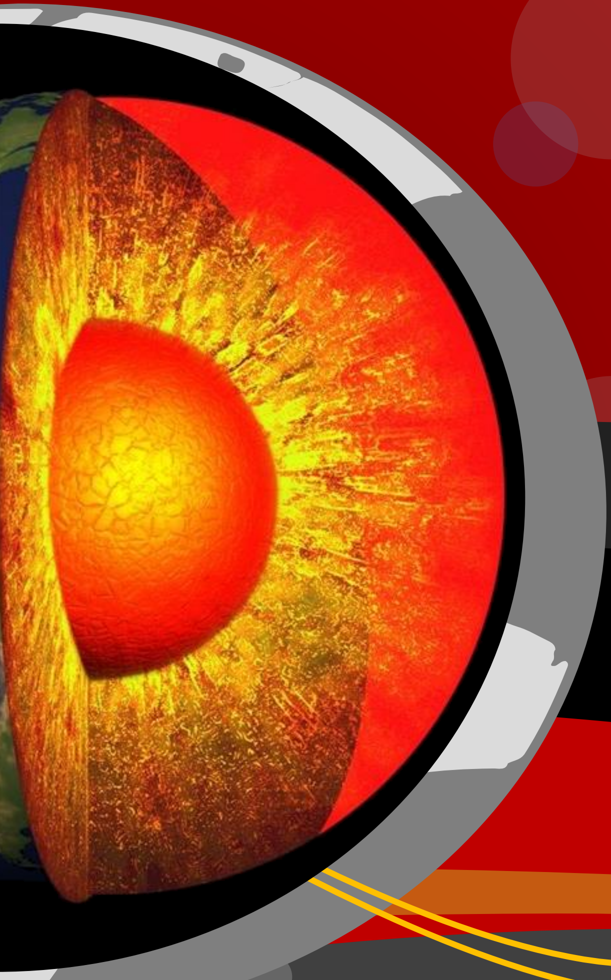
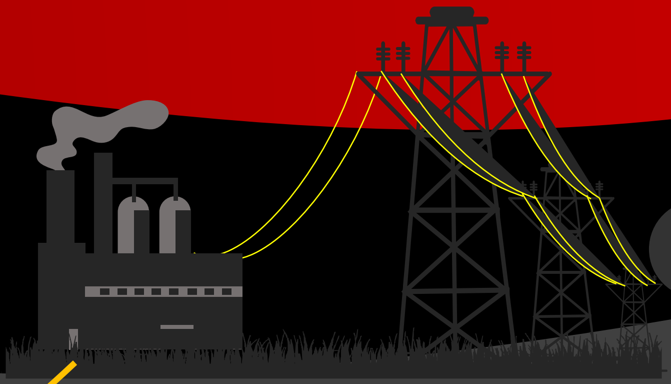
University of Miskolc
Faculty of Earth Science and Engineering
Institute of Environmental Management
Department of Hydrogeology and Engineering Geology

