Deliverable 3.2

PILOT DESCRIPTION AND ASSESSMENT

HUNGARY

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Mining and Geological Survey of Hungary

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LIST OF ABBREVIATIONS & ACRONYMS

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1 EXECUTIVE SUMMARY

Pilot name	Hungary	
Country	Hungary	
EU-region	Central Europe	
Area (km^2)	93000	
Aquifer geology and type classification	Sands and gravels, Limestones/dolomites, Volcanic rocks	
Primary water usage	Irrigation/Industry	
Main climate change issues	By the end of the 21st century in 100 years, the mean annual temperature in Hungary may increase by 3.5-4 °C and by 2.2 °C following the RCP8.5 and RCP4.5 scenarios, while precipitation results indicate that a small increase of 5% is projected by 2071–2100.	
Models and methods used	Modular modelling (hydrological model with WHI UnSat Suite software HELP module, hydrogeological model-series Visual Modflow)	
Key stakeholders	Water supply companies, farmers, water authorities	
Contact person	Éva Kun, Mining and Geological Institute of Hungary	

A dynamic modular approach was developed in order to quantitatively simulate the groundwater table under various climate conditions. The applied methodology included:

1. Determination of climate zones based on measured and simulated climate variables;
2. Determination of recharge zones (Hydrological Response Units, HRU's) based on surface geology, land use, and slope conditions.
3. Calculation of recharge for each recharge zone using 1D analytical hydrological model series.
4. Simulation of the groundwater table under various climate conditions using numerical groundwater flow models.

The climate data used in our hydrological modelling comprised gridded daily observed data from the CARPATCLIM-HU and CORDEX database and projections of different regional climate model.

Results of recharge calculation indicate that recharge could decrease up to 50 mm/year by the end of the 21st century in the elevated areas, while in other climate scenario we can presume wetter climate. Slight recharge increase is projected in parts of the Great Hungarian Plain and the Transdanubian Hills. Water levels most probably will increase over the Alpokalja, Mecsek, Transdanubian and Northern Mountain Ranges. Moderate water level drops in the Duna-Tisza

Interfluve and Tiszántúl areas are probable, while slightly rising groundwater levels are projected in parts of the Great Hungarian Plain and the Transdanubian Hills.

Our studies have highlighted the high degree of uncertainty in climate models. As a result, there has been both drought and a wetter climate trend and this can often vary from area to area. It has shown spatial and temporal fluctuations in precipitation and other climatic parameters, so the long-term trend may result opposite changes compared to the short or even medium-term.

The presented outputs were determined at the regional scale and as such cannot be used for local investigations. The presented methodology though can be applied for modelling the climate impact both at the regional and local scales for assessing the climate vulnerability of groundwater resources.

2 INTRODUCTION

Groundwater resources are impacted by global climate change through the modification of water balance. The changes of rainfall and temperature have direct effects on recharge and evapotranspiration conditions, and indirect influence on groundwater extractions. The purpose of this study was the development of a methodology for the assessment of direct impacts of climate change on shallow groundwater resources and its country-scale application in Hungary. A modular methodology was applied, which included the delineation of climate zones and recharge zones, the calculation of recharge using hydrological models and the simulation of groundwater table for various climate scenarios using numerical groundwater models. Observed climate parameters and historical groundwater level data were applied for the groundwater model calibration. Results from regional climate model projections were applied for the future groundwater simulations and for two future time slices.

3 PILOT AREA

3.1 Site description and data

The pilot area covers the entire Hungarian territory. Hungary is located in Central Europe, within the Carpathian Basin. It measures about 250 km from north to south and 524 km from east to west. It has 2,106 km of borders, shared with Austria to the west, Serbia, Croatia and Slovenia to the south and southwest, Romania to the southeast, Ukraine to the northeast, and Slovakia to the north.

Hungary has three major geographic regions (which are subdivided to seven smaller ones).
The Great Plain, a flatland lying east of the Danube River; Transdanubia, a hilly region lying west of the Danube and extending to the Austrian foothills of the Alps; and the North Hungarian Mountains, which is a mountainous and hilly country north of the Great Plain.

A great part of Hungary is a basin filled with marine and fluvial deposits, sometimes as thick as several kilometres (Figure 1). The marine deposits situated at larger depth are mainly clays and clayey marls with low water yield. The alluvial sediments deposited in the Pannonian Sea comprise sand and sandstone layers with a thickness of 1-2 kilometres.
In the Quaternary fluvial sediments were deposited with silty, sandy and gravel deposits. The thickness of these sediments can reach up to 1 km in the Kisalföld and in the southern region of the Great Hungarian Plain. The edges of the basin fans contain gravel aquifers. Their thickness is usually only a few tens of metres, however in the Szigetköz region their thickness is several hundred meters. Some rivers flow across these formations and their water is in direct contact with the water contained in the gravel layers.

One of the most significant group of aquifers comprise coarse sand and gravel layers of the clastic basin deposits. At larger depth, sandstone replaces the loose sandy layers. These aquifers can be found in more than three quarter of the country's area facilitating local drinking water production, and also the abstraction of thermal water from greater depths (usually deeper than 500 m).

From the shallow gravel aquifers along the riverbanks, bank-filtered water is extracted. The upper layers down to the depth of 10 to 20 m are of fine-grained formations with the possibility of local production of small discharges only. The majority of dug wells in the villages and countryside homesteads are producing water from such formations.

Another main type of aquifers is karstic rocks that can be found in highland areas covering one fifth of Hungary's territory. These comprise Mesozoic limestones and dolomites. While these are important drinking water resources, at large depth they contain thermal water, part of which come to the surface in the form of the well-known thermal springs (Héviz, Budapest, Eger, etc.).

Besides the main groundwater types (bank-filtered, shallow and deep groundwaters and karst waters), water can also be exploited to a smaller extent from other geological formations.

Parts of the highland regions are built up of fractured rocks (crystalline and volcanic) which feed smaller springs of local significance.

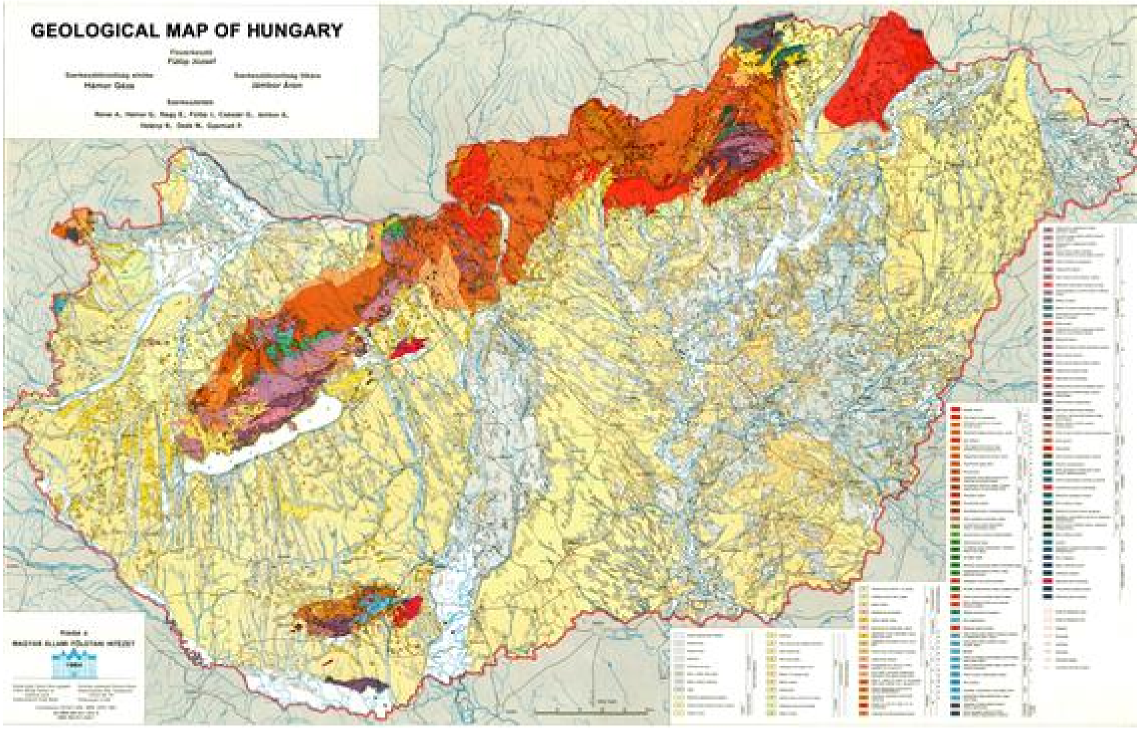

Figure 1. Geological map of Hungary

The total area of Hungary is 9,303,000 ha, of which 79% or 7,356,000 ha is agricultural land, and 48.2% or 4,502,000 ha is arable land. The topsoil textures of Hungarian soils can be characterised by sand 15%, sandy loam 12%, loam 47% and loamy clay or clay 26%.

