Resources of groundwater, harmonized at
Cross-Border and Pan-European Scale

Deliverable 6.2

Database with information on volumes and depths at 10x10 and/or 25x25 km grids

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INTRODUCTION

Although EU member states generally have a comprehensive overview of the groundwater resources in their homeland, a coherent overview of all fresh groundwater over Europe is not available for policy development and evaluation. The aim of the RESOURCE project and Work Package 6 (Pan-EU Groundwater Resources Map) is to produce a first information product at pan-European scale (for the participants, see figure 1) where available data is compiled and integrated to produce a map of the fresh groundwater resources of Europe. Work Package 6 is divided in several tasks so that this goal can be achieved:

- Task 6.1: Criteria for harmonization across Europe;
- Task 6.2: Collection of data on depths and volumes;
- Task 6.3: Compilation of the map;
- Task 6.4: First estimate of water balance of EU's principal groundwater resources;
- Task 6.5: Data exchange with the Information Platform.

This document is the deliverable for task 6.2 of Work Package 6. It describes the database that stores the data on the average depths of aquifers and aquitards and the depth of the active fresh water groundwater system at a 10x10 km resolution that has been collected by all participating surveys. The database is filled by the final version of the template that was compiled after the Zagreb WP6 workshop. This template was used for task 6.2 where each participating survey collected the required data so that the map can be compiled under task 6.3.

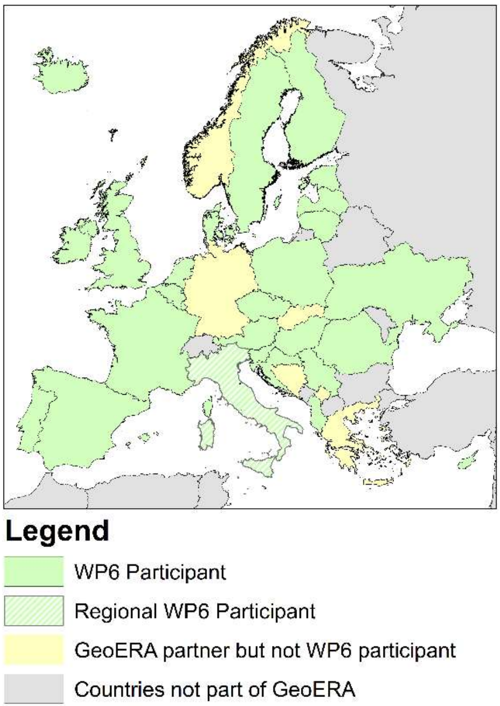

Figure 1 RESOURCE WP6 participants

In chapter 1, the general idea behind the project is explained. In chapter 2, the final version of the template that was used to gather the data is described in more detail as to what information is asked and how this should be filled in.

In chapter 3, the contents and structure of the database are described. Appendices provide further background to some of the decisions that were made during the WP6 workshops in Vienna, Budapest and Zagreb. As such, these appendices justify some the choices behind the final template and database.

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1 GENERAL IDEA

The general idea behind the RESOURCE WP6 project is to provide a map with the depths and volumes of fresh groundwater at a spatial scale that is feasible and useful for identifying the main patterns of groundwater availability, interpreting recharge and abstractions to and from the resource, providing base characterization for European and global scale models, and getting insight in the presence of paleo resources and its use as strategic reserves. To be able to get this information from all RESOURCE WP6 partners a template has been developed and discussed during the WP6 meetings in Vienna, Budapest and Zagreb. This template has been used by all surveys to collect the required data on a 10x10 km scale. The individual templates have been gathered in a database. This deliverable 6.2 describes the final content of the database as elaborated after all RESOURCE meetings and gives background on how it has been filled in.

The spatial scale at which the data was gathered is very important. During the filling of the template, the European scale has been kept in mind. This means that not every detail which is included in the national data/models is included in the database. We suggested keeping the maximum amount of layers to at most 10, so that not every small layer that is most likely not significant of an European scale is included in the final maps.

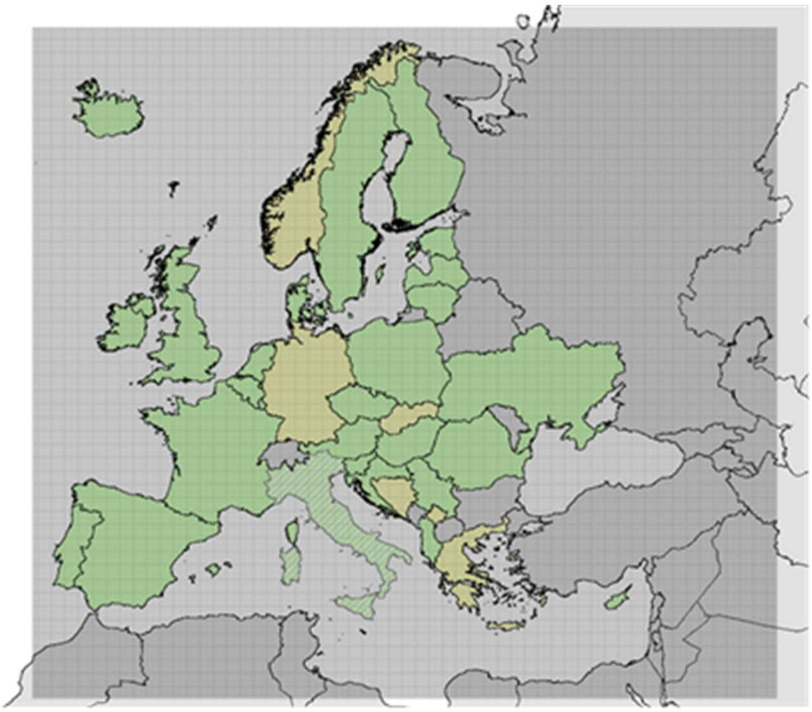


Figure 2: 10 x 10 km INSPIRE grid

The template is a xlsx file where each row indicates a grid cell. The cell-id's correspond with an existing 10x10 km INSPIRE shapefile grid over Europe (see figure 2 and https://www.eea.europa.eu/data-and-maps/data/eea-reference-grids-2). The coordinate system of this grid is ETRS89, with the Lambert Azimuthal Equal Area projection (LAEA).

Each participant received their own template (excel file, see figure 4) and grid (shapefile, see figure 3) which covers their country, which is joined in the database to cover Europe. The grid for each participating survey was distributed along with previous deliverables. The grid cells have fixed ID's that were provided by the WP6 coordinator. These county grids extend beyond the borders, each participant logically only filled in cells which are within their border. During the meeting in Budapest it was decided that cells which extend over multiple countries are filled by the country that covers the majority of that cell.

