

# **A 3D Heat Transport Model for the Sustainable Use of Thermal Water in Hungary**

**IAH-BGR-2006 14&15 Sep.2006**

**Interaction between Groundwater and Surface Water**

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# Agenda

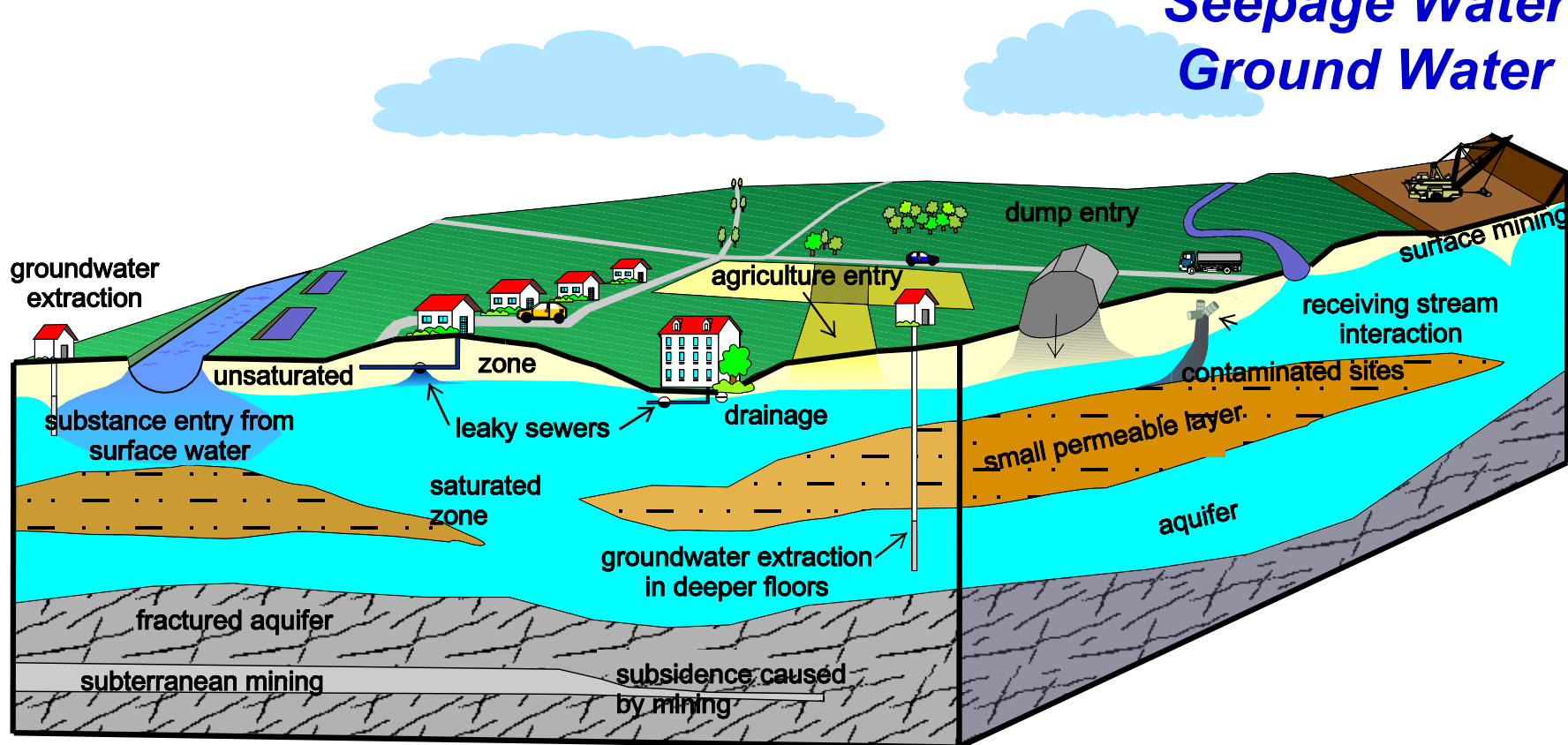
- delta h Consultants GmbH
- Introduction into the project EnvPollMod
- The problem
- The processes
- The modeling
- The results

# Hydraulic System Modeling

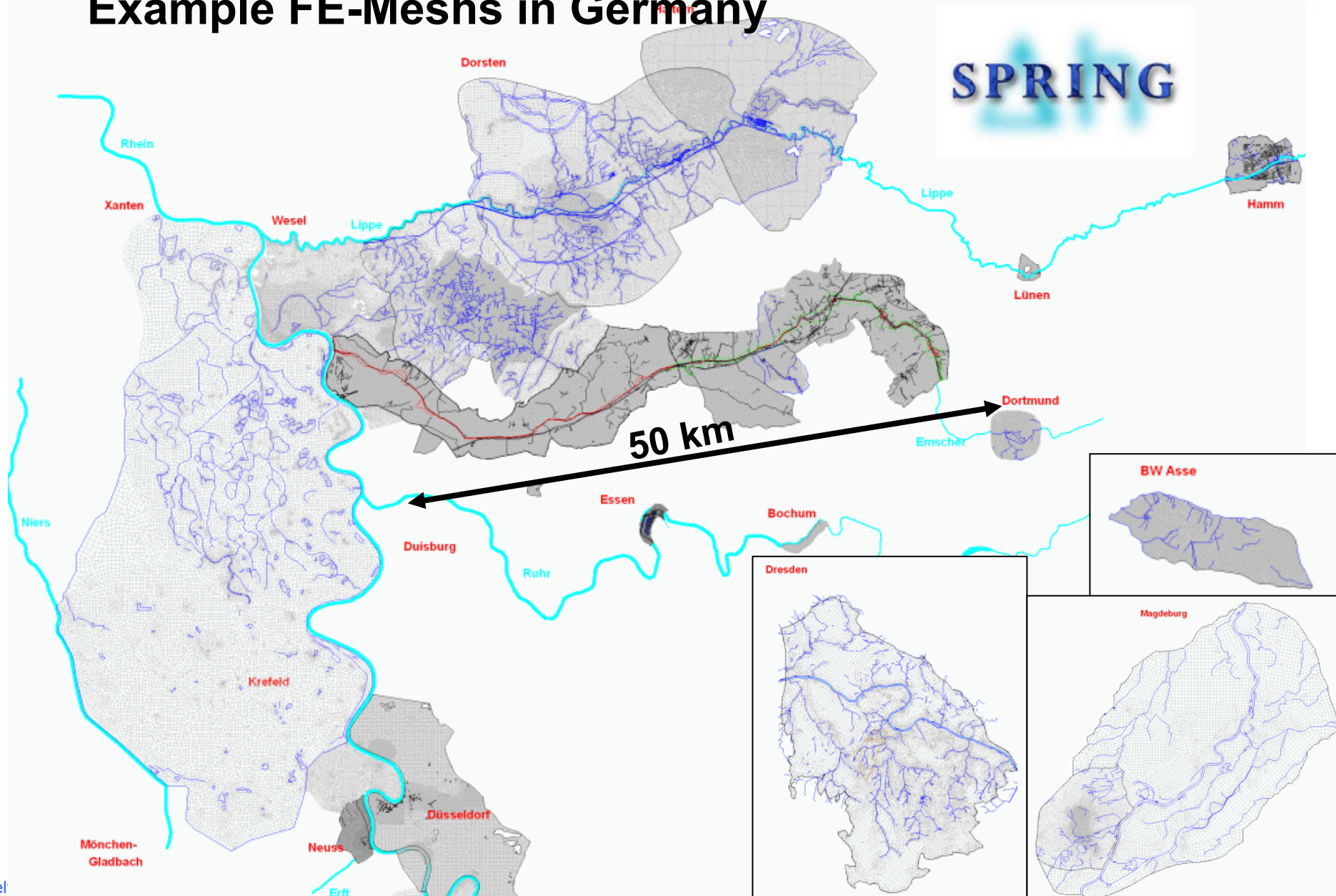
## Surface Water

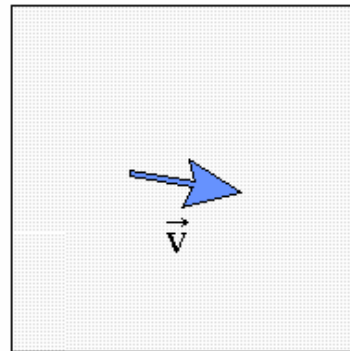
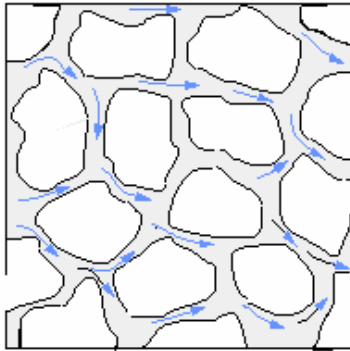
## Seepage Water

## Ground Water



# Example FE-Meshes in Germany





$$v_i = - K_{ij} \frac{k_{rel}}{\mu} \left[ \frac{\partial}{\partial x_j} p - \rho \vec{g}_j \right]$$

$v_i$  Darcy flow [m/s]

$K_{ij}$  Permeabilitätstensor [m<sup>2</sup>]

$\rho g$  Density \* Gravity [N/m<sup>3</sup>]

$\mu$  dynamical Viskosity [kg/ms]

$k_{rel}$  relative Permability [-]

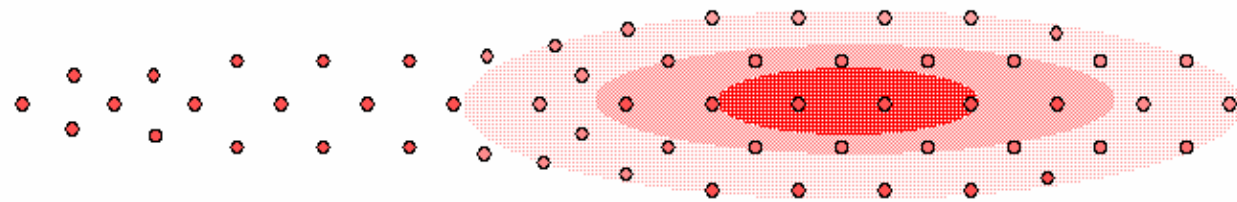
$$\rho \left[ S_w S_{op} + n \frac{\partial S_w}{\partial p} \right] \frac{\partial p}{\partial t} + \left[ n S_w \frac{\partial \rho}{\partial c} \right] \frac{\partial c}{\partial t} - \frac{\partial}{\partial x_i} \left[ \rho K_{ij} \frac{k_{rel}}{\mu} \left[ \frac{\partial}{\partial x_j} p - \rho \vec{g}_j \right] \right] = \rho Q$$

Storage

density -  
storage

massflow

source/  
sink



advektion

dispersion

diffusion

**Transport**

$$(nS_w \varrho) \frac{\partial c}{\partial t} + \varrho v_i \frac{\partial c}{\partial X_i} - \frac{\partial}{\partial X_i} (nS_w \varrho (D_{ij} + D_{mol} \delta_{ij}) \frac{\partial c}{\partial X_j}) = q(c^* - c)$$

storage

advektion

dispersion & diffusion

source

**coupled**

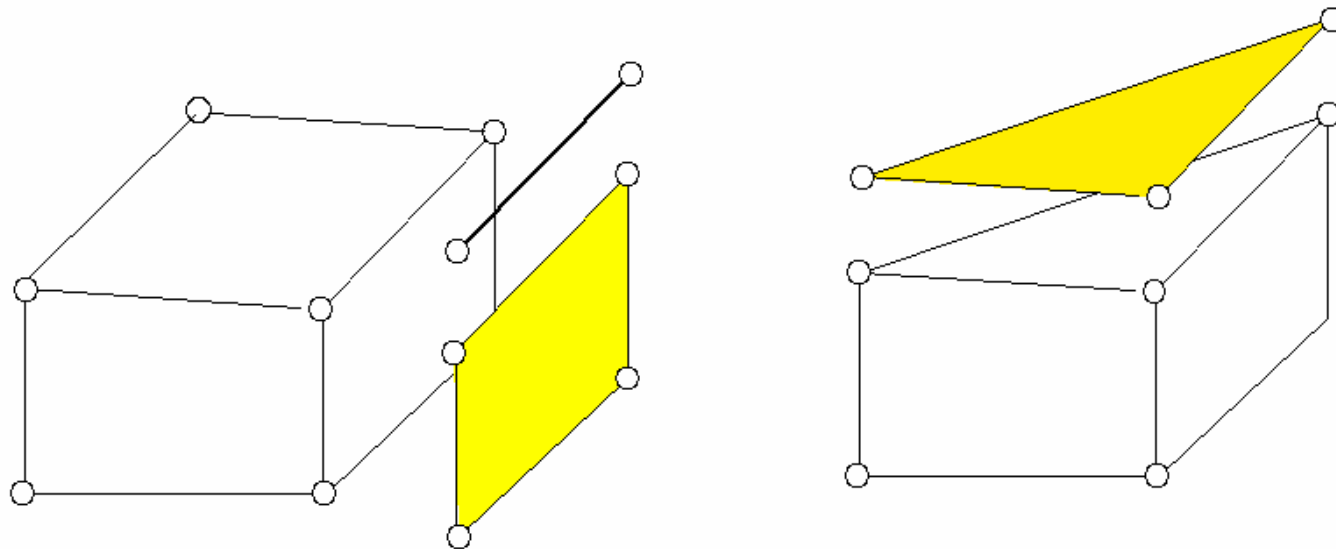
$$\varrho(c) = \varrho_0 + \frac{\partial \varrho}{\partial c} * c$$

or PHREEQC-2

[ f<sub>s</sub>

## → finite element in space

- primary variables      flow: waterpressure  $p$   
                                  transport: concentration  $c$
- element typs



