QUANTITATIVE ASSESSMENT OF CLIMATE IMPACT ON GROUNDWATER CONDITIONS USING MODELLING TOOLS

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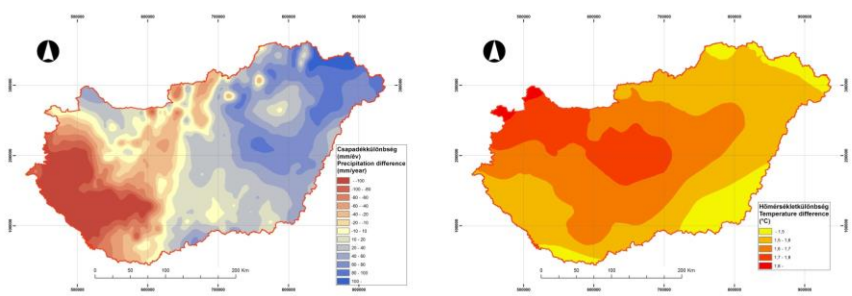
CLIMATE CHANGE AND GROUNDWATER

- Climate projections of the Intergovernmental Panel on Climate Change (IPCC) indicate:
  - significant temperature rise, and
  - alterations in the amount and frequency of precipitation

Changing climate variables influence the hydrological cycle through impacting on:

- Surface runoff;
- Evapotranspiration;
- Groundwater recharge;
- Soil water content;
- Surface water levels and quality;
- Groundwater levels and quality;
- Snow and ice cover.



Rainfall and temperature differences between 1961-65 / 2005-2009, CC data

MOTIVATION & GOALS

- Changing climate $\rightarrow$ changing water balance (recharge-runoff-evapotranspiration) $\rightarrow$ Changing water table
- Environmental consequences (gw storage, droughts, floods, contaminants, ecology, forestry, agriculture, etc.)

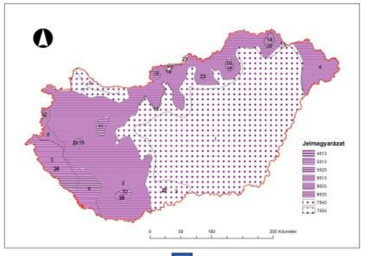
Goals:

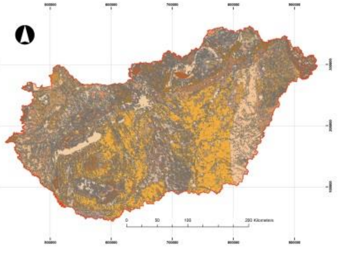
- To develop and demonstrate a methodology for the evaluation of climate change impact on shallow groundwater conditions
- To calculate groundwater table changes at the country scale (Hungary)

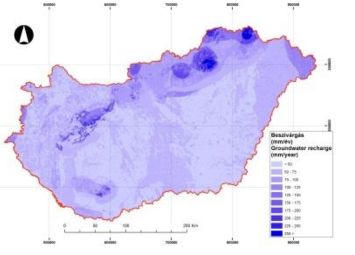
METHODOLOGY

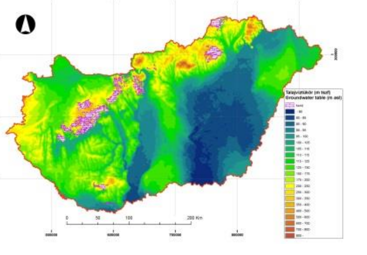
Modular quantitative methodology:

1. Delineation of climate zones (Thorntwaite methodology)
2. Delineation of recharge zones (Hydrological Response Units, HRU's – surface geology, landuse, slope)
3. Recharge calculation for recharge zones (HELP)
4. Numerical simulation of groundwater table (MODFLOW-NWT)









PRO'S AND CON'S OF METHODOLOGY

ADVANTAGES

- Quantitative link between climate conditions and shallow groundwater conditions;
- Each step of the workflow is replicable and provides coherent results for various climate conditions;
- Modular structure provides flexibility and facilitates changes in input data, calculation tools and spatio-temporal resolution at various levels
- Artificial effects can be simulated (gw extraction)

DISADVANTAGES

- Complex and time consuming

APPLIED DATABASES

- CARPATCLIM climate data grids (interpolated from 258 climate and 727 rainfall time series on ~10x10 km grid) (delineation of climate zones and recharge calculation)
- ALADIN regional climate model on a 10 km grid (delineation of future climate zones and recharge calculation)
- Surface geology (Delineation of recharge zones and parameter zones)
- Shallow borelog data (definition of soil profiles)
- Landuse (CORINE) (Definition of recharge zones)
- DEM 50 (Definition of recharge zones and BC's)
- Hydrograph data (model calibration)
- Spring elevation (model calibration)
- River stages (BC's, model calibration)

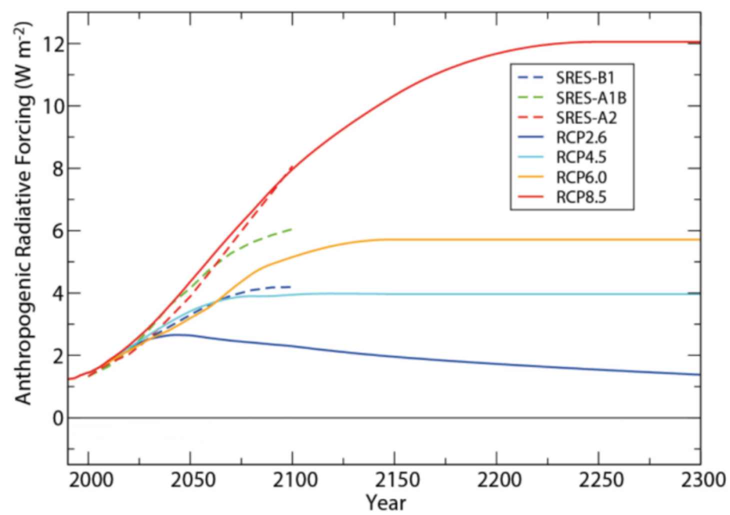
GLOBAL CLIMATE MODELS

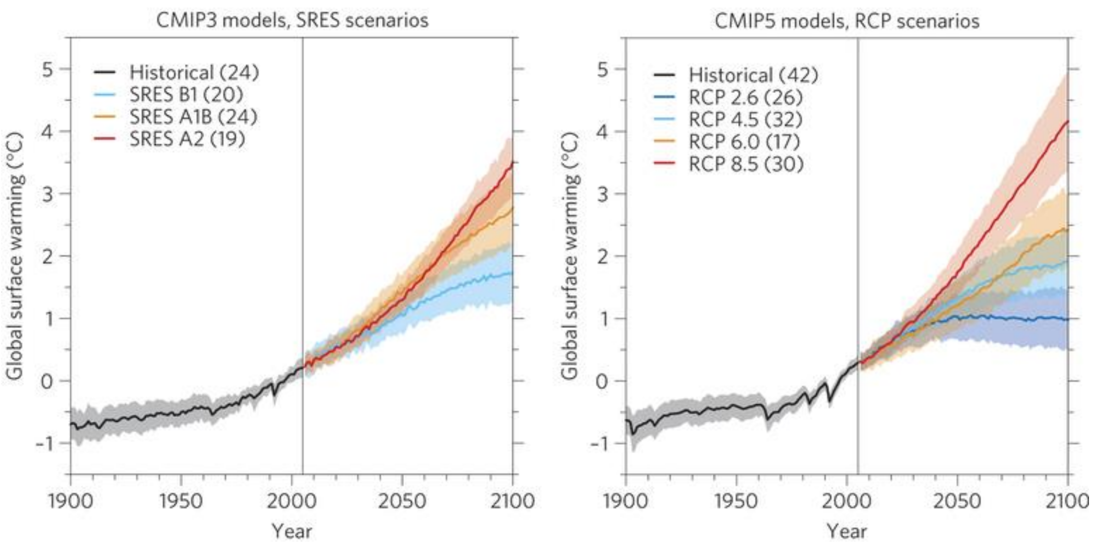
CO_2 emission scenarios:

- SRES, Special Report on Emissions Scenarios (Nakicenovic et al., 2000)
- RCP, Representative Concentration Pathways (Meinshausen et al., 2011) →
    - Considers emission mitigation efforts
    - Scenarios based on radiative forcing changes in W/m² by 2100 (RCP2.6, RCP4.5, RCP6 és RCP8.5)

Simulation projects:

- CMIP3 (Coupled Model Intercomparison Project Phase 3, Meehl et al., 2007) based on SRES scenarios
- CMIP5 (Coupled Model Intercomparison Project Phase 5, Taylor et al., 2012) based on RCP scenarios