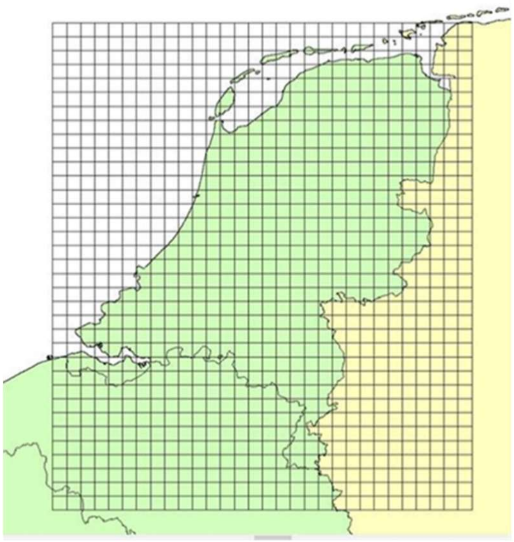


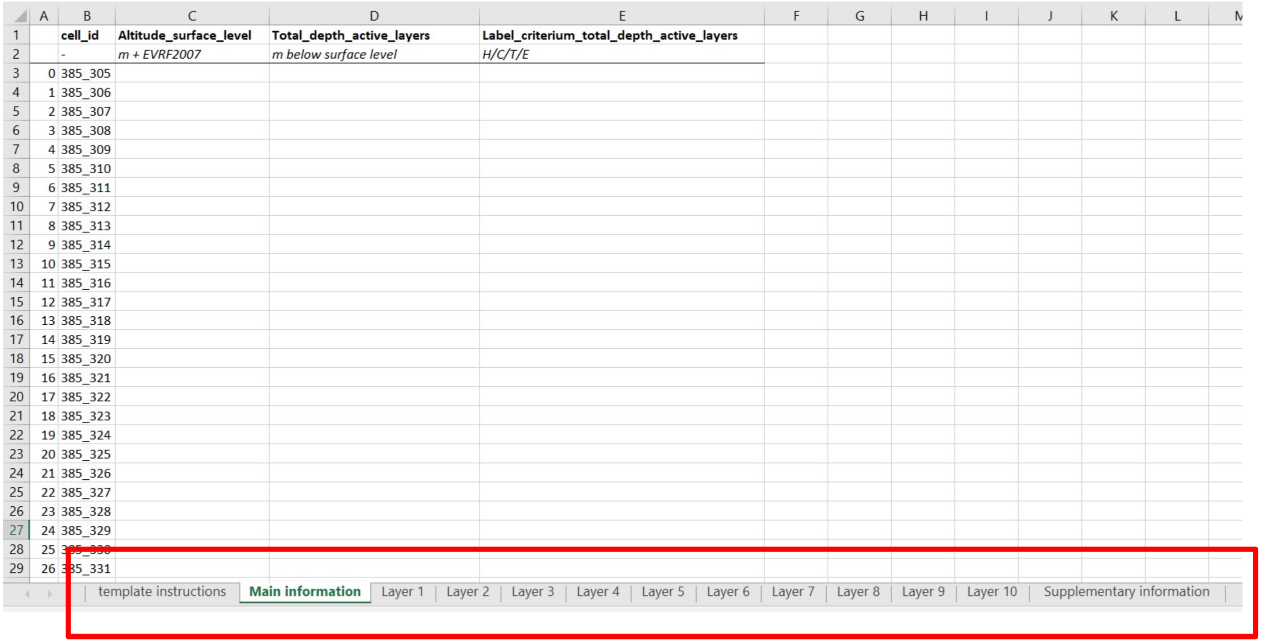
Figure 2 Country grid of the Netherlands

2 DESCRIPTION OF THE TEMPLATE AND COMMON CRITERIA

This chapter contains descriptions for each of the columns in the template of what should be filled in and how this should be done. This is based on the decisions after the Vienna, Budapest and Zagreb meetings, and is the final version of the template. The template is an excel file consisting of multiple tabs (see Figure 4). These tabs are labelled as followed:

- Template instructions (this tab contains the same information as this chapter)
- Main information;
- Layer 1 to layer 10;
- Supporting info;

Below, for each of these tabs is a description of what information is required.



	A	B	C	D	E
1		cell_id	Altitude_surface_level	Total_depth_active_layers	Label_criterium_total_depth_active_layers
2		-	*m + EVRF2007*	*m below surface level*	*H/C/T/E*
3	0	385_305			
4	1	385_306			
5	2	385_307			
6	3	385_308			
7	4	385_309			
8	5	385_310			
9	6	385_311			
10	7	385_312			
11	8	385_313			
12	9	385_314			
13	10	385_315			
14	11	385_316			
15	12	385_317			
16	13	385_318			
17	14	385_319			
18	15	385_320			
19	16	385_321			
20	17	385_322			
21	18	385_323			
22	19	385_324			
23	20	385_325			
24	21	385_326			
25	22	385_327			
26	23	385_328			
27	24	385_329			
28	25	385_330			
29	26	385_331			

Figure 4 Template example with tabs indicated

2.1 Main information

The first tab includes information that is of importance to the entire 10x10 km grid cell (see figure 4). The columns are explained below.

B. cell-id

Unique identifier for each grid cell provided by the WP coordinator. The id's are labelled as col_row with column numbers increasing from west to east and row numbers increasing from south to north. Please do not change anything in this column, these will be used to link the individual county grids to the Europe-wide grid.

Border cells

Cells which are on the border between 2 countries are filled by the country which occupies more than 50% of that cell.

C. Altitude_surface_level

This column contains the average altitude over the grid cell in meters relative to the EU height reference level EVRF2007 (European Vertical Reference Frame). All other depths in the template are relative to surface level.

The reference level can be obtained by adding/substracting from the national reference frames as seen in figure 5. This is not very precise, but the regional differences are only a few centimetres which, on a European scale, are not of any large influence on the calculation for the total volume of fresh groundwater.

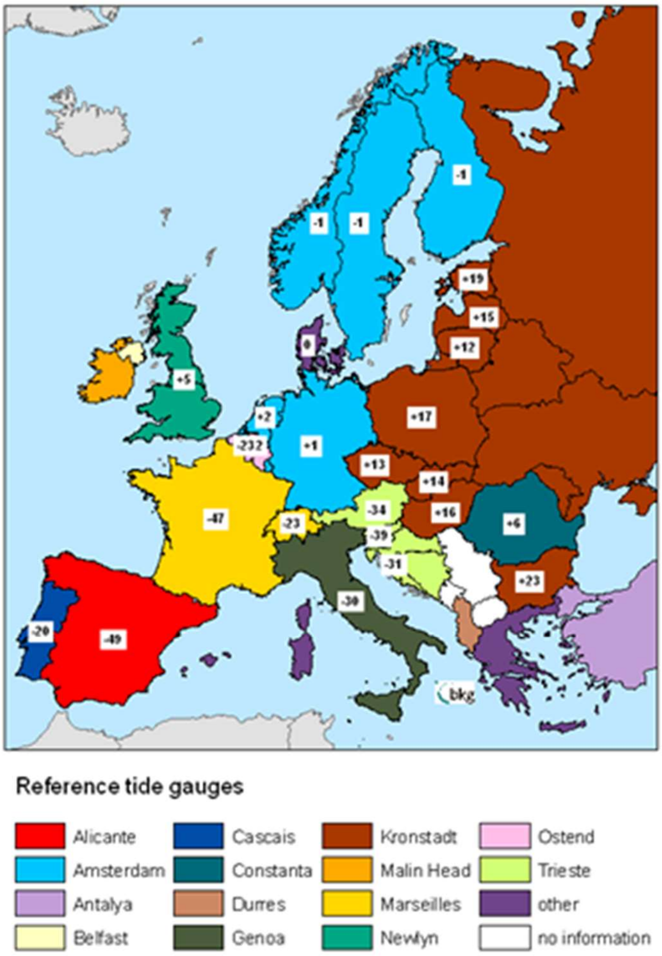


Figure 5: Difference between the Europan National Height Systems and EVRF2007 in cm.

D. Total_depth_active_layers

This indicates the maximum depth of the layers that are defined are of importance considering the fresh water volume. This could either be the top of layer with a very high vertical resistance (hydrogeological base) or the interface between fresh and saline

groundwater if this falls above the hydrogeological base. The boundary that is used can be indicated in the next column.
The definition of the lowermost boundary of the fresh groundwater system is broader that previously thought, because different surveys use different thresholds and parameters to delineate that boundary. It is accepted to use a hydrogeological boundary (a low permeability aquitard at some depth) or a salinity-based threshold (the fresh-saline boundary). See next item.

E. Label_maximum_depth_active_layers
In this column you can indicate what is used as a label for the maximum depth of the active layers. This can be indicated by the following letters:

- H = hydrogeological boundary (e.g. depth of aquitard, extent of fractured zone in karst systems)
- C = based on chloride concentration (1000 mg/l Cl)
- T = Based on TDS concentration (1500 mg/l TDS)
- E = Based on EC (2500 µS/cm, EU drinking water standard)

We agreed for countries to make their own choice, using the 4 labels above.

Since the general goal of the RESOURCE WP 6 project is to provide a map with the volumes and depths of fresh groundwater, we stop at the depth that is relevant for the total amount of available flowing fresh groundwater. This could either be the fresh-salt water interface or the top of a layer with very low conductivity that prevents further downward flow and effectively creates a boundary for the fresh groundwater flow system. Alternatively, for karst systems, the active zone boundary could be defined as the vertical extent of the fractured zone, instead of a change in lithology. Both hydrological criteria result in label H (hydrogeological boundary), the chemical criteria have labels C, T and E.

For the chemical criteria based on the fresh-salt interface it became apparent that each country has their own threshold, which could be generally be divided in three groups: 1. based on chloride concentrations, 2. based on Total Dissolved Solids (TDS), and 3. based on Electrical Conductivity (EC). For chloride, the threshold concentration was set at 1000 mg/l, for TDS a concentration of 1500 mg/l is generally used, and for EC the boundary between fresh and salt is 2500 µS/cm. It is now agreed that each participating survey picks one of these three thresholds based on which best fits their current data. This choice must be indicated in the supporting information tab in the excel file (labels H, C, T and E, see above).

We provide an example in appendix 1, delineating the active fresh groundwater system in a cross-section within the Netherlands. In this figure, the red vertical lines show the fresh-salt interface, the black vertical lines show the top of clay layers with a high vertical resistance (thus the hydrogeological base). In this example, the fresh-salt interface determines the depth of the total fresh water domain.