## → time discretisation with finite difference

Crank Nickolson

$\theta \geq 0,5$  stabil

→ transport equation: symmetric + stabilisation

- streamline upwind

→ solver

- SuperLU..... $O(n^2)$
- PCG method..... $O(n^{3/4})$   
preconditioning:  
ICC, SSOR, BlockSSOR, AMG
- Multigrid ..... $O(n)$

→ nonlinearity

- Leakage condition with limited mass flow rates
- Saturation
- Density
- Sorption → Picard iteration



## The Project EnvPollMod

# EnvPollMod - Environmental Pollution Modeling

**Development of an innovative site evaluation model  
for geothermal utilisation in Hungary  
- environmental pollution prognosis  
by missing thermal water re-injection -**

in co-operation with

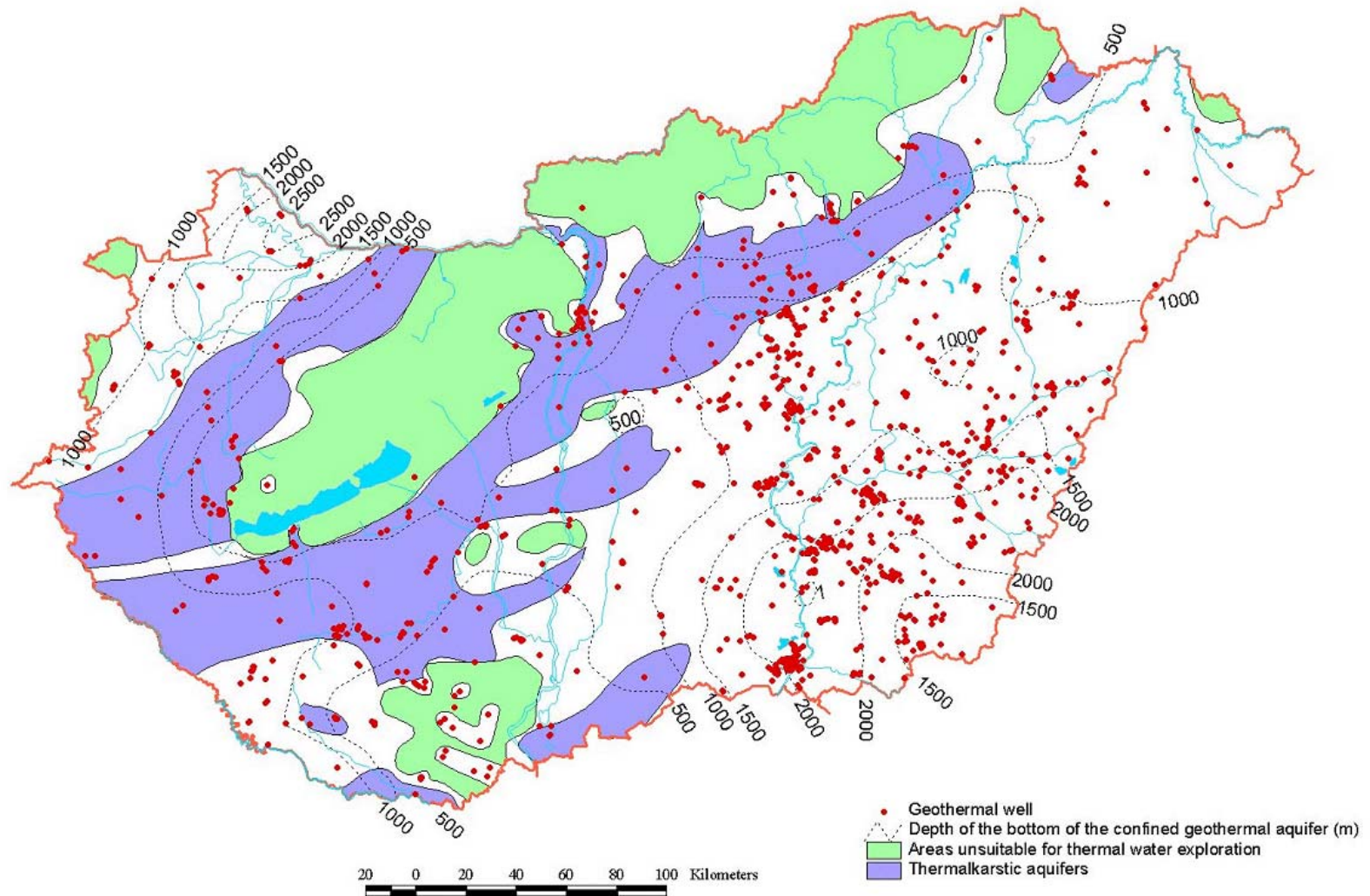


supported by



Arbeitsgemeinschaft industrieller  
Forschungsvereinigungen  
„Otto von Guericke“ e.V. (AIF) Berlin

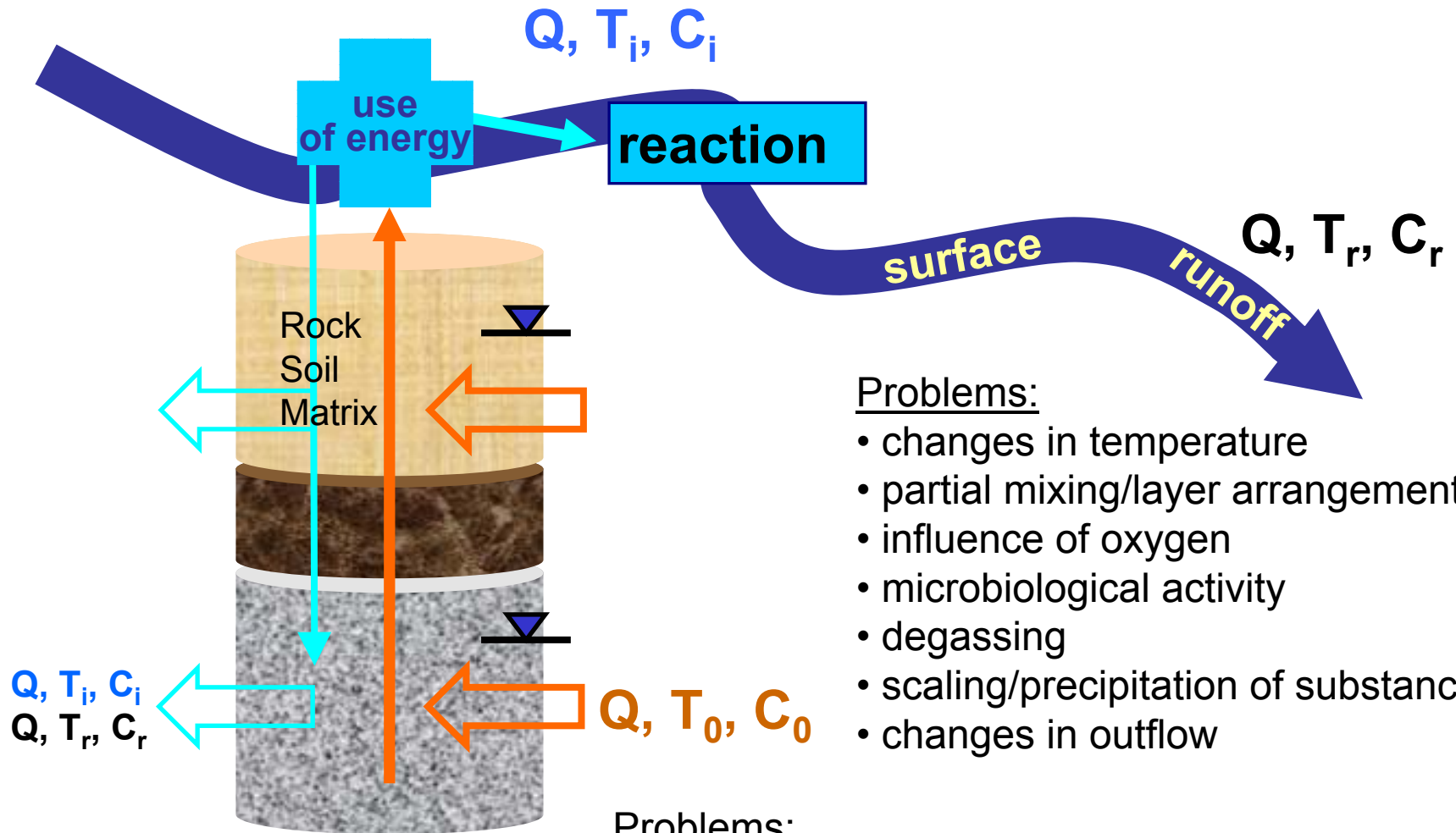
# Hungary – Geothermal Resources



# Use of Geothermal Water



# The Problem



**Problems:**  
reduction of the reservoir pressure

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# Sustainability and Modeling

## Geothermic Energy:

- Production
- Storage
- Optimisation

With the use of a Numerical Model!

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# Sustainability and Modeling

## What is the Aim of numerical Groundwater Model ?

- Plausibility of Inputdata
- Massbalance
- Prognosis
- Avalibility
- Sensitivity analysis

# References

besides the field trips:  
 ~ 250 papers, articles, books  
 ~ 40 maps  
 ... links in the internet

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Benedikt Steingrímsson	MODELING STUDIES OF THE NESJAVELLIR GEOTHERMAL FIELD, ICELAND	28. May-10. June 2000.	Proceedings World Geothermal Congress 2000 Kwushu-Toboku

Autor	Titel	Datum	Ort/Verlag
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L. Rybach	Szita, G., Kocsis, E. HOW TO DO GEOTHERMAL PROJECTS IN HUNGARY? DREAMS AND REALITIES	2000	Ungarn

Peter Kralj

Battocletti, L., Bob Lawrence and Associates, Inc. Rybach, L.

Travis L. McClure, Robert W. Strickland

Liz Battocletti

John W. Lund, Derek H. Frey

Antics, M.

Baradács, E., Dezső Z., Hunyadi, I. Rátóti, B.

Liebe, P. (Hydrological Institute of Vítků Plc.) Deák, J., Liebe, P.

Liebe, P. (Hydrological Institute of Vítků Plc.)