About 85% of Hungary's territory is suitable for different purposes in agriculture and forestry, depending on the fertility of soils. Accordingly, agriculture is the largest user of land. The quality of cultivated lands, soil types, physical features, slope and climatic conditions are good for various agricultural production with substantial regional differences.

Hungary has a continental climate, with hot summers and cold winters. Mean annual temperature is between 10-11 °C. All-time temperature extremes are 42 °C in the summer and −35 °C in the winter. July is the hottest month with mean temperature above 21 °C, and January is the coldest with below -1 °C. The average rainfall sum is around 600 mm per year, June being the wettest month, February the driest on average. The mean annual temperature of Hungary between 1973–2004 is shown in Figure 2, while annual rainfall distribution for 1973–2004 is indicated in Figure 3.

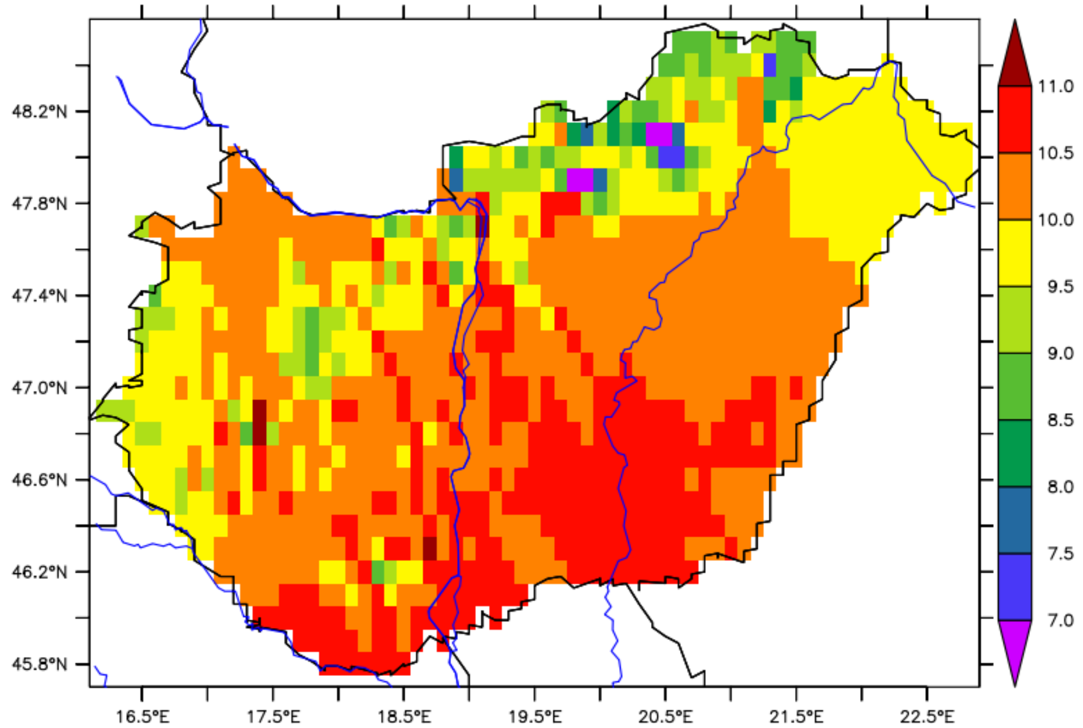

Figure 2. Mean annual temperature distribution for 1971–2000 [°C]

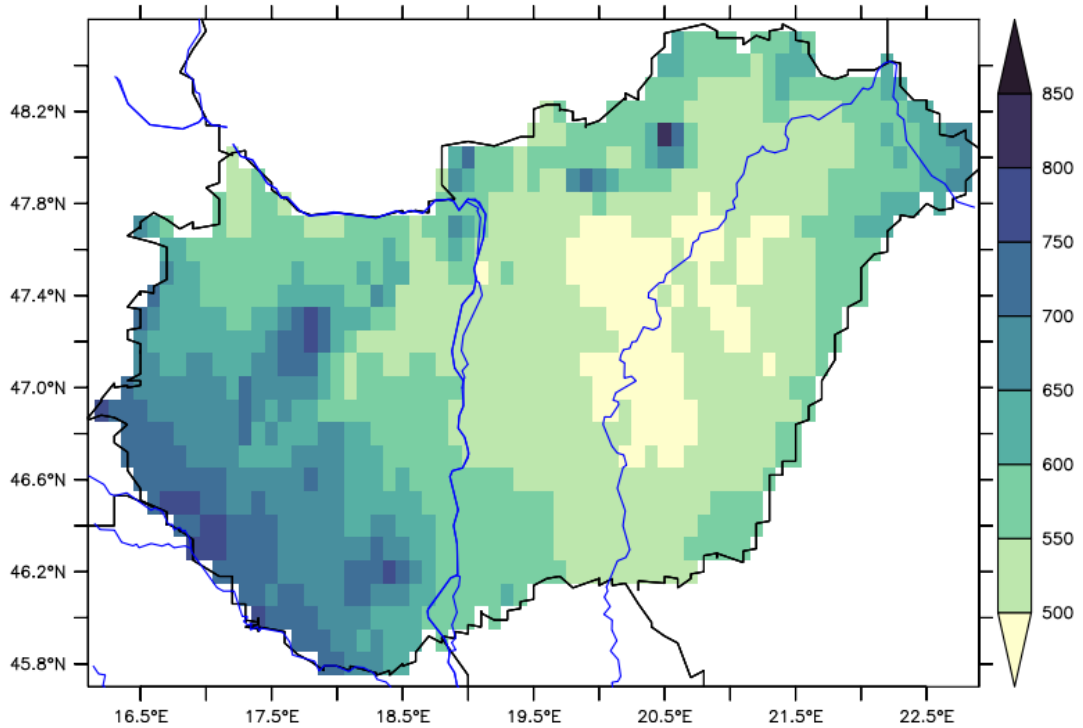

Figure 3. Annual average precipitation distribution for 1971–2000 [mm/yr]

3.2 Climate change challenge

In Central Europe, both warm and cold tails of the temperature distribution in all seasons warmed over the entire 20th century regardless of maximum and minimum temperature, though the largest increase in the cold tail occurred for the minimum temperature.

The analysis of observed climate data indicates a general tendency of more frequent, longer, and more intense heatwaves in the entire Carpathian region. On the other hand, the cold-waves show a general tendency to become less frequent and less intense. The Carpathian region and the Mediterranean are the two European hotspots showing a drought frequency, duration and intensity increase from 1990 onwards (Spinoni et al., 2013).

The amount of annual precipitation decreased (with around 5-10%) since the beginning of the 20th century. The strongest decrease happen during spring, while the summer precipitation amount did not change and the autumn and winter precipitation also decreased. The precipitation also became more intense, which is likely to increase run-off rates and flood risks, and decrease recharge rates and groundwater resources.

The results of two locally run models, the ALADIN-Climate and RegCM regional climate models following the SRES A1B medium scenario (Nakicenovic and Swart, 2000) indicate that annual mean temperature in Hungary is expected to rise by 3-3.5 °C by the end of the 21st century. Highest warming is expected in summer (Illy et al., 2015). Regarding four RCA4 regional climate model simulations from the EURO-CORDEX initiative (Jacob et al., 2014), one could conclude that the results from the RCP4.5 scenario provide significantly lower warming (around 2-2.5 °C) than RCP8.5 (Meinshausen et al., 2011), which could reach 4-4.5 °C by 2071–2100 (higher values coming from the EC-EARTH global model conditions). Temperature increase is stronger for the North of the country (Figure 4).

Following the two locally run climate simulations, ALADIN-Climate and RegCM, a small decrease ((-5)%) of the annual rainfall amount is projected by the end of the 21st century (Illy et al., 2015). The currently wettest season, summer could become around 20% drier, while the fall will most probably be 5-10% wetter besides other seasons being uncertain in the direction of change for 2071–2100. Regarding the four RCA4 climate simulations from the EURO-CORDEX, we can see a different change pattern: regardless of the scenario and the global model conditions, simulations show a small annual precipitation increase almost for all of Hungary. One model results have higher positive change for the RCP8.5, while the other one for the RCP4.5 scenario run. This signal reaches 5-12% values, and only small parts of the country are around zero change (Figure 5).