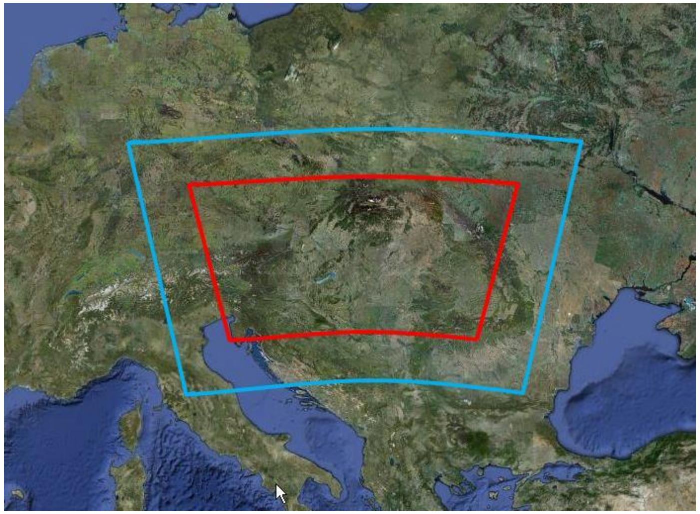


CMIP3 and CMIP5 global climate predictions
(Knutti and Sedlacek, 2012)

SRES projected global average surface warming until 2100		
	economic focus	environmental focus
Globalisation (homogeneous world)	A1 rapid economic growth (groups: A1T; A1B; A1 FI) 1.4 - 6.4 °C	B1 global environmental sustainability 1.1 - 2.9 °C
Regionalisation (heterogeneous world)	A2 regionally oriented economic development 2.0 - 5.4 °C	B2 local environmental sustainability 1.4 - 3.8 °C

REGIONAL CLIMATE MODELS

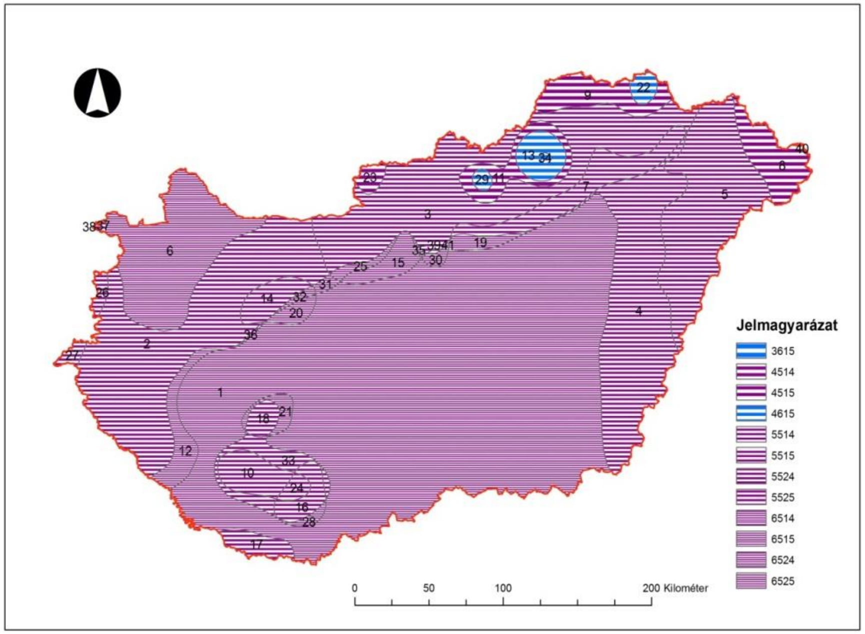
- Downscaling of Global Models
- CALE: Carpathian Basin
- ALADIN-Climate (OMSZ)
  - Based on ARPEGE-Climat (Météo-France)
    - Global and spectral general circulation model
    - Resolution is 50 km
- RegCM (ELTE)
  - Based on ECHAM (Max-Planck Institute)
    - atmospheric general circulation model,
    - coupling between diabatic processes and large-scale circulations,
    - driven by radiative forcing



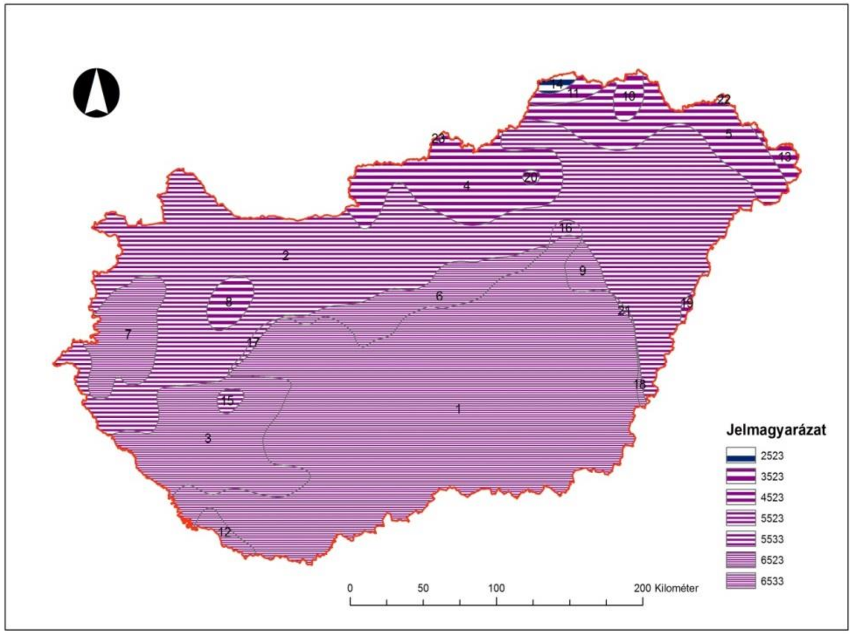
Regional model	ALADIN-Climate	RegCM
Modell version	4.5	3.1
Horizontal resolution	10 km	10 km
Boundary conditions	ARPEGE-Clima	ECHAM5/MPI-OM, RegCM_25
Emission scenario	SRES A1B	SRES A1B

ALADIN VS. REGCM

- ALADIN: Smaller model error
- ALADIN: Returns topographic zonation better



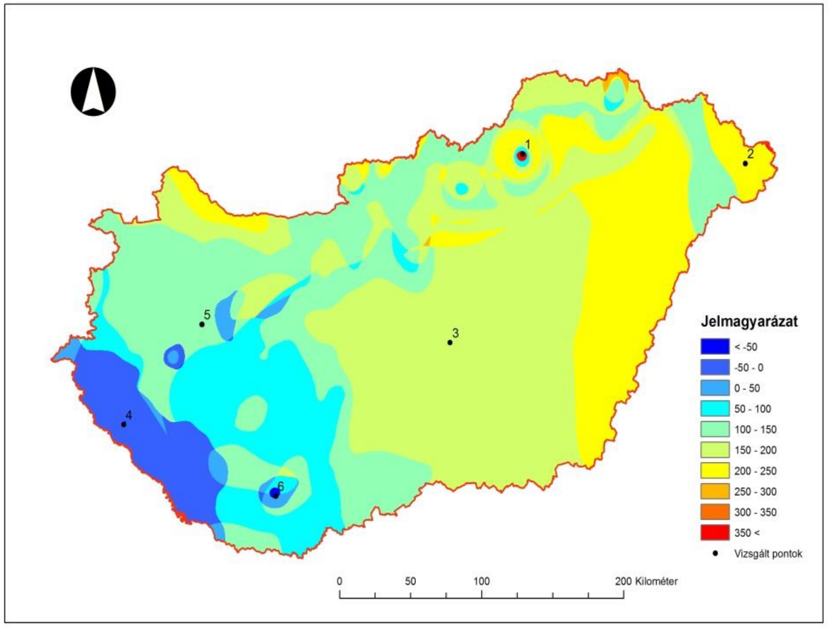
ALADIN climate zones

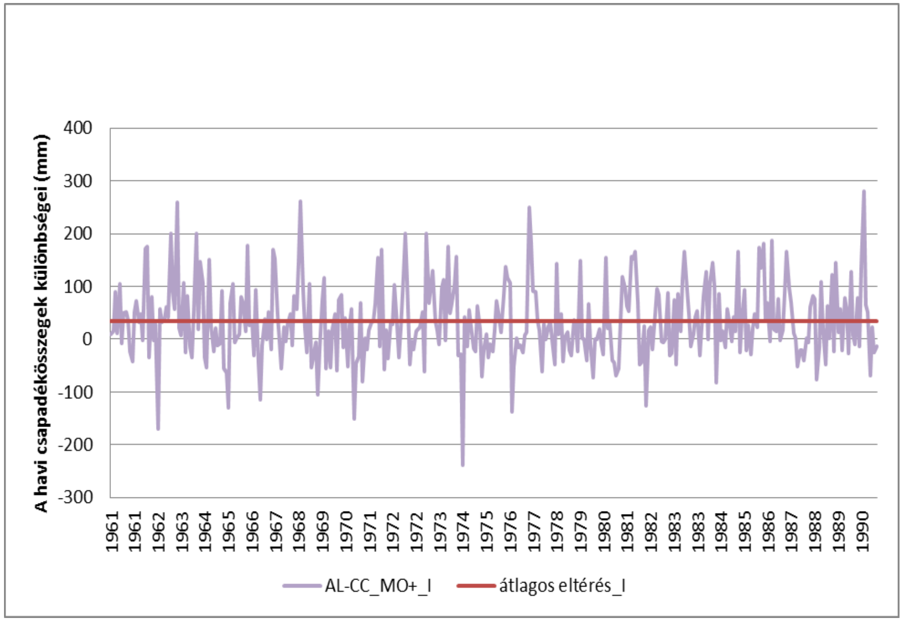


REGCM climate zones

UNCERTAINTIES OF ALADIN CLIMATE MODELS

- Comparison with CARPATCLIM data
- Time series at 5 points
- ALADIN overestimates rainfall in E
- ALADIN underestimates rainfall in W
- Uncertainties in temperature simulation





