Geological Survey of Finland
Water Management Solutions Unit
Espoo

30.6.2020 GTK/12/03.01/2018

Vulnerability assessment of the shallow groundwater in Finland

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Contribution to the HOVER - WP7, Deliverable D.7-2 report:

Compilation of the examination results of the data sets of input data for the respective methodologies assessing vulnerability of the upper aquifer to pollution

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GEOLOGICAL SURVEY OF FINLAND

DOCUMENTATION PAGE

35/2020/ GTK/12/03.01/2018

Authors	Type of report
Samrit Luoma and Juuso Ikonen	GTK Open File Work Report
	Commission by EU-GeoERA-HOVER (WP7) Project

Title of report

Vulnerability assessment of the shallow groundwater in Finland

Abstract

This report is part of work package (WP) 7 in the GeoERA-HOVER project - Hydrogeological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems. The scope of WP7 was to harmonize the vulnerability assessment methods for the upper aquifers among the member states partners. This report summarizes the details of the vulnerability assessment of the shallow groundwater for the whole of Finland by using the DRASTIC method and provides the results of the DRASTIC parameters that contributed to the Deliverable D.7-2 report of the GeoERA-HOVER, WP7. The intrinsic vulnerability assessment DRASTIC method is based on 7 parameters: Depth to water (*D*); Recharge (*R*); Aquifer media (*A*); Soil media (*S*); Topography (*T*); Impact of the vadose zone (*I*); and Hydraulic conductivity (*C*). The depth to water, one of the most important DRASTIC parameter, was well identified based on 13 057 mean groundwater level data measured during 1971-2020. Due to the sparse drilled borehole data and insufficient information of the confined layers beneath the subsurface some uncertainty in the assessment remains. This is highlighted in the limited data on soil and aquifer media. The DRASTIC vulnerability index maps of Finland range from 46 to 210 (of total from 23 to 230) for the standard weight, and from 49 to 242 (of total from 26 to 260) for the pesticide weight. High vulnerability index scores are found in the areas that contain porous coarse-grained glacial and post-glacial sediments. The vulnerability index maps produced from this study can be used as a regional screening tool to prioritize the areas in most urgent need of detailed site investigation of the shallow groundwater areas in risk of contamination. Furthermore they provide useful information for groundwater protection schemes and land use planning in Finland for the future.

Keywords

Groundwater vulnerability, DRASTIC, shallow groundwater, glacial deposit, Finland

Geographical area

Finland

Report serial		Archive code	
-		35/2020	
Total pages	Language	Price	Confidentiality
30	English	-	Public report
Unit and section		Project code	
Water Management Solutions Unit (VER)		50403-30112	
Prepared by:		Prepared by:	
Samrit Luoma, GeoERA HOVER-WP7 Project manager		Juuso Ikonen, Geologist	

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1 INTRODUCTION

This report is part of work package (WP) 7 in the GeoERA-HOVER project - Hydrogeological processes and Geological settings over Europe controlling dissolved geogenic and anthropogenic elements in groundwater of relevance to human health and the status of dependent ecosystems. The scope of WP7 was to harmonize vulnerability to pollution mapping of the upper aquifer among the member states partners. During this project, the common vulnerability assessment methods that can be applied to all study areas were selected. For the upper aquifer with the clastic sediments, a well-known intrinsic vulnerability assessment method DRASTIC (Aller et al. 1987) was selected. The vulnerability index map will be harmonized and compared in order to identify the specific areas of high aquifer vulnerability across Europe. The results of the assessment will be stored later on in the GeoERA Information Platform (GIP). For the Finland case, the vulnerability assessment of the shallow aquifer was carried out at the national scale.

This report summarized the details of the vulnerability assessment of the shallow groundwater for the whole of Finland by using the DRASTIC method with the rates and weights of parameters assigned from the agreement of all partners. The results of the DRASTIC parameters maps will contribute to the Deliverable D.7-2 report of the GeoERA-HOVER, WP7: Compilation of the examination results of the data sets of input data for the respective methodologies assessing vulnerability of the upper aquifer to pollution (Broda et al. 2020). The vulnerability index map produced from this study can be used as a regional screening tool to prioritize the areas in most urgent need of detailed site investigation of the shallow groundwater areas in risk of contamination. Furthermore they provide useful information for groundwater protection schemes and land use planning in Finland for the future.

2 STUDY AREA

The shallow groundwater areas in Finland are derived from the Quaternary sediments deposited during the Weichselian and Holocene deglaciation of the Scandinavian Ice Sheet (Saarnisto & Saarinen 2001). The Quaternary sediments form a sharp contact with the underline crystalline Precambrian bedrock and consist of glacial till, gravel, sand and fine-grained sediments (silt and clay), and in some areas with postglacial littoral gravel, sand and clay. Based on the exposed Quaternary deposit map of Finland scale 1:200 000 (GTK 2020b) (Fig. 1), the most common superficial sediment is glacial till, which covers 46.5% of the total area of Finland, while the coarse-grained sediments cover only 7.5% of total.

Finland belongs to the temperate coniferous-mixed forest climate zone with cold and wet winters. According to Köppen-Geiger climate classification, this climate is classified as Dfb (Kottek et al. 2006). The mean annual temperature during the period 1981–2010 (Pirinen et al 2012) is 2.8 ºC, with mean minimum and maximum temperatures of -1.9 and 6.5 ºC, respectively. The average annual precipitation was 592 mm, with mean minimum and maximum of 433 and 682 mm, respectively, during the same period.

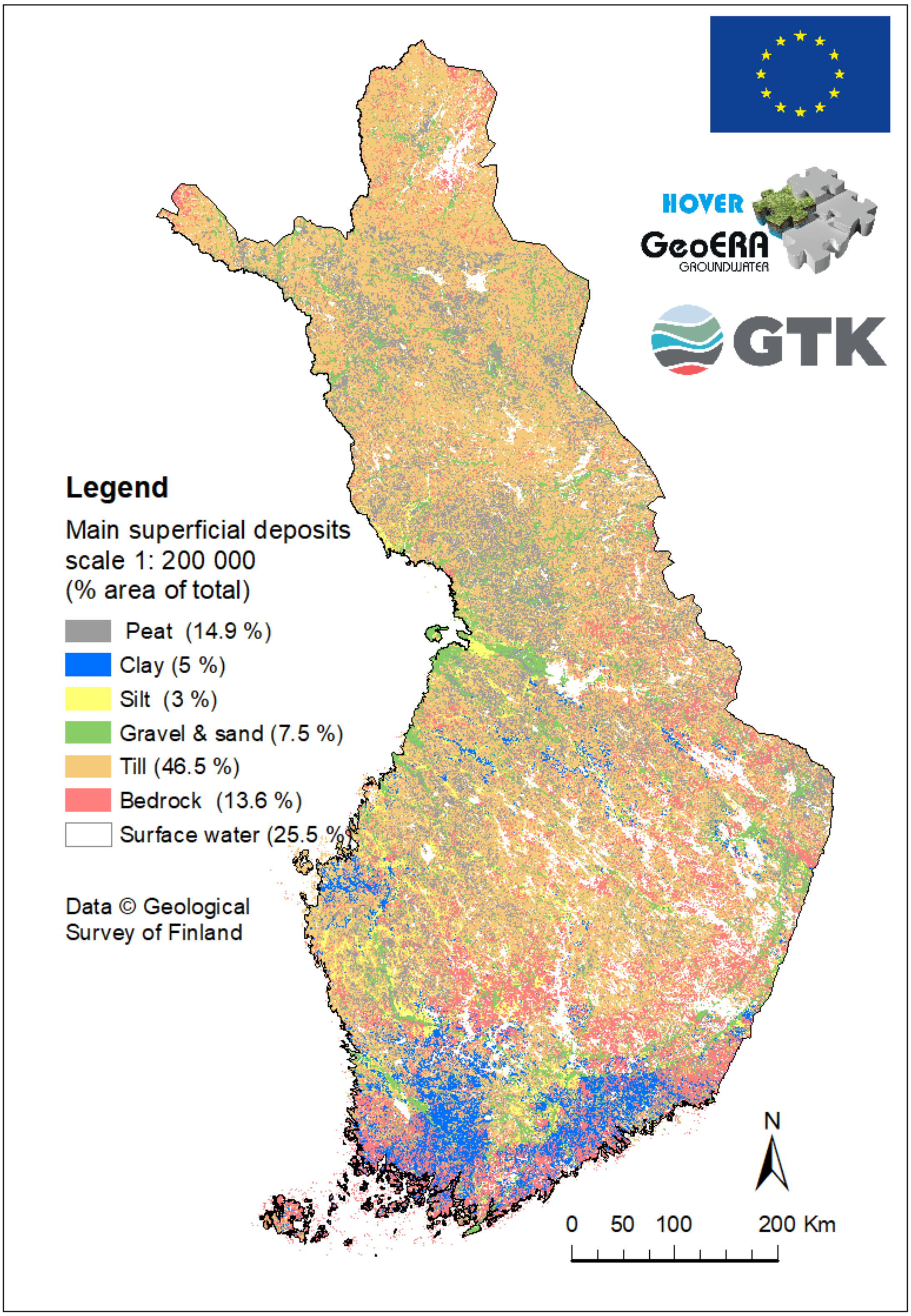

Fig. 1 Quaternary geological deposit map of Finland. Data © Geological Survey of Finland.

3 DATA AND METHODS

In this study, a well-known intrinsic vulnerability mapping method DRASTIC was used to assess the vulnerability to contaminations of the shallow aquifer in Finland. The DRASTIC method (Aller et al. 1987) is a parametric system with rating scores and weights for seven parameters that influence the vertical infiltration of water and potential contaminants from surface down through groundwater table: **D**epth to water (*D*); **R**echarge (*R*); **A**quifer media (*A*); **S**oil media (*S*); **T**opography (*T*); **I**mpact of the vadose zone (*I*); and hydraulic **C**onductivity (*C*). Each parameter was rated based on its characteristics and susceptibility to groundwater contamination from 1 (the lowest vulnerability) to 10 (the highest vulnerability). In each grid cell, the assigned parameter ratings were then multiplied by the weight strings which depend on the hydrogeological environments of the aquifer areas. Each weight string was assigned a value from 1 to 5, with the most significant factors receiving a weight of 5 and the least significant a weight of 1. In this study two weight systems: a standard weight for a normal situation and a pesticide weight that reflects the agricultural usage of pesticides were applied. The final vulnerability index in each grid cell was the sum of the scores for the seven parameters and was obtained by superposition of the seven thematic maps:

$$\text{DRASTIC index} = Dr*Dw + Rr*Rw + Ar*Aw + Sr*Sw + Tr*Tw + Ir*Iw + Cr*Cw \quad (1)$$

where *r* is the rating for each parameter,

w is the weight associated with each parameter in each weight string, and

D, R, A, S, T, I and *C* are seven parameters of the DRASTIC vulnerability index

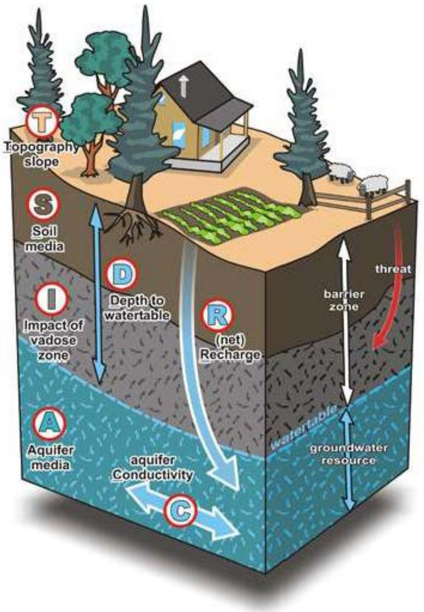

Fig. 2 DRASTIC parameters. Source: Franklin, R. & Turner, R. Geological Survey of Canada. Modified by Cyrille Médard de Chardon (2009).