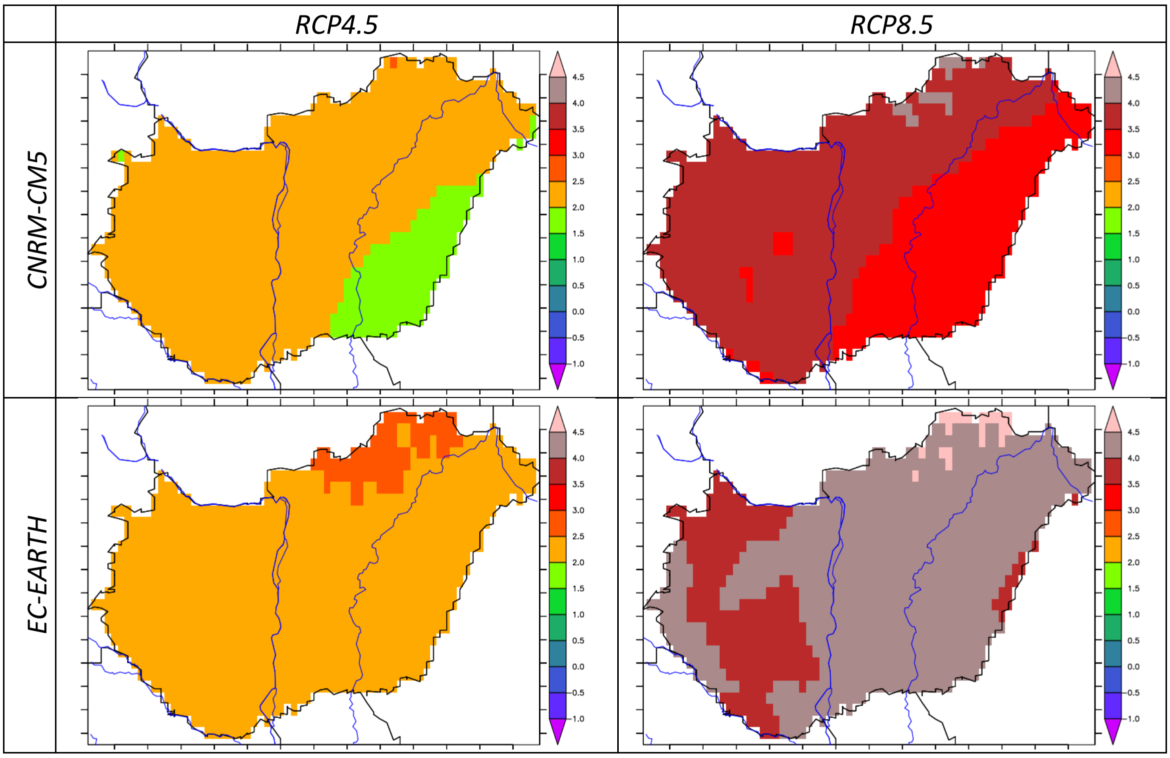

Figure 4. Annual temperature change [°C] between 1971–2000 and 2071–2100 based on four RCA4 regional climate model simulations (following the RCP4.5 and RCP8.5 scenarios and using two different global climate model boundary conditions, CNRM-CM5 and EC-EARTH)

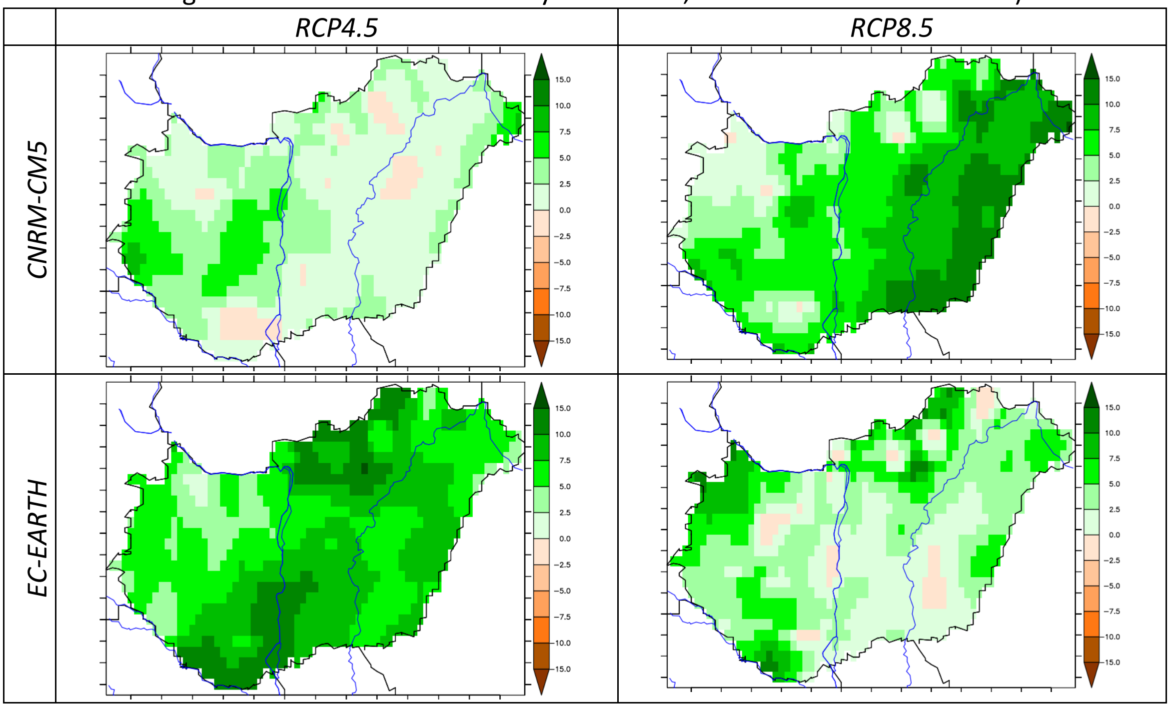

Figure 5. Annual precipitation change [%] between 1971–2000 and 2071–2100 based on four RCA4 regional climate model simulations (following the RCP4.5 and RCP8.5 scenarios and using two different global climate model boundary conditions, CNRM-CM5 and EC-EARTH)

4 METHODOLOGY

Within the frameworks of the project, a dynamic modular approach was developed in order to quantitatively simulate the groundwater table under various climate conditions. The calculations were done in 2 phases (maps can be found at: https://map.mbfsz.gov.hu/nater/; documentation at: https://nater.mbfsz.gov.hu/). In the 1st phase climate conditions were derived from the ALADIN-Climate regional climate model and Thornthwaite's climate zones were applied. The observed and simulated climatic parameters per grid point was not yet possible due to the large amount of data and the current performance of the given software and Thornthwaite's zones were too rough in some places. In the 2nd phase (Figure 6) new improved concept was applied: four regional climate projections were used, new territorial units on the gridpoint level and new infiltration calculations for done.

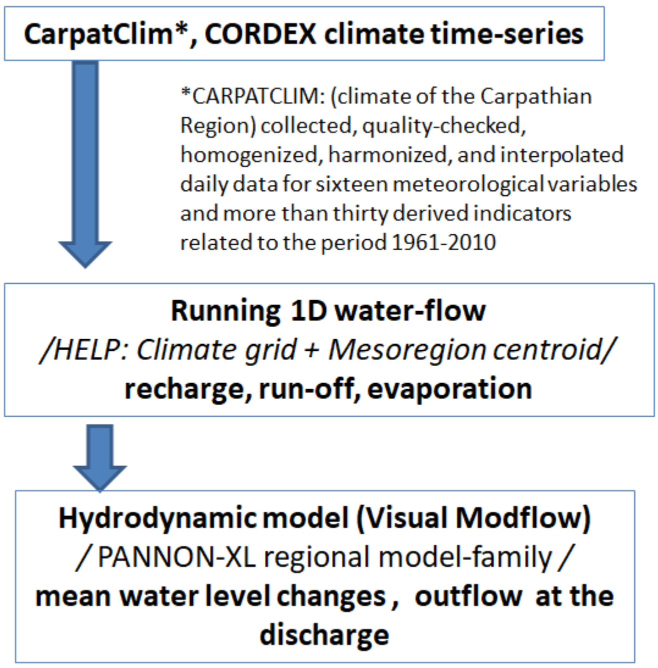

Figure 6. Simplified workflow of the second phase of the project

The climate data applied in our hydrological calculations comprised gridded daily observed data from CARPATCLIM-HU (Bihari et al., 2017), while future climate conditions previously from the ALADIN-Climate (Illy et al., 2015) and in the 2nd phase from RCA4 (Jacob et al., 2014).