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Richard Buckley	UNDERSTANDING GLOBAL ISSUES	1993	The Runnings, Cheltenham GL51 9PG, England
Burkhard Sanner Ladislaus Rybach	GROUND-SOURCE HEAT PUMP SYSTEMS THE EUROPEAN EXPERIENCE	March 2000	GHC Bulletin
T.M. Sullivan M. Gitten P.D. Moskowitz	EVALUATION OF SELECTED ENVIRONMENTAL SOFT		USA Department of Energy
Gabor Szita Edina Kocsis	HOW TO DO GEOTHERMAL PROJECTS IN HUNGARY? DREAMS AND REALITIES	2000	Ungarn

Autor	Titel	Datum	Ort/Verlag
	GRUNDSATZPAPIERE ZUR THERMALWASSERNUTZUNG IM NIEDERBAYERISCHEN-OBERÖSTERREICHISCHEN MOLASSEBECKEN	2002	Ad hoc Expertengruppe „Tiefenwasser“ im Auftrag der Ständigen Gewässerkommission nach dem Regensburger Vertrag

Autor	Titel	Datum	Ort/Verlag
Miklós Árpási, György Szabó	GEOTHERMAL DEVELOPMENT IN HUNGARY, COUNTRY UPDATE REPORT 1995 - 1999	2000	Ungarn

Autor	Titel	Datum	Ort/Verlag
Jane Brotheridge Margaret Leniston Christyono	POTENTIAL OF GEOTHERMAL ENERGY IN RURAL AREAS OF THE PHILIPPINES		USA Department of Energy
Csáki, Chikán et al.	GUIDE GROUNDWATER		Ungarn

Autor	Titel	Datum	Ort/Verlag
	BROSCHÜRE INSTITUT FÜR HYDROLOGIE, UNIVERSITÄT BUDAPEST		Ungarn
	ANNUAL REPORT - 2001 GEOLOGICAL INSTITUTE OF HUNGARY		Ungarn

Autor	Titel	Datum	Ort/Verlag
Abdurrahman Satman Umran Serpen Ibrahim Metin	ASSESSMENT OF GEOTHERMAL POTENTIAL IN KILIKIA		Ungarn
Kovacs & Szabo	EXPERINCES ON CO-GEOTHERMAL ENERGY TRANSPORT MODELS		Ungarn
László Trunkó	GEOTHERMAL ENERGY POTENTIAL IN HUNGARY		Ungarn

Autor	Titel	Datum	Ort/Verlag
	<a href="http://www.ungarn-tourismus.de/wellness_presse4.htm">http://www.ungarn-tourismus.de/wellness_presse4.htm</a>	Sep 04	
	<a href="http://c.grocceri.com/neilbad.html">http://c.grocceri.com/neilbad.html</a>	Sep 04	
	<a href="http://www.spa.hu">http://www.spa.hu</a>	Sep 04	
	<a href="http://www.fae.sk/Dieret/Geothermal/geothermal.html">http://www.fae.sk/Dieret/Geothermal/geothermal.html</a>	Sep 04	
	<a href="http://geothermal.inel.gov/publications/articles/reed-reed-renner.pdf">http://geothermal.inel.gov/publications/articles/reed-reed-renner.pdf</a>	Sep 04	
	<a href="http://www.geothermal.marin.org/pwrheat.html">http://www.geothermal.marin.org/pwrheat.html</a>	Sep 04	
	<a href="http://www.geothermie.de/gec-geonet/positive_social_and_environmenta.htm">http://www.geothermie.de/gec-geonet/positive_social_and_environmenta.htm</a>	Sep 04	
	<a href="http://www.eere-energy.gov/geothermal/energysystems.htm">http://www.eere-energy.gov/geothermal/energysystems.htm</a>	Sep 04	

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## The Project Evolution

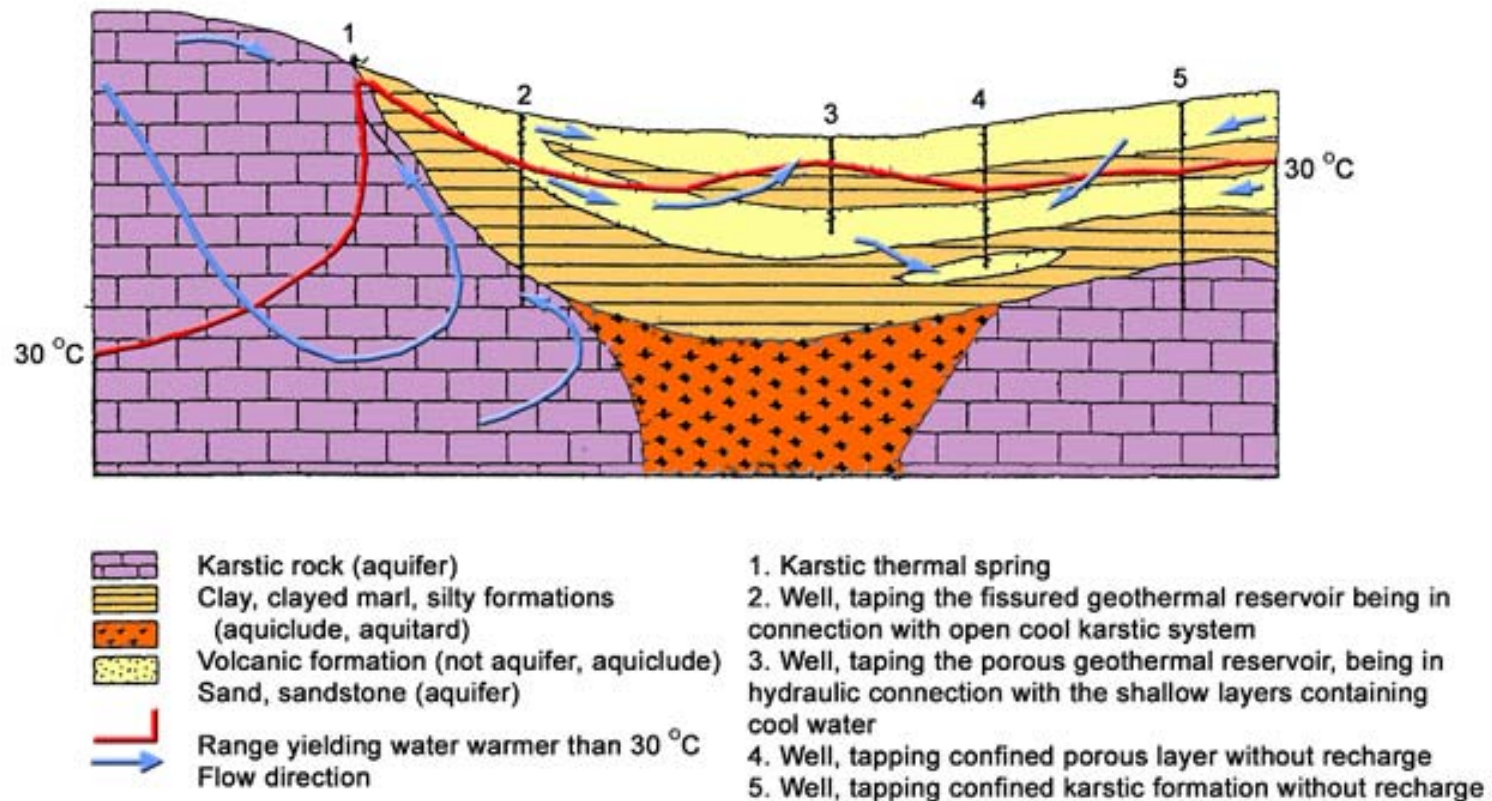
- on site measurements
- off site measurements - Laboratory - characterization of the different waters
- cluster analysis to classify the parameters
- information system – data base
- **numerical modeling**
  - **regional modeling**
  - **local modeling**
  - **detail modeling**
- development of an innovative site evaluation model