The data sources for each of the parameters were obtained from different sources as shown in table 1. Table 2 presents the DRASTIC parameters, ratings and weight strings. The detailed calculations of the DRASTIC parameters are described in the following sections. Each parameter was converted to a grid map with a grid cell size of 200 m by 200 m using the ArcMap program, covering an area of 338 440 km^2 for the whole of Finland. The projected coordinate system used in this study was ETRS-1989-LAEA with the geographic coordinate system of GCS-ETRS-1989.The rating and weighting was performed for each parameter using the map overlay analytical function in the Spatial Analyst module of the ArcMap program. The final vulnerability map was a compilation of these maps, where each cell in the grid model is represented by a vulnerability value that corresponds to the cumulative rating and weighting of all the parameters. The final vulnerability index scores varied between 23 and 230 for the standard weight and between 26 and 260 for the pesticide weight.

Table 1. Data sources.

Data	Source	Description / Coverage
Land use and land cover map	Finnish Environment Institute (SYKE)	Polygon map of the Corine-Land use data.
Digital Elevation Model (DEM)	National Land Survey of Finland (NLS)	Grid map of the DEM 10 m grid size.
Superficial deposit map	Geological Survey of Finland (GTK)	Polygon map at scales 1:20K (covers 44.3% of Finland) and 1:200K (covers 100%).
Groundwater level data	SYKE-POVET and GTK-Lähde database	Groundwater level data points from 13 075 observation boreholes during 1971-2020 throughout the groundwater areas in Finland.
Drilled borehole data	GTK-Lähde and SYKE-POVET database	Information of groundwater level, soil and grain-size analysis of soil samples.
Climate (temperature and precipitation) data	Finnish Meteorological Institute (FMI)	A 30-year mean of daily weather data (temperature and precipitation) during 1981-2010
Snow water equivalent data	SYKE	Regional data from monitoring stations throughout the whole of Finland during 1981-2010.
Surface runoff data	SYKE	Regional data from monitoring stations throughout the whole of Finland during 1981-2010.

Table 2 DRASTIC parameters, rating and weight strings.

Parameter	Range						
	D	*R*	*A*	*S*	*T*	*I*	*C*
Rating (1-10)	**Depth to water (m)**	**Recharge (mm/yr)**	**Aquifer media**	**Soil media**	**Topography (slope, %)**	**Impact of the vadose zone**	**K-value (m/s)**
1	> 50	< 50	Clay & clay lens	Clay	> 18	Confining layer	< 5.0E-07
2	25-50		Massive shale	Muck			5.0E-07 - 5.0E-05
3	15-25	50-100	Metamorphic / igneous	Clay loam	12-18	Silt/clay, shale	5.0E-05 - 1.5E-04
4			Weatherd metam/igneous	Silty loam		Metamorphic / igneous	1.5E-04 - 3.5E-04
5	10-15		Glacial till	Loam	6-12		
6		100-175	Bedded sedimentary rocks, sandstone, limestone	Sandy loam		Bedded sedimentary rocks, sandstone, limestone, sand and gravel with fines	3.5E-04 - 5.0E-04
7	5-10			Shrinking / aggregated clay			
8		175-250	Sand and gravel	Peat		Sand and Gravel	5.0E-04 - 1.0E-03
9	1.5-5	250-500	Basalt	Sand	2-6	Basalt	1.0E-03 - 1.0E-02
10	< 1.5	> 500	Karst limestone	Thin or Absent, gravel	0-2	Karst limestone	> 1.0E-02
Weight string (1-5)							
Standard	**5**	**4**	**3**	**2**	**1**	**5**	**3**
Pesticide	**5**	**4**	**3**	**5**	**3**	**4**	**2**

Depth to water (*D*)

The depth to water parameter is the distance from the ground surface to the groundwater level of the uppermost aquifer. The deeper the groundwater table, the longer it will take for contaminants to reach an unconfined aquifer, allowing more time for natural attenuation and lowering of the vulnerability (Aller et al. 1987). A grid map of the mean groundwater level was produced from the interpolation of mean groundwater levels from 13 057 observation boreholes obtained from the SYKE-POVET database (SYKE 2020) and groundwater level map data from the GTK-Lähde database (GTK 2020a) using the Topo to Raster method in the Spatial Analyst module in ArcMap program. The depth to water grid map was produced from the subtraction between the topographic (DEM 10m grid) and the groundwater level grid maps. The average depth to water grid map during the period 1971–2020 ranges between 0 and 14.5 m, with an average value of 4.5 m. Detailed calculation of the groundwater level and depth to groundwater level is presented in appendix 1. The vulnerability rating for the depth to water parameter is presented in table 2.

Recharge (*R*)

Groundwater recharge is an important process that can transport contaminants into the subsurface and towards the water table. In this study, groundwater recharge was estimated by using the water balance approach of a 30-year mean of climate data (temperature and precipitation) during 1981-2010 (Pirinen et al. 2012) and the infiltration coefficient of different soil types:

Recharge = (*P* - *PET* - *R*off) x infiltration coefficient (2)

where *P* is precipitation (rainfalls and snowmelts),

PET is potential evapotranspiration, and

*R*off is Surface runoff.

Precipitation (rainfalls and snow-water equivalent) and surface runoff data was obtained from the FMI and SYKE database (Pirinen et al. 2012; SYKE 2020), while the infiltration coefficient was applied based on soil types, for which the data was obtained from the superficial deposit of Finland from GTK. Annual mean precipitation in Finland varies between 433 and 682 mm. High infiltration coefficient could be around 40-60% of precipitation in sandy and gravelly soils and 5-15% in clay soils. The potential evapotranspiration (PET) was estimated using a temperature-based method (Hamon 1963) as follows:

$$\text{PET (mm/d)} = 29.8 \times D \times (e_a/(T+273.2)) \quad (3)$$

where D is day length (hour),

T is mean daily temperature (°C), and

e_a is saturation vapour pressure (kPa) at mean daily temperature;

$$e_a = 0.6108 \exp[17.27\, T / (T + 237.3)] \quad (4)$$

The vulnerability ratings used for the recharge are presented in table 2.

Aquifer media (*A*)

Highly porous media results in high aquifer vulnerability because of the lower natural attenuation capacity of more permeable aquifers (Aller et al. 1987). The aquifer media data was obtained from drilled borehole information from the GTK-Lähde database (GTK 2020a) and the SYKE-POVET database (SYKE 2020). However this data was not available for the whole of Finland and for the areas that lack drilled borehole information the aquifer media was based on the base sediment of the superficial deposit maps of Finland at scales 1:20 000 and 1:200 000 (GTK 2020b). The lower resolution 1:200 000 superficial deposit map covers the whole country, while the higher resolution 1:20 000 superficial deposit map covers only 44.3% of the country. The map scale 1:20 000 was first used for the interpretation and where the data was not available at 1:20 000 scale the 1:200 000 scale data was applied. The vulnerability ratings used for the aquifer media are presented in table 2.

Soil media (*S*)

The thickness and texture of the soil can influence the natural attenuation capacity and permeability of the soil zone. The fine-grained sediments (clay and silt) provide a barrier to groundwater flow and have a lower vulnerability than more permeable sands (Aller et al. 1987). Similar to the aquifer media, the soil material was based on the surface sediment of the superficial deposit of Finland scales 1:20 000 and 1:200 000 (GTK 2020b). The vulnerability rating was based on the soil texture as shown in table 2.

Topography (*T*)

The vulnerability due to topography was assessed based on the percentage slope of the land surface. The greater the slope, the more potential there is for runoff and the less potential for infiltration of contaminants, meaning vulnerability is consequently lower (Aller et al. 1987). The Digital Elevation Model (DEM) from the National Land Survey of Finland (NLS 2020) was used for the slope calculation (in percentage, %) in the Spatial Analyst module in ArcMap. The vulnerability ratings used for topography are provided in table 2.

Impact of the vadose zone (*I*)

The attenuation capacity of the unsaturated zone or the vadose zone was rated based on the permeability of the aquifer materials. The more permeable the material, the shorter the transit time and lower the attenuation capacity, and hence the more vulnerable the aquifer (Aller et al. 1987). Similar to the aquifer media, the unsaturated zone material was identified from the drilled borehole information and the base sediment of the superficial deposit of Finland scales 1:20 000 and 1:200 000 (GTK 2020b). The vulnerability ratings used for the unsaturated zone attenuation capacity are presented in table 2.

Hydraulic conductivity (*C*)

The higher the hydraulic conductivity (K-value) of an aquifer, the faster water and contaminants are able to move from the source to the groundwater, and hence the higher the vulnerability of the aquifer (Aller et al. 1987). K-values of the aquifer media in the saturated zone were obtained from the grain-size analysis of 294 soil samples from drilled boreholes data in the GTK-Lähde database (GTK 2020) (Fig. 3). In addition, the median K-values from the previous studies (Airaksinen 1987; Ronkainen 2012) were also used for the interpretation. Due to inadequate K-value data available for the whole of Finland, the median K-values of each soil type were then applied directly to the base sediment of the superficial deposit of Finland scales 1:20 000 and 1:200 000. Detailed estimation of K-values is presented in appendix 2. The vulnerability ratings used for different K-values are presented in table 2.