Rainfall difference 1961-1990

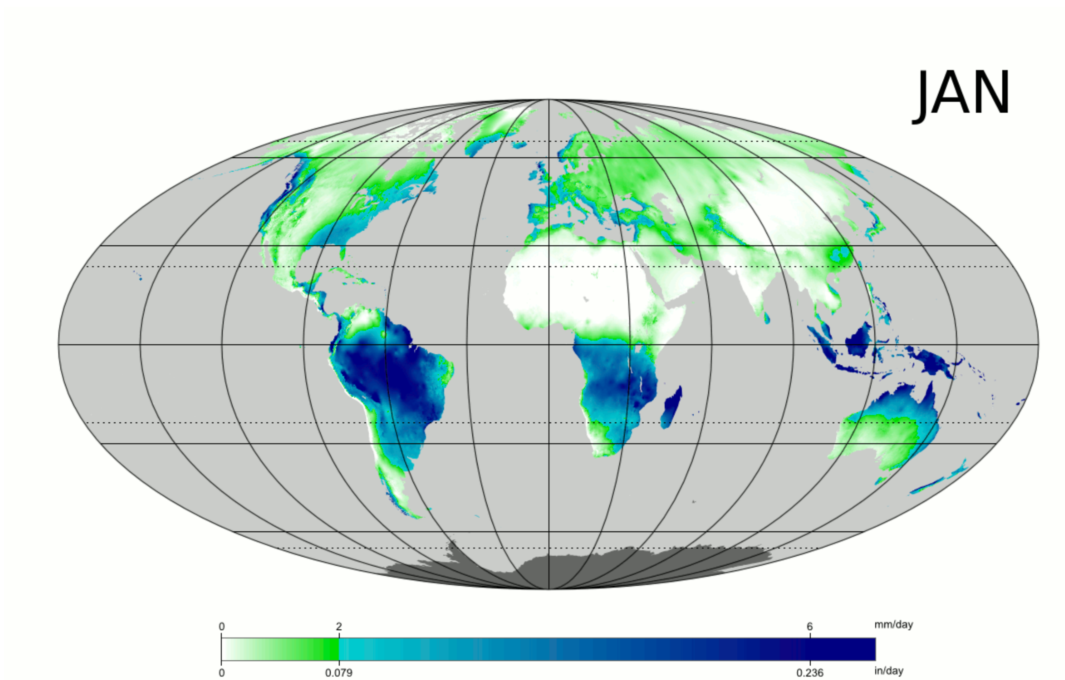
Rainfall diference at point No. 1

ALADIN MODEL ERROR SUMMARY TABLE

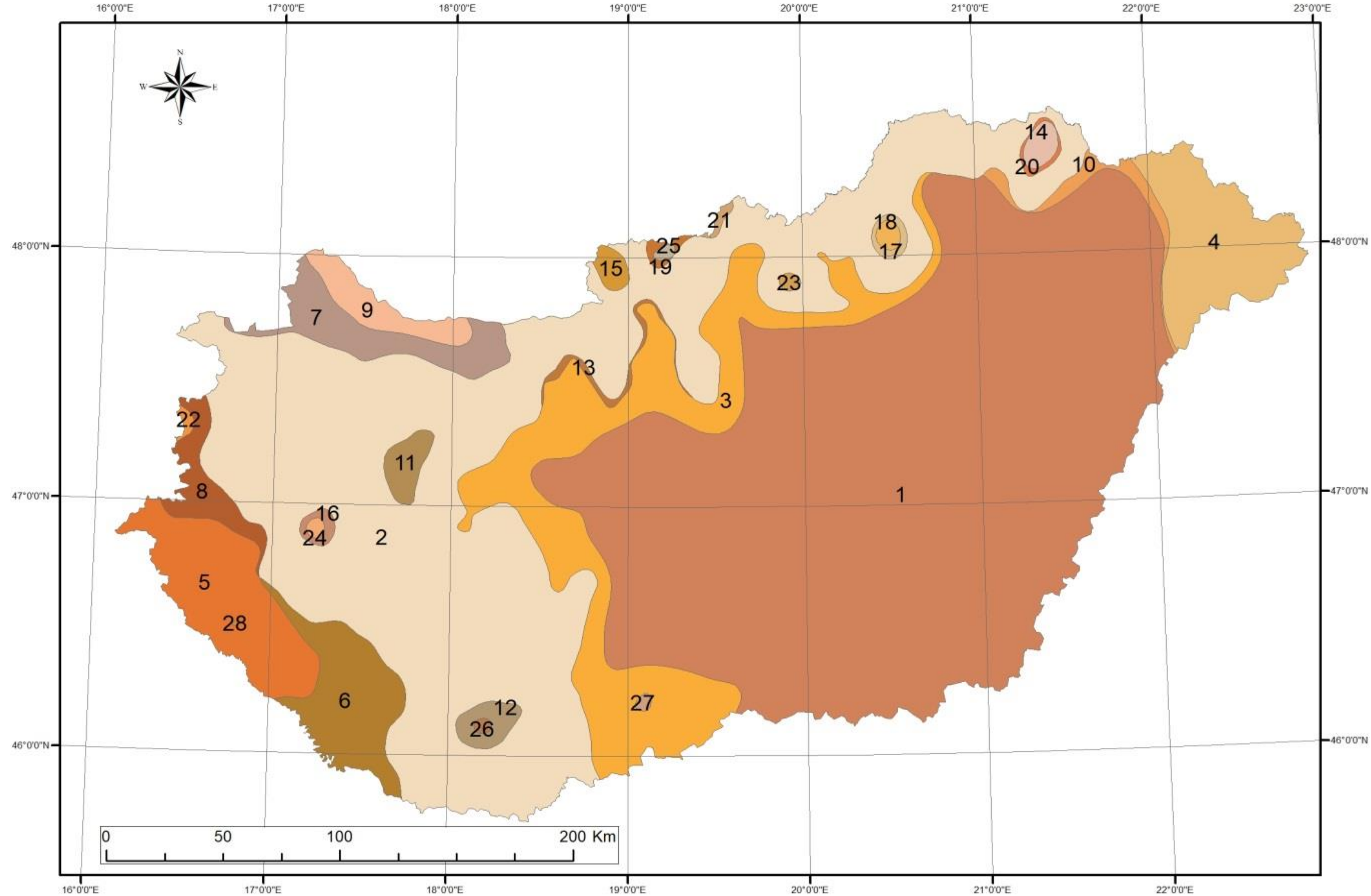
Point No.	Parameter	I	II	III	IV	V	VI
Monthly rainfall difference (mm)	average	33.47	21.18	15.62	-4.23	3.36	-8.11
	STD	72.21	52.37	45.18	54	49.73	55.32
Monthly temperature difference (C°)	average	0.89	-0.46	-0.15	0.25	-1.6	0.99
	STD	3.43	3.27	3.14	3.19	3.16	3.45

DELINEATION OF CLIMATE ZONES

- Thorntwaite (1948) biophysical method
- Suitable for regional scale characterisation
- Monitors the soil water budget using PET
- Uses humidity index and an aridity index to determine moisture regime based upon average t°, rainfall, and vegetation type
- Climate zones calculated for 4 time intervals based on temporally averaged CARPATCLIM (1961-1990, 1981-2010) and ALADIN (2021-2050, 2071-2100) data.
- Climate data averaged for each climate zone



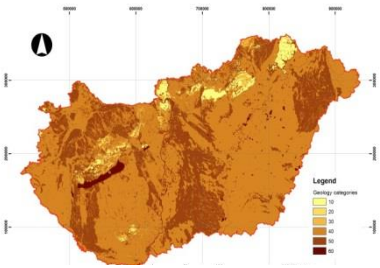
CLIMATE ZONATION

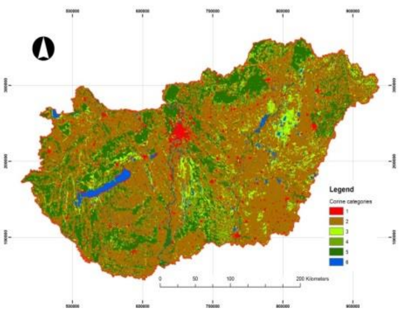


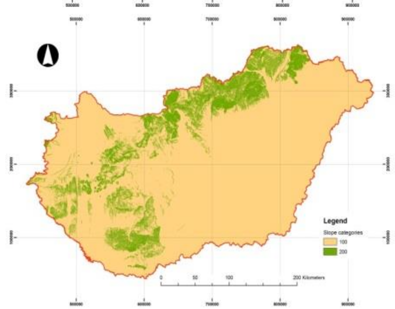
Climate classification based on the Thorntwaite method for the period of 1961–1990 based on CARPATCLIM data.