Recharge zones (HRU's) were determined based on surface geology, landuse, slope and climatic conditions. The HELP hydrological model (Schroeder et al., 1994) used for calculation of 1D water balance for recharge zones. The MODFLOW numerical groundwater modelling (Waterloo Hydrogeologic Inc., 2005) was applied for the calculation of the water table under various climate conditions. The groundwater simulations for the past were undertaken based on both CARPATCLIM-HU observed conditions and on projections from ALADIN-Climate and RCA4 outputs.

4.1 Methodology and climate data

The CARPATCLIM-HU (Lakatos et al., 2013) observational database was applied as the past input parameters for the hydrological models. CARPATCLIM-HU is a homogenized, gridded dataset interpolated from climate observations inside and outside of Hungary. It was derived from weather observations at 258 regular stations and 727 rain gauge ones from the involved 9 countries (Czech Republic, Slovakia, Poland, Ukraine, Romania, Serbia, Croatia, Austria and Hungary). Solely from Hungary 37 regular and 176 precipitation stations were used (Lakatos et al., 2013). This database has a horizontal resolution of 0,1° (around 10 km) and temporal resolution of a day for the basic meteorological variables from 1961 to 2010. The gridding was obtained by the Multiple Analysis of Series for Homogenization software (MASH version 3.03; Szentimrey, 2008) and the Meteorological Interpolation based on Surface Homogenized data (MISH, version 1.03; Szentimrey and Bihari, 2007).

Meteorological data of mean temperature, precipitation were used on a daily basis, while global radiation, evapotranspiration, mean wind speed and relative humidity were used on a monthly or seasonal basis averaged for each recharge polygon and served as input parameters in the hydrological model of HELP for the recharge calculations.

Using the same meteorological variables on the same temporal resolution mentioned above, future simulations were based on outputs of the ALADIN-Climate regional climate model and the RCA4 model. ALADIN-Climate was developed within an international framework at Météo France (Csima and Horányi (2008)). RCA4 model (Samuelsson et al. (2014)) is a Swedish regional climate model and its results are freely available to download within the EURO-CORDEX framework (Jacob et al., 2014).

The future anthropogenic activity was considered as hypothetical emission scenarios for the climate models and the SRES A1B (considered as a medium one) emission scenario (Nakicenovic et al., 2000) and the RCP4.5 and RCP8.5, medium and high-end scenarios, respectively were applied (Meinshausen et al., 2011). The below table summarizes the used climate model outputs for the different phases of the project.

regional climate model	**boundary conditions from a global climate model**	**simulation run**
ALADIN-Climate	ARPEGE-Climat	1961-1990 SRES A1B scenario
RCA4	CNRM-CM5	1975-2004 RCP4.5 scenario RCP8.5 scenario
RCA4	EC-EARTH	1975-2004 RCP4.5 scenario RCP8.5 scenario

4.1.1 Climate classification

Climate classification was necessary as soil water balance is necessary for the assessment of groundwater conditions. Out of the internationally accepted biophysical climate classification methods, the Köppen (1936), the Holdridge (1947) and the Thornthwaite (1948) methods were applied in Hungary. The comparative analysis of these methods were made by Szelepcsényi et al. (2009) and proved that Thornthwaite's method is appropriate for the mezo-scale characterization of the climatic diversity of Hungary (Ács and Breuer, 2012). The methodology described in Ács and Breuer (2013) was applied for the calculation in the first step of Thorntwaite climate zonation. A detailed description of the calculation scheme applied is provided in Kovács et al. (2015a,b). In the second step, climatic zones were prepared for grid points and simplified for the centroid of mesoregions.

Climate zones were determined for different time periods using mean monthly values of climate variables.

4.1.2 Recharge zones

Recharge zones used in this study are hydrogeological units, in which recharge conditions are assumed to show an insignificant variability. Recharge zones are also called Hydrological Response Units according to the SWAT modelling methodology (Neitsch et al. 2002).

Recharge zones were delineated as a superposition of four data layers including climate zones, surface geology, landuse and slope conditions.

The surface geological map constructed by Gyalog and Síkhegyi (2005) was applied in the first data layer. Geological formations were reclassified into six lithological categories such as fractured, dolomite, limestone, fine porous, coarse porous and surface waters.

Landuse polygons were derived from the CORINE (EEA, 2006) map. The large number of original landuse categories were regrouped into six main classes such as urban areas, arable land, pastures, permanent crops, forests, and water bodies.

Slope categories were determined based on the 50 m resolution Digital Elevation Model of Hungary. Two slope categories were applied such as flat areas (0-5%) and slopes (> 5 %). The resulting map of recharge zones is indicated in Figure 7 .

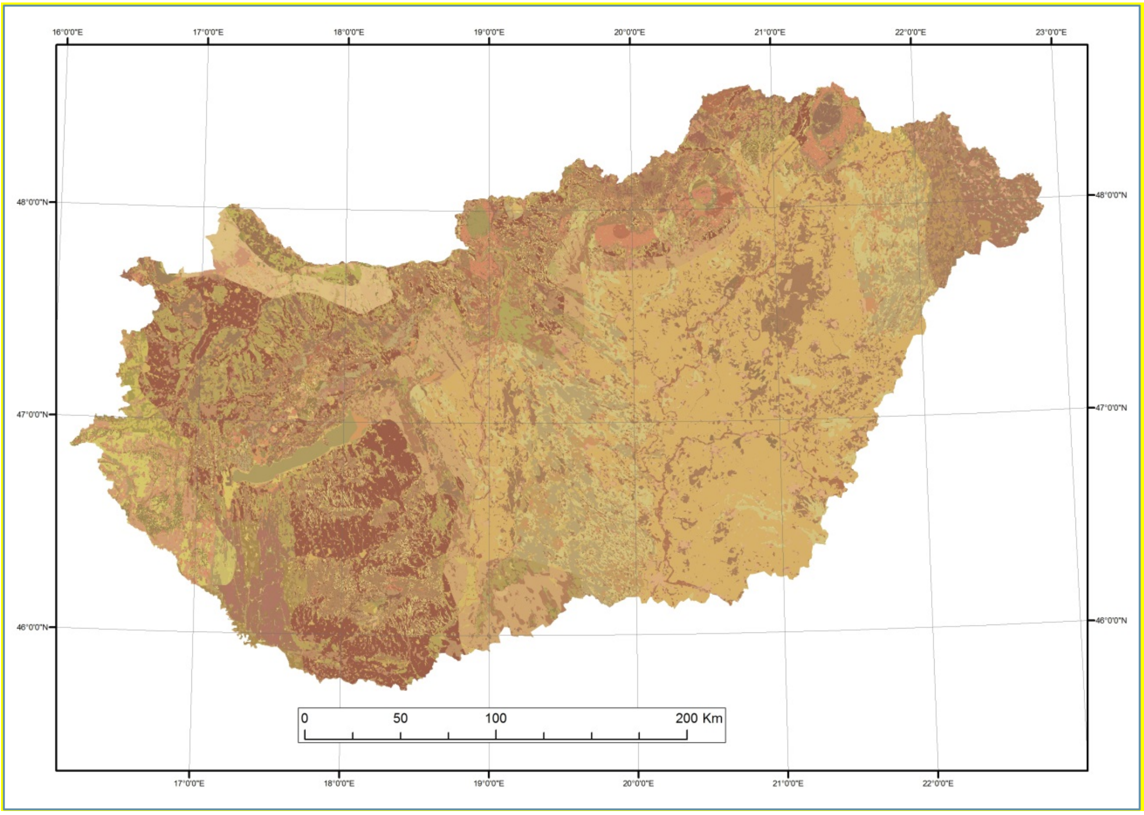

Figure 7. Applied recharge zones

4.1.3 Hydrological modelling

The potential effects of climate change on groundwater conditions were represented via water budget calculations for each recharge unit (HRU). The HELP model (Schroeder et al., 1994) was applied to calculate daily water balances. The applicability of this model is well known from the literature (Gogolev, 2002; Jyrkama and Sykes, 2007) and the methodology has successfully been applied in Hungary. The simulated percolation rates (recharge values) were imported into the numerical groundwater flow model aimed at simulating the groundwater table.