# Investigation Sites

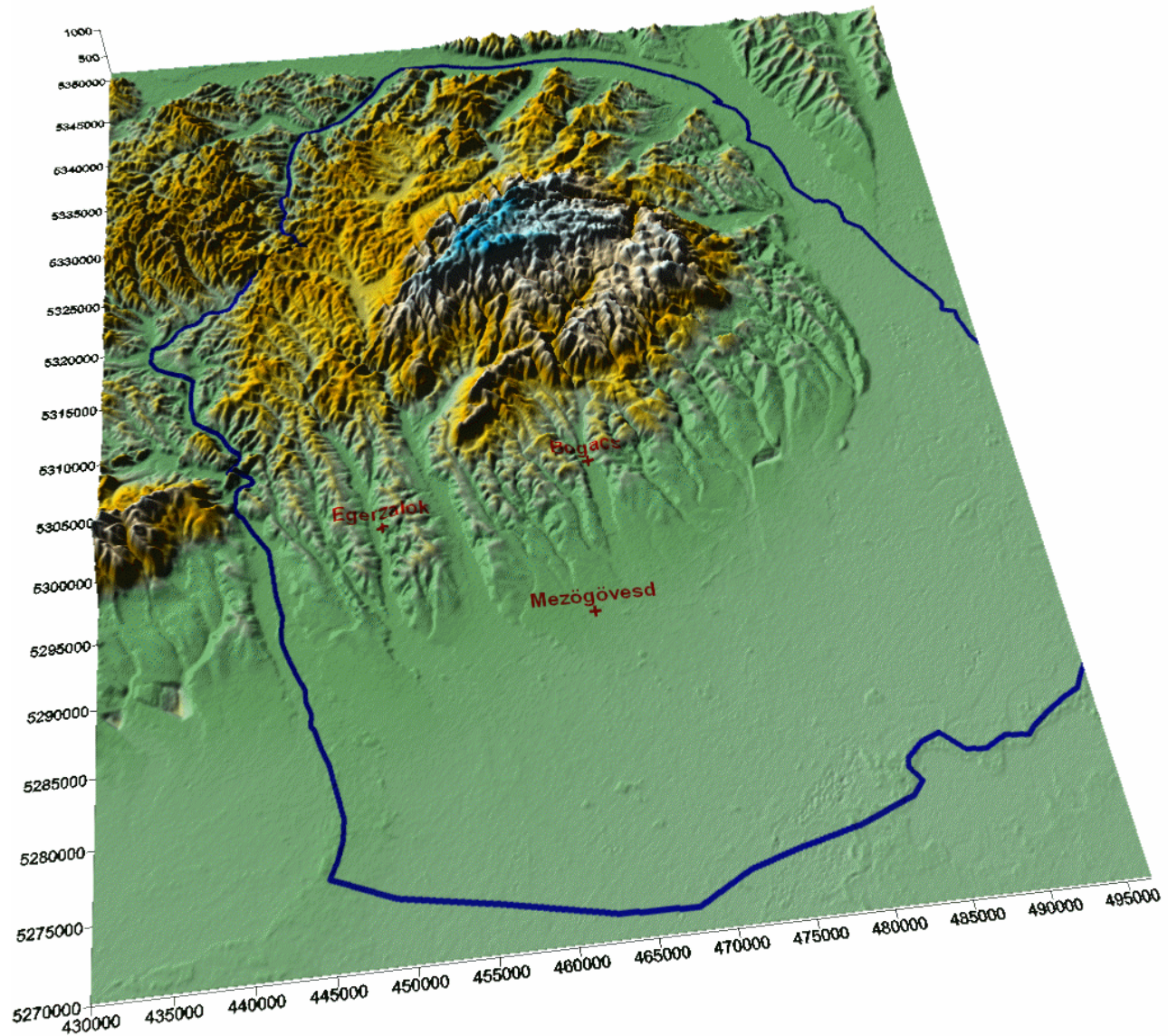


# Principle of the Bükk Mountain Range and the Pannonian Basin

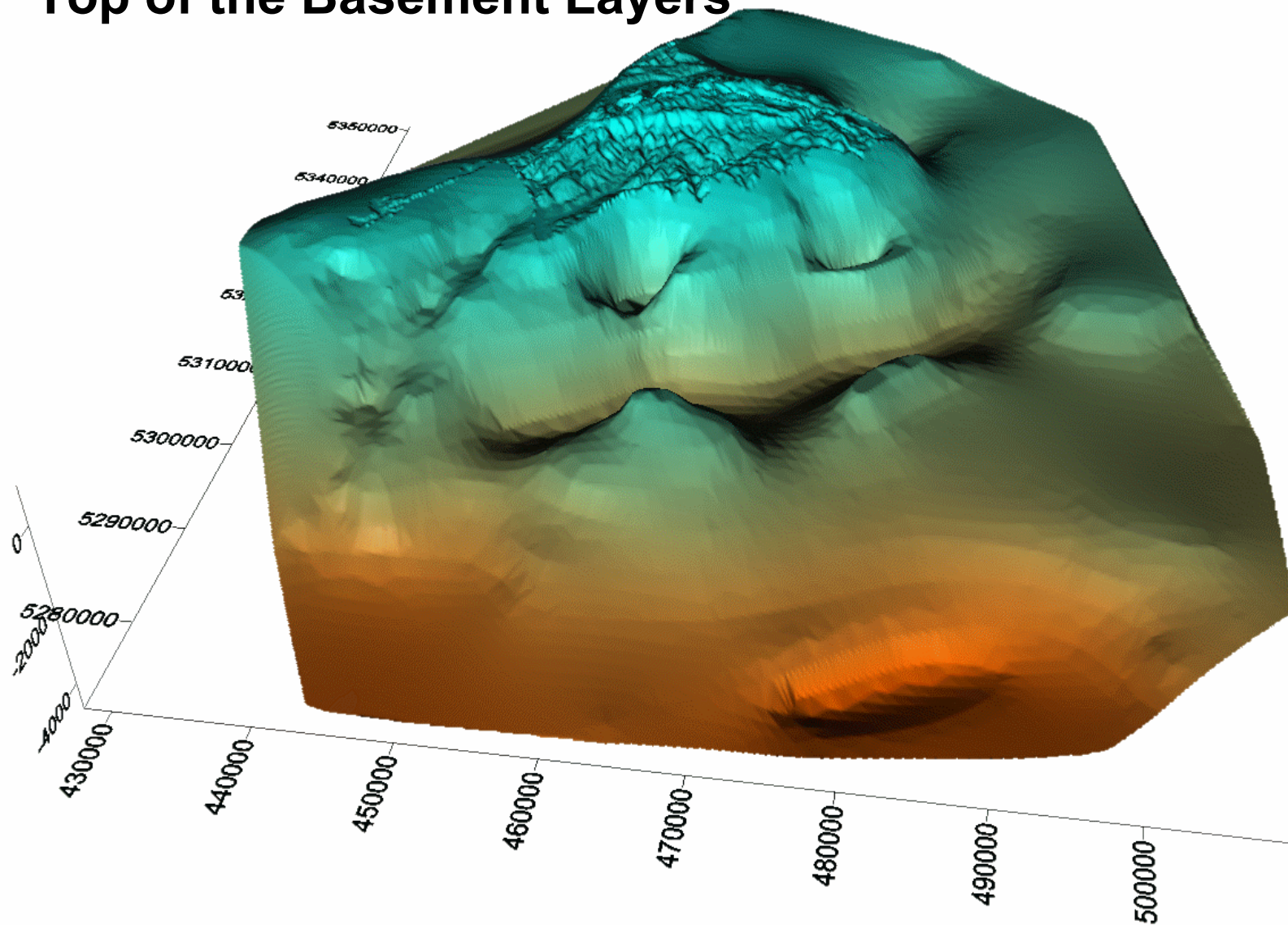


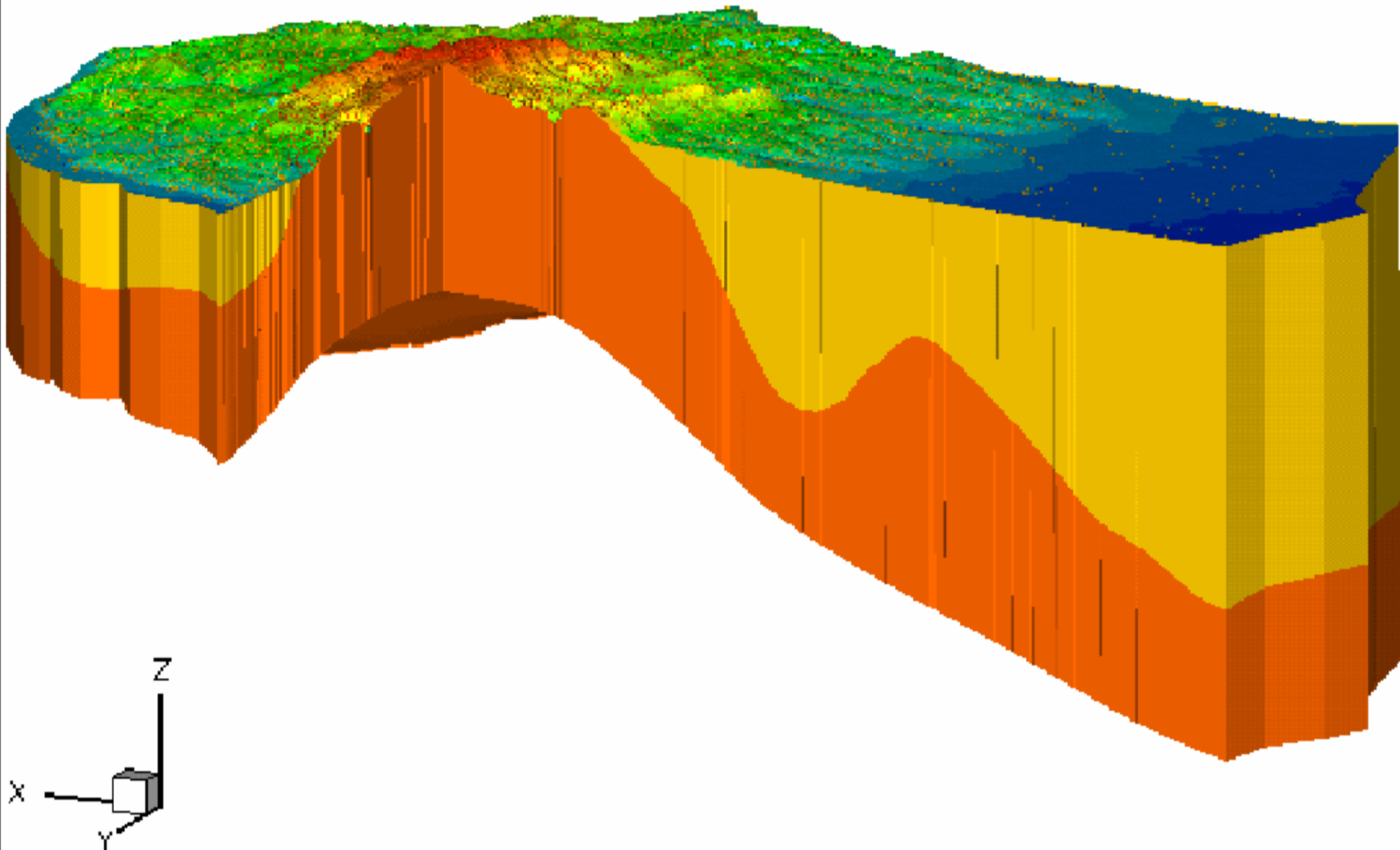
Hydrological Institute of VITUKI Plc.