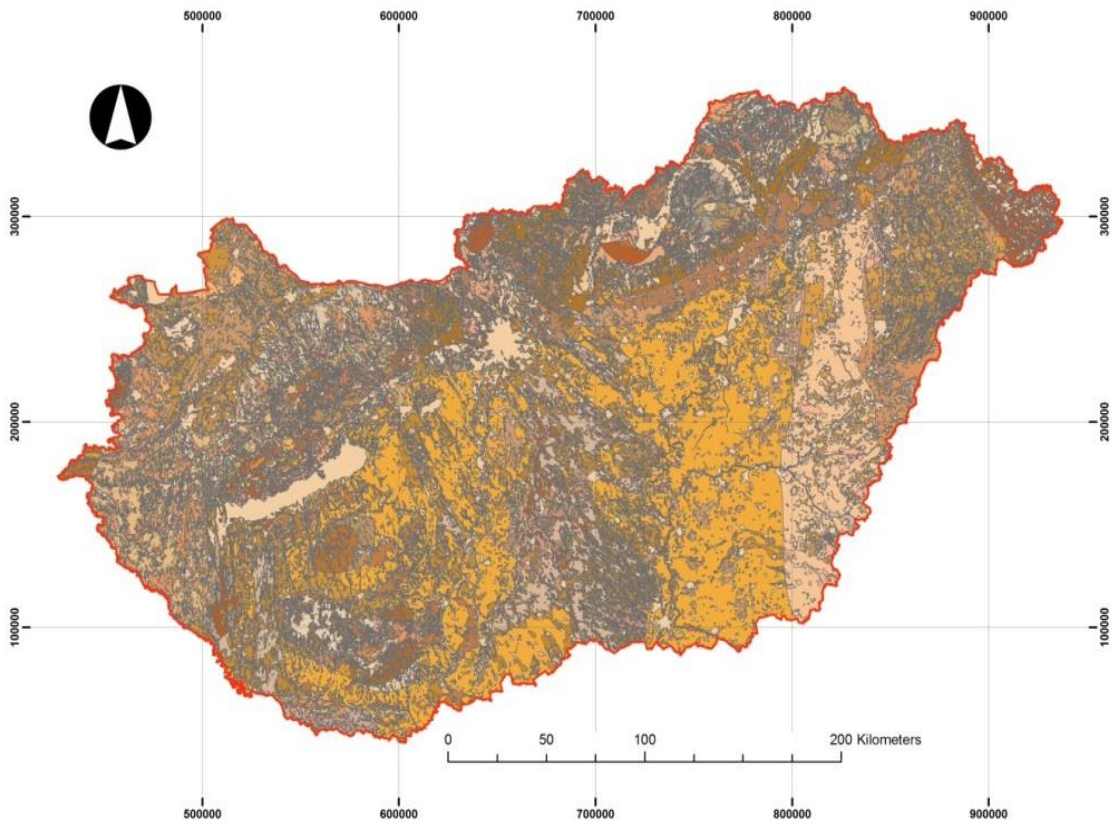
DELINEATION OF RECHARGE ZONES

- Surface geology (5 categories: fractured, limestone, dolomite, fine porous, coarse porous)
- Landuse (6 categories: Urban areas, Arable land, Pastures, Permanent crops, Forests, Water bodies)
- Slope (2 categories: 0-5%, >5%)



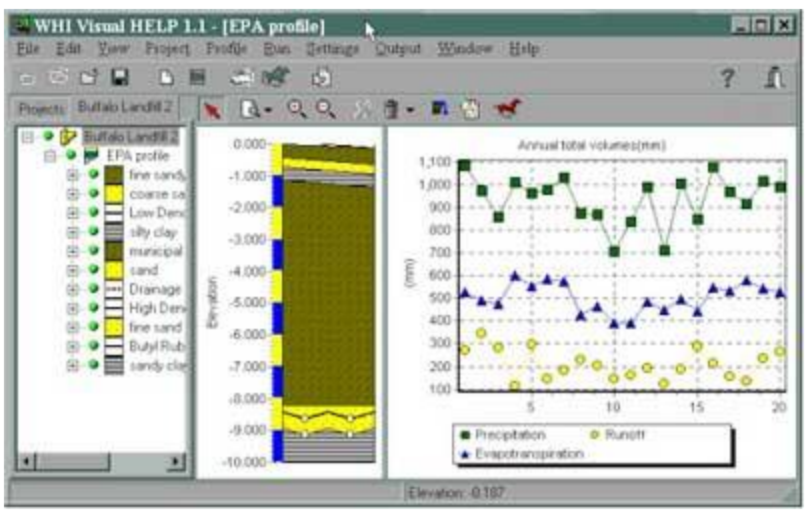


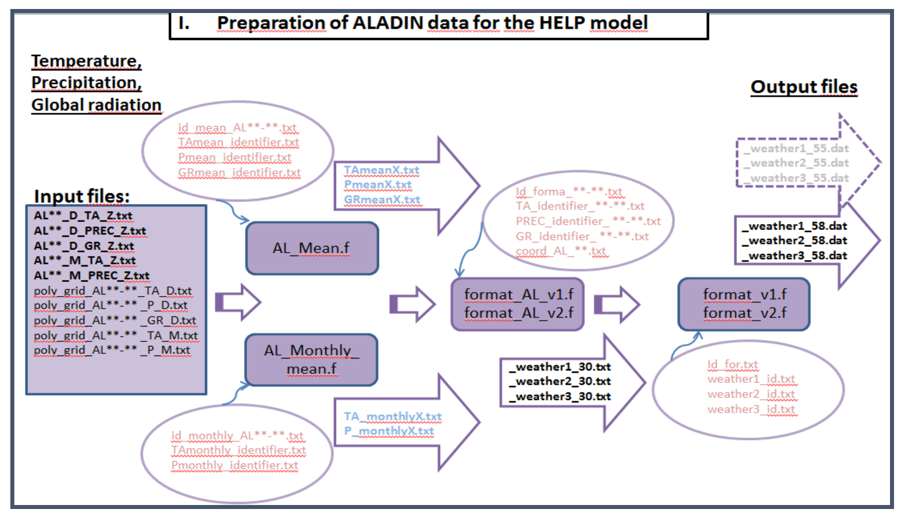




RECHARGE MODELLING

- Numerical hydrological models
- Applied software: HELP (Hydrologic Evaluation of Landfill Performance) (Schroeder et al. 1994 - USEPA)
- 1D numerical transient water balance approach
- Input data: Daily temperature, rainfall, global radiation, biannual relative humidity, annual wind speed) → averaged for each climate zone
- Soil profiles: Geology, landuse, slope → for each recharge zone
- Automation with scripts

