3.5	0.3	1.1	3.7
Nitrate	mg l^{-1}	0.0	0.0	0.6	0.0	0.3	1.7
Silica	mg l^{-1}	0.3	3.6	13.2	0.3	7.1	17.9
Oxygen	%	86.0	104.0	142.0	0.0	60.0	116.0
Carbonic acid	mg l^{-1}	0.0	2.0	14.7	0.0	14.0	41.0
Temperature	°C	8.1	17.2	22.4	0.0	1.5	4.5

Changes in groundwater quality in the vicinity of gravel extraction sites The groundwater formed at a gravel extraction site flows into the surroundings and towards the areas where groundwater discharges by itself or towards places where groundwater is withdrawn i.e. at water intakes. The impact in the surroundings of the gravel extraction site depends, inter alia, on the following factors (Hatva, 1989; Hatva *et al.*, 1993a):

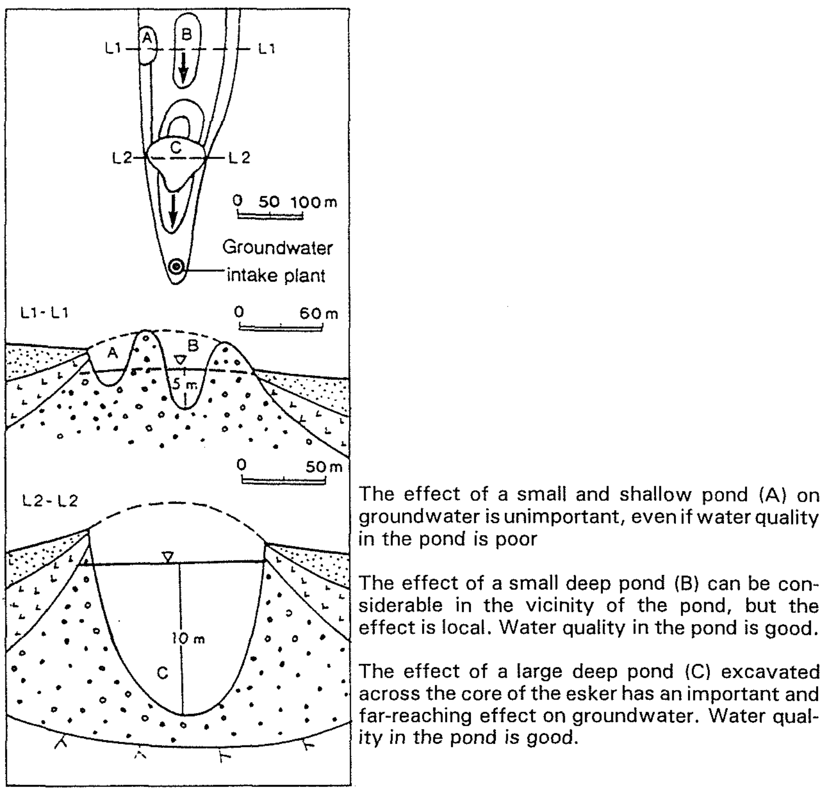

Fig. 5 Different types of groundwater ponds in gravel pits and their effect on groundwater (Hatva *et al.*, 1993a).

- extent of the gravel extraction site and thickness of the soil layer that remains on top of the groundwater table;
- location of the gravel extraction site in the groundwater area;
- direction and velocity of groundwater flow;
- effect of water withdrawal on the flow pattern of groundwater;
- natural quality of groundwater and its variation;
- geological structure of the aquifer and its geographic location;
- other activities affecting groundwater quality such as application of salt for dust control, burying or dumping of wastes etc.

If the gravel extraction site is small, its effect on groundwater that is in natural state is small or it cannot be observed at all. The effects get more pronounced when the size of the gravel extraction site grows. If the area of the gravel extraction site is more than 50% of the groundwater formation area and the groundwater flows from the gravel extraction site towards the natural groundwater area, the effects of gravel extraction on the groundwater of the intact (natural) area will be clearly observed. The impact of groundwater ponds formed in gravel pits depends on the size and depth of the pond and its location in the groundwater area. If the pond extends across the highly permeable core of the esker, the effect may be felt as far as at a distance of 1 km (Hyyppä & Penttinen, 1993).

RISK OF CONTAMINATION AND THE NEED FOR TREATMENT

The seepwater studies revealed, inter alia, that many heavy metals and easily degrading organic substances as well as viruses and bacteria are retained relatively well in the natural podsol layer (Sandborg, 1993; Kuusinen, 1993). Under an exposed gravel surface the retention was much weaker. The seepwater studies show that the risk of groundwater contamination is clearly higher at gravel extraction sites than in natural groundwater areas.