HELP (Hydrologic Evaluation of Landfill Performance) is a hydrologic numerical model developed by the United States Environmental Protection Agency for landfills. The model uses a water-balance approach to model evapotranspiration and drainage through soil layers. The model is often used for simulating the effects of various climate scenarios.

The weather generator of the HELP model needs several meteorological variables, such as daily and monthly average mean temperature, daily and monthly accumulated total precipitation, monthly average horizontal wind speed, daily global radiation and monthly relative humidity.

Besides meteorological input, the HELP code requires the definition of soil profiles for the calculation of one-dimensional transient water balance. Soil profiles were defined by analyzing grain size distributions of soil samples collected systematically as part of the national soil mapping campaign, and organized in a soil logging database. A characteristic soil profile was assigned to each lithological category. Based on grain size distribution data, soil layers were classified according to the United States Department of Agriculture (USDA) soil classification triangle. Default hydraulic parameters defined in HELP were assigned to each soil category.

As the uppermost three metres of observed soil profiles show negligible vertical variability, and the average depth of groundwater is within this range, homogeneous soil profiles were applied. The applicability of homogeneous profiles was verified and confirmed through extensive sensitivity analysis.
Simulated percolation rates (recharge) were verified against literature annual values and were also compared with monitoring well hydrographs of selected test sites. Default soil parameters were fine-tuned through calibration against observed water level fluctuations.

Table 1. Adjusted hydraulic parameters applied for different soil types throughout the HELP simulation of recharge rates.

Parameter	**Profile**				**Unit**
	Fine porous (Silty Loam)	**Coarse porous (Loamy Sand)**	**Karst (Sand)**	**Fractured (Fine Sand)**	
Total porosity	0.46	0.43	0.44	0.38	vol/vol
Field capacity	0.23	0.20	0.05	0.20	vol/vol
Wilting point	0.12	0.08	0.02	0.03	vol/vol
Sat.hydr.conductivity	5	10	500	8	cm/day
Subsurface inflow	0	0	0	0	cm/day
Evapotranspiration zone depth	115	125	125	125	cm

Calibrated soil parameters for each type profile are indicated in Table 1. The effects of landcover and slope were simulated using a range of runoff curve numbers. The runoff curve number (also called a curve number or simply CN) is a lumped empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area. Applied curve numbers were adjusted in order to obtain realistic recharge rates for each type profile.
Recharge rates were simulated using the finalised soil profiles for each recharge zone applying spatially averaged climate parameters for the corresponding climate zones.
Differences in recharge between the simulated periods and future time periods are indicated in Figure 8. – Figure 12.

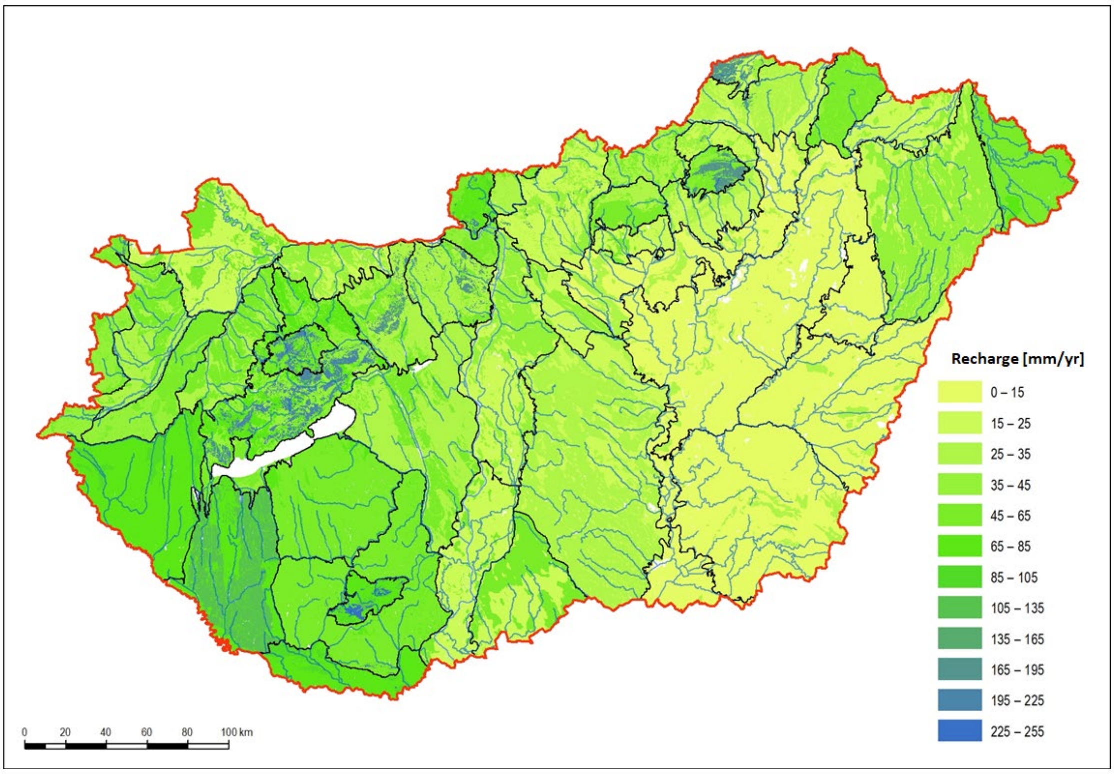

Figure 8. Simulated mean **recharge distribution** for 1975-2004 based on the CARPATCLIM-HU observations.

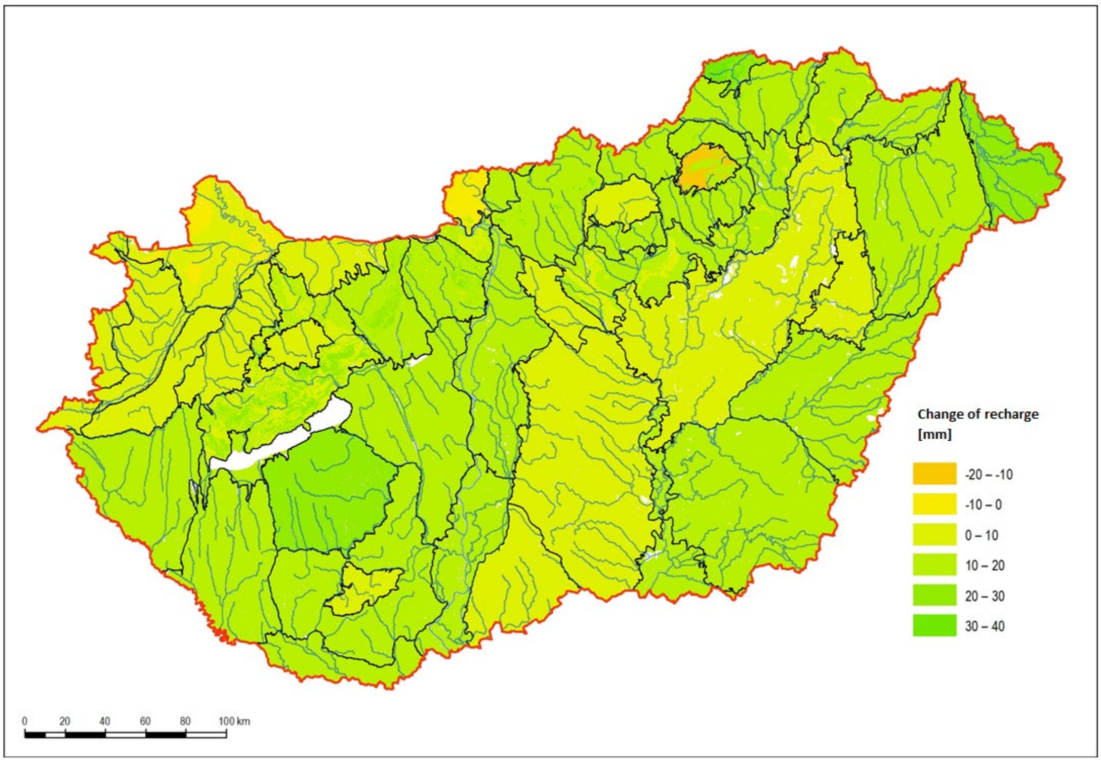

Figure 9. Simulated recharge change between 1975-2004 and 2071-2100. RCA.C (Calculated based on RCP45 model scenario)