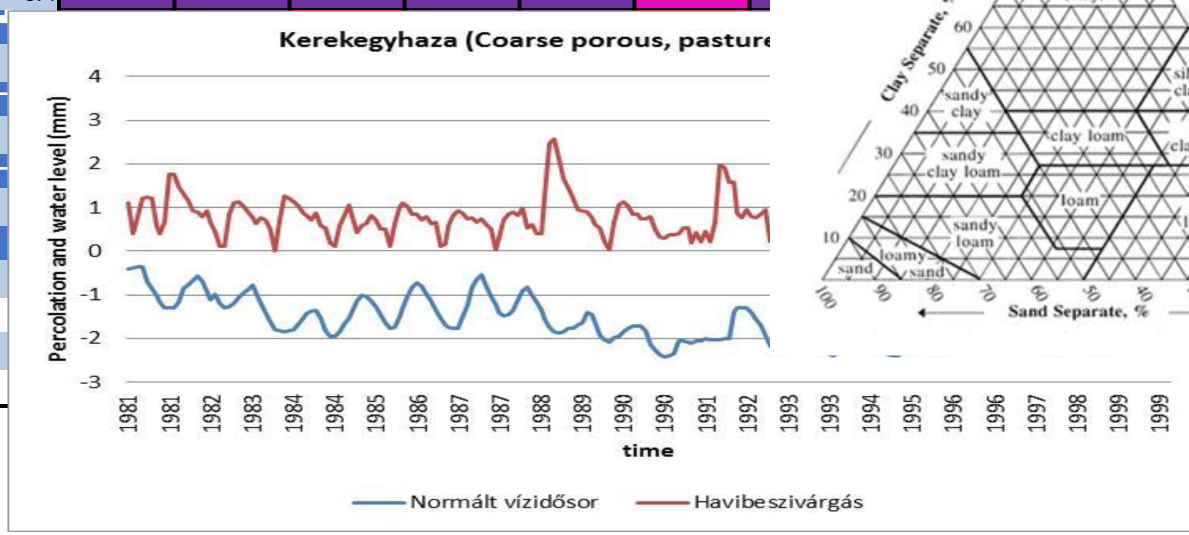


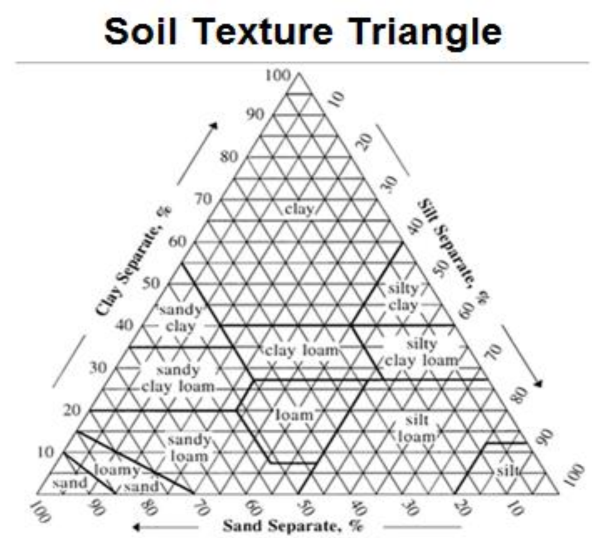


DEFINITION OF SOIL PROFILES

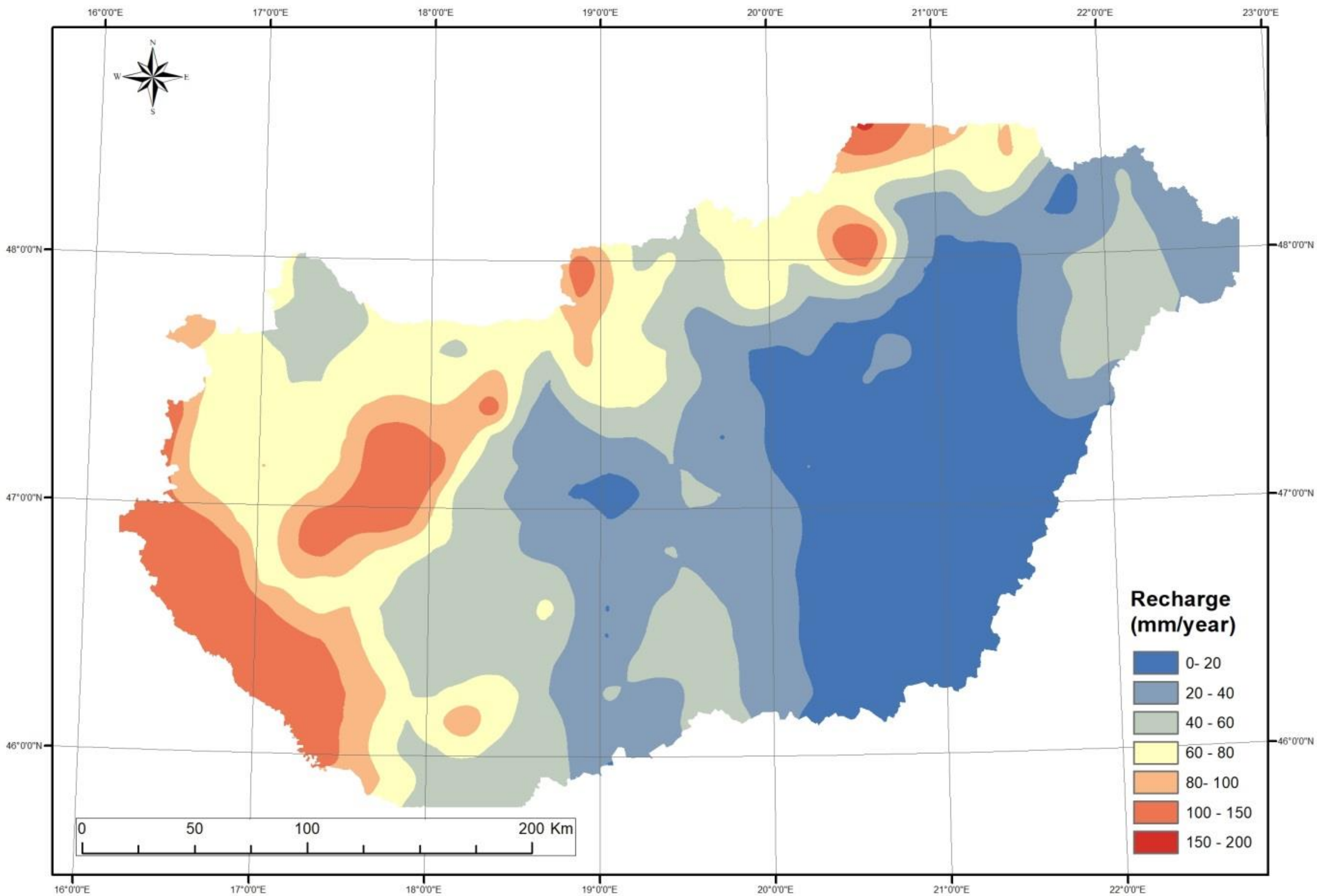
- Selection of representative recharge zones
- Analysis of shallow borelogs → development of type profiles
- Grain size distributions → Soil classification → Assignment of representative hydraulic parameters
- Landuse and slope → Represented by Runoff curve number
- Measured well hydrographs → Adjustme ... ation t

Layers			Typical geological profile by spots in the test area					
Number of samples	Lower boundary layer (m)	Upper boundary layer (m)	Kisalföld _1 Hgeo_4	Kisalföld _1 Hgeo_5	Kisalföld _1 Hgeo_6	Kisalföld _2 Hgeo_4	Kisalföld _2 Hgeo_5	Kisalföld _2 Hgeo_6
1	0.2	0						
2	0.4	0.2						
3	0.6	0.4						
4	1.1							
5	1.6							
6	2.1							
7	3.1							
8	4.1							
9	5.1							
10	6.1							
11	7.1							
12	8.1							
13	9.1							
14	10.1							