2.2 Layer 1 – Layer 10

Below is an explanation for each of the columns in the layer tabs in the template. The layers are numbered one to ten. In the template there is space for 10 layers, please try to not use any more layers. However, if you do need more it can easily been done by creating a new tab and copy-pasting one of the previous layers (be sure to change the layer numbers and to add the cell id's from column B).

General ideas on identifying layers

Layer numbers

Layer numbers are not the same across multiple cells. This means that layer 1 is always the top layer in every cell. Not all layers have to have 100% extension over a cell; the extent of a layer can be introduced per layer.

Layer grouping

Individual geological layers as mapped by each survey can be grouped to form one layer based on similar hydraulic parameters. When there are large differences in these hydraulic parameters the layers can be split. Further information on hydraulic parameters an layer definitions can be found below.

Criteria for delineating layers that are significant at EU scale

As we want to reduce the number of layers to make a product that is representative at EU scale, surveys are encouraged to define criteria to decide about the number of layers to be produced. This can be done using hydrogeological expert judgement about the importance of aquifers and aquitards, but could also be based on thresholds on transmissivities for aquifers and/or hydraulic resistance of aquitards. Below is just an example that could be applied, where threshold values can be adapted to the conditions in a specific country:

- criterium to create a separate aquitard based on its vertical hydraulical resistance
    - Vertical hydraulic resistance c = thickness of the aquitard divided by the vertical hydraulic conductivity (in days), or $c = D / kv$ (in days)
    - If c > 5.000 days: take this aquitard into account as separate layer
    - Example:
        - clay layer with k_v = 0.001 m/day and thickness 5 m yields this 5.000 days
- Analogous, a transmissivity threshold (kD m^2/d) can help to decide on the importance of an aquifer at EU scale.

Unsaturated zone

Each layer in the grid may include an unsaturated zone, as to allow for non-saturated parts of aquifers, also in the deeper subsurface.

Layers below the seafloor
Some fresh water aquifers extend below the sea floor. Including those aquifers as layers, we agreed to take the sea floor as the top of the first layer.

Chronostratigraphic ordering of layers
During the meetings in Budapest and Zagreb, we agreed to follow a chronostratigraphic order for layering. This allows to identify layers within a cell with large elevation differences or complex geological build-up. This helps to schematize the layers at 10x10 km resolution in cells in mountainous regions or subsurface tunnel valleys. The main issue in these regions was that there can be multiple layers next to each other in one grid cell, which was difficult to deal with in the first version of the template.

The agreed procedure is to order the layers by chronostratigraphy first, and then determine the average thickness of both the saturated and unsaturated zone and the % extent of the layer in each cell. An example of how this would work is shown in Figure 6. The top left image shows a hypothetical cross section of a 10x10 km cell with a mountain (layer B), an underground tunnel valley (layer C) and several other layers in between. The unsaturated zones are indicated by the vertically striped layers. The top right image of Figure 6 shows the layers separated and ordered from top to bottom by chronostratigraphy. The same layers are schematized and converted to a 10x10 km scale on the bottom left image. Here, the black bars next to the layers indicate the extent of that layer. The final visualization will look like the image on the bottom right, where all layers are put beneath each other on chronostratigraphic order. In the Figure, the horizontal axis denotes the extent of the layer in the 10 x 10 km grid, where 100% extent is visualized as a fully filled horizontal axis.

The advantage of the approach chosen is that the final map will give a good representation of the volumes and thicknesses of the groundwater resource, at a scale which is useful at the Pan-EU level. The schematized cross-section has some shortcomings and cannot be used for some other purposes that one could think of. For one, it does not represent the actual depths that the layers are in reality. For example, in the “real” cross-section of the top left, the bottom of the last layer (G) is at -1400 meters, while in the schematized cross section it falls below that. This means that the schematized cross-sections that we will produce for the groundwater map are not a real representation of the geology, and it will be important that we stress that when presenting our final results.

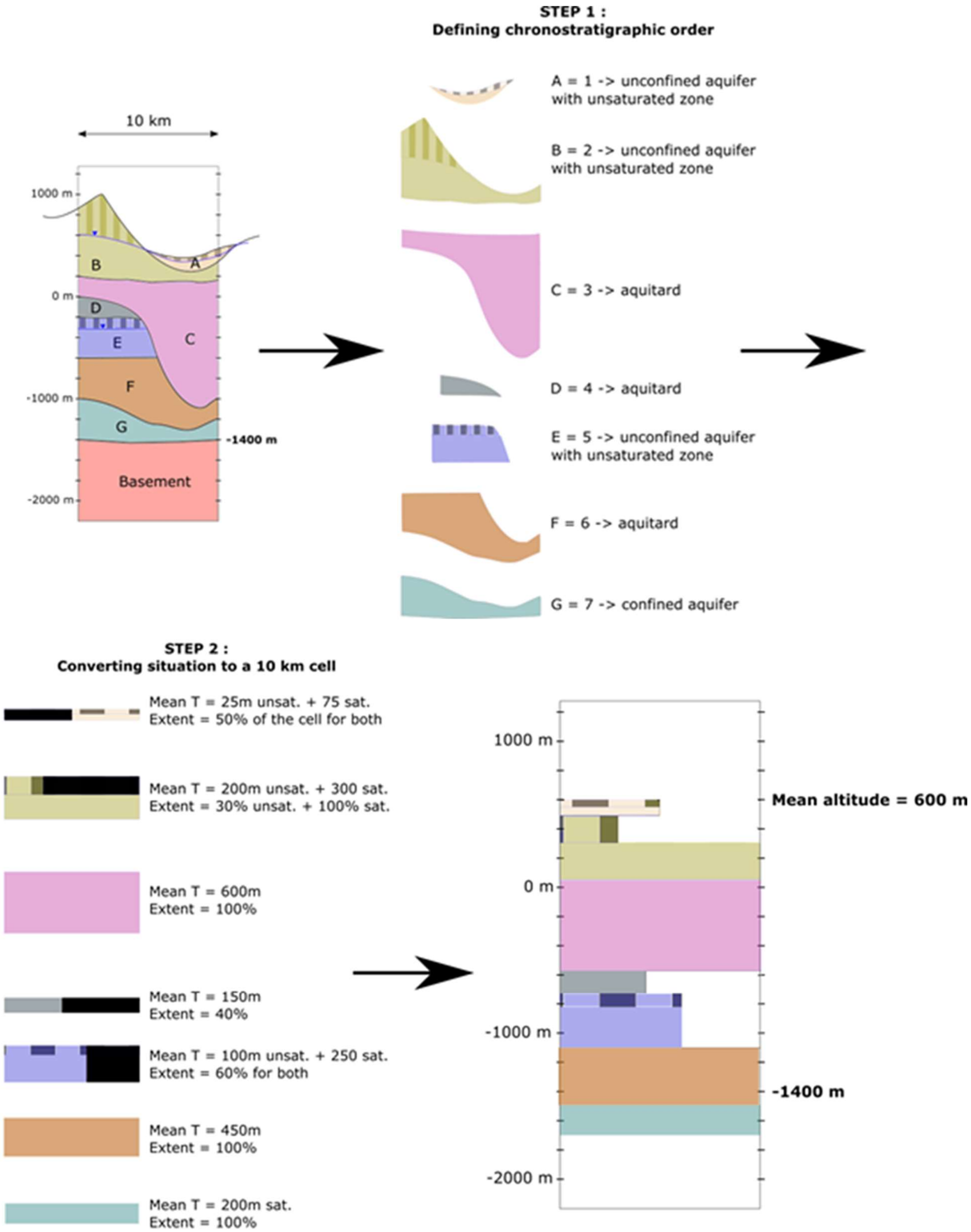


Figure 6 Approach for schematizing areas based on chronostratigraphic order

The Template for each layer is now alike Figure 7. A description of all inputs is given below.

	A	B	C	D	E	F	G	H	I	J	K
1		cell_id	L1_Unsat_Thickness	L1_Unsat_Extent	L1_Label_dynamic	L1_GW_Level_Amplitude	L1_Saturated_Thickness	L1_Saturated_Extent	L1_Hydrogeofacies	L1_Geological_age	L1_Confidence_label_delineation
2		-	*m*	*% of grid cell*	*N/K/R/P*	*m*	*m*	*% of grid cell*	*see hydrogeofacies list*	*see age list*	*EI/MOD/BH*

template instructions | Main information | **Layer 1** | Layer 2 | Layer 3 | Layer 4 | Layer 5 | Layer 6 | Layer 7 | Layer 8 | Layer 9 | Layer 10 | Supplementary information

Figure 7 Layer 1 - Layer 10 tabs example, columns A-K

C. L1_Unsat Thickness

The average thickness of the unsaturated zone of this layer in meters. If the layer has no unsaturated zone this can be left empty. By default, for layer 1 the unsaturated zone thickness is the cell elevation minus the water level depth. For karst aquifers the minimum water level is used to define the unsaturated zone thickness.