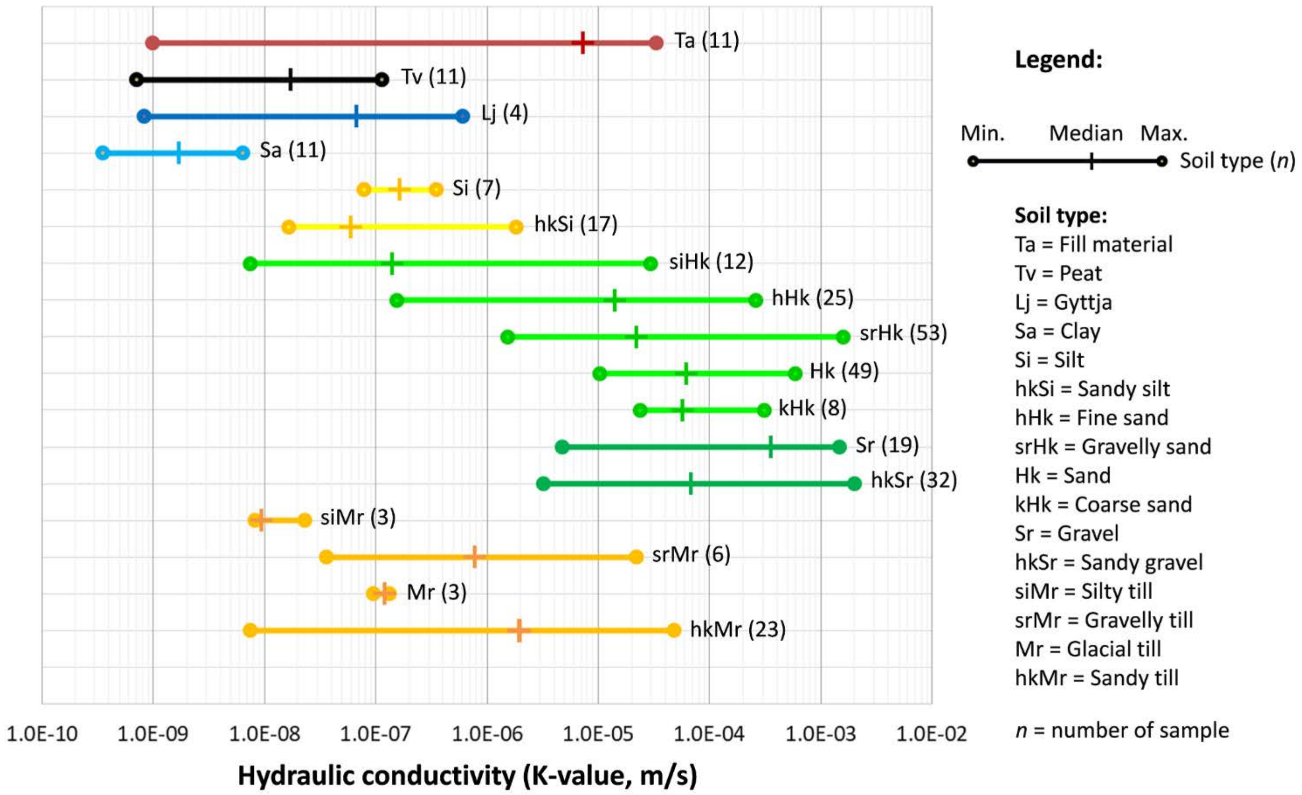

Fig. 3 Hydraulic conductivity values of the different soil type from soil analysis (*n*=294) obtained from the GTK-Lähde database.

4 RESULTS

Maps of DRASTIC parameters with ratings are presented in Fig. 4 and in appendix 3 for an enlarged scale. The relative vulnerability index map with a continuous color scale is presented in Fig. 5a for the standard weight with range from a low vulnerability of 46 to a high vulnerability of 210 (of total from 23 to 230) and Fig 5b for pesticide weight 49 to 242 (of total from 26 to 260). Fig.6 presents a close-up feature of the DRASTIC vulnerability index map in the southern part of Finland.

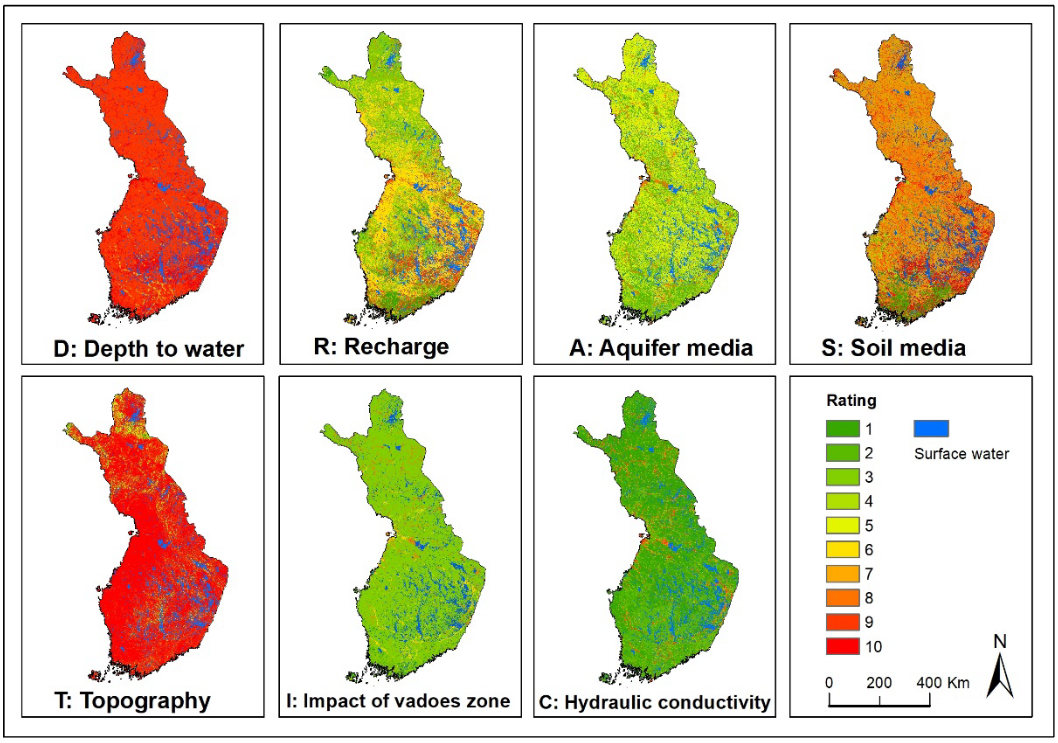

Fig. 4 Maps of DRASTIC parameters with ratings. Maps in the larger scale are presented in appendix 3.

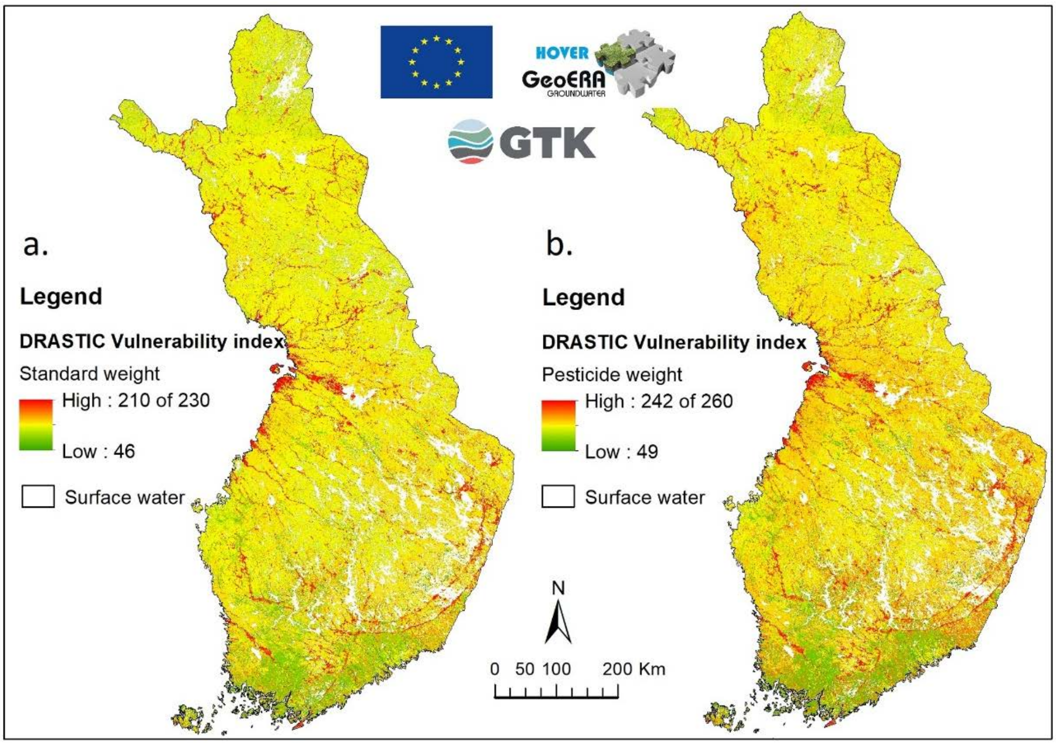

Fig. 5 Relative DRASTIC intrinsic vulnerability index maps: a) with standard weight, and b) pesticide weight. Maps in the larger scale are presented in appendix 3.