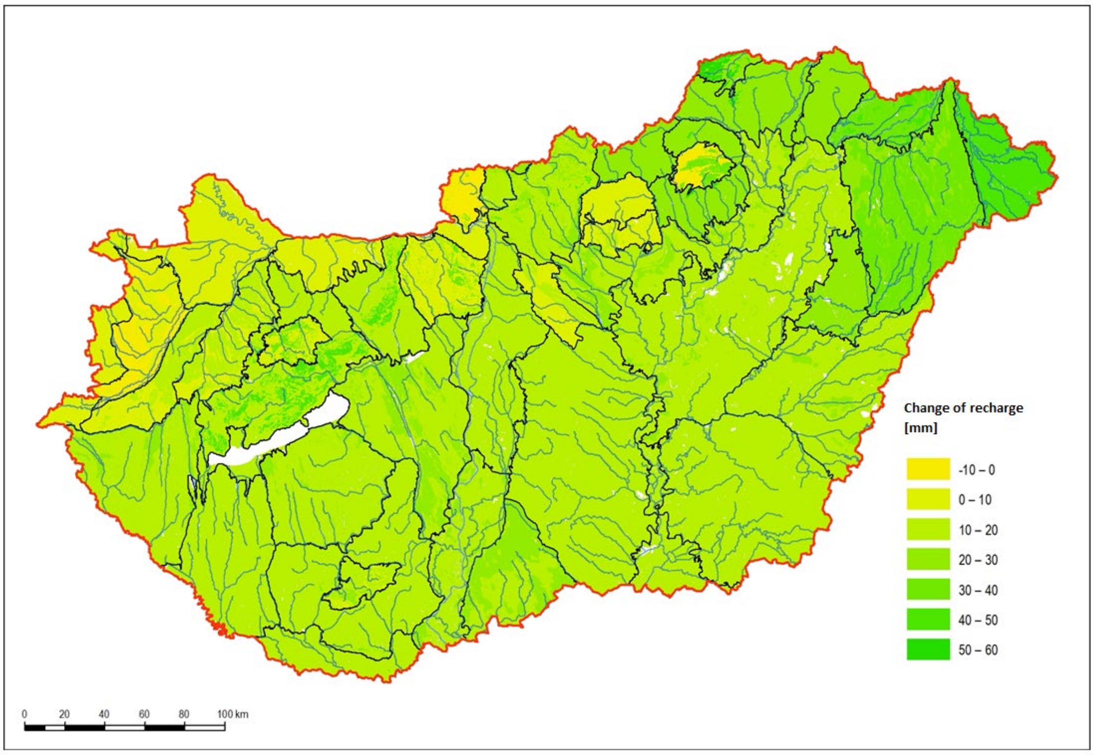

Figure 10. Simulated recharge change between 1975-2004 and 2071-2100. RCA.C Calculated based on RCP85 model scenario

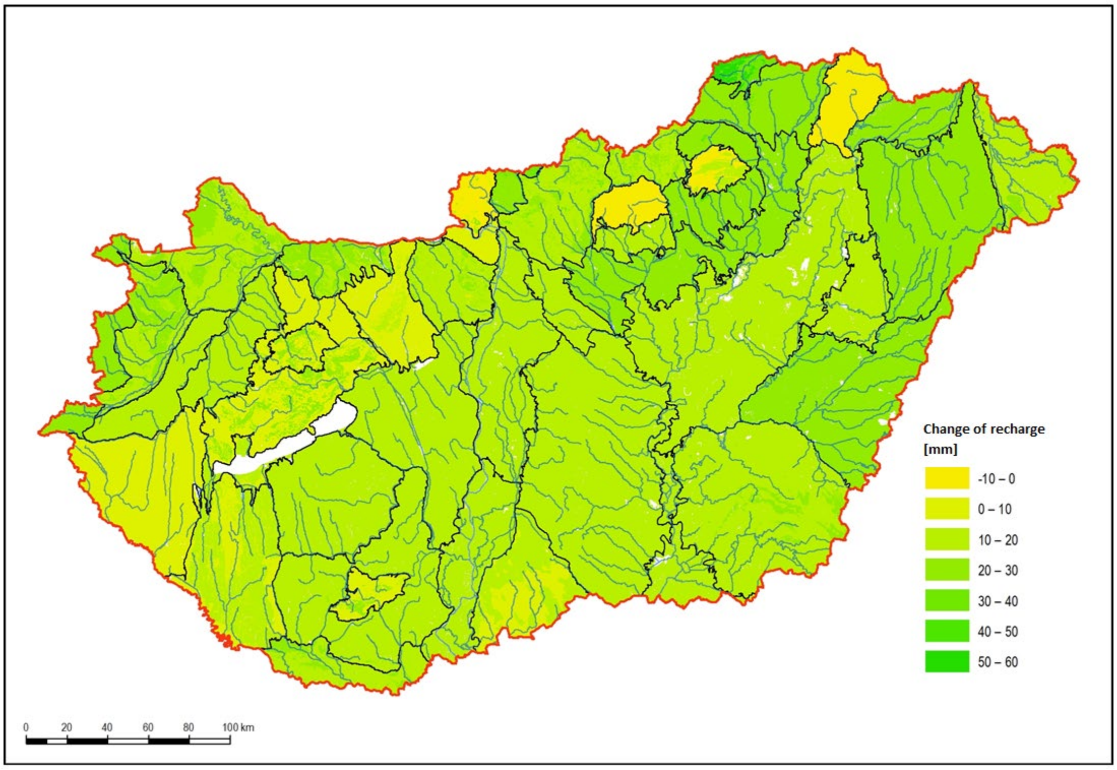

Figure 11. Simulated recharge change between 1975-2004 and 2071-2100 based on RCA.E RCP85 model scenario

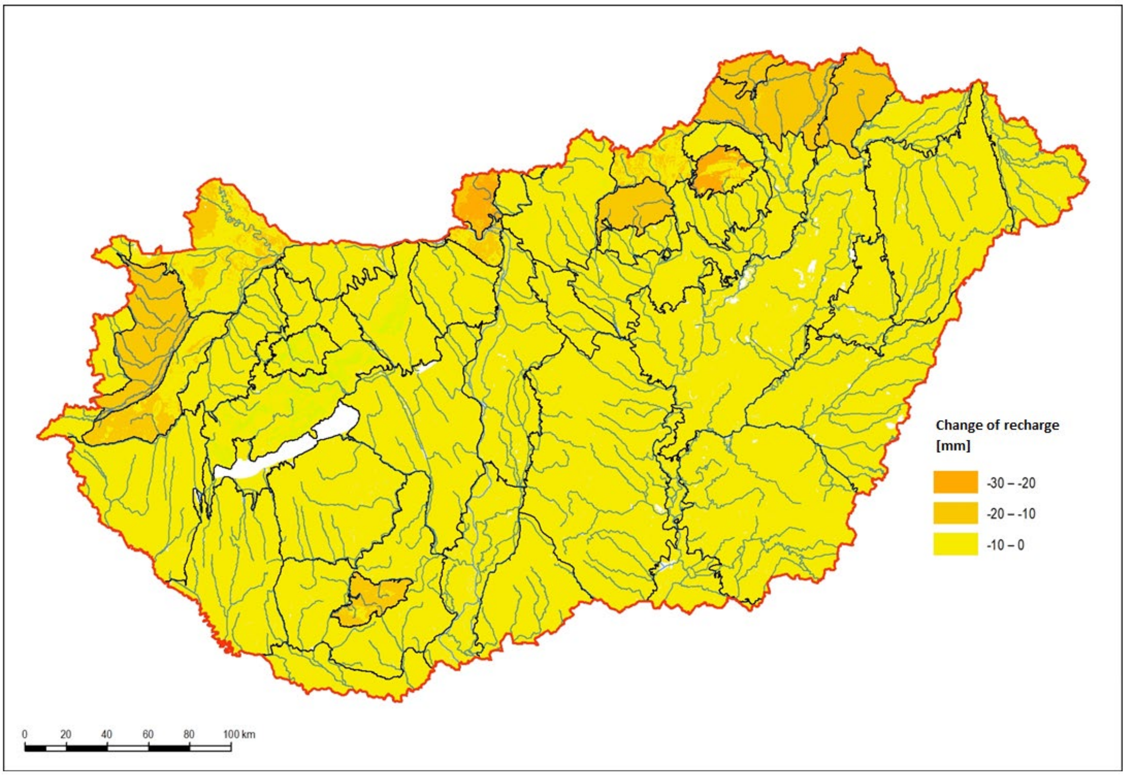

Figure 12. Simulated recharge change between 1975-2004 and 2023-2052 based on RCA.C RCP45 model scenario

The difference maps basically show the increase in recharge for the largest area of the country between the first and last simulation period for all model scenarios. The average rate of growth is 10-30 mm/year, but in the eastern part of the country it can be 40 mm/year. However, in the mountainous regions – mainly in Bükk and Börzsöny – the RCA.C scenarios show a decrease in infiltration of about 10 mm / year. The RCA.E scenarios predict the infiltration change differently in mountainous regions. While in the RCP45 scenario the infiltration shows an increase here as well, in the RCP85 scenario the infiltration in the Northern Mountain Ranges is expected to decrease.