An unsaturated zone can be attributed to each layer separately. In the example of figure 6, both layers 1, 2 and 5 have an unsaturated zone so for these layers, columns C, D, E, and F under the layer tabs will be filled in (along with the other columns on the saturated zone). The other layers do not have an unsaturated zone, so the columns C to F will remain empty for these layers.

D. L1_Unsat_Extent

The average extent of the unsaturated zone in percent of the grid cell.

E. L1_Label_dynamic

Label which describes the dynamics of the groundwater level. There are several options which can be indicated by the following letters:

- N = Naturally seasonal variability;
- K = Karst systems with seasonal groundwater level fluctuation;
- R = Recovery after mining;
- P = Groundwater depletion by pumping.

Most cells will be coded as N as groundwater levels are mostly naturally fluctuating on a seasonal basis, which can be considered static on a European scale and will be denoted by code N. For Karst aquifers label K is available, to indicate the large seasonal fluctuations that are typical in these systems. Special labels are available for aquifers that expose groundwater depletion by pumping, yielding large drops in groundwater heads over that period 2000-2010 (P) or contrary, reveal recovery of groundwater heads after the termination of mining activities (R).

F. L1_GW_level_amplitude

This field is only filled for label K, R and P under L1_Label_Dymnamic and represents the period 2000-2010. The amplitude is defined as the the difference between average lowest groundwater level and average highest groundwater level over this 10 year period. For cells with label N, no amplitude is given.

G. L1_Saturated_thickness
The average thickness of the saturated zone of this layer in meters.

H. L1_Saturated_Extent
The average extent of the saturated zone in percent of the grid cell.

I. L1_Hydrogeofacies
Description of the hydrogeofacies of the layer. The hydrogeofacies should be chosen from the RESOURCE WP6 Hydrogeofacies list, which is distributed along with the template. The typology used is in line with the HME1500 - International Hydrogeological Map of Europe 1:1,500,000.
The colors reflect the following and will be used in the final information products based on the grids:

- Blue: extensive and highly productive intergranular aquifers
- Lightblue: local or discontinuous intergranular aquifers or extensive but only moderately productive intergranular aquifers
- Green: extensive and highly productive fissured aquifers, including karst aquifers
- Lightgreen: local or discontinuous fissured/karst aquifers or extensive but only moderately productive fissured/karst aquifers
- Brown: strata with essentialy no groundwater resources
- Lightbrown: minor aquifers with local and limited groundwater resources

Unconsolidated sedimentary hydrogeofacies
Unweathered marine clay
Clay, clayey loam, mud, silt, marls
Clayey-loamy alteration products
Loess
Coarse sand
Medium sand
Fine sand
Gravel
Eskjer deposits and moraines
Glacial till
Peat and raised bogs
Lignite
Pyroclastic, ash and tuff
Made ground
alternation of unconsolidated sedimentary hydrogeofacies

Fissured sedimentary hydrogeofacies
Karstified limestone
Dual-porosity fissured limestone and dolomite
Fissured Limestone and dolomite
Karstified Chalk
Fissured Sandstone
Fissured marlstone, flysch
Fissured mudstone, siltstone, shale, slate
alternation of fissured sedimentary hydrogeofacies

Compact sedimentary hydrogeofacies
Mudstone, shale, slate, claystone
Sandstone
Conglomerate
Chalk
Limestone
Dolomite
Travertine
Flysch
Rock salt
Anhydrite/gypsum
Siltstone, marlstone
alternation of compact sedimentary hydrogeofacies

Compact igneous and methamorpic hydrogeofacies
Compact Basalt
Compact igneous and metamorphic rock
Lava

Fissured Crystalline Hydrogeofacies
Fissured igneous and metamorphic rock
Weathered granite
Weathered gabbro
Fissured basalt

Figure 8 RESOURCE WP6 Hydrogeofacies list

J. L1_Geological_Age

This column gives a rough indication for the geological age of the hydrogeofacies described in column I. The following options are available for the labels within this column. Intentionally, the list gives two levels of hierarchy, because upscaling at 10 x 10 km requires some flexibility, enabling to make predefined selections in a later stage.

Quarternary	Cretaceous
Tertiary undistinguished	Jura
Mesozoic undistinguished	Triassic
Paleozoic undistinguished	Permian
Tertiary Neogene	Carboniferous
Tertiary Paleogene	Devonian
	Silurian
	Ordovician
	Cambrian
	Precambrian

K. L1_Confidence_label_delineation

Label which describes the confidence level of which the above information about layer depths and extent is based on.

- EJ = Expert Judgement
- MOD = Based on (3D) subsurface model
- BH = Based on boreholes

	L	M	N	O	P	Q	R	S	T	U	V	W
1	L1_Layer_Type	L1_Aquifer_type	L1_Porosity	L1_kh	L1_KV	L1_Anisotropy	L1_Confidence_label_hydraulic_parameters	L1_Paleo	L1_Artesian	L1_Thermal	L1_Temp_Lower_Boundary	L1_Temp_Upper_Boundary
2	*AQF/AQT/MIX*	*U/C/SC*	*two decimals*	*m/day*	*m/day*	*kh/kv*	*EJ/MOD/BH*	*X*	*X*	*X*	*°C (Only when Lx_Thermal is X)*	*°C (Only when Lx_Thermal is X)*
3	AQF											
4	AQT											
5	MIX											

template instructions | Main information | Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 | Layer 6 | Layer 7 | Layer 8 | Layer 9 | Layer 10 | Supplementary information

Figure 9 Layer 1 - Layer 10 tabs example, columns L-W

L. L1_Layer_Type

Label which described the layer type. After the Zagreb workshop it was agreed to distinguish 3 main types:

- AQF (for aquifers)
- AQT (for aquitards)
- MIX (for mixed sequences of aquifers and aquitards).

Based on what is filled in this column, conditional formatting makes it clear which hydrological parameters should or should not be filled in in the next columns for this layer type (see the colors in Figure 10). Based on the input for Layer_Type, the cells for the next columns M to Q become either green or red, indicating if they should or should not be filled in.

In order to enable upscaling of thick sequences of mixed nature, we now introduce a third element "mixed aquifer/aquitard", which needs a different calculation of the effective horizontal and vertical conductivities and porosities. The MIX category are in principle only used for the hydrogeofacies-type "Alternation of sedimentary hydrogeofacies". We recommend using this category sparingly, only when it is not feasible to distinguish the different layers in aquifers and aquitards. It requires a somewhat more complicated method to calculate upscaled vertical and horizontal conductivities and porosities that still resemble representative volumes and transmissivities of the groundwater resources (see further under columns N,O and P and Appendix 2.

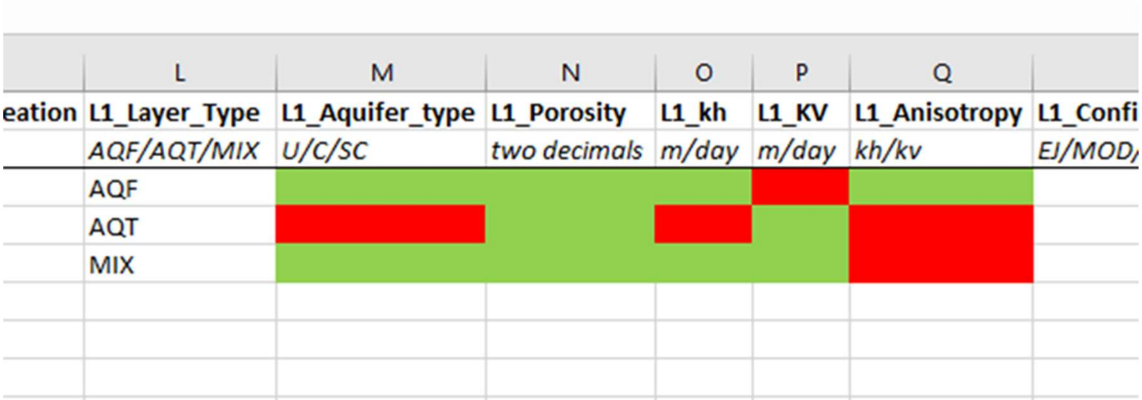


Figure 10. Columns L to Q of the template indicating the conditional formatting of these cells based on what is filled in as layer type in column L. Green indicates that the cell should be filled in, red indicates that it shouldn't.