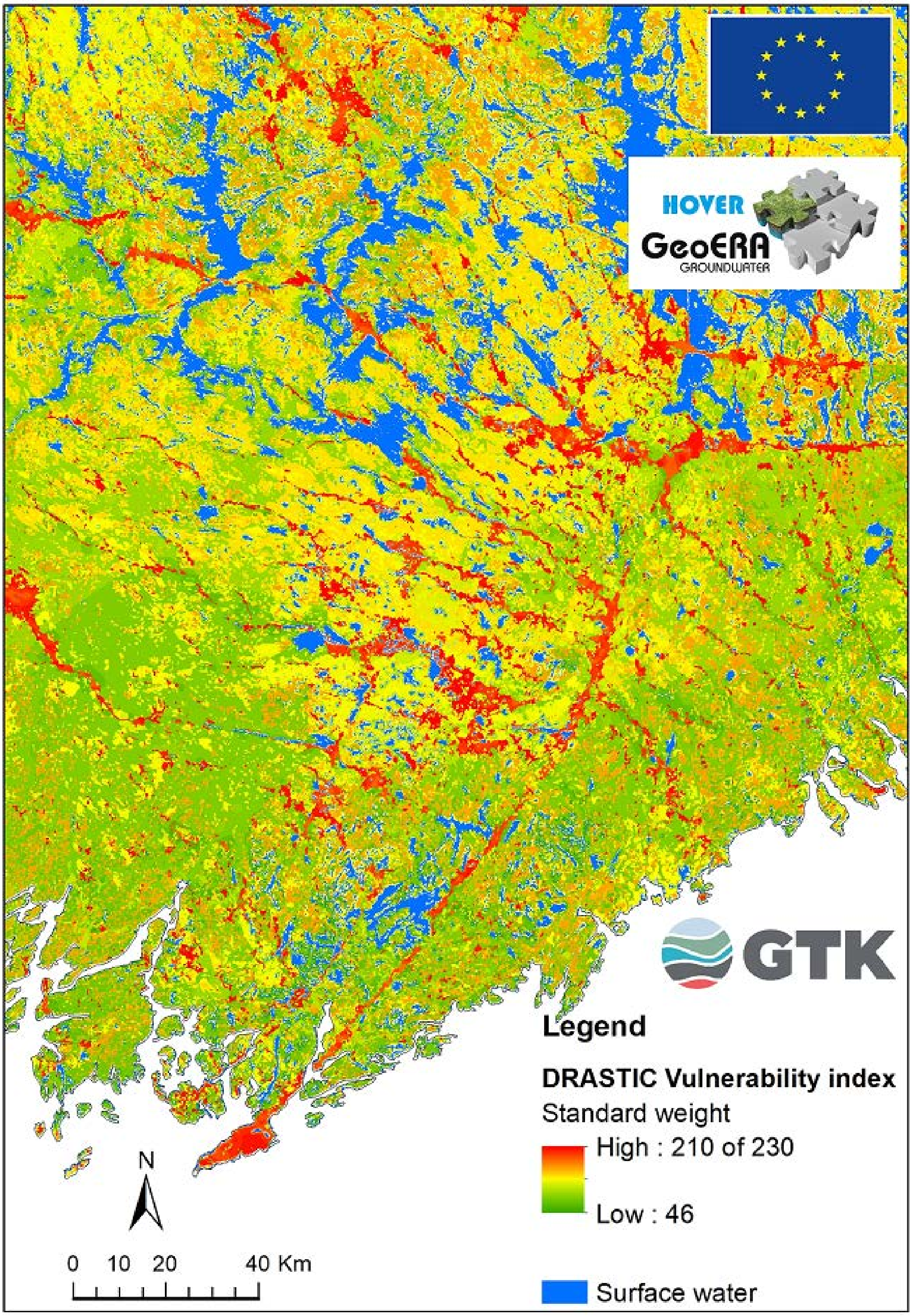

Fig. 6 A close-up feature of the DRASTIC vulnerability index map in southern Finland.

5 DISCUSSION

The main uncertainty of the assessment came from the limitation of soils and aquifer media data due to the sparse drilled boreholes data available in this study for the whole of Finland. This causes uncertainty for the DRASTIC parameters including recharge, aquifer media, soil media, impact of the vadose zone and K-values. For the depth to water parameter, although extensive groundwater levels data is available, the information of the confined layers is still sparse. As a result, only the mean groundwater levels were taken into account for the vulnerability assessment and the perched groundwater levels were neglected.

The DRASTIC vulnerability index maps of Finland ranges from 46 to 210 (of total from 23 to 230) for the standard weight, and from 49 to 242 (of total from 26 to 260) for the pesticide weight. High vulnerability areas are found in high porous coarse-grained sediments in the glacial and postglacial deposit areas. Concordantly, these coarse-grained sediment areas contain high K-values, high recharge values and in many areas have groundwater level close to the ground surface. The results of this study should be regarded as the preliminary assessment and shall be updated with new available data. Nevertheless, the vulnerability index map can be used as a regional screening tool to prioritize the most urgent needs for detailed site investigation of the aquifer areas to contaminations. The thematic map of the vulnerability index map can be integrated directly with the groundwater risk area and land use data for groundwater protection planning and water resources management. The final classification of the vulnerability index map should be done in cooperation with the decision-makers and the environmental authorities, same as the validation of the detailed site investigation in order to integrate groundwater protection into land use planning in the future.

6 CONCLUSIONS

The intrinsic vulnerability assessment of the shallow groundwater to contaminations was carried out throughout the entire Finland by using the DRASTIC method. The depth to water parameter, one of the most important parameters in the DRASTIC assessment, was well identified with a total of 13 057 mean groundwater level data measured during 1971-2020. The assessment was still constrained with the limitation of the soil and aquifer media due to the sparse drilled borehole data and insufficient information of the confined layers beneath the subsurface. The DRASTIC vulnerability index maps of Finland ranges from 46 to 210 (of total from 23 to 230) for the standard weight, and from 49 to 242 (of total from 26 to 260) for the pesticide weight. High vulnerability index scores are found in the areas that contain high porous coarse-grained glacial and post-glacial sediments, which are mainly in the groundwater areas. The relative vulnerability index map can be used to prioritize the aquifer areas for detailed site investigations. However, classification of the vulnerability index map should be done in cooperation with the environmental authorities same as the validation of the site investigation data. The final results of the vulnerability index map will provide useful information for the groundwater protection and land use planning in the future.

7 ACKNOWLEDGEMENT

This report is part of an EU-GeoERA-HOVER project (WP7) that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 731166.

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9 APPENDICES

Appendix 1. Groundwater level and depth to water level of shallow groundwater in Finland

Data sources

Groundwater level data used in this study were obtained from the SYKE-POVET database (SYKE 2020) and the HARA projects from the GTK-Lähde database (GTK 2020a). The data consists of the mean groundwater levels taken from the observation boreholes in the groundwater areas during 1971-2020. These groundwater levels represent the mean groundwater levels in the main groundwater areas where the aquifer materials mainly consists of coarse-grained sediments (sand and gravel). Outside the groundwater areas, there is insufficient data to identify the groundwater levels beneath the till and fine-grained sediment (clay and silt) layers and also in the bedrock areas. The following assumptions were applied to the till, fine grained sediments and bedrocks areas in the superficial deposit maps (the Quaternary deposit maps scales 1:20 000 and 1:200 000):

- In the bedrock exposed area, groundwater level is assigned as zero meter from the surface.
- In the weathered bedrock area with the cover of thin layer of the unconsolidated sediment, groundwater level is assigned at 0.5 m below the surface.
- In the till and fine grained sediment (clay and silt) areas, the median groundwater level of the shallow aquifers of 4.5 m below the surface was is assigned for the calculation.
- In the peats and wetland areas, groundwater level is assigned at 3 m below the surface, based on the median thickness of peat areas from the Quaternary deposit maps scales 1:20 000 and 1:200 000.
- The surface water areas and the artificial areas (e. g. urban areas) are excluded from the calculation.

Methods

Groundwater level data points were interpolated into the raster map (at a grid size of 200 m x 200 m) by using the interpolation method Topo to Raster in the Spatial Analyst module in ArcMap program. The depth to water grid map was calculated from the subtraction between the Digital Elevation Model (DEM 10m grid size) from the National Land Survey of Finland and the interpolated groundwater level grid map.

Results

A total of 13 057 groundwater level data points is presented in Fig. A1-1. The interpolated groundwater level map of the entire Finland is presented in Fig. A1-2. The Digital Elevation Model (DEM 10m grid size) from the National Land Survey of Finland is presented in Fig.A1-3. The interpolated depth to groundwater level map is presented in Fig. A3-1. Based on the groundwater level data points the average depth to water grid map during the period 1971–2020 ranges between 0 and 14.5 m, with an average value of 4.5 m.

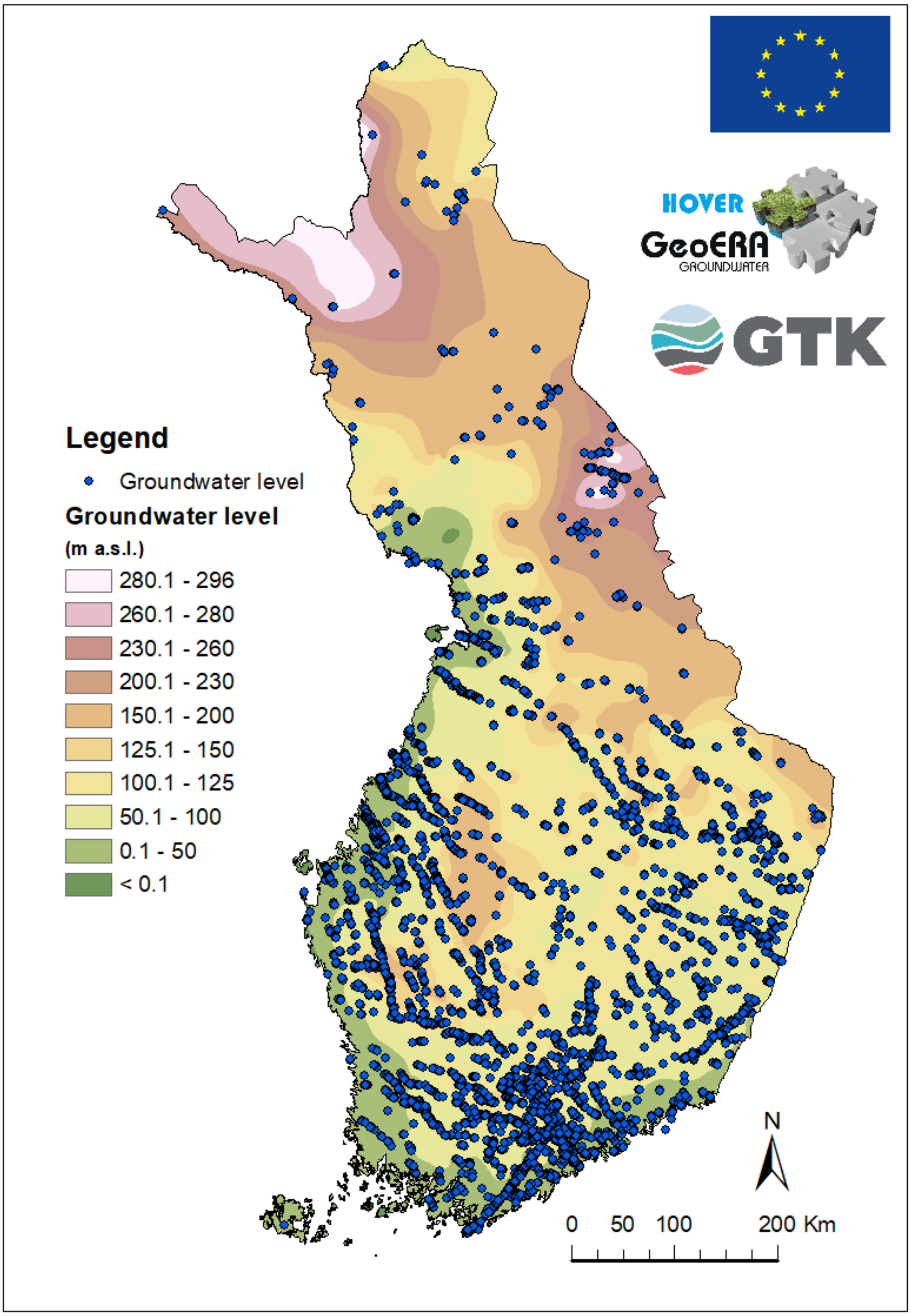


Fig. A1-1. Locations of groundwater level data points from the SYKE-POVET and the GTK-Lähde databases (*n* = 13 057 data points).