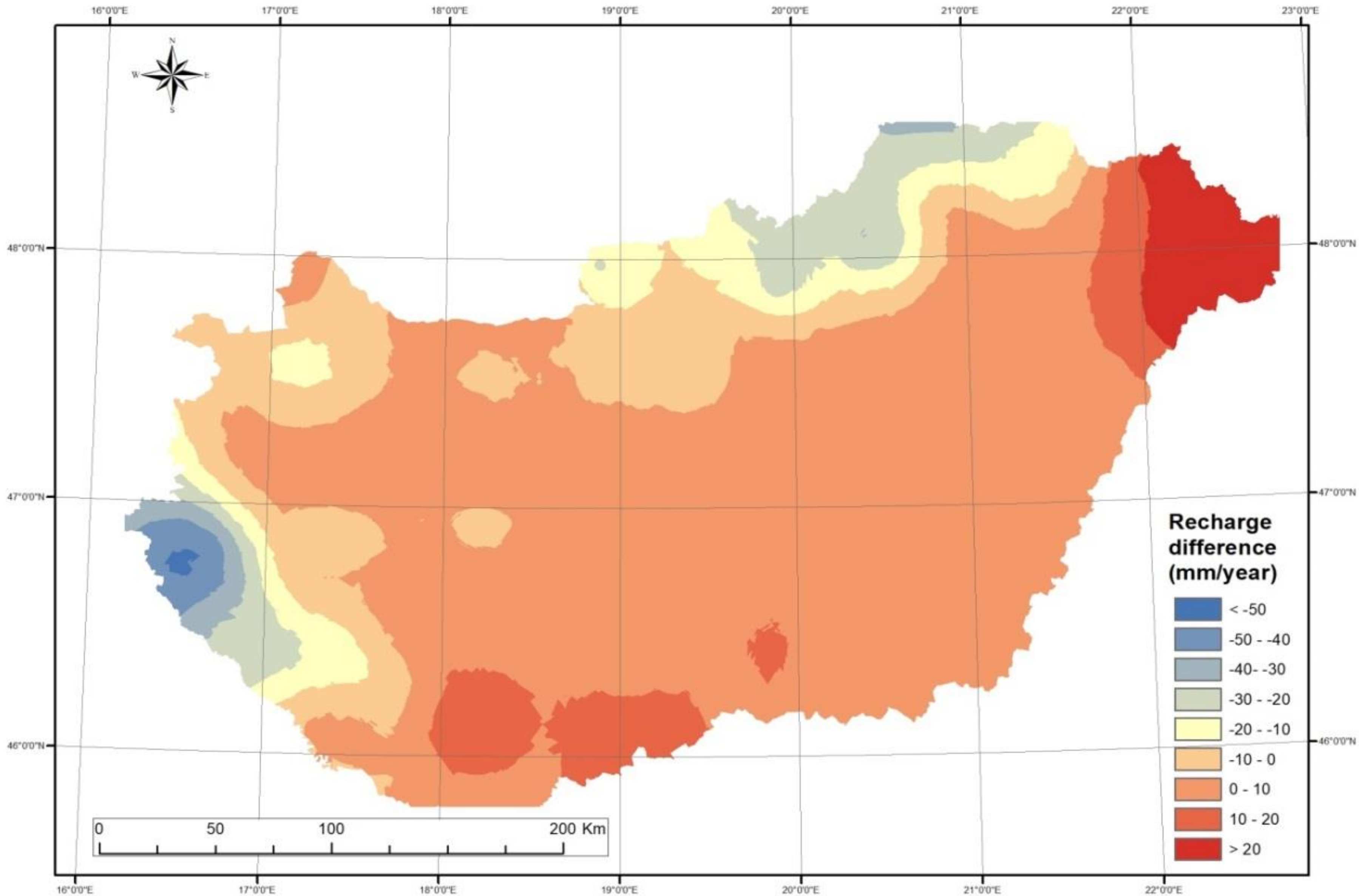




CALCULATED AVERAGE RECHARGE 1961-1965



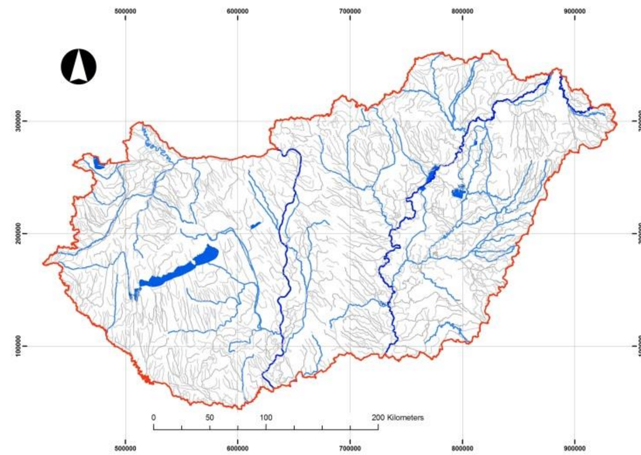
RECHARGE DIFFERENCE BETWEEN 1961-1965 / 2005-2009



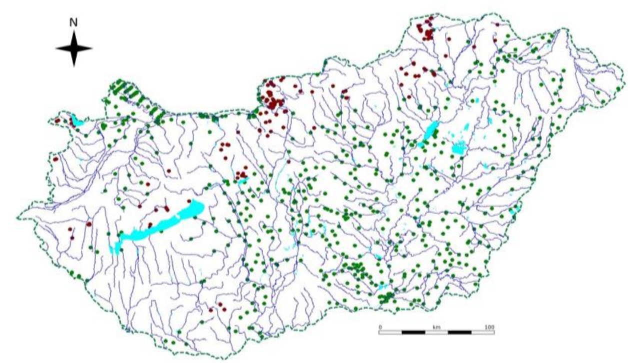
GROUNDWATWER MODELLING

- 2D steady-state models
- Applied software MODFLOW NWT
- 1000 m grid size
- Applied BC's: Recharge, constant head
- Calibration period: 1961-1965 average conditions (undisturbed)
- Calibration data: Well hydrographs, Spring levels, River stages
- Parameter zones: Hydrostratigraphic units
- Simulated scenarios:
  - CARPATCLIM: 1961-1965, 2005-2009 (measured climate data)
  - ALADIN: 1961-1990, 2021-2050, 2071-2100 (simulated climate data)