M. L1_Aquifer_Type

This label describes the type of the aquifer. This only needs to be filled in if the layer type in column L is AQF or MIX. A choice can be made between U (for Unconfined), C (for Confined) and SC (for Semi-Confined). These characteristics apply to the layer as a whole over the extent of the grid cell that is occupied by the layer

N. L1_Porosity

Porosity is indicated as a fraction of total pore volume using two decimals. This column list the effective porosity, since this is best known and most relevant. We are mainly interested in the volume of groundwater that is available for groundwater flow, which is best represented by the effective porosity. This column should be filled in for all layer types. If there is no data on the porosity of the layer and you cannot give an expert judgement, standard values can be used from the RESOURCE WP6 Hydrogeofacies list. Special care is needed to define the effective, mean porosity of a MIX aquifer type, in order to representatively calculate the total volume of water in the more permeable parts of the subsurface (see Appendix 2 for details of the calculation).

O. L1_kh

Horizontal conductivity in m/d (1 decimal). This column needs to be filled if the layer type in column L is AQF or MIX. If there is no data on the horizontal conductivity of the layer and you cannot give an expert judgement, standard values can be used from the RESOURCE WP6 Hydrogeofacies list.

By default, data of AQF type layers will be entered as hydraulic horizontal conductivities in m/day, and vertical conductivities will be based on an estimated ratio between k_h and k_v (or anisotropy factor). It needs to be realized that the k_h values need to be representative at the scale of the whole grid cell and layer thickness and will require some expert judgement or modelling experience to come up with a value that is representative for the scale of pan-EU map. In other words, k_h is the effective horizontal conductivity, representative of the whole grid cell and layer thickness. For layer type MIX, a method for calculation of this average, effective horizontal hydraulic conductivity is given in Appendix 2.

P. L1_kv

Vertical conductivity in m/d (multiple decimals). This column needs to be filled if the layer type in column L is AQT and MIX. If there is no data on the vertical conductivity of the layer and you cannot give an expert judgement, standard values can be used from the RESOURCE WP6 Hydrogeofacies list.

By default, data of AQT type layers will be entered as vertical hydraulic conductivities in m/day, and no horizontal conductivities need to be specified. It needs to be realized that the k_v values need to be representative at the scale of the whole grid cell and layer thickness and will require some expert judgement or modelling experience to come up with a value that is representative for the scale of pan-EU map. In other words, k_v is the effective vertical hydraulic conductivity, representative of the whole grid cell and layer thickness. For layer type MIX, a method for calculation of this average, effective vertical hydraulic conductivity is given in Appendix 2.

Q. L1_Anisotropy

A factor which describes the anisotropy factor (ratio k_h/k_v) of the layer. This column needs to be filled if the layer type in column L is AQF.

R. L1_Confidence label_hydraulic_parameters

Label which indicates the confidence level of which the hydraulic parameters are based on.

- EJ = Expert Judgement
- MOD = Based on (3D) subsurface model
- BH = Based on boreholes

S. L1_Paleo

Checkbox indicating that there is some presence of paleo groundwater within the layer, where paleo groundwater was defined to be older than 10.000 years. This column only needs to be checked if it is known that there is paleo groundwater in part of the cell. It is thus not required that the entire layer in the cell contains paleo groundwater. The column can be left blank if it is known that there is no Paleogenic water or if there is no information or if it is not applicable. Typically, knowledge about the presence of paleo groundwater is derived from tracer studies on stable and radioactive isotopes or noble gas compositions.

R. L1_Artesian

Checkbox indicating if the part of the groundwater in the cell is artesian. The cells only needs to be filled (by checking with a X) if there is existing knowledge that at least part of the aquifer in that cell has artesian water, which means a groundwater head higher than the surface elevation at the location of the monitoring point where this is known. Thus, it is not required that all the water in the layer is artesian. This column is only checked when expert judgement indicates that this artesian situation is still present in the current situation. Aquifers that were known to be artesian once, but now lost artesian status because of groundwater depletion should not be checked. Indication for groundwater depletion are given in the “Label_Dynamic” column, type P (for pumped). The cell can be left blank if it is either known that the groundwater is not artesian, or if there is no information or it is not applicable.

U. L1_Thermal
Checkbox indicating if the groundwater in this layer is considered to be thermal in your country. Different countries adhere to different thresholds for thermal water, partly depending on latitude (e.g. Hungary = 30 °C, Romania = 20 °C, UK 15 °C). This is appreciated by letting each country decide about their own definition but giving temperature ranges for cells that contain thermal water according to the definitions used in the country. The cell is marked with an X if it is known that there is presence of thermal groundwater in (a part of) the cell. Thus, it is not required that all the water in the layer is thermal. The cell can be left blank if it is known that the water is not thermal, or if there is no information on it or if it is not applicable. If the layer contains thermal groundwater and the cell is checked, temperature range should be given in the next two columns.

V. L1_Temp_Lower_Boundary
Here you must indicate the lower temperature boundary of the groundwater in the layer. This only needs to be filled in when there is thermal water in the layer as indicated in column U.

W. L1_Temp_Upper_Boundary
Here you must indicate the upper temperature boundary of the groundwater in the layer. This only needs to be filled in when there is thermal water in the layer as indicated in column U.

2.3 Supplementary information

This worksheet can be used to add extra information that is not yet part of the template, but you think is important for good use of the data (free format per grid cell).

3 DESCRIPTION OF THE DATABASE

This chapter describes the contents and structure of the database which was developed under task 6.2. The database is used to store all the information which was gathered by the individual surveys in their own templates. The goal of the database is to store the data on volumes and depths of groundwater resources in a structured way, so that it can be used by the GeoERA Information Platform to display the maps that will be compiled under task 6.3 on EDGI.

3.1 Visualization ideas

During the RESOURCE WP6 workshop in Zagreb some ideas for the visualization of the final data were discussed. These ideas form the basis for the database, as these make up the requirements that the data format has to comply with. These visualization ideas can be split in three groups, which are discussed below.

3.1.1 Plane view

The first option for viewing the data is in plane view. We should be able to view maps from above from different parameters in the database. Some ideas include:

- Map of the total volume of fresh groundwater within aquifers
    - The total volume is calculated by selecting the layers with layer type AQF, and then multiplying the thickness of these layers with the extent and porosity.
- Map of the total thickness of the layers with fresh groundwater within aquifers
- Map of the total Transmissivity of the aquifers
    - The transmissivity is calculated by selecting the layers with layer type AQF, and then multiplying the thickness by the horizontal conductivity kh.
- Map of the total depth of the active groundwater system
- Overlay with the location of the RESOURCE case studies from RESOURCE WP3, 4, and 5.

For each of these maps, different selections should be able to be made. These selections include:

- Selection for the specific aquifer geological age
    - E.G. a map of the total volume of fresh groundwater within Cretacious aquifers.
- Specific hydrogeofacies:
    - E.G. a map of the total transmissivity for fissured limestone aquifers.
- Confined/unconfined/semiconfined
    - E.G. a map of the total thickness of unconfined aquifers
- Artesian aquifers/Thermal water/Paleo water
    - E.G. an overlay which shows the locations where paleo water is present within the 10x10 km cell.

3.1.2 *Chronostratigraphic Groundwater Resource Columns (CRGC's)*

The second option for viewing the data is by Chronostratigraphic Groundwater Resource Columns (CRGC). An example of a CRGC can be seen in the last panel of Figure 6. These are shown when a specific 10x10 km cell is selected from a plane view map as described in the previous paragraph. The CRGC's show the thickness of the layers on the y axis, and the extent of the layers on the x axis. Some visualization ideas for these columns include:

- Hydrogeological UNESCO legend colors
  - This will show the colors for highly productive/locally productive aquifers. For a detailed description, see figure 8 and paragraph I. L1 Hydrogeofacies on page 13[1].
- Hydrogeofacies using Unesco legend[1]
- Total depth of the active fresh groundwater system
  - Since layers which are in real life beside each other are placed below each other in the CRGS's, the value from column D (Total depth active layers) is shown as a thick horizontal line in the column to represent the actual depth of the total system.
- Transmissivity ranges
  - The aquifers are colored based on their calculated values for transmissivity.
- Hydraulic resistance ranges
  - The aquitards are colored based on their calculated values for hydraulic resistance (= thickness of aquitard divided by the vertical conductivity).
- Geological ages
- Thermal/Paleo/Artesian
  - Symbols within the layers indicate if the layer has thermal, paleo, or artesian water in line with the UNESCO legend.