# Regional Modell DEM

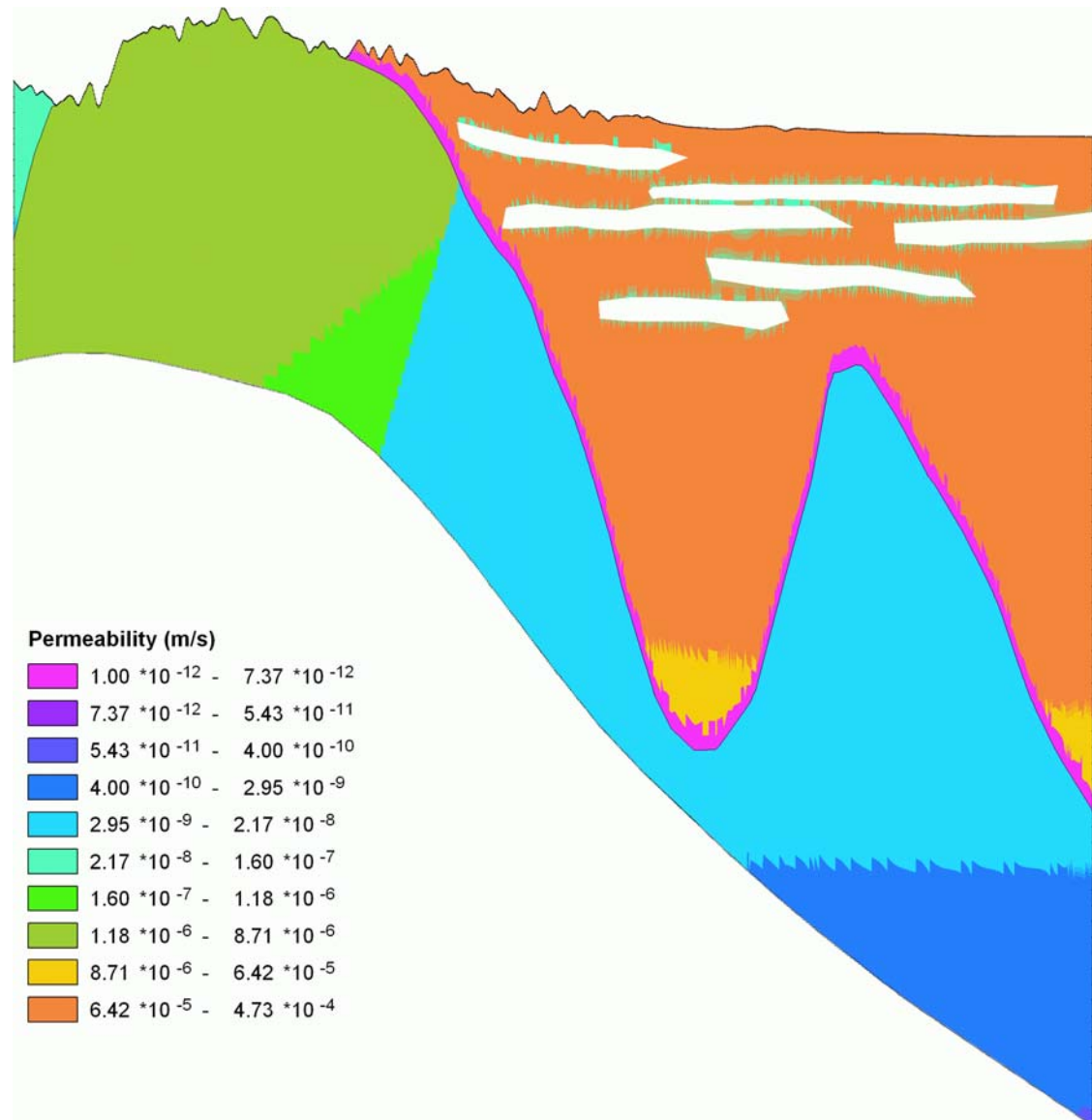


# Top of the Basement Layers

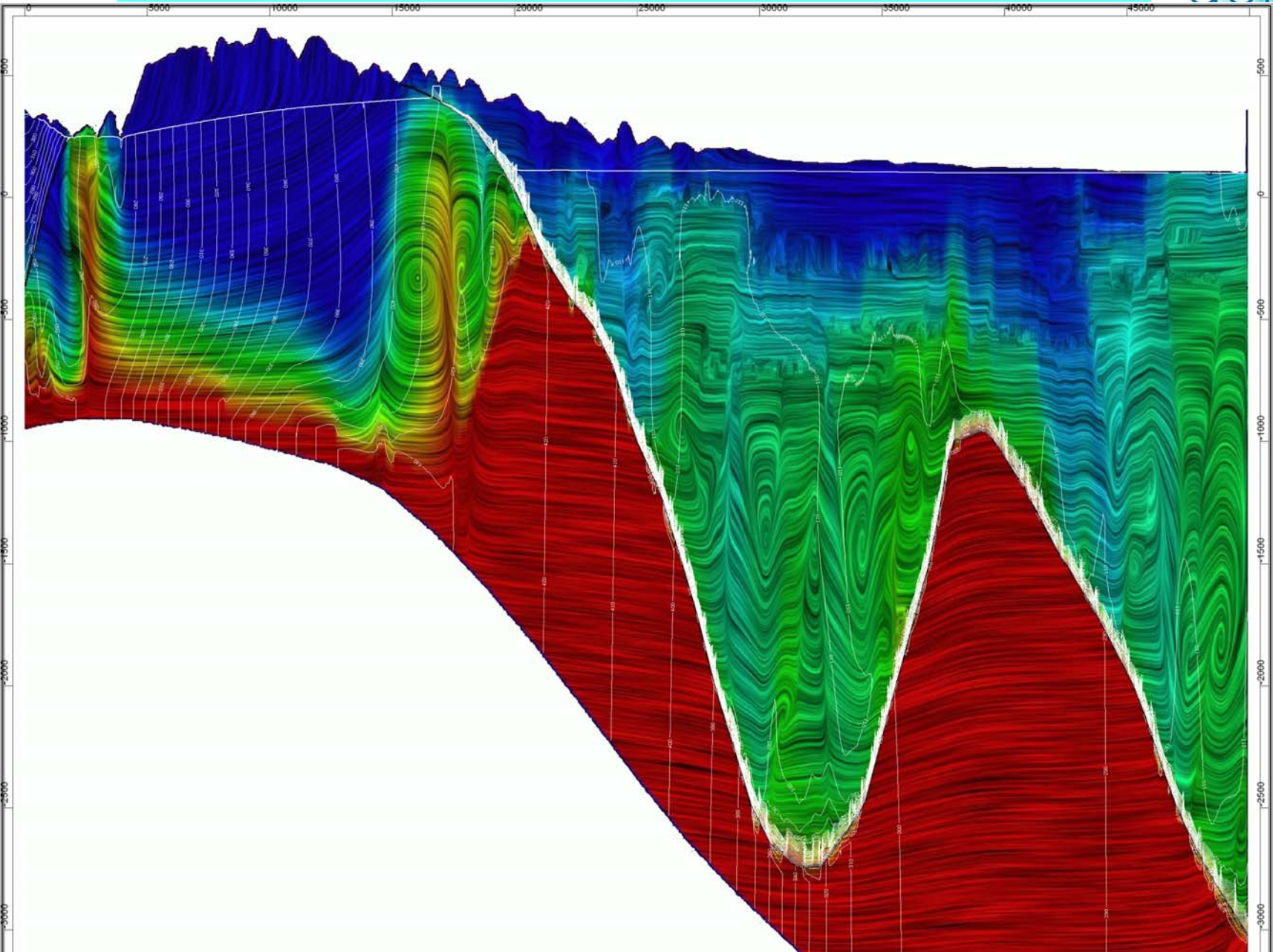




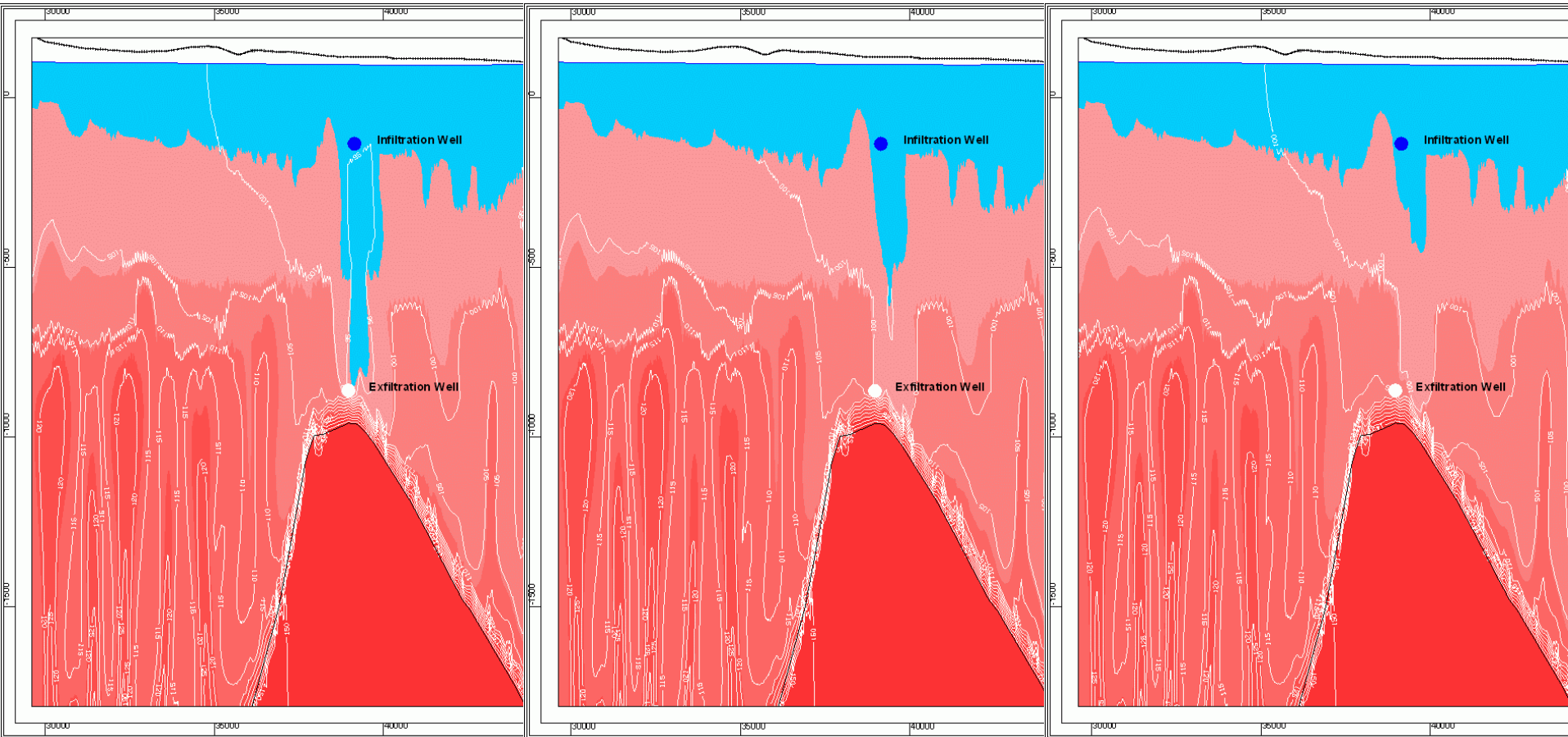
# Cross Section – Permeabilities



# Cross Section – Heat Transport and Ground Water



# Prognosis - Variation of Drawdown and Re-Infiltration



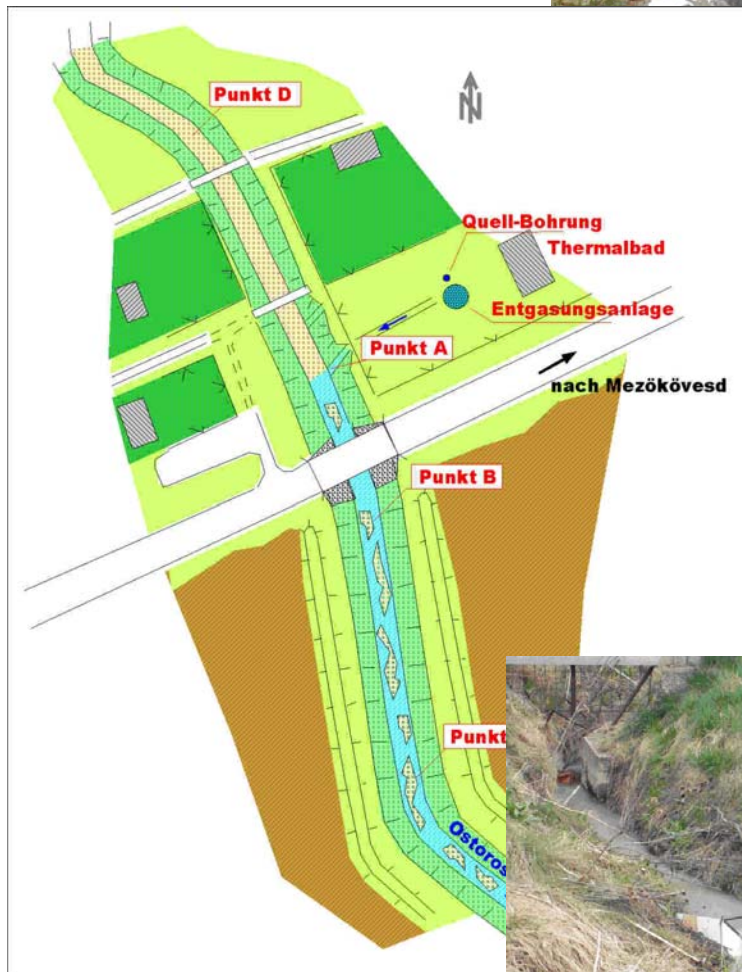
**150.000 m<sup>3</sup>/a**

**60.000 m<sup>3</sup>/a**

**30.000 m<sup>3</sup>/a**



# Site Investigation – data management



EnvPollMod - Auswahlgebiet

**EnvPollMod** Auswahl Gebiet: Mezökövesd

Area Kennwerte Aufschlüsse Dokumente Literatur

**Aufschlusspunkte**

Stammdaten Schichtenverzeichnis Proben GW-Messungen Sonstige Daten

Stammdaten Schichtenverzeichnis Proben GW-Messungen Sonstige Daten

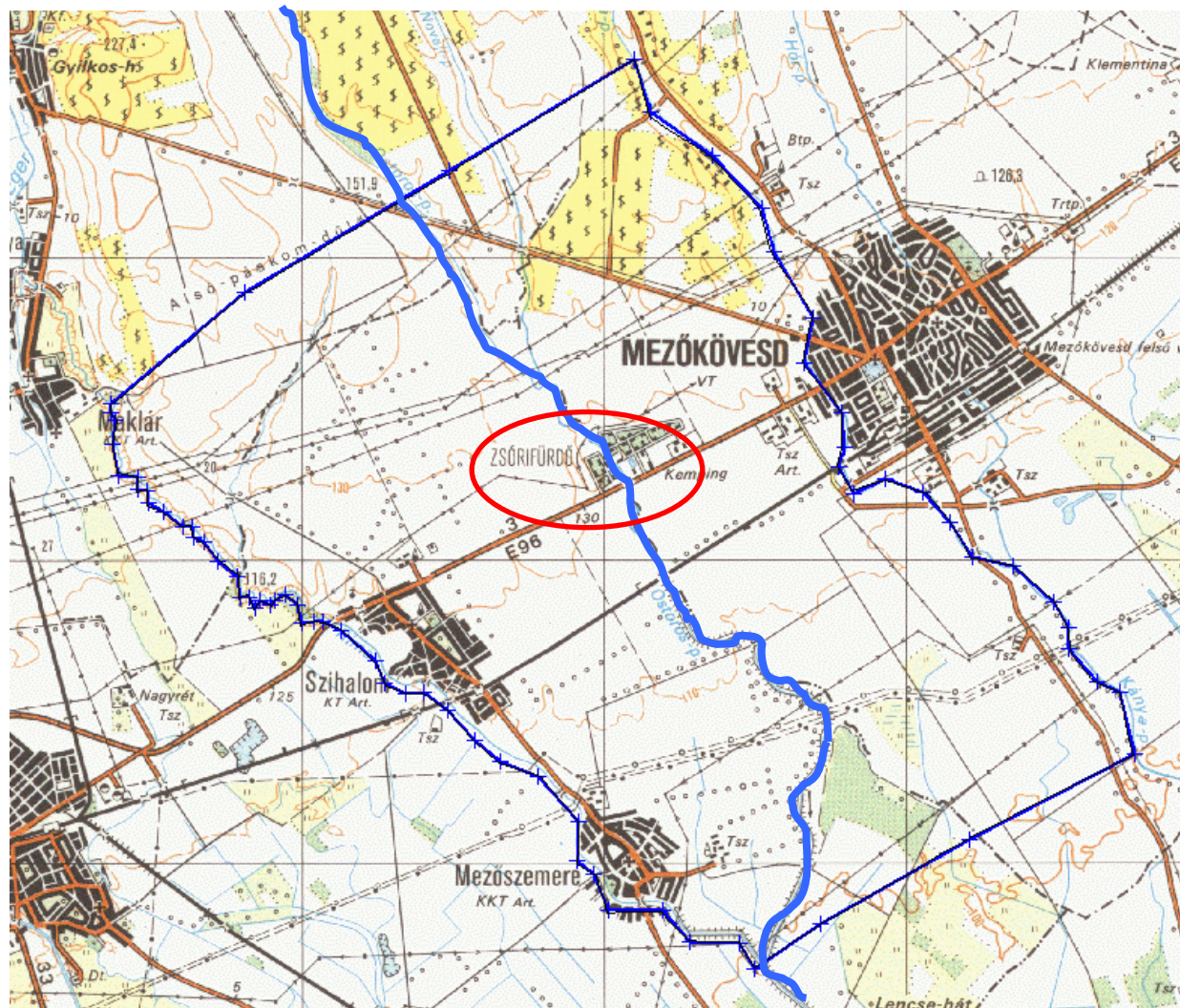
Stammdaten Schichtenverzeichnis Proben GW-Messungen Sonstige Daten