BC's

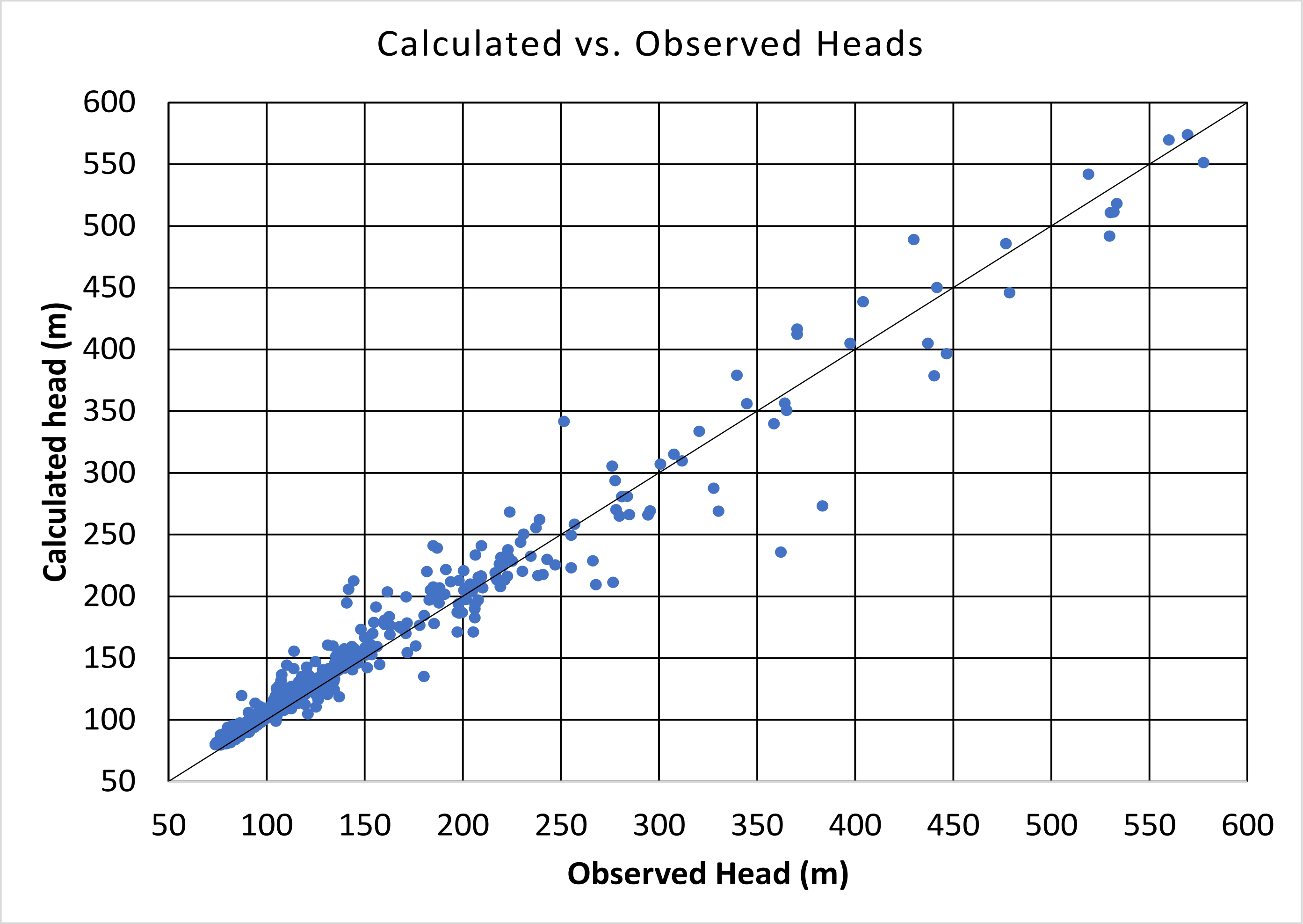


Calibration points

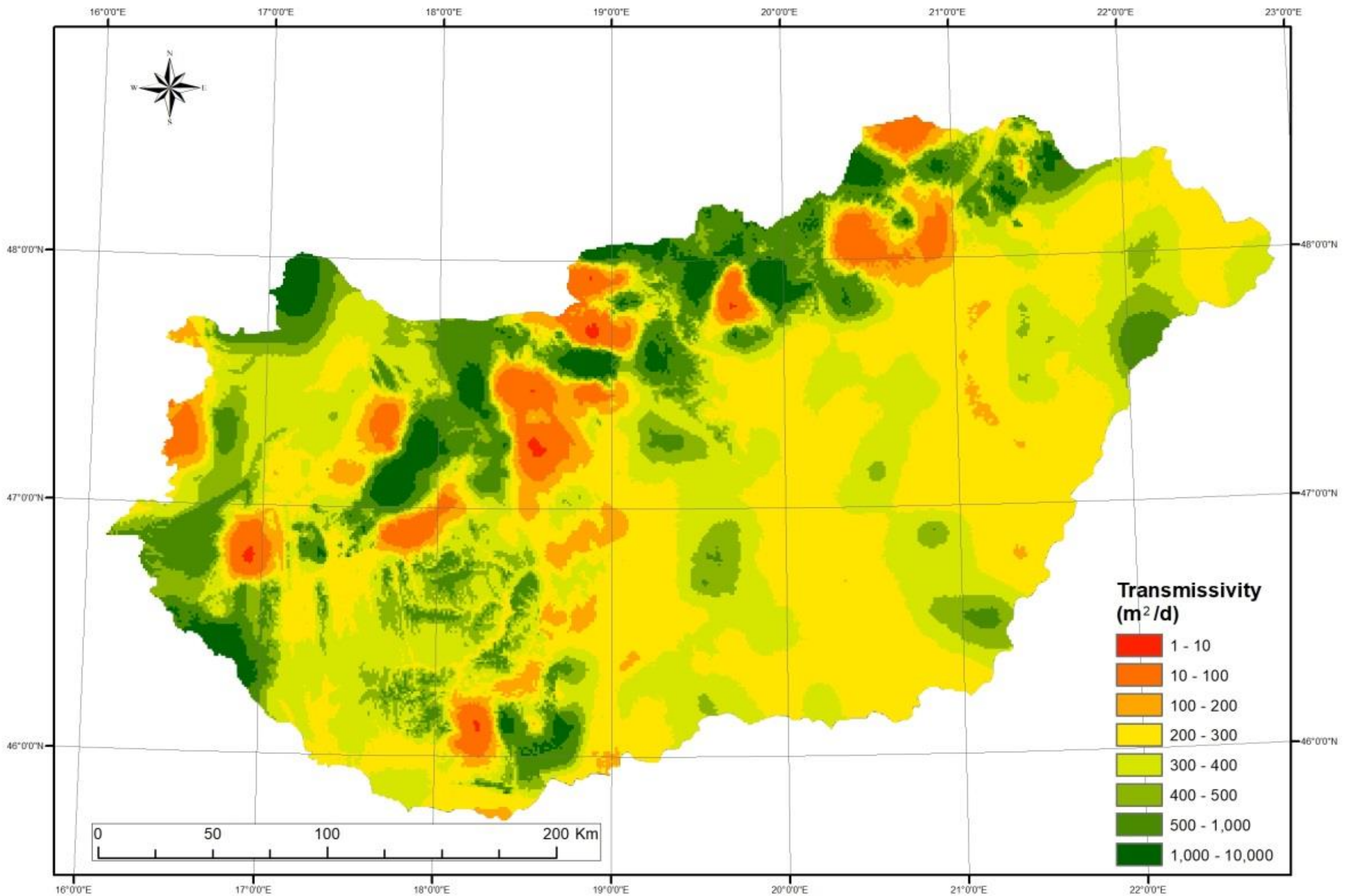


CALIBRATION

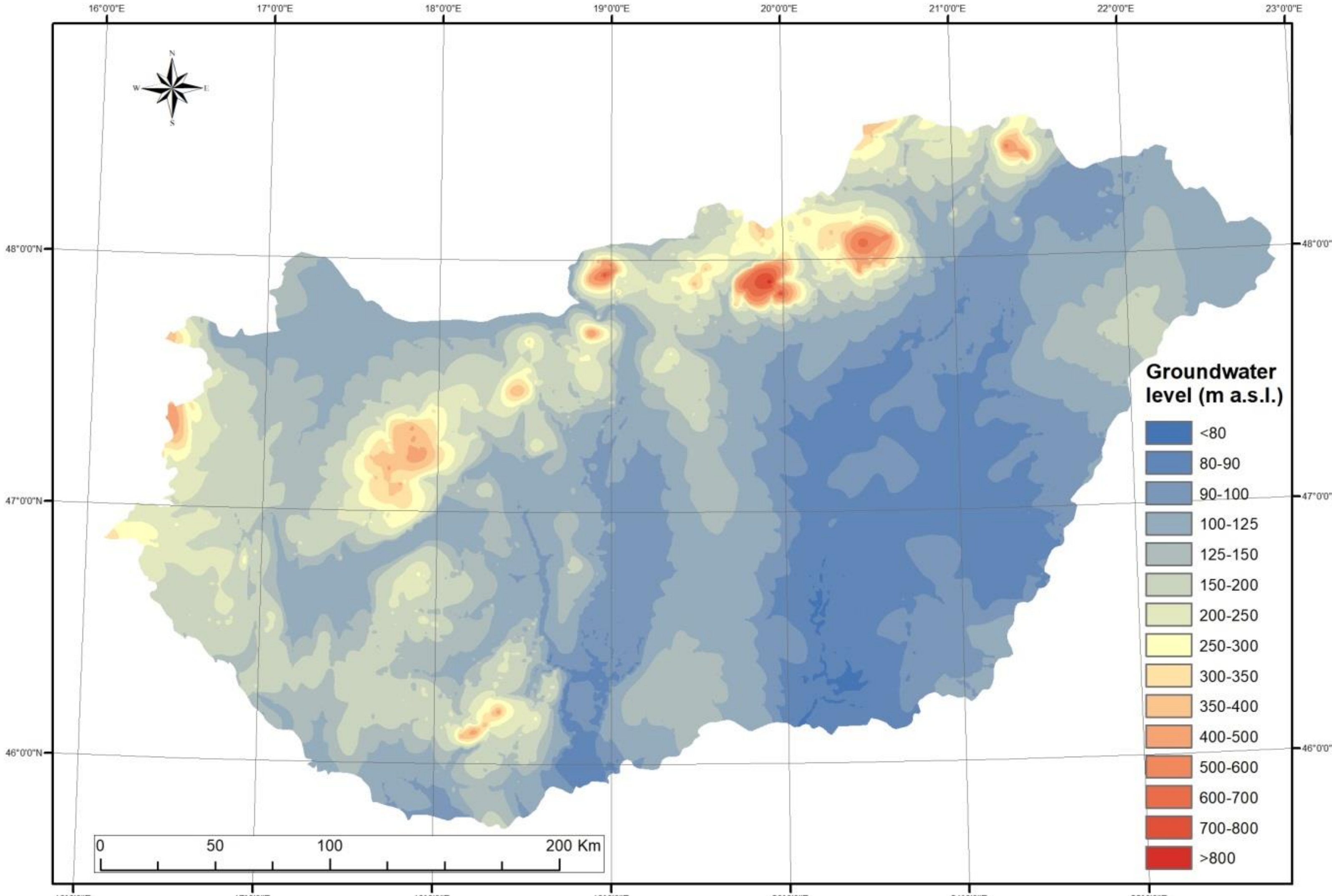
- Calibration achieved by using PEST (automated calibration algorithm)
- Pilot points used: 592