3.1.3 *Chronostratigraphic Groundwater Resource Cross sections*

The third option for viewing the data is by Chronostratigraphic Groundwater Resource Cross sections. These are similar to the CRGC's from the previous paragraph, but multiple neighboring columns are placed beside each other to show a cross section. The visualization ideas are the same as for the CRGC's.

3.2 Database structure

During discussing the visualization ideas with the GeoERA Information Platform, it was decided that the best way to store the data from the individual templates was in the NetCDF file format. NetCDF (Network Common Data Form) stores array-oriented data, and is often used in the geosciences to show gridded data.

[1] See Struckmeier, W.F. et al (1995). *Hydrogeological maps: a guide and a standard legend*. Association of Hydrogeologists. Hannover: Heise.

The variables in the RESOURCE NetCDF file are:

```
float64 Altitude_surface_level(y, x)
float64 Total_depth_active_layers(y, x)

float64 L1_Unsat_Thickness(y, x)
float64 L1_Unsat_Extent(y, x)
float64 L1_Label_dynamic(y, x)
float64 L1_GW_Level_Amplitude(y, x)
float64 L1_Saturated_Thickness(y, x)
float64 L1_Saturated_Extent(y, x)
float64 L1_Hydrogeofacies(y, x)
float64 L1_Geological_age(y, x)
float64 L1_Confidence_label_delineation(y, x)
float64 L1_Layer_Type(y, x)
float64 L1_Aquifer_type(y, x)
float64 L1_Porosity(y, x)
float64 L1_kh(y, x)
float64 L1_KV(y, x)
float64 L1_Anisotropy(y, x)
float64 L1_Confidence_label_hydraulic_parameters(y, x)
float64 L1_Paleo(y, x)
float64 L1_Artesian(y, x)
float64 L1_Thermal(y, x)
float64 L1_Temp_Lower_Boundary(y, x)
float64 L1_Temp_Upper_Boundary(y, x)
float64 L1_Saturated_Volume(y, x)
```

Similar variables are available for L2-L10. The detailed explanations on these variables can be found in chapter 2. Each variable has the following attributes:

```
missing_value: -9999.0
long_name: L10_Saturated_Volume
grid_mapping: crs
```

The database has two dimensions, defined by the coordinates in the variables x and y:

```
float32 x(x)
current shape = (500,)
float32 y(y)
current shape = (450,)
```

The spatial reference is defined in the variable crs:

```
int32 crs()
    spatial_ref:              PROJCS["ETRS89              /              ETRS-
LAEA",GEOGCS["ETRS89",DATUM["European_Terrestrial_Reference_System_1989",SPHER
OID["GRS
1980",6378137,298.257222101,AUTHORITY["EPSG","7019"]],AUTHORITY["EPSG","6258"]
```

```
],PRIMEM["Greenwich",0,AUTHORITY["EPSG","8901"]],UNIT["degree",0.0174532925199
4328,AUTHORITY["EPSG","9122"]],AUTHORITY["EPSG","4258"]],UNIT["metre",1,AUTHOR
ITY["EPSG","9001"]],PROJECTION["Lambert_Azimuthal_Equal_Area"],PARAMETER["lati
tude_of_center",52],PARAMETER["longitude_of_center",10],PARAMETER["false_easti
ng",4321000],PARAMETER["false_northing",3210000],AUTHORITY["EPSG","3035"],AXIS
["X",EAST],AXIS["Y",NORTH]]
```

All data layers in the NetCDF file have type float. Layers with text values (e.g. L1_Hydrogeofacies) have been converted to float during pre-processing. The conversion is stores in csv files which can be used to return the floats back to string for legends for the maps.

The NetCDF file can be used to make the necessary calculations for the visualization ideas. Some examples of plain view maps are shown below. Note that these maps are from an early version of the database, more countries now completed than shown here.

Total depth of active layers

The map is made from the variable Total_depth_active_layers in the NetCDF database.

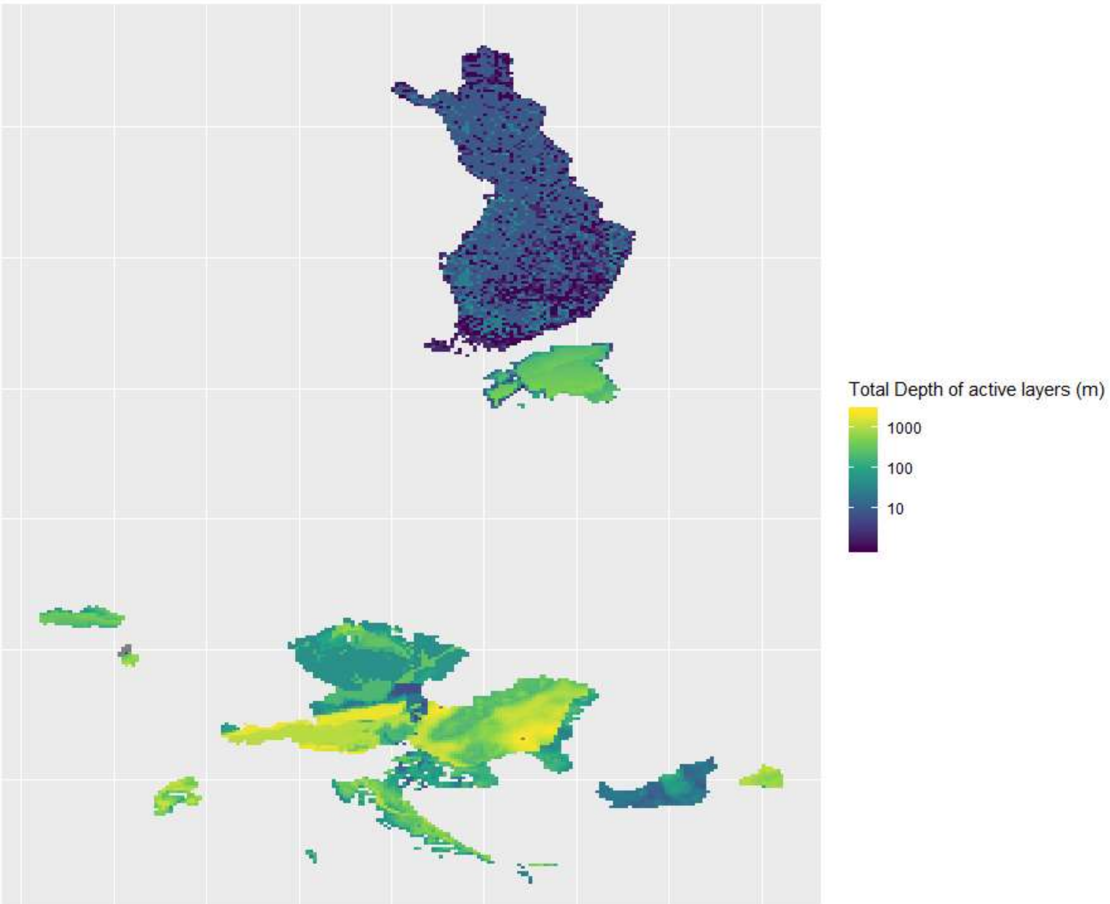


Figure 11. Example from the NetCDF database showing the total depth of the active fresh groundwater system in m below surface level. The map is not yet in the appropriate projection that will be shown in EGDI.

Total thickness of fresh groundwater within aquifers
The total thickness of the fresh groundwater within aquifers is calculated by taking the sum of the variable Lk_Saturated_Thickness for the layers with Lk_Layer_Type = 0 (which are the aquifers).