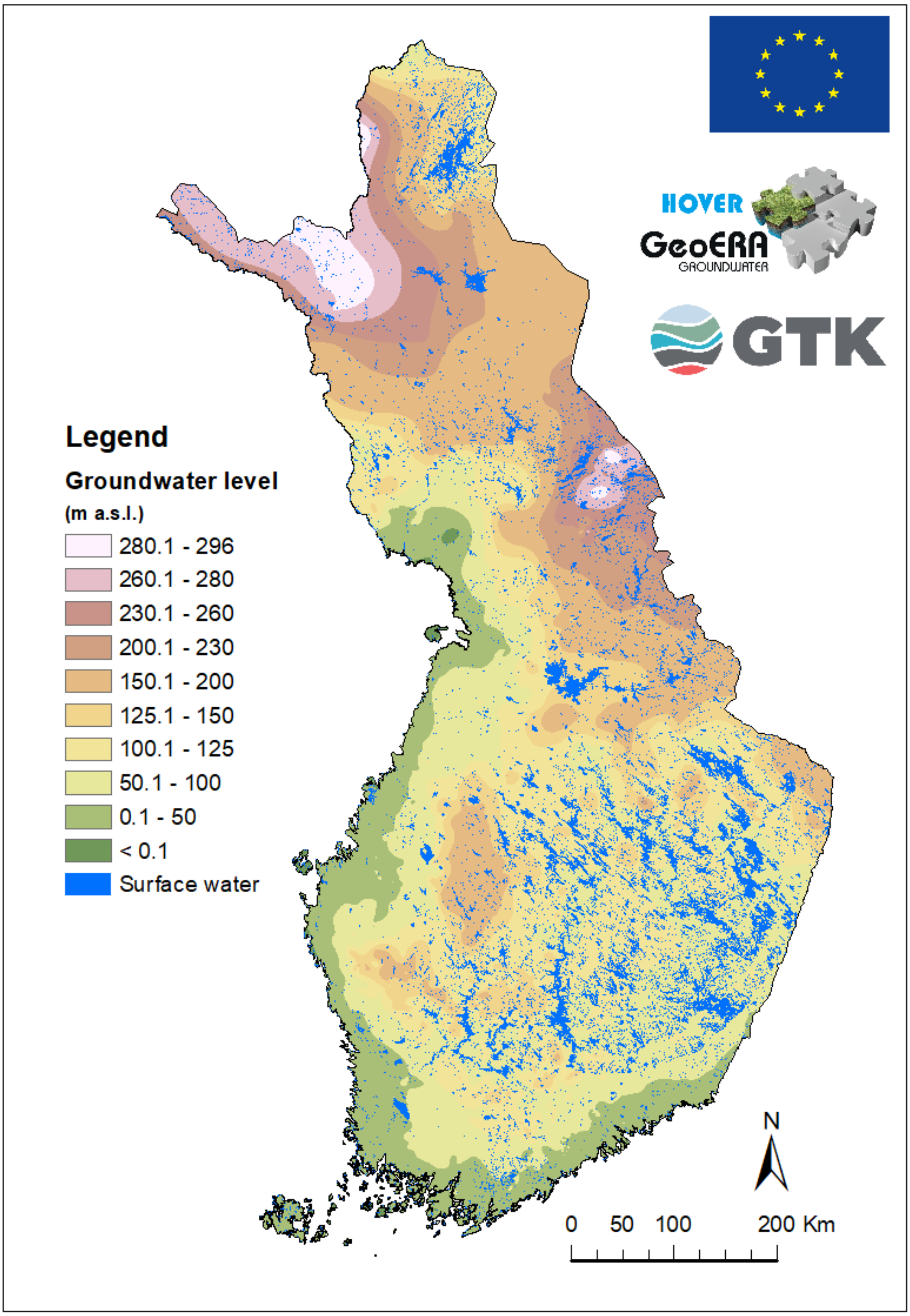


Fig. A1-2. Interpolated map of the mean groundwater level of the shallow groundwater in Finland during 1971 - 2020 (*n* = 13 057 data points).

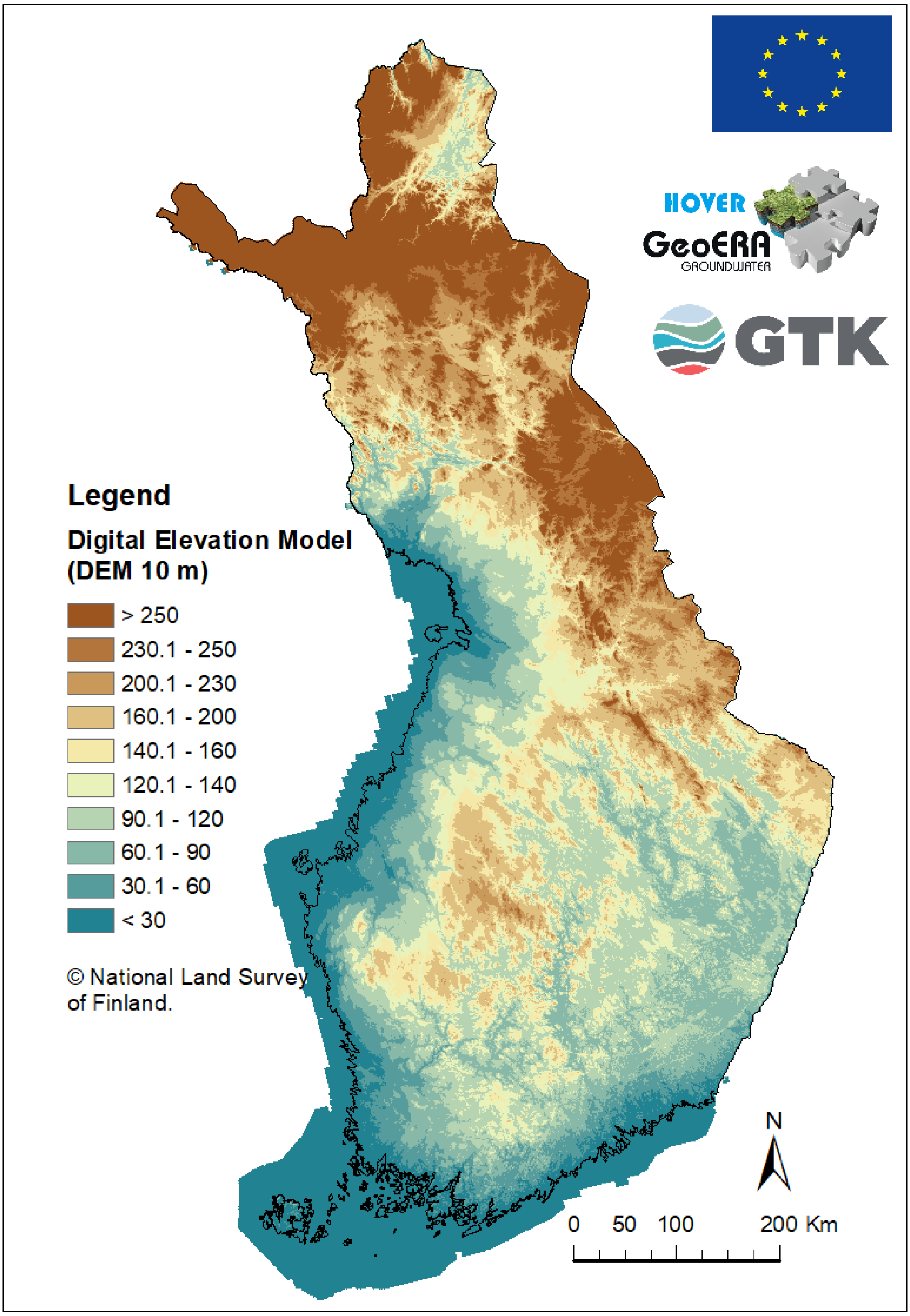


Fig. A1-3 Digital Elevation Model (DEM 10 m grid) of Finland. Data © the National Land Survey of Finland.

Appendix 2. Estimation of hydraulic conductivity (K-values) of the aquifer media.

Hydraulic conductivity (K-values) of the different soil types obtained from the HARA studies from the GTK-Lähde database by using the Kozeny-Carman method, which required the grain diameter data *D*10 and *D*60 from the grain size distribution plots. The total numbers of soil samples was 294. The K-values for each soil type are presented in table A2-1. Tables A2-2 to A2-3 are the typical K-values of soil in Finland obtained from the literatures. The input K-values for the DRASTIC calculation in this report were compiled from all K-values from those tables.

Table A2-1 Hydraulic conductivity values in different soil type from GTK-HARA data using Kozeny-Carman method from grain size analysis of soil samples (*n*=294).

Soil type,	Sample	Hydraulic conductivity - (K-value, m/s)			
soil code	number	Minimum	Median	Mean	Maximum
Fill material, Ta	11	9.79E-10	7.30E-06	7.50E-06	3.31E-05
Peat, Tv	11	7.06E-10	1.72E-08	2.16E-08	1.13E-07
Gyttja, Lj	4	8.30E-10	6.76E-08	1.86E-07	6.07E-07
Clay, Sa	11	3.50E-10	1.69E-09	1.96E-09	6.42E-09
Silt, Si	7	7.80E-08	1.63E-07	1.76E-07	3.48E-07
Sandy silt, hkSi	17	1.67E-08	5.96E-08	2.48E-07	1.82E-06
Silty sand, siHk	12	7.44E-09	1.40E-07	4.35E-06	2.97E-05
Fine sand, hHk	53	1.56E-07	1.40E-05	3.80E-05	2.60E-04
Gravelly sand, srHk	25	1.53E-06	2.20E-05	1.26E-04	1.60E-03
Sand, Hk	49	1.02E-05	6.20E-05	1.30E-04	5.83E-04
Coarse sand, kHk	8	2.40E-05	5.65E-05	1.20E-04	3.10E-04
Gravel, Sr	19	4.69E-06	3.55E-04	3.72E-04	1.46E-03
Sandy gravel, hkSr	32	3.20E-06	6.82E-05	1.96E-04	1.99E-03
Silty till, SiMr	3	8.19E-09	9.39E-09	1.35E-08	2.30E-08
Gravelly till, SrMr	6	3.60E-08	7.73E-07	4.35E-06	2.20E-05
Glacial till, Mr	3	9.58E-08	1.21E-07	1.16E-07	1.31E-07
Sandy till, HkMr	23	7.41E-09	1.96E-06	6.79E-06	4.84E-05

Table A2-2 Hydraulic conductivity values in different soil types after Airaksinen (1987).