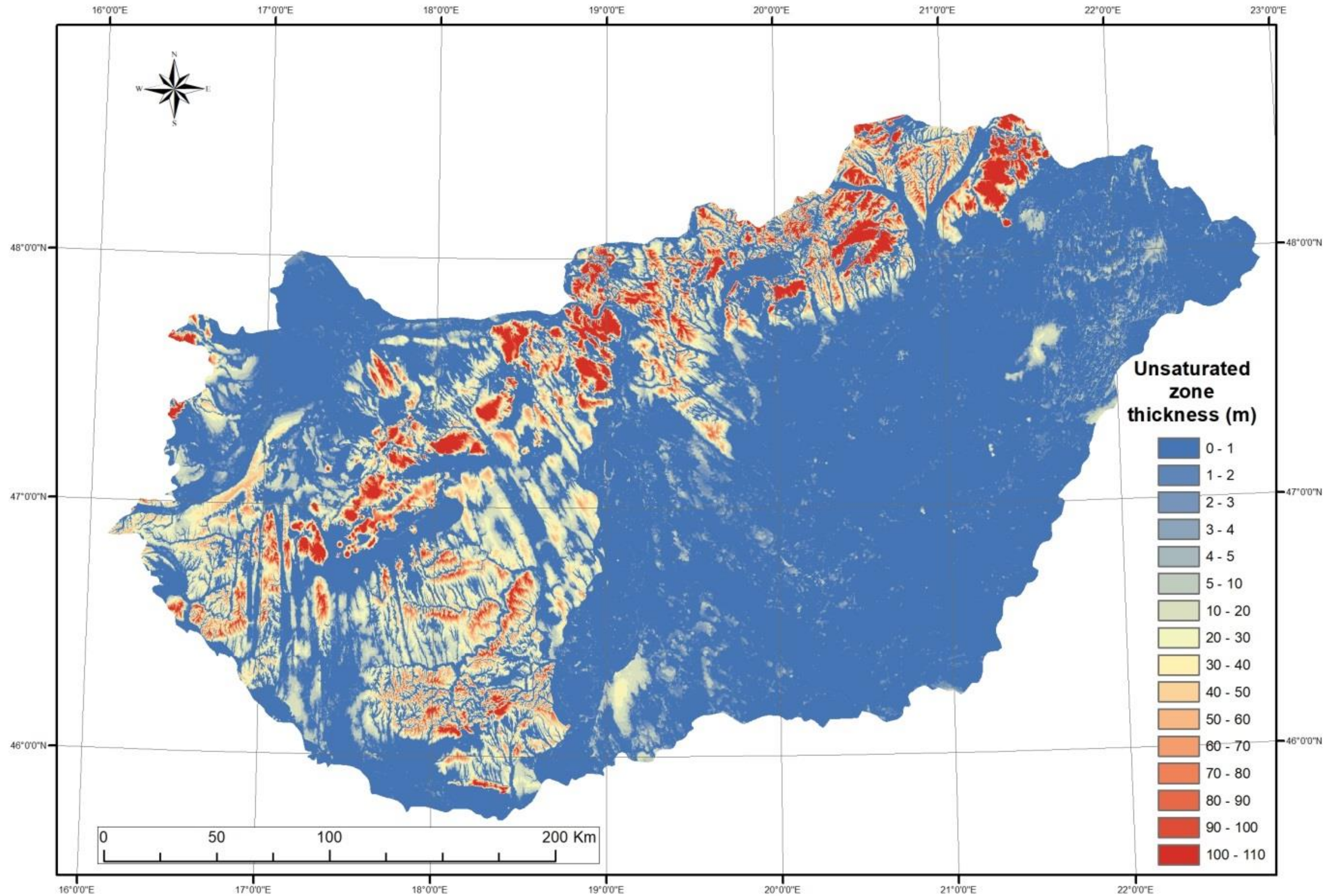
CALIBRATED TRANSMISSIVITY DISTRIBUTION



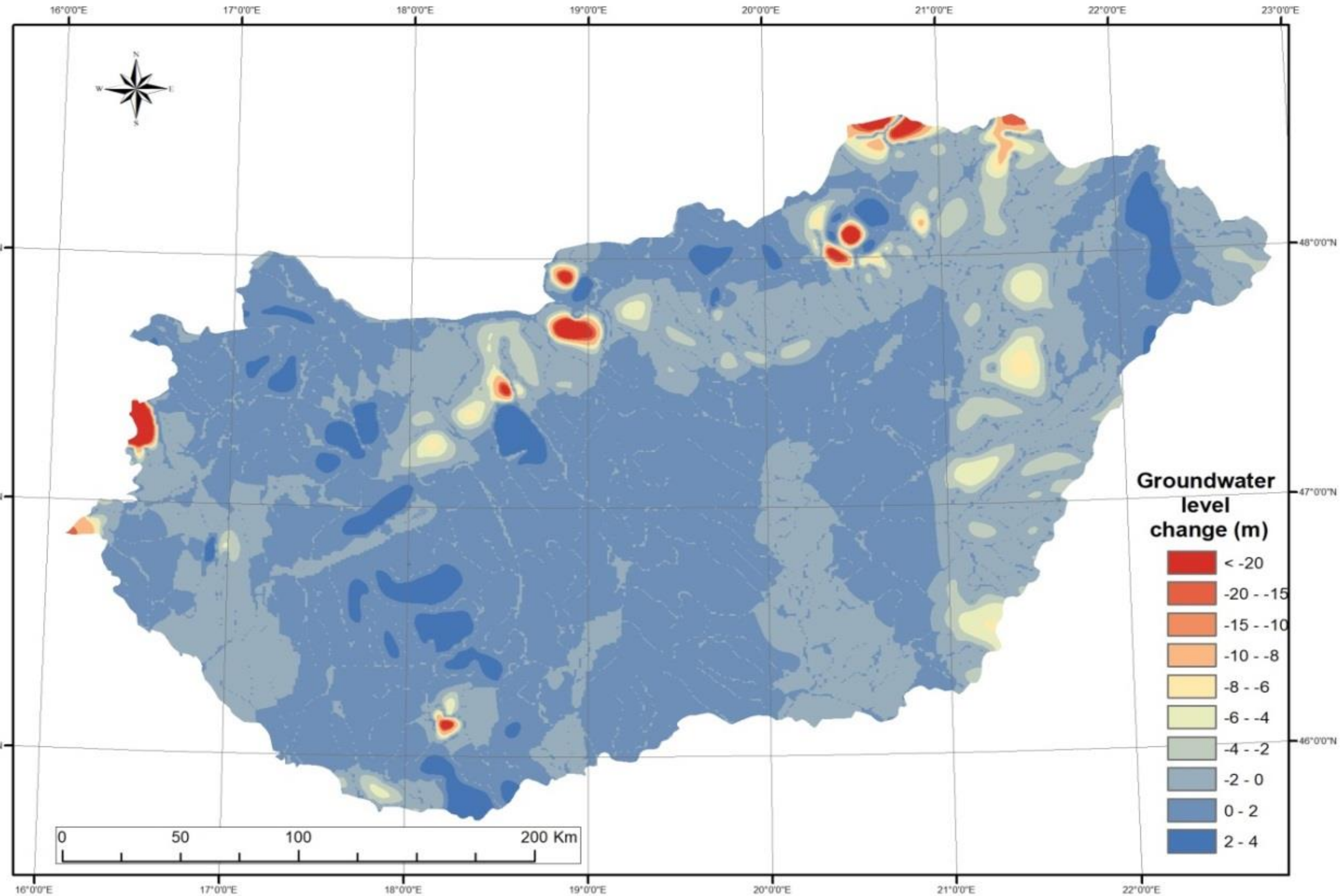
CALCULATED NATURAL-STATE WATER TABLE 1961-65



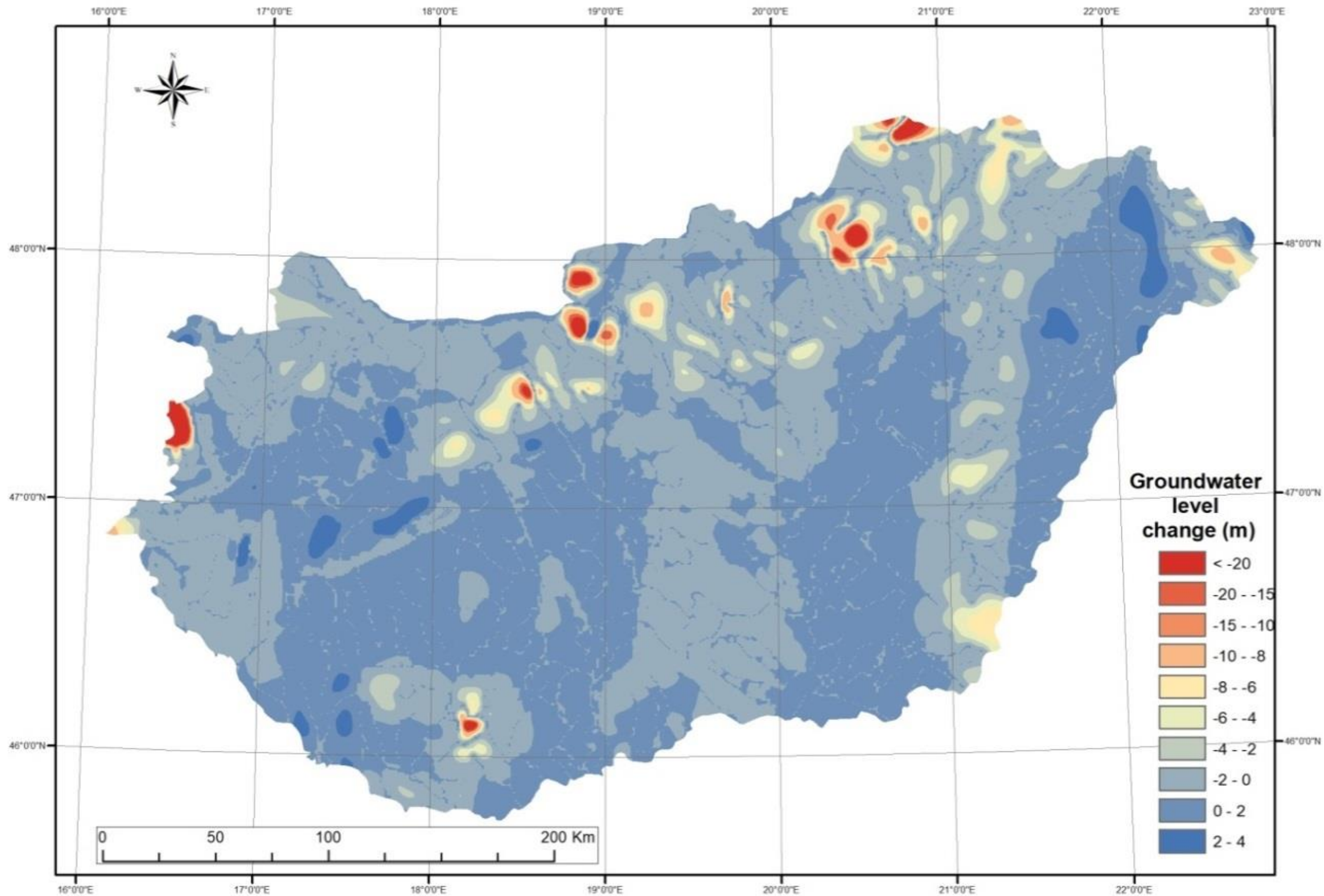
WATER TABLE DEPTH 1961-65



SIMULATED GROUNDWATER TABLE DIFFERENCE, 2021–2050 AND 1961–1990



SIMULATED GROUNDWATER TABLE DIFFERENCE 1961-1990 / 2071-2100



CONCLUSIONS

- A modular methodology has been developped for the calculation of shallow groundwater table at various climate conditions
- The methodology is suitable for the assessment of climate vulnerability
- Recharge and water table distributions have been calculated for five periods in past and future
- Based on model simulations
  - Recharge and groundwater level are predicted to drop in some elevated areas of the North
  - Recharge and groundwater level are predicted to increase slightly in Southern zones
- Results are valid at regional scale
- Methodology applicable at any scale (local scale requires higher resolution)