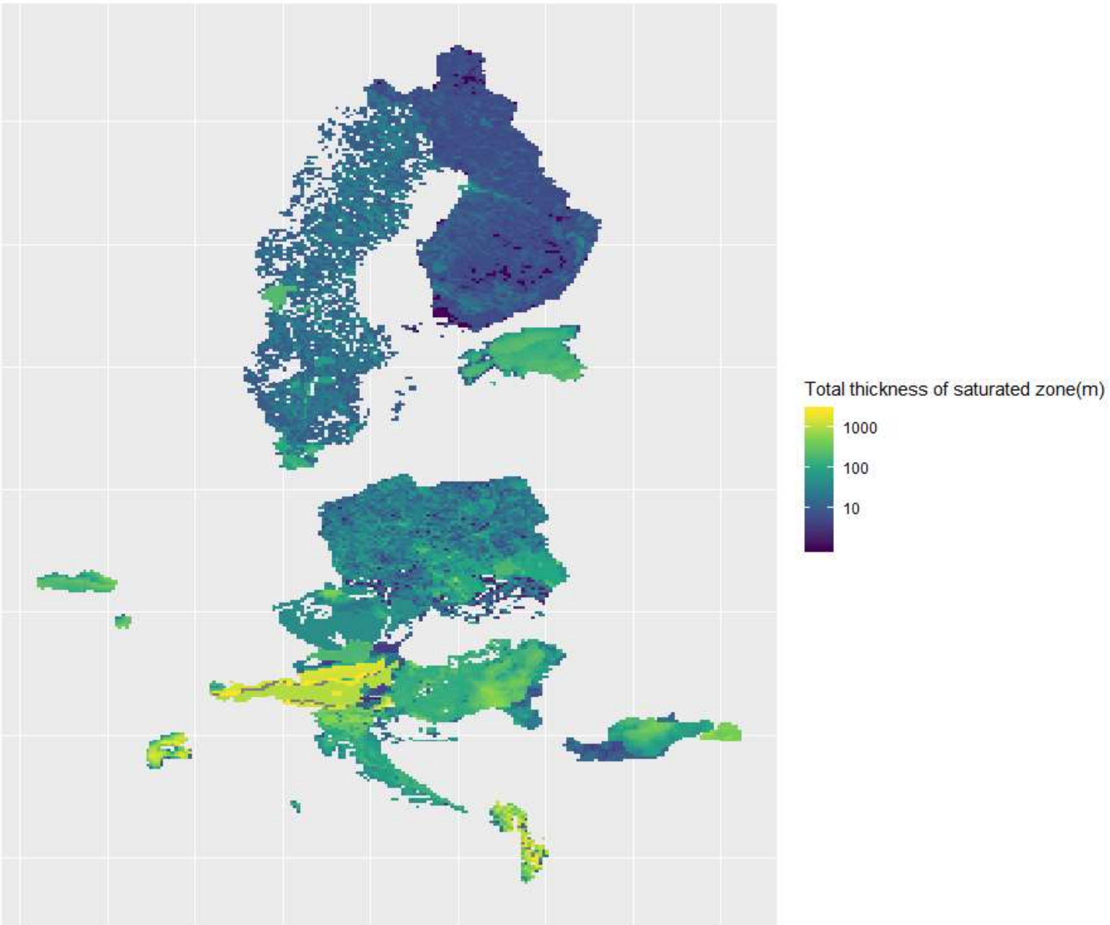


Figure 12. Example from the NetCDF database showing the total thickness of aquifers containing fresh groundwater in m. The map is not yet in the appropriate projection that will be shown in EGDI.

Total volume of fresh groundwater
This map shows the total volume of fresh groundwater in each 10x10 cell, calculated by multiplying the variable Lk_Saturated_Thickness by Lk_Saturated_Extent and Lk_Porosity for each layer in the 10x10 km cell. This results in a map showing the volume in m^3.

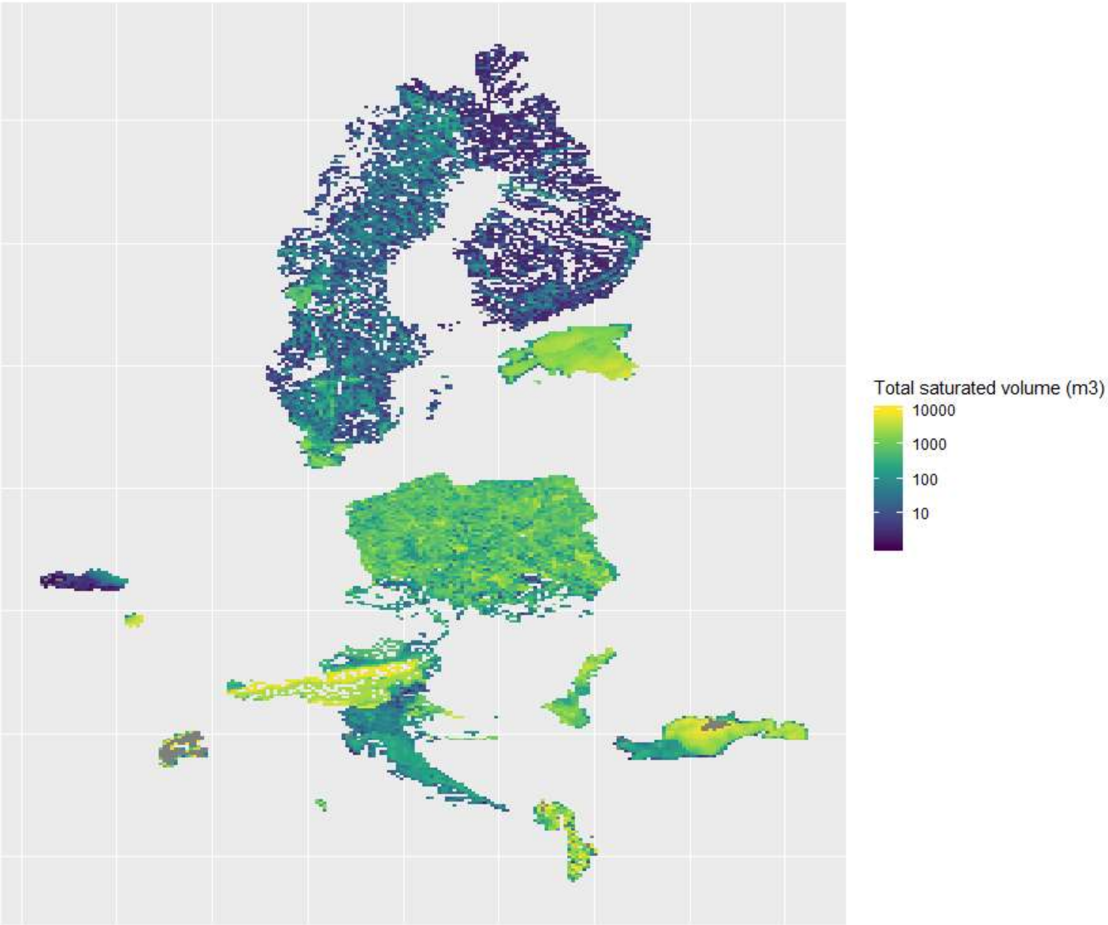


Figure 13. Example from the NetCDF database showing the total volume of fresh groundwater in the saturated aquifers of each 10x10 km cell. The map is not yet in the appropriate projection that will be shown in EGDI.

APPENDIX 1 EXAMPLE OF DEFINING THE TOTAL DEPTH OF ACTIVE LAYERS

Below, an example is given for several grid cells within the Netherlands. Figure 1.1 shows a vertical cross-section of several 10x10 km grid cells within the Netherlands. In this figure, the colours of the layers indicate different stratigraphic units. Colour differences within each layer indicate the presence of clay layers (e.g. the difference between dark blue and light blue in the layer at -250 to -400 m depth, the dark colour indicates clay). This is used to distinguish aquitards from aquifers (see cells E, F, G, and H, indicated by a dashed layer).

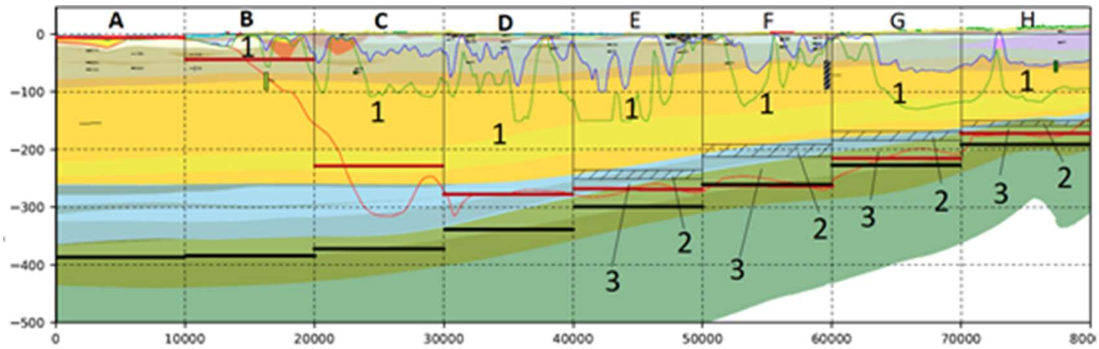


Figure 1.1 Cross-section of several grid cells in the Netherlands

The horizontal red lines indicate an approximation of the fresh-salt applying a threshold of 1.000 mg/l chloride, horizontal black lines indicate the top of the layers with very low vertical hydraulic conductivity (and corresponding high vertical hydraulic resistance). We used these layers to define our hydrogeological boundary. Effectively, in our case, we define our total depth of fresh groundwater by the fresh-salt interface, as the hydrogeological base is typically below that interface. In cell 1 the salt-fresh interface is on the same level as the surface level (this cell covers sea), so no layers are defined. For cell B to D, only 1 layer is defined since there are no aquitards of any importance (as far as relevant for the EU scale product). In cell E to H there is an aquitard above the fresh-salt interface so here there are multiple layers.