Faecal coliform bacteria were observed more in gravel extraction areas than in natural groundwater areas. In some places nitrate was observed in groundwater; this may be a result of dumping of wastes in gravel pits. A serious factor that caused changes in groundwater quality was the seepage of surface water and especially of bog water into the groundwater area as a result of carelessness in gravel extraction. In many places the concentration of organic matter exceeded the quality target of 12 mg l^{-1} ($KMnO_4$-consumption). Other direct adverse effects of gravel extraction were the elevated concentrations of chlorides, due to the use of dust-control salts, and of sulphates, due to the use of the residual sludge from gravel-washing in the post-extraction maintenance of the extraction site (Hyyppä & Penttinen, 1993).

An increase in organic matter, even in small concentrations, creates difficulties in the removal of iron when biofiltration methods are applied (Hatva, 1989). The acidity of groundwater and related variations in carbonic acid make the alkalization of water more difficult. The variations are greatest in areas affected by groundwater ponds.

The maximum limit value of 25 mg l^{-1} recommended for chloride content can be exceeded, when calcium chloride is used for dust-control. As the sulphate content rises due to gravel extraction, the ratio expressing the corrosiveness of water is in most cases too small. It is recommended that the ratio of milliequivalents is as follows(Hedberg *et al.*, 1990):

$$\frac{HCO_3}{SO_4 + Cl} > 1.5$$

In natural groundwater areas the ratio is usually more than 1.0 and often it exceeds the value of 1.5. In gravel extraction areas the ratio usually stays clearly below 1.5. The change in the ratio is mainly caused by the elevated chloride and sulphate concentrations at gravel extraction sites. At water works the corrosiveness can be diminished by increasing the bicarbonate concentration in connection with alkalization.

GROUNDWATER PROTECTION AND GRAVEL EXTRACTION

Among the groundwater protection goals related to gravel extraction is to see to it that no such changes are caused in groundwater that make it hazardous for human health or otherwise impair its quality. In addition, the attainment of quality requirements and quality targets as well as other guidelines and recommendations that have been set for groundwater quality should be safeguarded.

In order to guarantee the supply of good groundwater with stable quality it its recommended that gravel extraction be directed to areas where the adverse effects and risks are as small as possible. Gravel extraction and the restrictions put on it are managed through a zoning system based on the need to protect groundwater intakes.

It is recommended that the intake area and its inner protection zone be left in their natural state. Should there be gravel extraction in the inner protection zone of the water

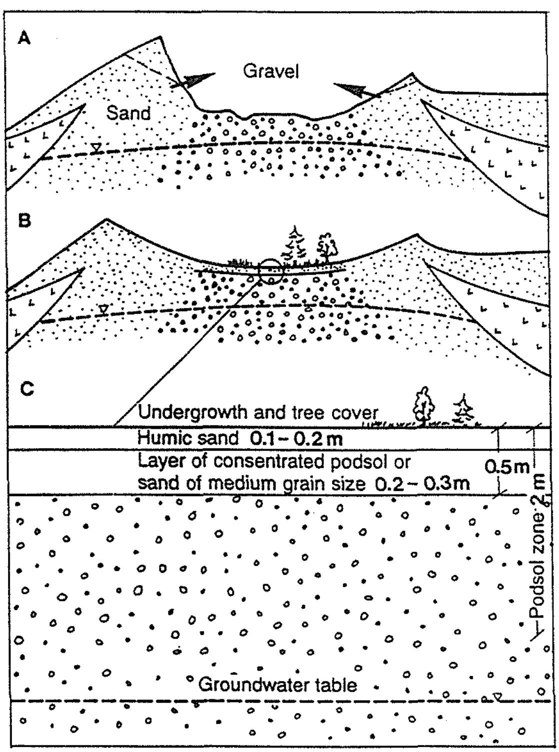

Fig 6. Earth moving (A) in connection with post-extraction maintenance, and high-level protective surface layers (B and C) (Hatva *et al.*, 1993).

intake, a protection layer of 4-6 m should be left on top of the maximum groundwater table. In the outer protection zone of the water intake the thickness of the protection layer should be at least 2 m. No gravel extraction below the groundwater table is allowed in groundwater areas classified as important.

The post-extraction maintenance should be carried out gradually as the extraction proceeds. The objective of post-extraction maintenance is to create a growth base for trees and other vegetation that will eventually protect the groundwater, the development of a biologically active surface layer, prevention and slowing down of acidification, controlling the variations in groundwater table, and acceleration of the development of a new podsol layer.

The protective layer should be made so that the gravel core of the esker is covered with clean sand of high permeability. On top of the sand layer a growth base of about 0.3-0.5 m in thickness is constructed consisting of organic matter and sand. On this plants characteristic of the area are planted to form the undergrowth. The tree cover should be of mixed stock (Fig. 6).