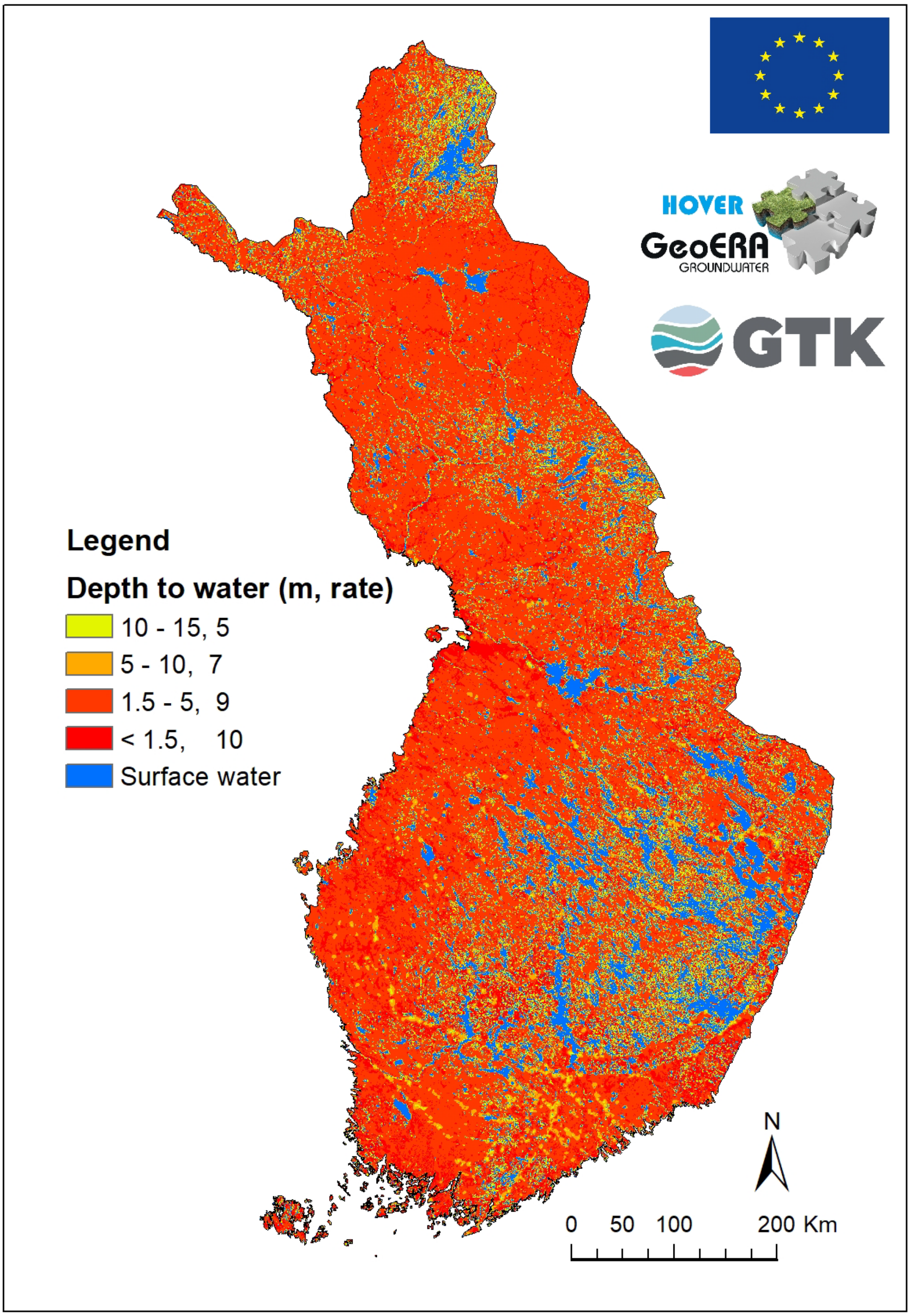
Soil type	Soil code	K-value (m/s)
Gravelly till	SrMr	1.0E-5 - 1.0E-7
Sandy till	HkMr	1.0E-6 - 1.0E-8
Finer sand till	HtMr	1.0E-7 - 1.0E-9
Clayey till	SaMr	1.0E-8 - 1.0E-10
Moraine clay	MrSa	1.0E-9 - 1.0E-11
Gravel	Sr	1.0E-1 - 1.0E-3
Coarse sand	KSa	1.0E-2 - 1.0E-4
Sand	Hk	1.0E-3 - 1.0E-5
Coarser fine-sand	KHt	1.0E-4 - 1.0E-6
Finer fine-sand	HHt	1.0E-5 - 1.0E-7
Silt	Hs, Si	1.0E-7 - 1.0E-9
Clay	Sa	<1.0E-9

Table A2-3 Hydraulic conductivity values in different soil types after Ronkainen (2012).

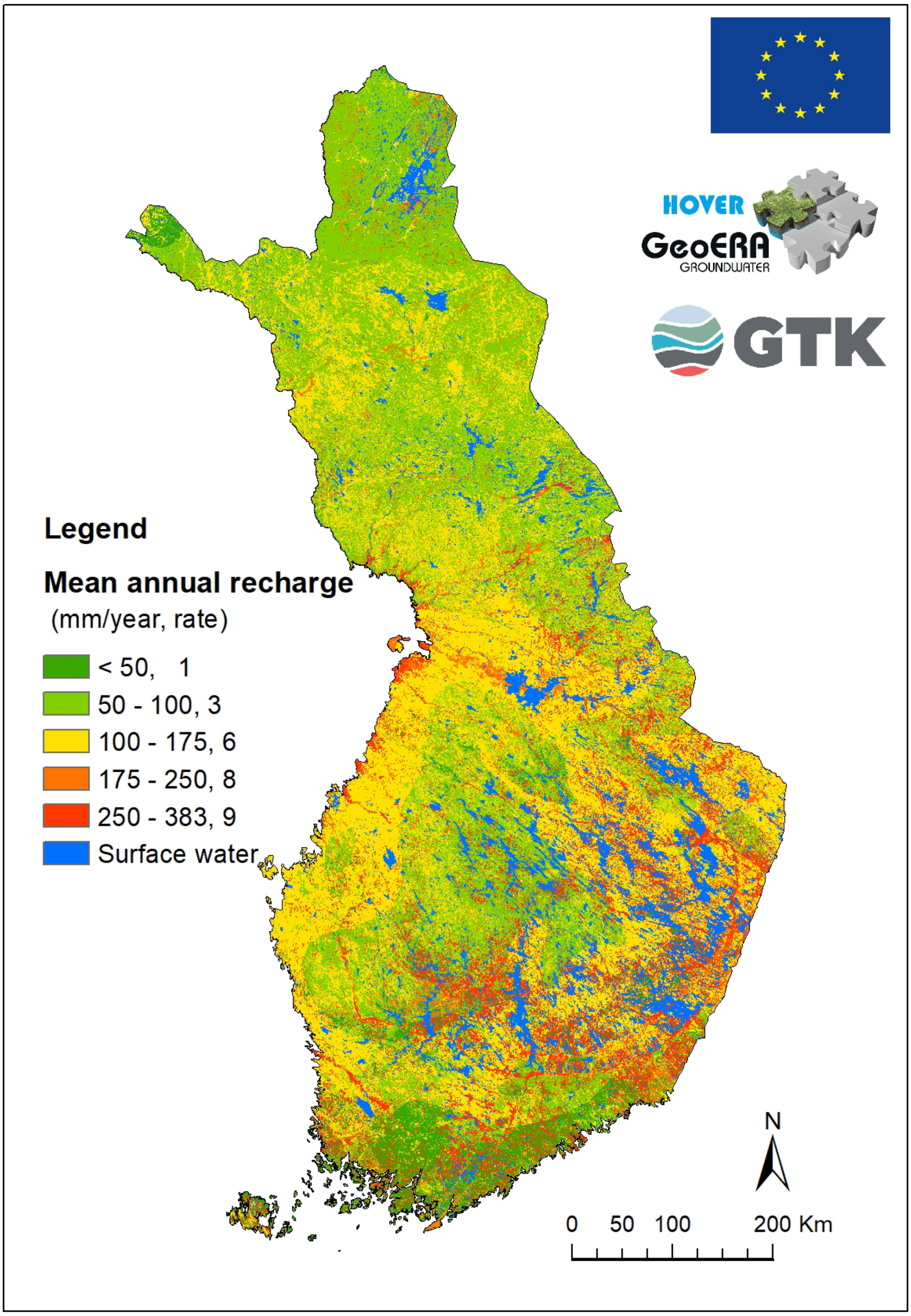
Soil type	Soil code	Median K-value (m/s)	Number of samples
Silty sand	siHk	5.0E-07	62
Fine sand	huHk	8.0E-06	64
Sand	Hk	2.0E-05	308
Silty sand and till	siHkMr	8.0E-08	160
Gravelly sand and till	srHkMr	1.0E-07	58
Sandy till	HkMr	6.0E-07	334
Silt	Si	2.0E-07	124
Sandy silt	hkSi	2.0E-07	94
Clayey silt	saSi	2.0E-08	128
Clay	laSa	1.0E-08	94

Appendix 3. Maps of DRASTIC parameters and vulnerability indices.