APPENDIX 2: UPSCALING HYDRAULIC PARAMTERS FOR MIXED AQUIFER TYPES

In order to enable upscaling of thick sequences of mixed nature, we have introduced a third element “mixed aquifer/aquitard”, which needs a different calculation of the effective horizontal and vertical conductivities and porosities. The MIX category is in principle only used for the hydrogeofacies-type “Alternation of sedimentary hydrogeofacies”. We recommend using this category sparingly, only when it is not feasible to distinguish the different layers in aquifers and aquitards. It requires a somewhat more complicated method to calculate upscaled vertical and horizontal conductivities and porosities that still resemble representative volumes and transmissivities of the groundwater resources.

For MIX aquifer types, the upscaled, average porosity and effective, upscaled $\overline{k_h}$ and $\overline{k_v}$ and $\overline{\epsilon}$ are required. Here, $\overline{k_h}$, $\overline{k_v}$ and $\overline{\epsilon}$ represent the upscaled effective horizontal and vertical conductivity and porosities, representative of the whole grid cell and layer thickness. Below is an example on how to calculate this. As noted before, it is strongly advised to not use this layer type when not strictly necessary, but instead choose between aquifer and aquitard.

The figure below shows an example which was in the presentation from Serbia during the Zagreb meeting. This shows a thick sequence of a mix between aquifers and aquitards. If it is preferred to include this as one layer, instead of multiple aquifers/aquitards, it can be noted as MIX for the layer type. This however requires more calculations to include the upscaled $\overline{k_h}$, $\overline{k_v}$, and $\overline{\epsilon}$. An example on how to do this, based on figure 2.1, is shown below.

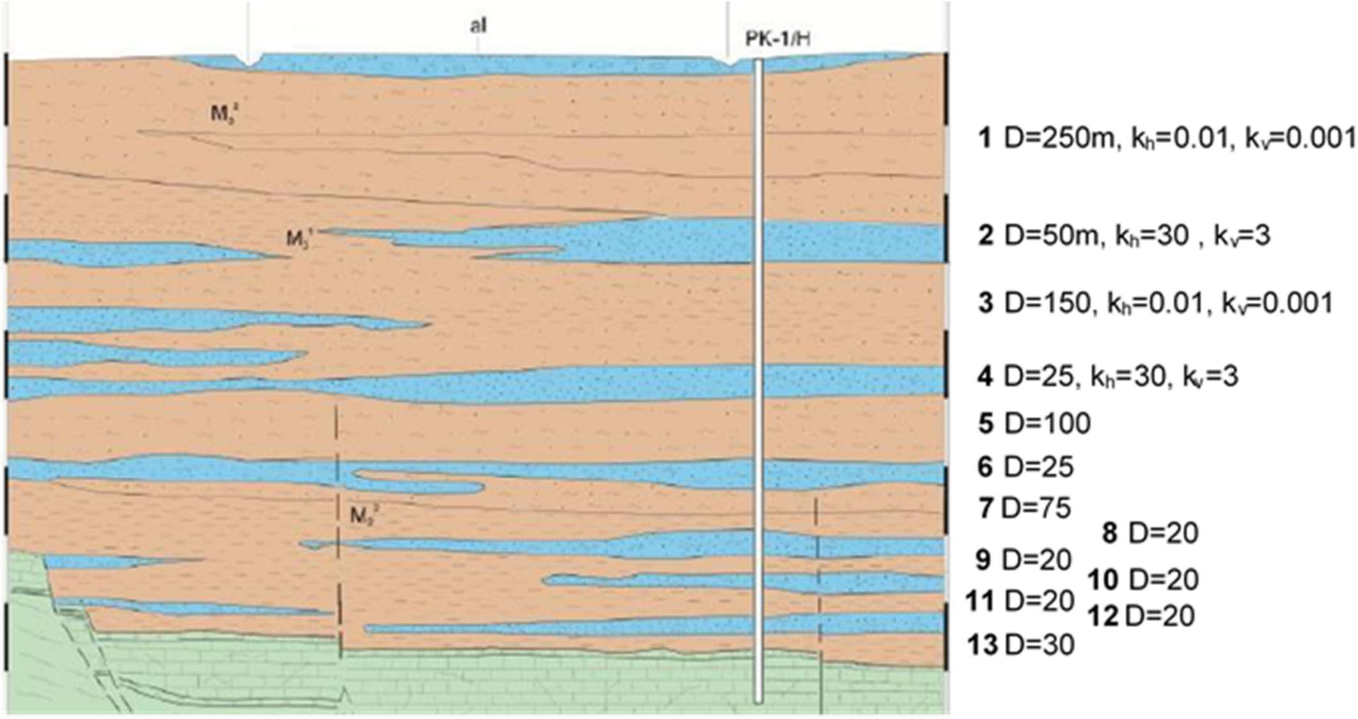


Figure 2.1. Example of a Mixed layer type from the presentation of Serbia with hypothetical values for thicknesses of layers, k_h, k_v and porosity. For Aquifers: k_h= 30 m/d, k_v = 3 m/d, ε = 0.35. For aquitards: k_h = 0.01 m/d, k_v=0.01 m/d, ε = 0.55.

Calculation of $\bar{k}_h$

The effective upscaled value $\bar{k}_h$ is calculated by deriving the transmissivities for the separate layers and adding them up (equation 1) and dividing this by the total thickness of all the layers (equation 2).

1.

$$\Sigma T = k_{h_1^*} D_1 + k_{h_2^*} D_2 + \cdots k_{h_n} * D_n$$

2.

$$\bar{k}_h = \frac{\Sigma T}{\Sigma D}$$

So for the hypothetical values of Figure 2.1, the effective upscaled $\bar{k}_h$ would be calculated like this:

$$\Sigma T = 0.01 * 250 + 30 * 50 + 0.01 * 150 + 30 * 25 + \cdots 0.01 * 30$$
$$\Sigma T \approx 4800\ m^2/d$$

$$\Sigma D = 250 + 50 + 150 + 25 + \cdots 30$$
$$\Sigma D = 805\ m$$

$$\bar{k}_h = \frac{4800}{805} \approx 6\ m/d$$

Calculation of $\overline{k}_v$

The effective upscaled value $\overline{k}_v$ is calculated by first calculating the hydraulic resistance for each layer and adding them up (equation 3) and dividing the total thickness of all layers considerend by the summed resistance (equation 4).

3.

$$\sum C = \frac{D_1}{k_{v_1}} + \frac{D_2}{k_{v_2}} + \cdots \frac{D_n}{k_{v_n}}$$

4.

$$\overline{k_v} = \frac{\sum D}{\sum C}$$

For the example of figure 7, the calculation would be as follows:

$$\sum c = \frac{250}{0.001} + \frac{50}{3} + \frac{150}{0.001} + \cdots \frac{30}{0.01}$$

$$\sum c \approx 645000\ d$$

$$\overline{k_v} = \frac{805}{645000} \approx 0.0012\ m/d$$

Calculation of $\overline{\epsilon}$

The upscaled effective porosity is calculated by dividing the summed thicknesses from all the aquifers by the summed thicknesses from both the aquitards and the aquifers, and multiplying this by the porosity from the aquifers (see equation 5).

5.

$$\bar{\varepsilon} = \frac{D_{AQF}}{D_{AQT} + D_{AQF}} * \varepsilon_{AQF}$$

For the example of figure 7, the calculation would be as follows:

$$\bar{\varepsilon} = \frac{160}{805} * 0.35 \approx 0.07$$

Note: the result of this example leads to a very low porosity which seems to be counterintuitive. However, since we use the porosity and thickness of the complete layer to calculate the total volume of water and we want to exclude the aquitards, the porosity value has to be lower than the porosities of the aquifers. In this way, the final calculation on volumes will correctly represent the actual amount of water in the aquifers in the mixed layer.