We would like to draw the attention to the map version that illustrates the 30-year average infiltration changes calculated from the RCA.C RCP45 model scenario between 1975-2004 and 2023-2052 (Figure 12). In this version, unlike other versions, the recharge change is negative. This scenario could have a rather negative impact on both groundwater-dependent ecosystems and increasing irrigation needs in terms of opportunities.

4.2 Tool(s) / Model set-up

4.2.1 Groundwater modelling

The overall aim of groundwater modelling was to simulate water table distribution under various climate conditions. For this reason a two and also three dimensional steady-state numerical model was developed.

The MODFLOW numerical groundwater flow model has been chosen for this study, operating under the Visual Modflow v.4.6 software package (Waterloo Hydrogeologic Inc., 2005). MODFLOW is widely accepted numerical groundwater flow modelling code. The application of a finite-difference code ensured a simple data transfer between input and output data grids and the model interface.

In mountainous areas of open karst terrain, where shallow aquifers are absent, karst water table was simulated, and was considered to be hydraulically connected to adjacent shallow groundwater bodies. Model extent included the political borders of the country, and the model domain had a rectangular geometry.

The main boundary conditions applied in the model comprised surface streams, water bodies and drainage zones. The model was calibrated against water level monitoring stations, spring elevations and river stages.

Artificial influences on the groundwater system such as water extractions were not incorporated in the model scenarios. Simulated water tables are thus hypothetical distributions which are intended to demonstrate direct effects of climate impacts rather than to predict future groundwater levels.

4.3 Tool(s)/ Model calibration/ test

In the first step the natural-state model simulated average groundwater conditions for the period 1961-1965. It was assumed that shallow groundwater conditions were determined by climatic conditions during this period and that artificial influences were negligible. The natural-state model served for calibrating hydraulic properties against measured water levels. Calibrated parameters were applied for the simulation of predictive scenarios.

Shallow aquifers were regrouped into larger hydrogeological units to facilitate model calibration. Transmissivity values were adjusted to obtain an acceptable match between measured and simulated groundwater heads.

The objective of the model calibration process was to determine model-scale hydraulic parameters that reproduce the hydraulic functioning of the groundwater system. Transmissivity values were adjusted to obtain an acceptable match between measured and simulated groundwater heads.

The calibration process involved the continual adjustment of hydraulic transmissivity until the closest match between model predicted water levels and field measured water levels was obtained. Model calibration was undertaken with the assumption that field measured time-averagred water levels represent steady state (equilibrium) of the groundwater system.

Model calibration was performed by means of automated calibration using PEST. PEST (WNC, 2005) is a nonlinear parameter estimation code. Parameter optimisation is achieved using the

Gauss-Marquardt-Levenberg method to drive the differences between model predictions and corresponding field data to a minimum in a weighted least squares sense. The implementation of this search algorithm in PEST is particularly robust; hence PEST can be used to estimate parameters for both simple and complex models including large numerical spatial models with distributed parameters.

4.4 Uncertainty

The primary method for quantitatively assessing the goodness of fit of calculated data is through calculation of the Scaled Root Mean Square Error (RMS). The RMS error (or standard deviation) is the square root of the average of the squared differences in measured and simulated heads, expressed as (Eq. 1):

$$RMS = \sqrt{\frac{\sum_{i=1}^{n}(x_{calc} - x_{obs})^2}{n}} \quad \text{(Eq. 1)}$$

where n is the number of measurements. The Scaled Root Mean Square Error (SRMS) is the RMS divided by the range of observed values, or (Eq. 2):

$$SRMS = \frac{RMS}{(X_{obs})_{\max} - (x_{obs})_{\min}} \quad \text{(Eq. 2)}$$

where Xobs is the measured head, and Xcalc is the calculated head.

The scatter plot of simulated versus observed groundwater levels of the natural-state model is indicated in Figure 13.
According to international standards, the required calibration accuracy is generally set in accordance with the model complexity. For a medium complexity regional model such as this, an SRMS error of approximately 3.3 % is considered to be an acceptable calibration.

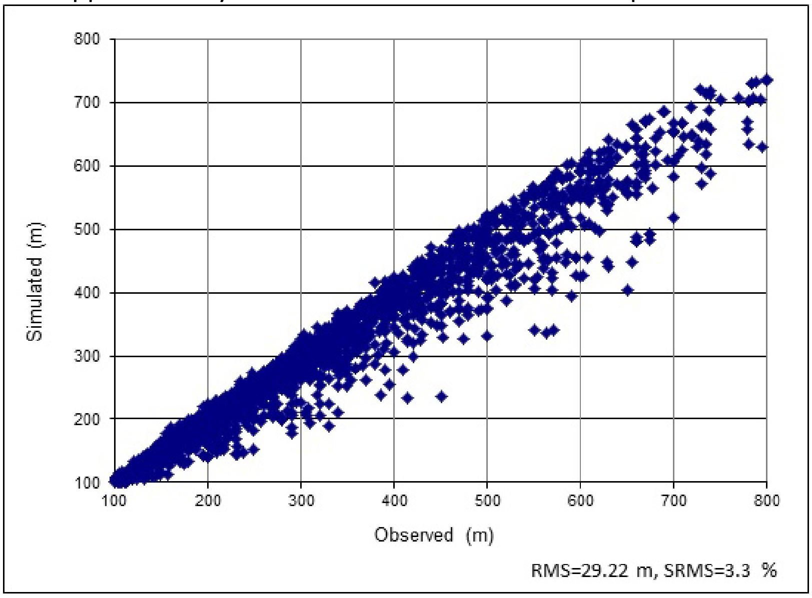

Figure 13. Scatter plot of simulated vs. observed groundwater levels of the natural-state model.

5 RESULTS AND CONCLUSIONS

5.1 Results of hydrogeological modelling

Using the Pannon XL v.3.0 version, in the 2nd step, we performed 22 runs based on the recharge distributions described above with no production ("natural") and production (2008-15 average values). The result maps contain the levels and water management elements of the groundwater flow systems for different climate scenarios and periods (surface net recharge, recharge, discharge [mm / year]). Here are some typical variations of this series of maps:

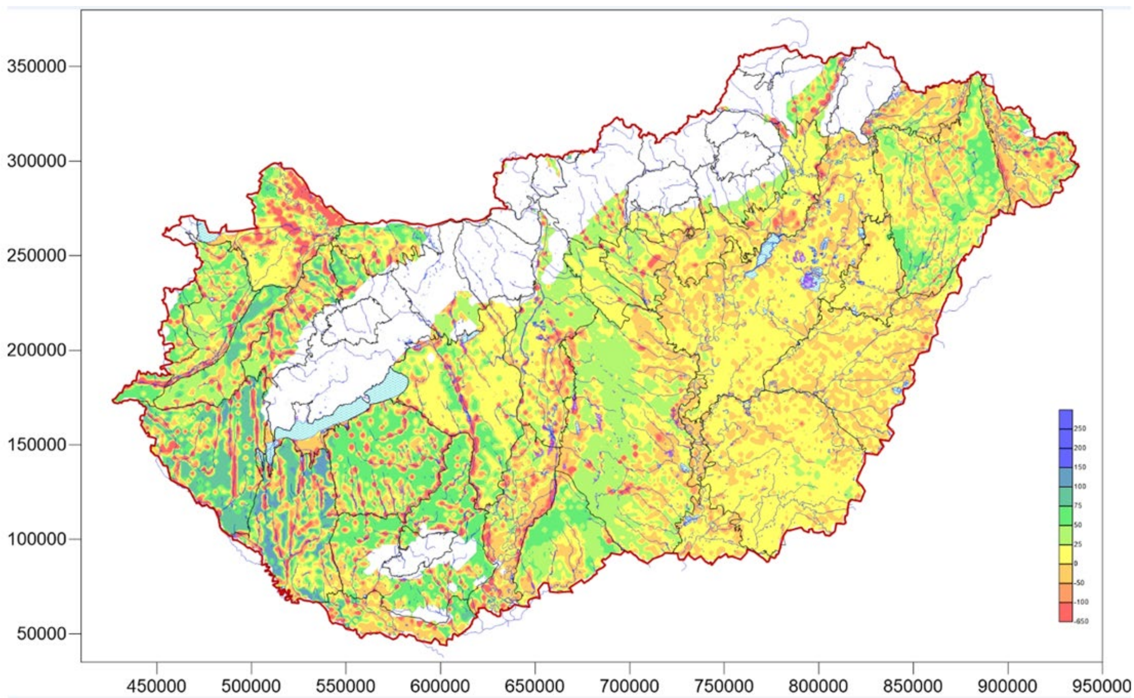

Figure 14. Net recharge on the surface (Pannon-XL v.3.0 - production version) modelled on the basis of calculated climate data of the near future (2023-2052) IPCC RCP 4.5 excluded mountainous areas [mm/year]