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Stammdaten Schichtenverzeichnis Proben GW-Messungen Sonstige Daten

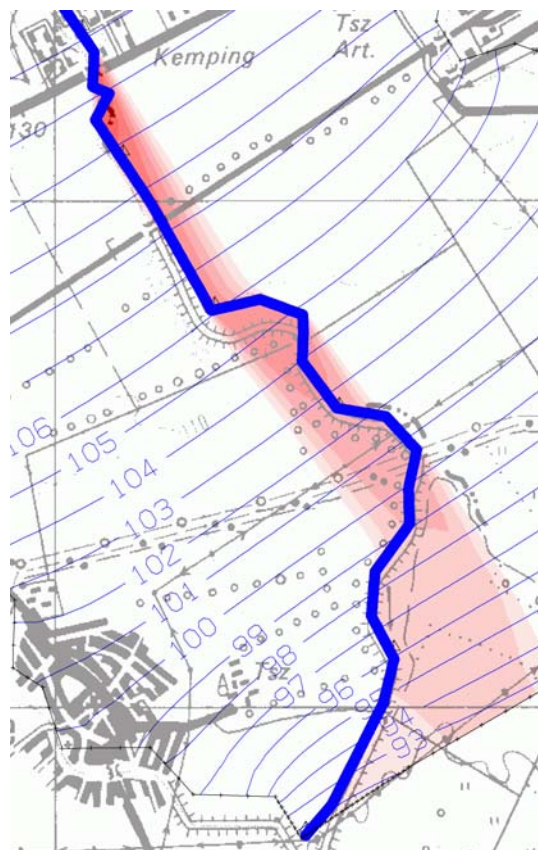
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03.07.1999	3,58	30,4
02.07.1999	3,55	30,4
01.07.1999	3,50	30,5
*		

# Lokal Model

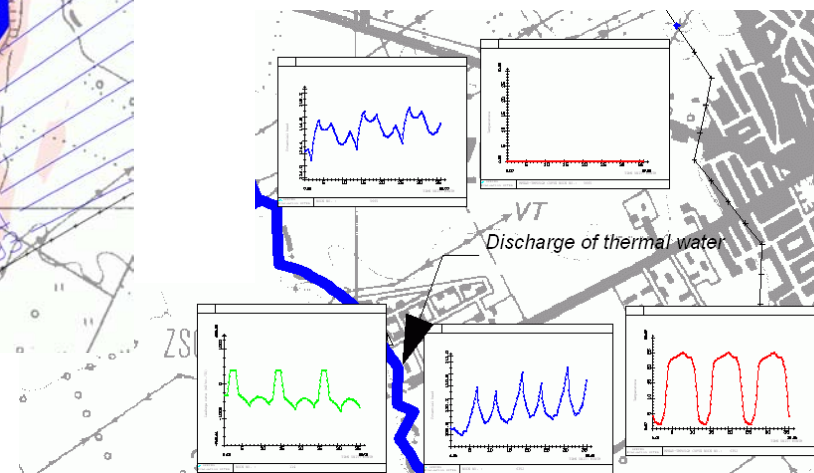
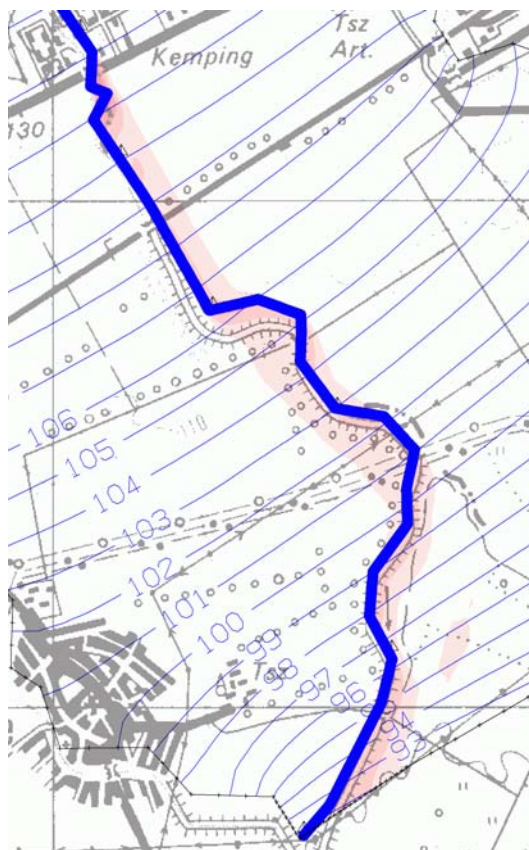


# Prognosis of 2D Modeling - Sensitivity

steady state



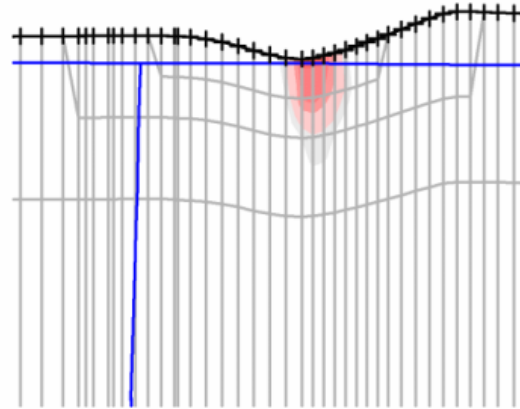
transient



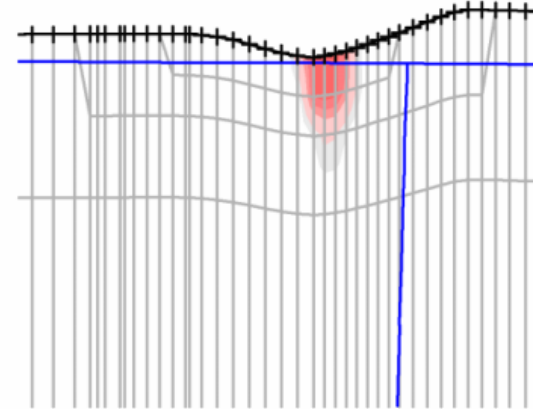
# 3D Detail Model – Heat Transport



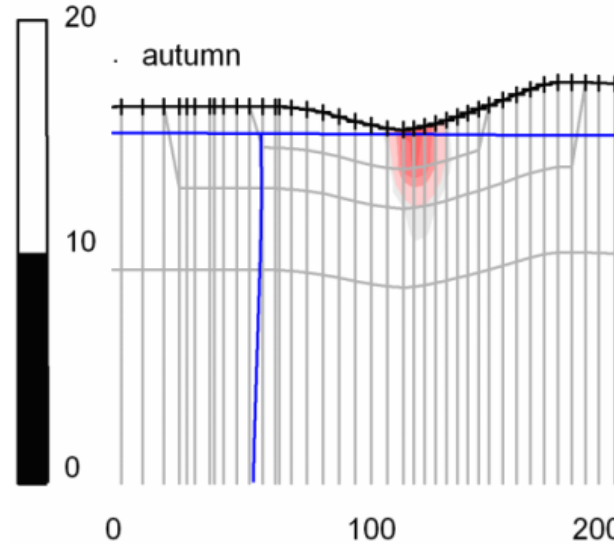
spring



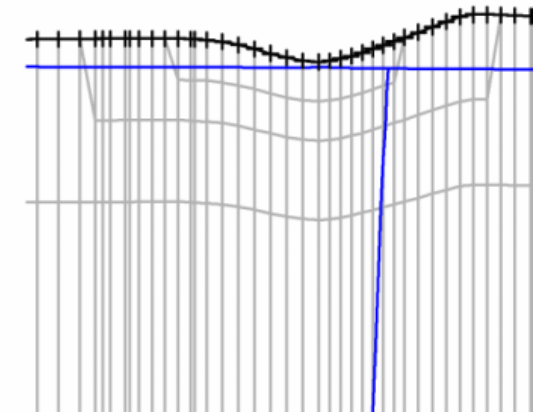
summer



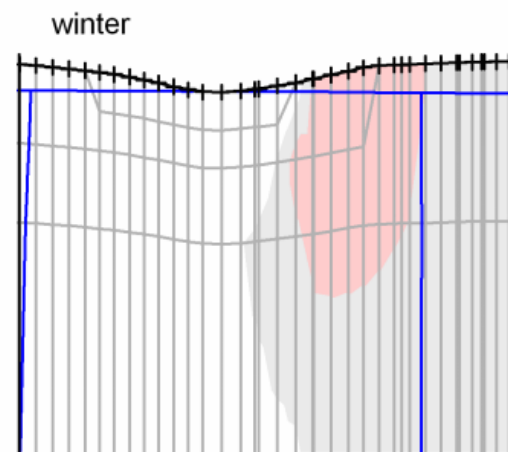
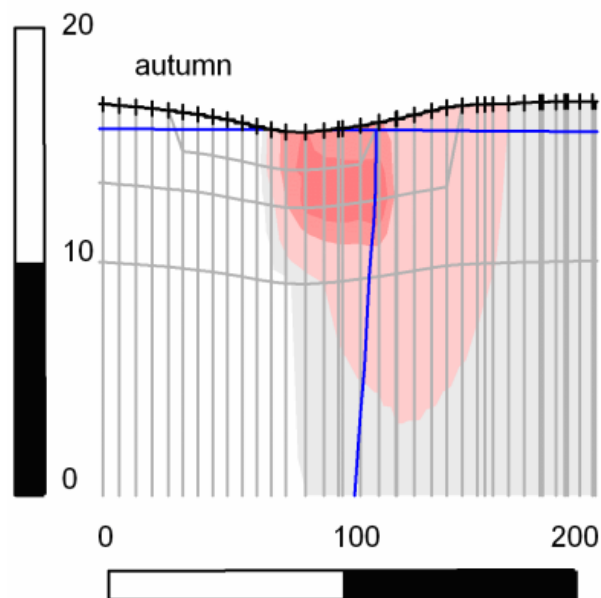
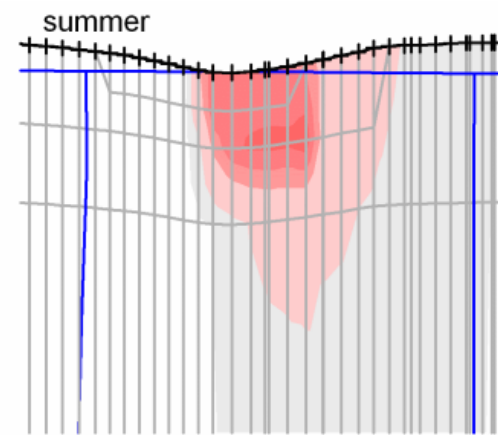
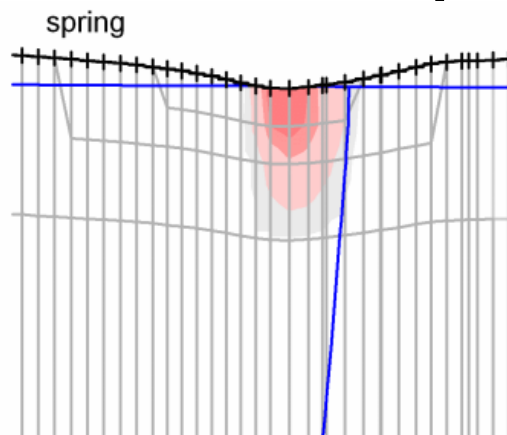
autumn