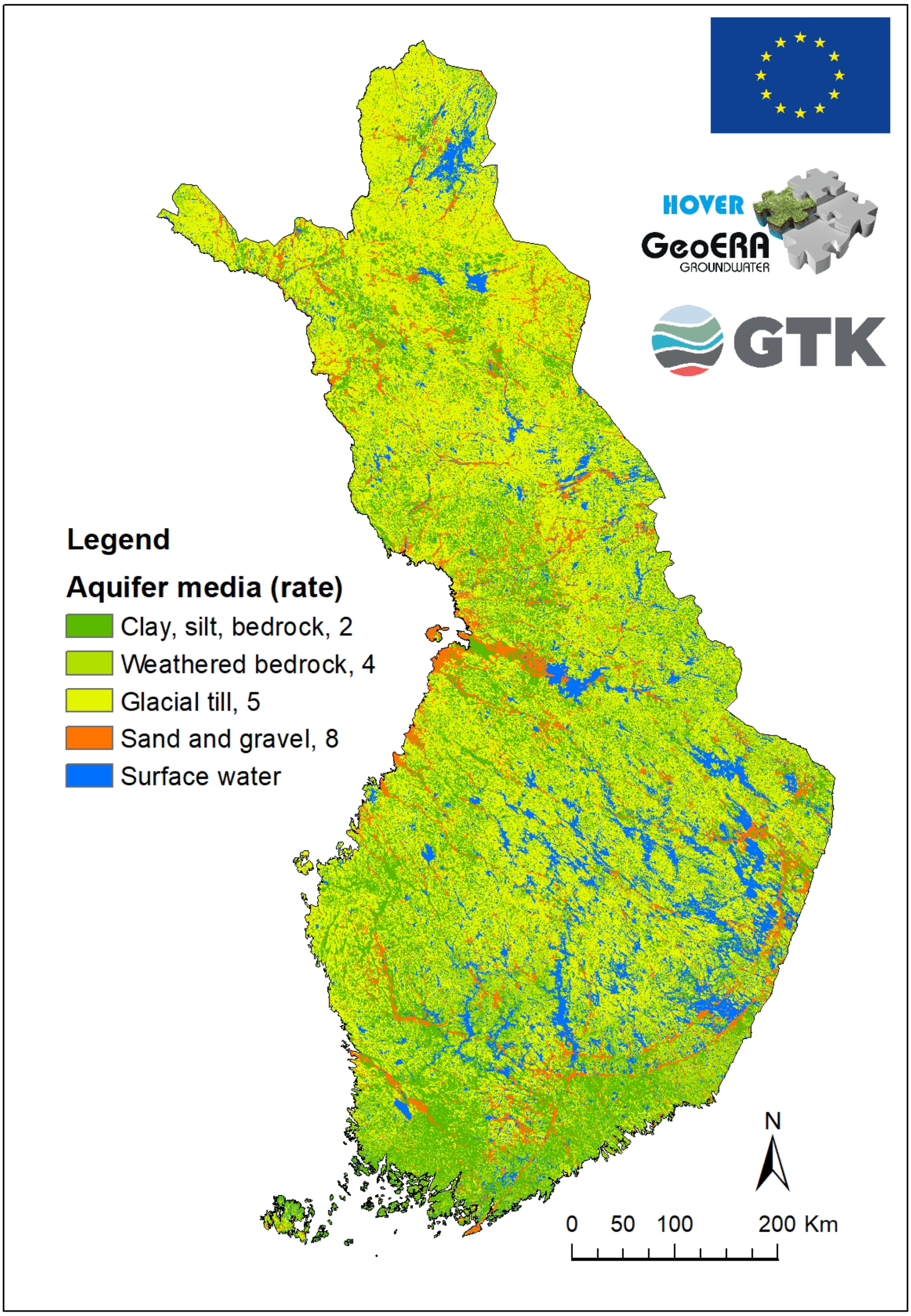
Appendix 3-1 Depth to Water Parameter Map.



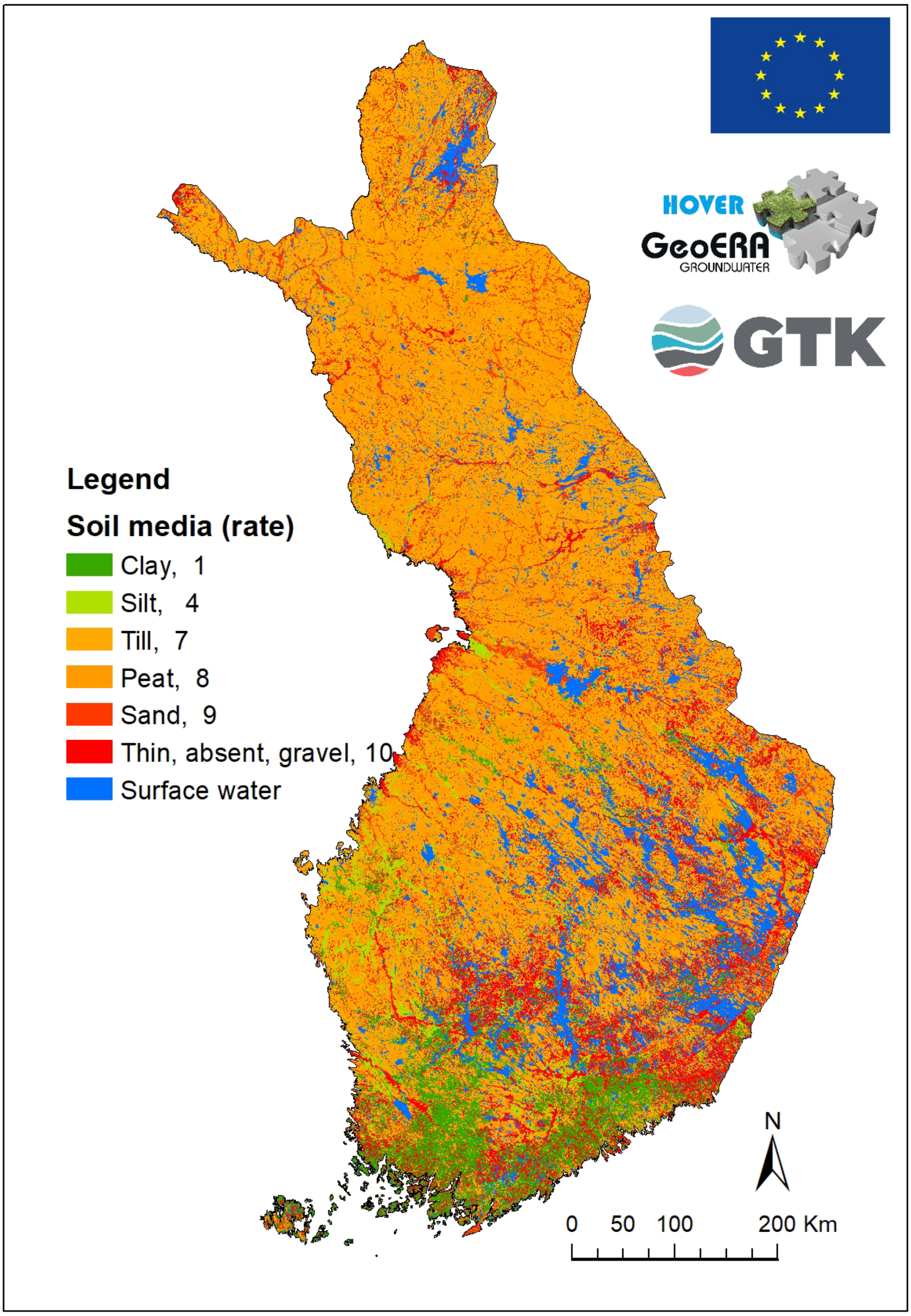
Appendix 3-2 Recharge Parameter Map.



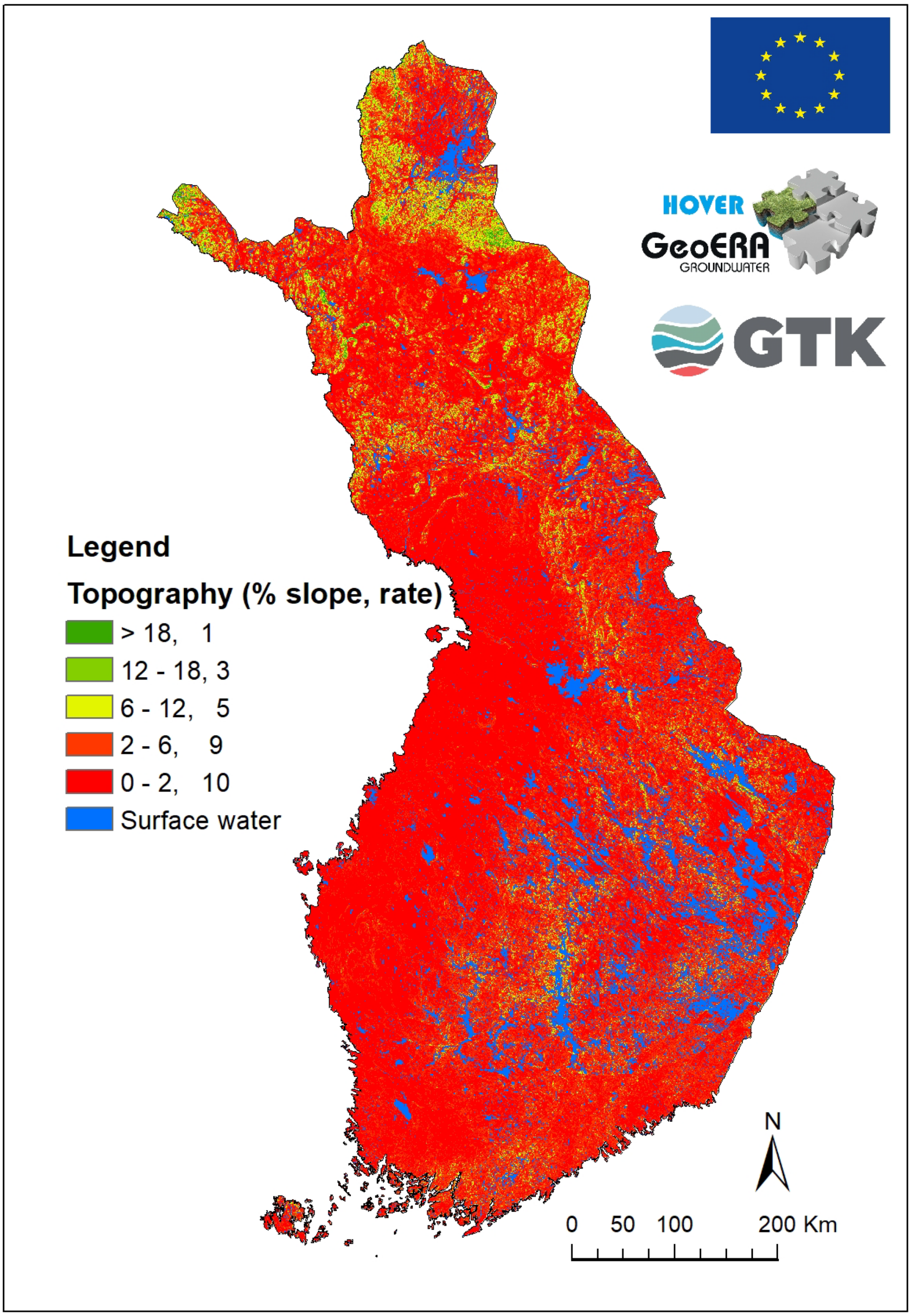
Appendix 3-3 Aquifer media parameter map.