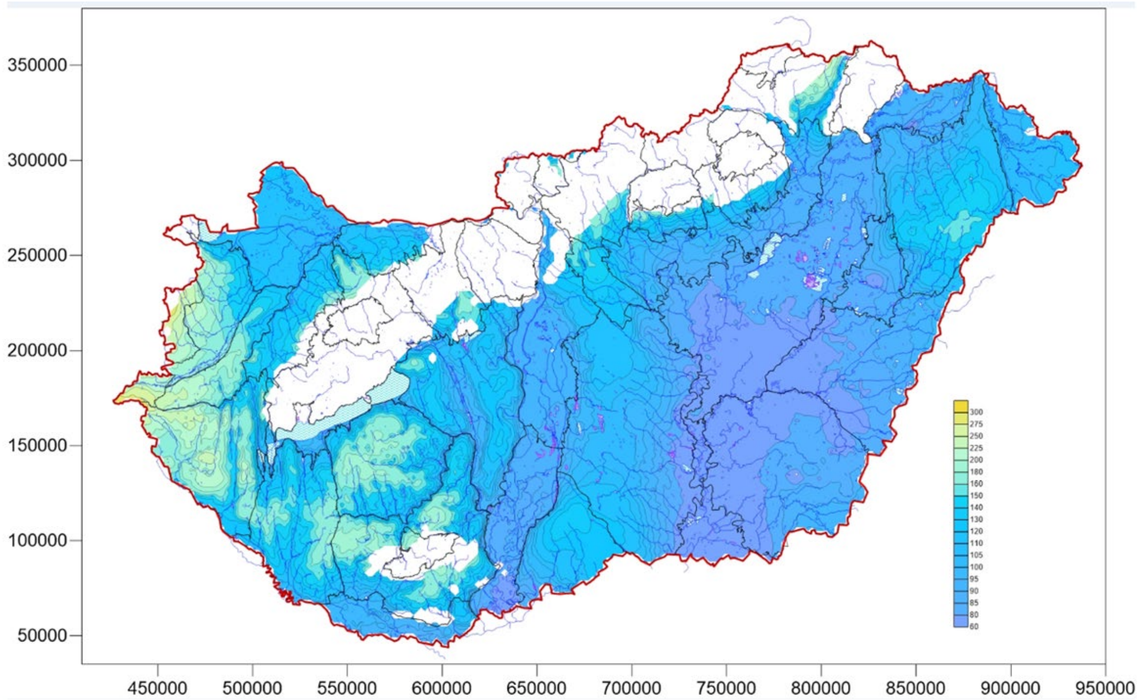

Figure 15. Groundwater level distribution modelled on the basis of climatic data measured for the reference period (1973-2004) CC-HU (Pannon-XL v.3.0 – production version) excluding mountainous areas [masl]

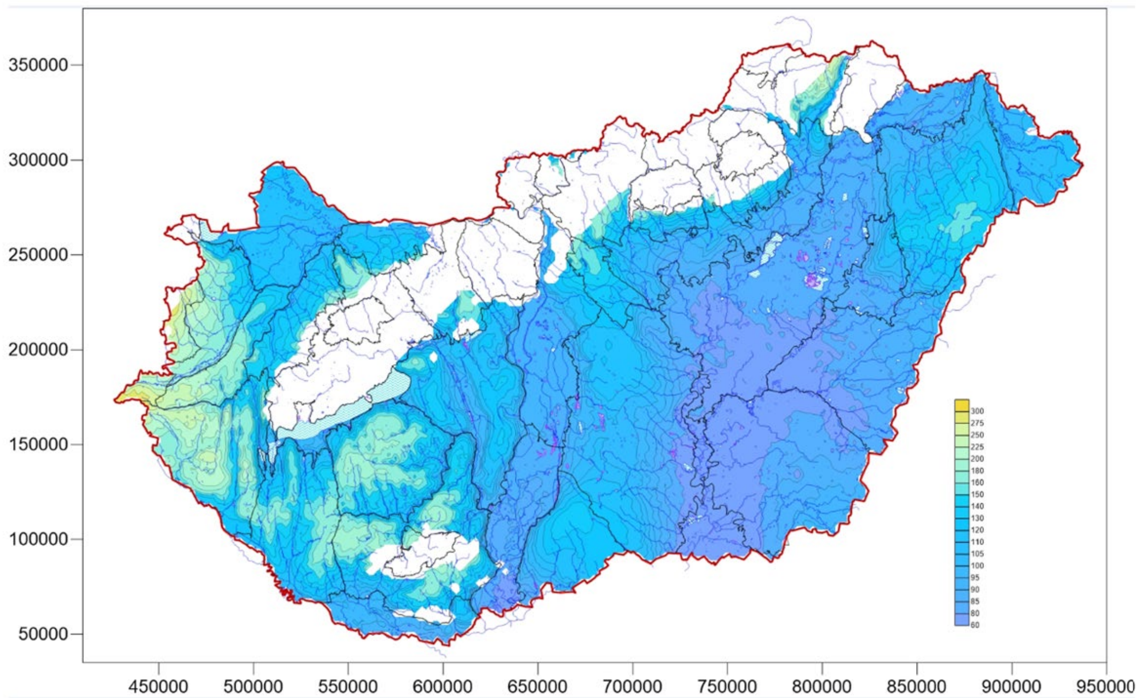

Figure 16. Groundwater level distribution modelled for the reference period (1973-2004) calculated on the basis of climatic data calculated by IPCC RCP4.5 (Pannon-XL v.3.0 - production version) excluding mountain areas [masl]

5.2 Conclusions

The present paper summarises a methodology developed for the calculation of groundwater table distributions from climate parameters. The goal of water table modelling was to develop a methodology which can be applied for calculation of the water table under different climate conditions. This was done in order to facilitate climate impact assessment and the evaluation of climate sensitivity of groundwater aquifers.

A dynamic modular approach was developed in order to quantitatively simulate the groundwater table under various climate conditions. The applied methodology included:

1. Determination of climate zones based on measured and simulated climate variables;
2. Determination of recharge zones (Hydrological Response Units, HRU's) based on surface geology, land use, and slope conditions.
3. Calculation of recharge for each recharge zone using 1D analytical hydrological model series.
4. Simulation of the groundwater table under various climate conditions using numerical groundwater flow models.

The climate data used in our hydrological modelling comprised gridded daily observed data from the CARPATCLIM-HU and CORDEX database and projections of different regional climate model.

Results of recharge calculation indicate that recharge could decrease up to 50 mm/year by the end of the 21st century in the elevated areas, while in other climate scenario we can presume wetter climate. Slight recharge increase is projected in parts of the Great Hungarian Plain and the Transdanubian Hills. Water levels most probably will increase over the Alpokalja, Mecsek, Transdanubian and Northern Mountain Ranges. Moderate water level drops in the Duna-Tisza Interfluve and Tiszántúl areas are probable, while slightly rising groundwater levels are projected in parts of the Great Hungarian Plain and the Transdanubian Hills.

Our studies have highlighted the high degree of uncertainty in climate models. As a result, there has been both drought and a wetter climate trend and this can often vary from area to area. It has shown spatial and temporal fluctuations in precipitation and other climatic parameters, so the long-term trend may result opposite changes compared to the short or even medium-term.

The presented outputs were determined at the regional scale and as such cannot be used for local investigations. The presented methodology though can be applied for modelling the climate impact both at the regional and local scales for assessing the climate vulnerability of groundwater resources.

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