winter



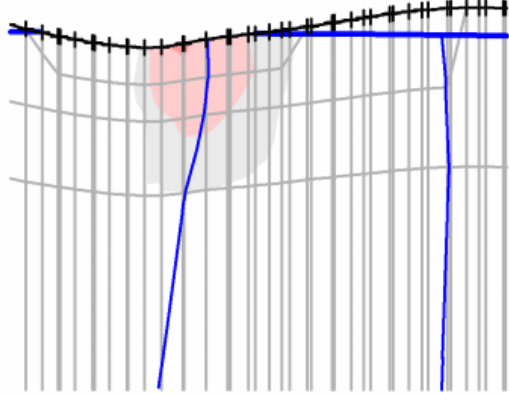
# 3D Detail Model – Heat Transport



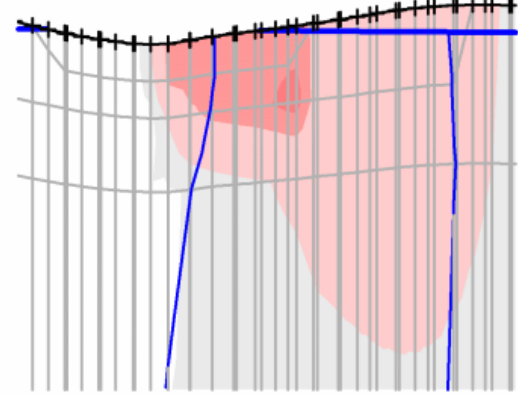
# 3D Detail Model – Heat Transport



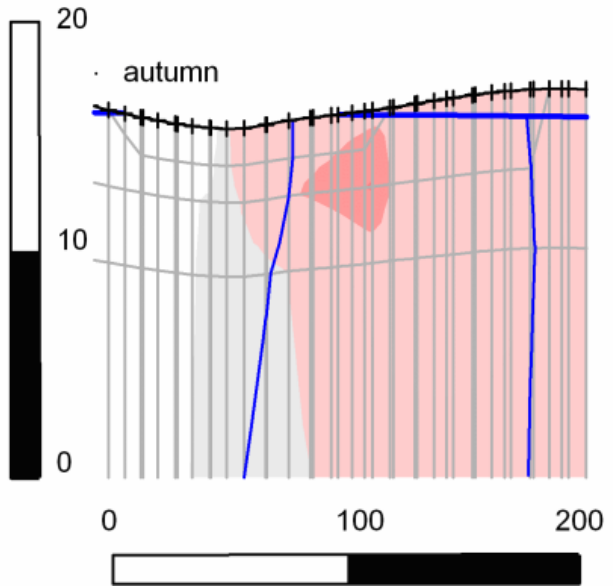
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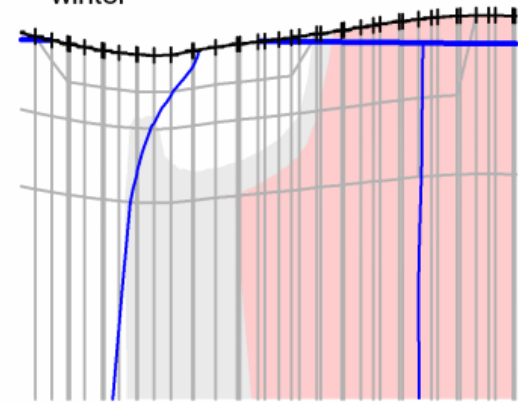
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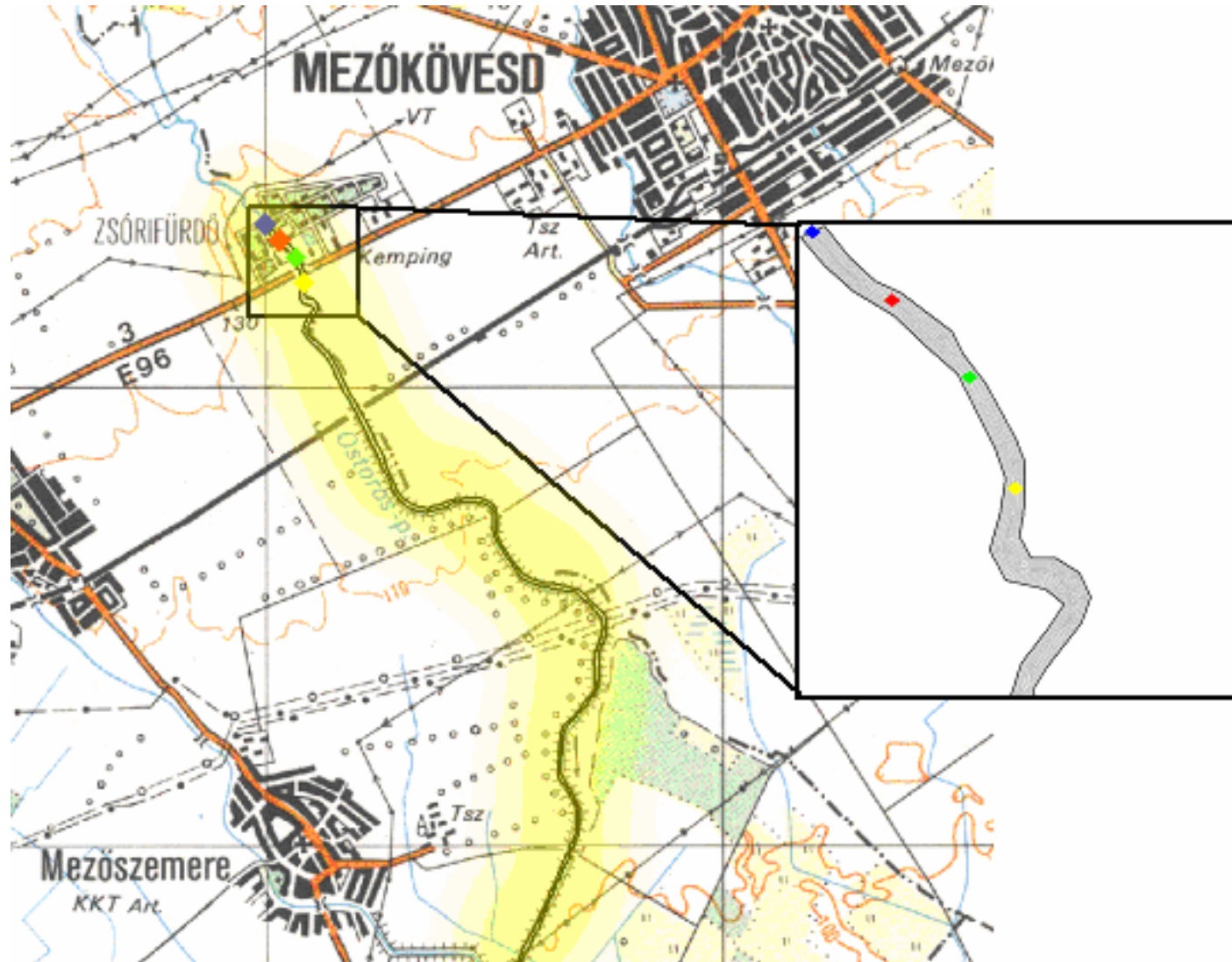
autumn