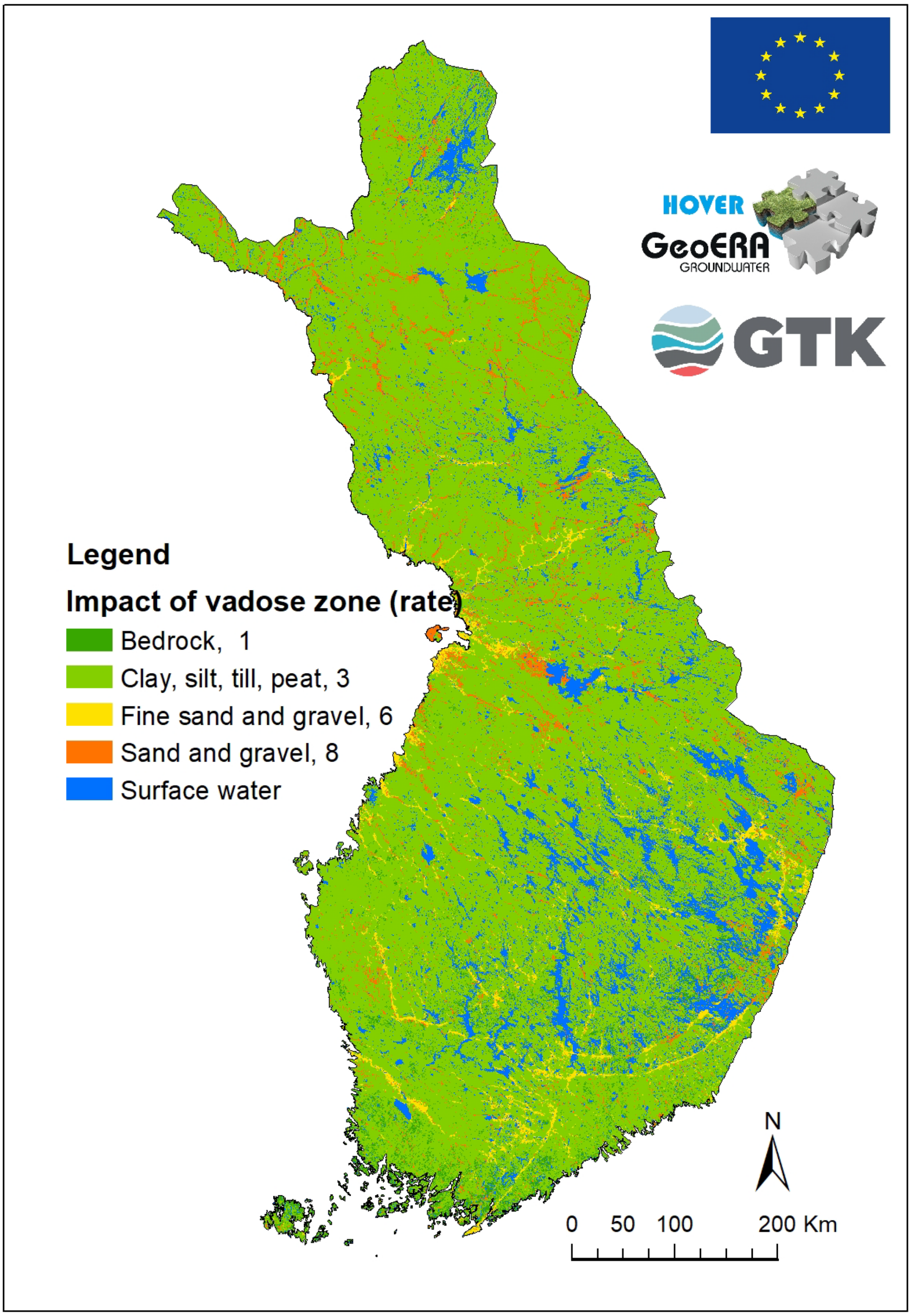
Appendix 3-4 Soil media parameter map.



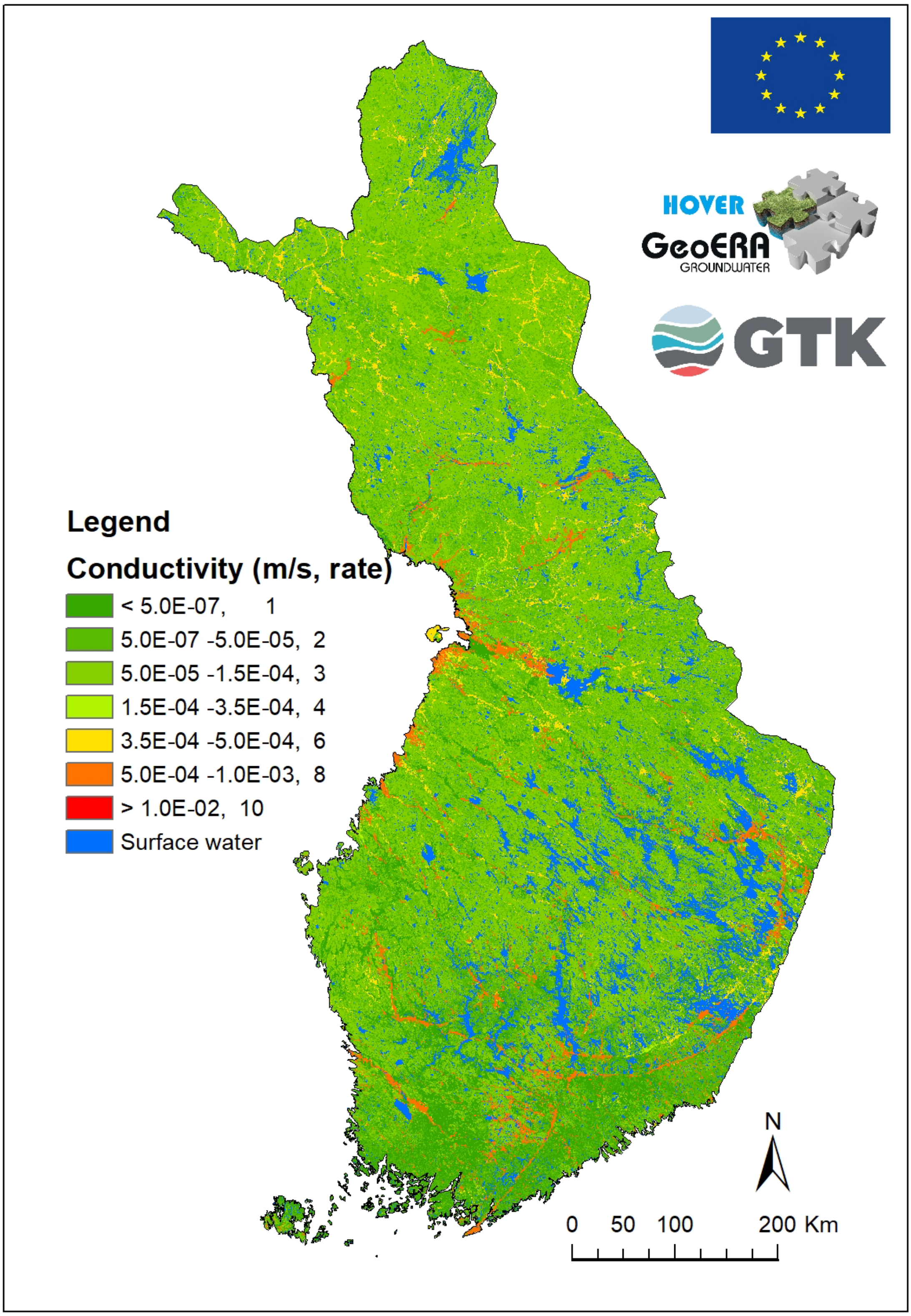
Appendix 3-5 Topography (% slope) parameter map.



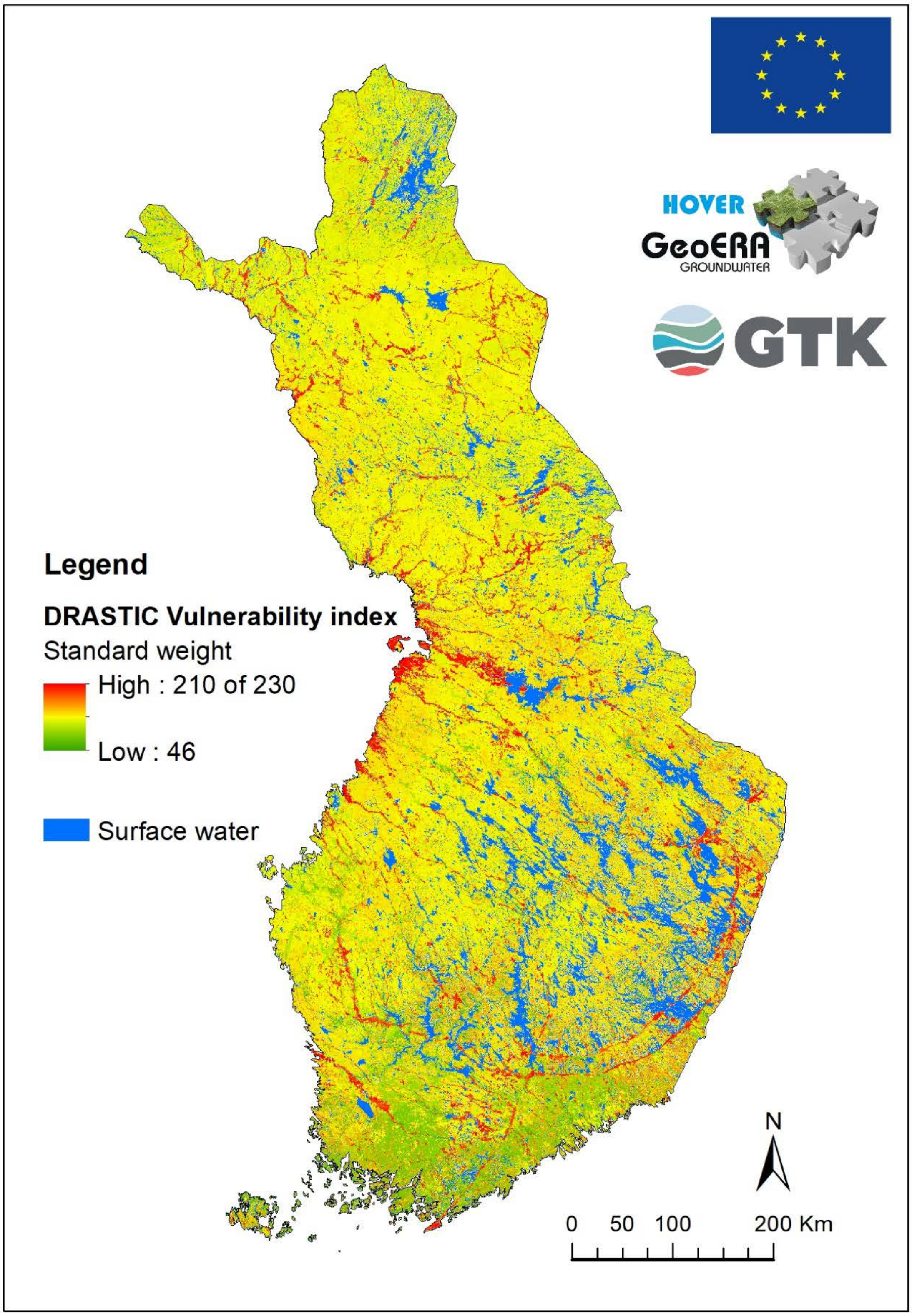
Appendix 3-6 Impact of vadose zone parameter map.



Appendix 3-7 Hydraulic conductivity (K-value) parameter map.



Appendix 3-8 Relative DRASTIC vulnerability index map at the standard weight.



Appendix 3-9 Relative DRASTIC vulnerability index map at the pesticide weight.