Management of gravel and groundwater resources requires that gravel extraction plans representing different levels are drawn up for different purposes. Master plans can be made for economic areas or municipalities on the use of gravel resources or groundwater resources, or detailed project plans can be drawn whose exactingness may be high-level, medium-level or basic in level.

REFERENCES

Hatva T. (1989) Iron and manganese in groundwater in Finland: occurrence in glaciofluvial aquifers and removal by biofiltration. *Publication of the Water and Environment Research Institute no. 4*. National Board of Waters and the Environment, Helsinki, Finland. ISBN 951-47-3097-6, ISSN 0783-9472.

Hatva, T., Hyyppä, J., Ikäheimo, J., Penttinen, H. & Sandborg, M. (1993a) Soranoton vaikutus pohjaveteen. Raportti V: soranotto ja pohjaveden suojelu (Effect of gravel extraction on groundwater. Report V: Gravel extraction and groundwater protection). Helsinki, vesi- ja ympäristöhallitus. *Vesi- ja ympäristöhallituksenjulkaisuja – sarja* **B15**. Finnish original with English summary. ISBN 951-47-7012-9, ISSN 0786-9606.

Hatva, T., Hyyppä, J., Ikäheimo, J. & Sandborg, M. (1993) Soranoton vaikutus pohja veteen. Raportti VI: Pohjavesi ja soranotto (Effect of gravel extraction on groundwater. Report VI: Groundwater and gravel extraction). *Helsinki, Ympäristöministeriö, kaavoitus-ja rakennusosasto*, 1/1993. Tutkimusraportti, Finnish original with English summary. ISBN 951-47-7155-9, ISSN 0786-5244.

Hedberg, T., Vik, E. A., Wagner, B., Oliphant, R., Ferguson, J. F., van den Hooven, T., Benjamin, M. M., Reiber, S., Nielsen, K., Pääkkönen, J., Fiksdal, L. & Forslund, J. (1990) The influence of water quality on different pipe materials and house installation – Conclusions from the Workshop on Corrosion and Corrosion Control in Drinking Water Systems. In: *Proceedings from a Corrosion Workshop and Seminar* (Oslo, March 1990), 4-7.

Hyyppä, J. & Penttinen, H. (1993) Soranoton vaikutus pohjaveteen. Tutkimusraportti II. Alueelliset pohjavesitutkimukset. Helsinki. Vesi- ja ympäristöhallitus. Osa A. Tutkimustulokset. Osa B. Tutkimustulosten tarkastelu (Research Report II A: Research results, Part B: Assessment of the results and conclusions). *Vesi- ja ympäristöhallituksen monistesarja* **329**. Finnish original with English summary, ISBN 951-47-4692-9, ISSN 0783-3288.

Järvinen, O. & Vänni, T. (1990) Sadeveden pitoisuus- ja laskeuma-arvot Suomessa vuonna 1988 (Rainwater quality and deposition values in Finland in year 1988). Helsinki, vesi- ja ympäristöhallitus. *Vesi- ja ympäristöhallituksen monistesarja* **235** in Finnish. ISBN 951-47-3018-6, ISSN 0783-3288.

Kuusinen, K. (1992) Soranoton vaikutus pohjaveteen. Tutkimusraportti IV. Mikrobien kulkeutuminen maaperässä ja pohjavedessä (Effect of gravel extraction on groundwater, Report IV: Movement of microbes in soil and groundwater). Helsinki. Vesi- ja ympäristöhallitus. *Vesi- ja ymäristöhallituksen monistesarja* **331**. Finnish original with English summary. ISBN 951-4-4694, ISSN 0783-3288.

Lemmelä, R. (1990) Water balance of a sandy aquifer an Hyrylä in southern Finland. Turku, Turun yliopisto. *Annales Universitates Turkuensis, Sarja-Ser. A, II. Biologica – Geogrophica – Geologica* **73**. ISBN 951-880-428-1, ISSN 0082-6979.

Sandborg, M. (1992) Soranoton vaikutus pohjaveteen. Tutkimusraportti III. Vajovesitutkimukset (Effect of gravel extraction on groundwater. Report III: Seepwater investigations). Helsinki, vesi- ja ympäristöhallitus, *Vesi- ja ympäristöhallituksen monistesarja* **330**. Finnish original with English summary. ISBN 951-47-4693-7, ISSN 0783-3288.

Soveri, J. & Ahlberg, T. (1989) Multiannual variations of groundwater level in Finland during the years 1962-1989. In: *Conference on Climate and Water* (Helsinki, Finland, September 1989). Helsinki, Valtion painatuskeskus. *The Publications of the Academy of Finland* **9/89**. ISBN 951-861-668-x, ISSN 0358-9153.