winter



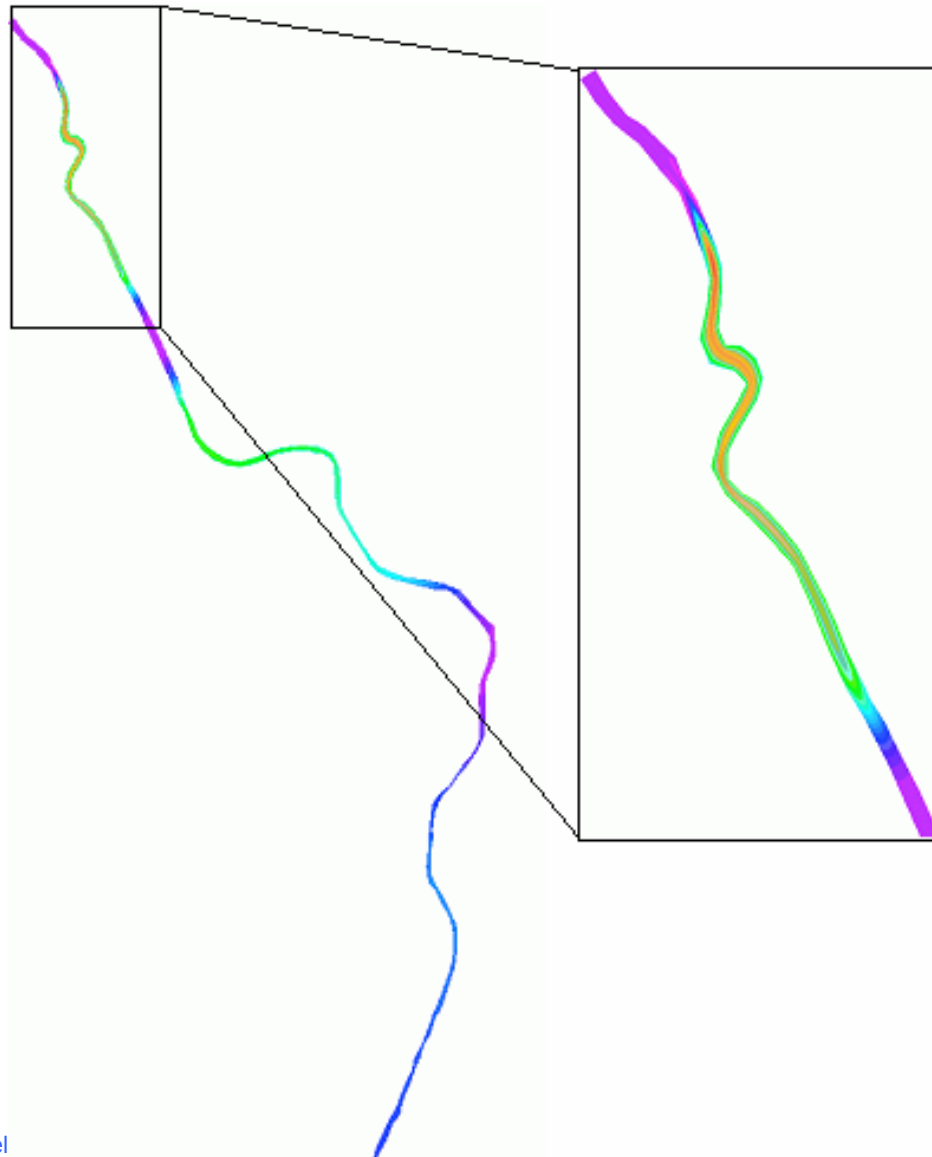
# Transport Modeling



# Transport Modeling Nickel

## LEGENDE

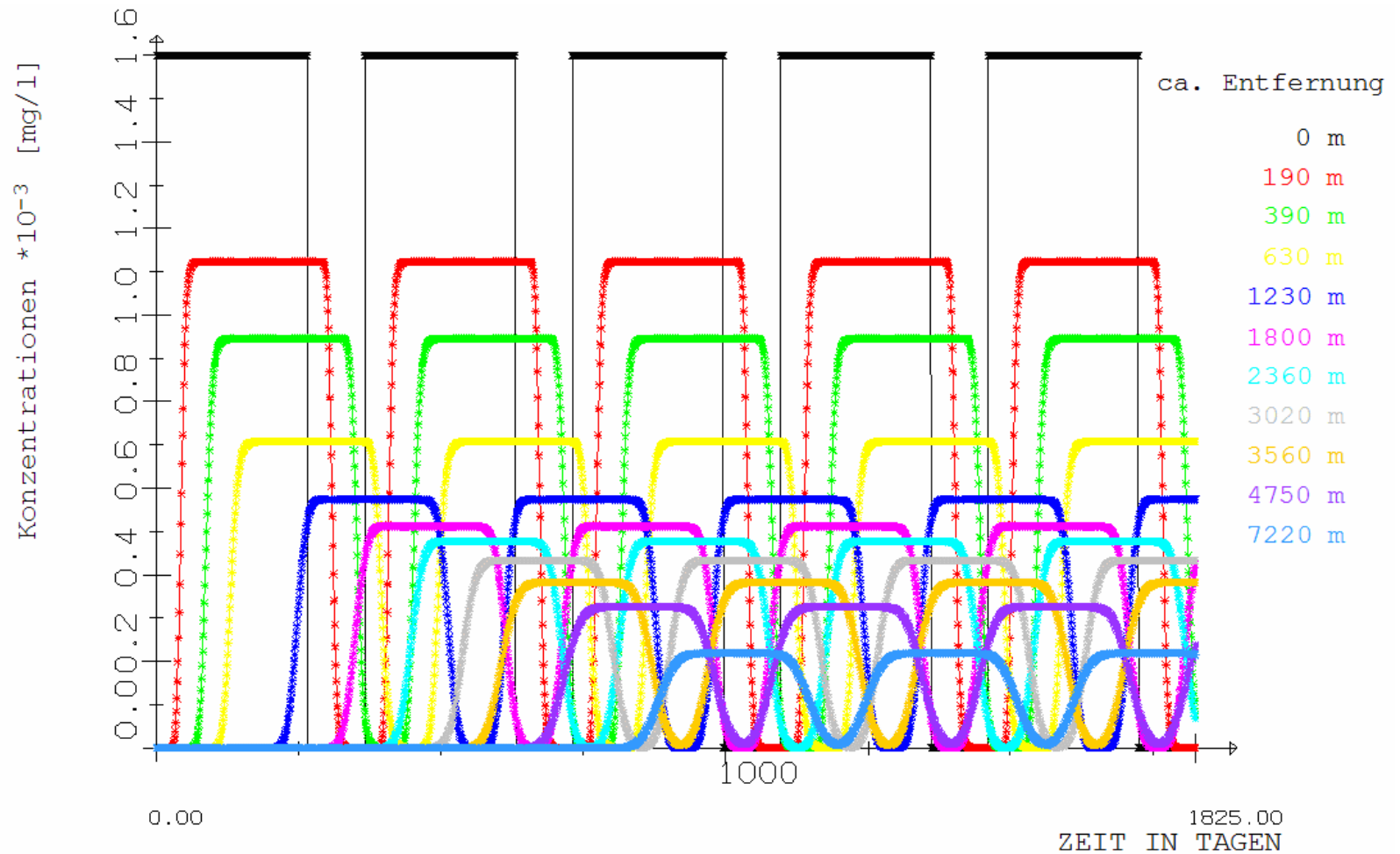
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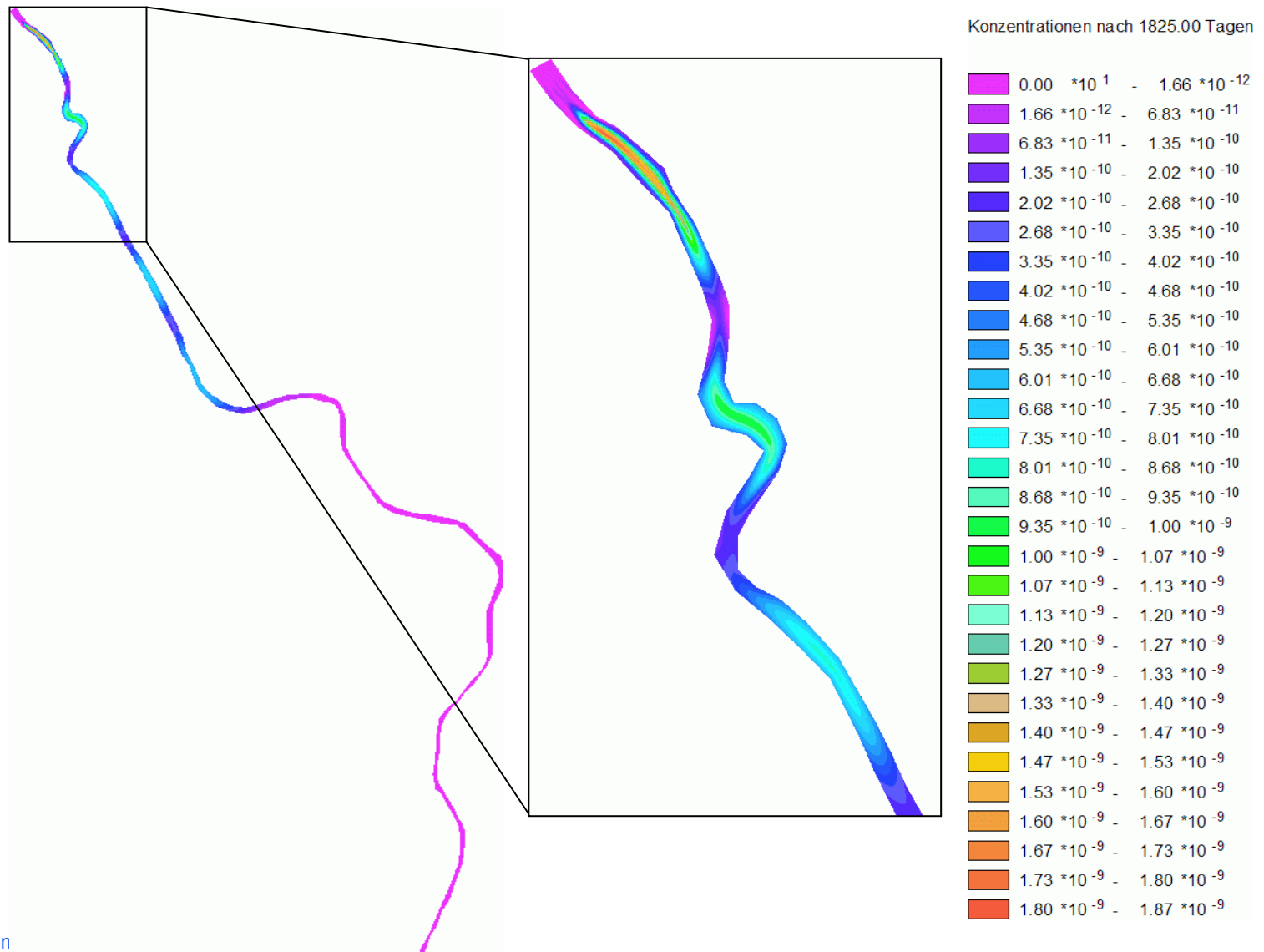
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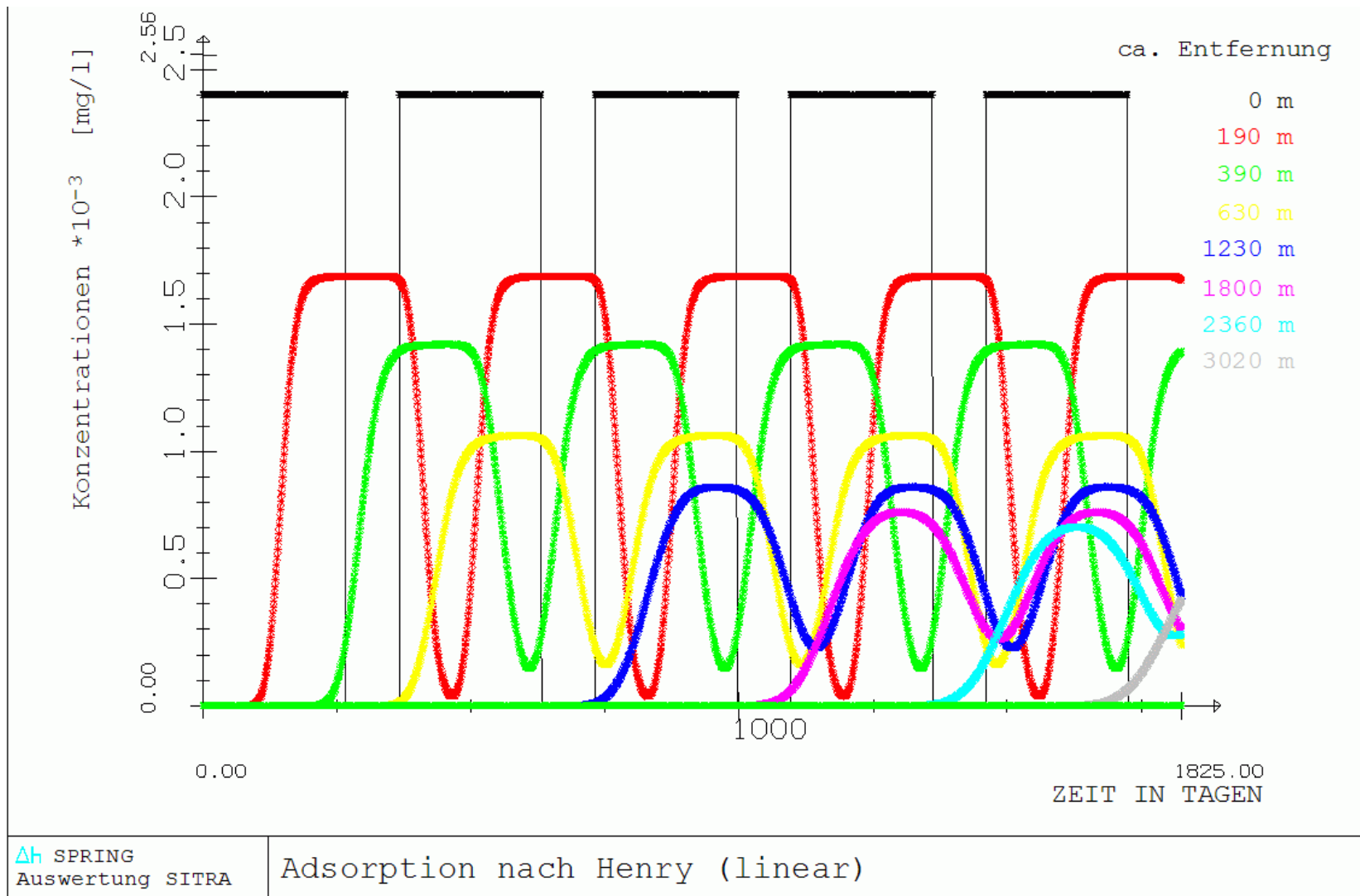
# Transport Modeling Nickel



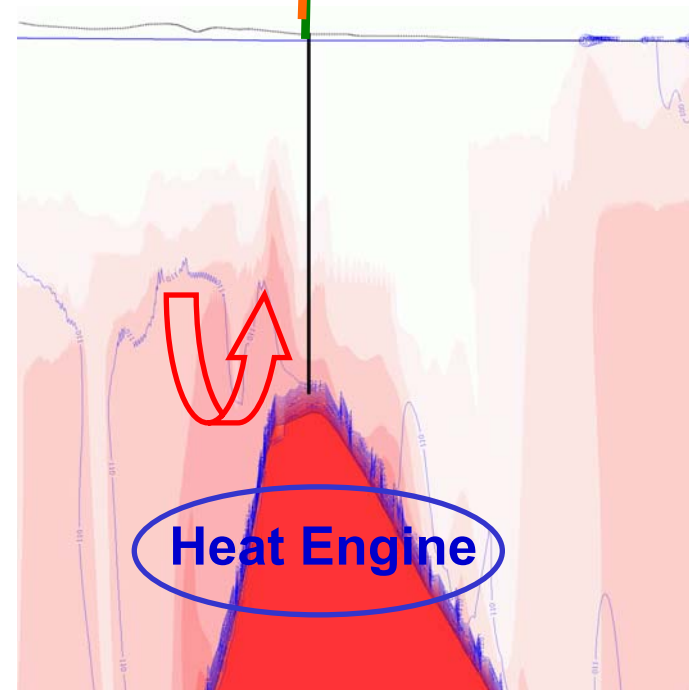
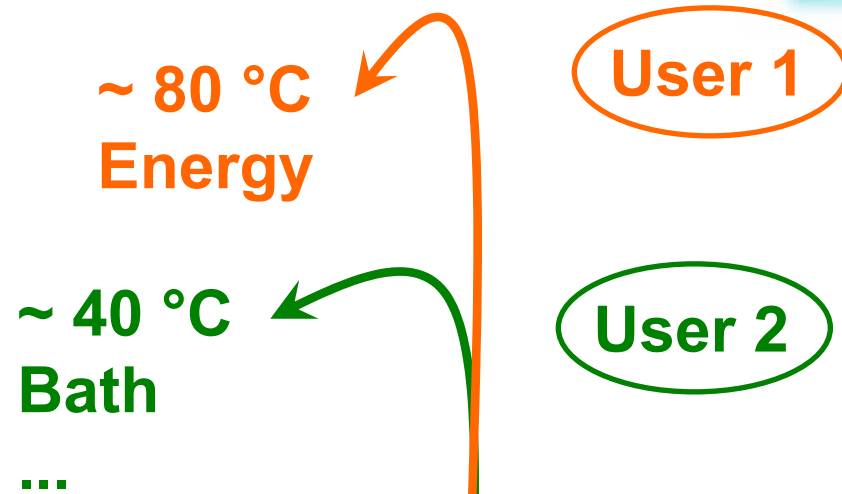
# Transport Modeling Chrome



# Transport Modeling Crome



# Sustainability



# Resulting Views