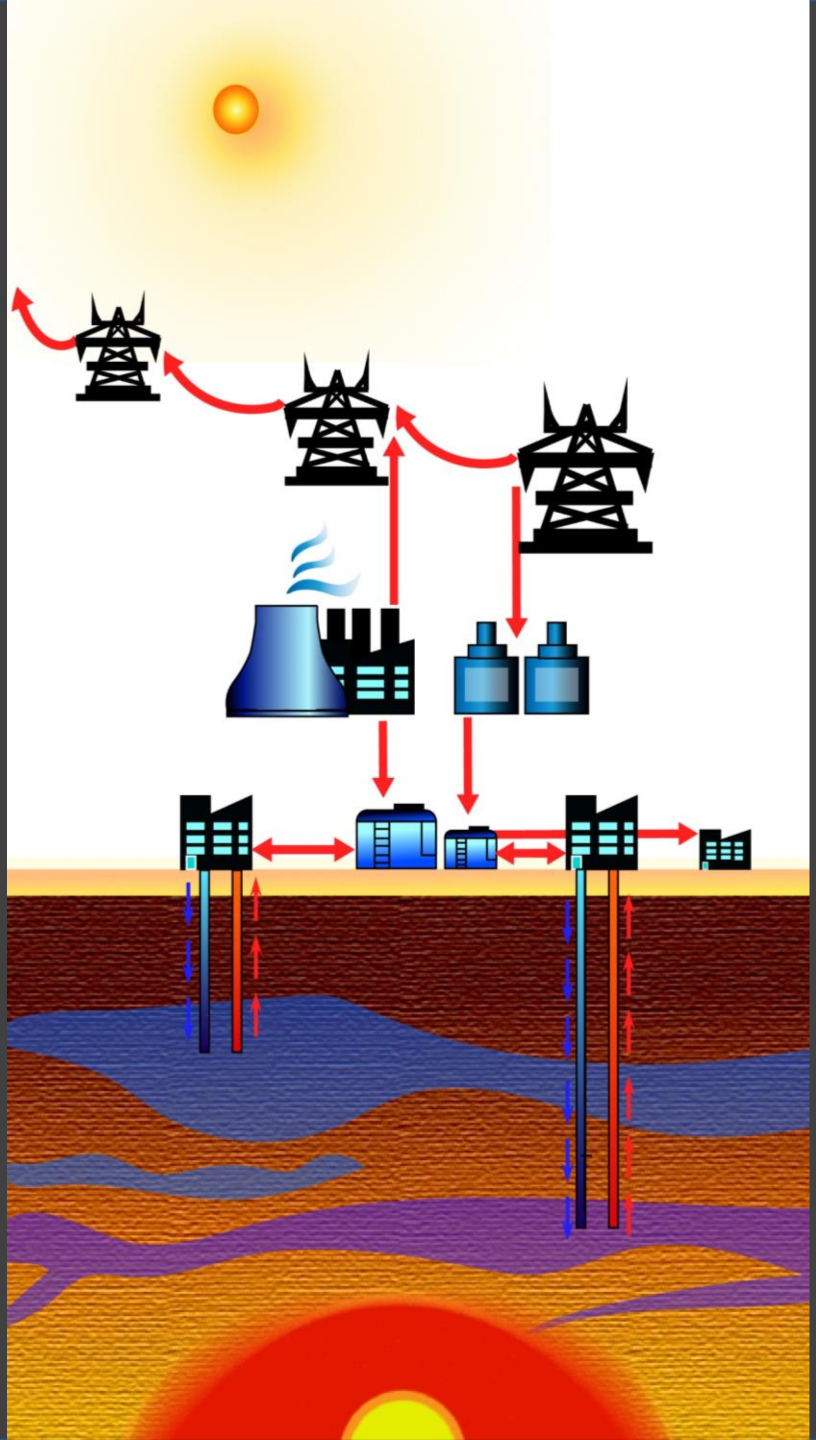


3D Numerical modelling and experimental simulations on thermal behavior of aquifer thermal energy storage in Tiszaújváros



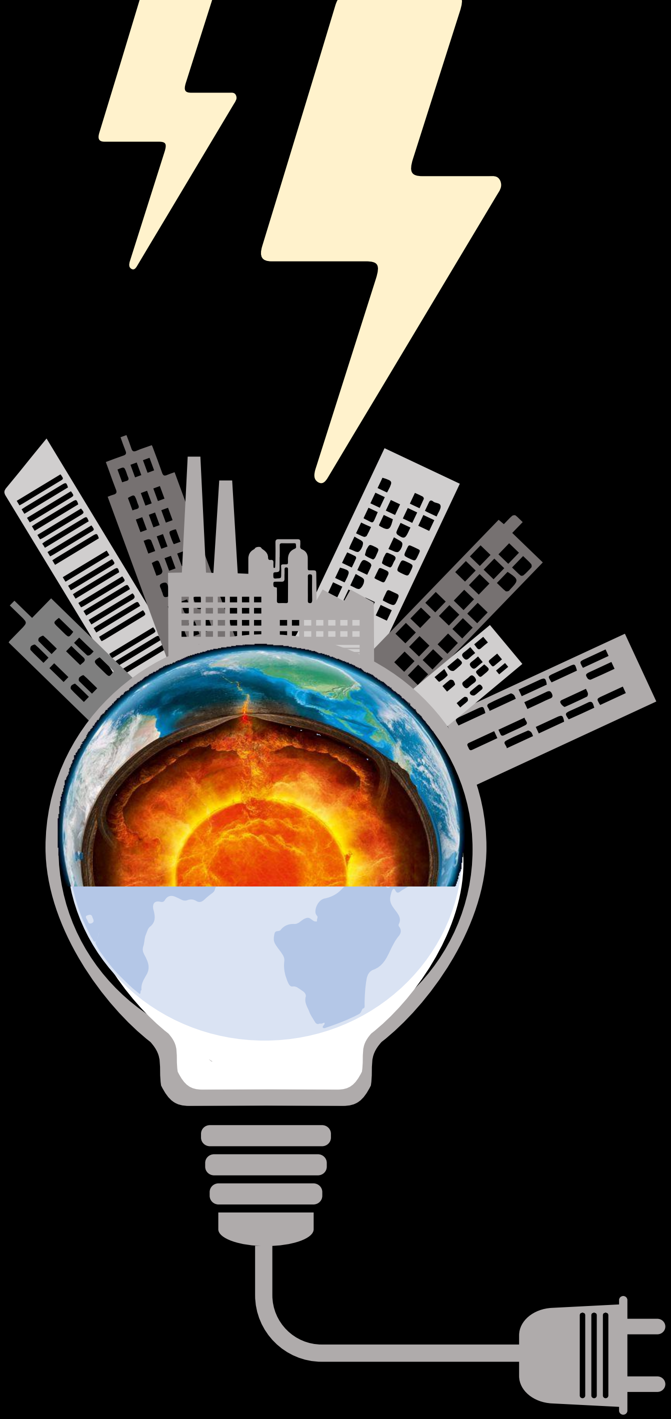
Department supervisor:
Gábor Nyiri
Dr. Péter Szűcs

Presented by
Udomporn TUPBUCHA



TOPICS

1. INTRODUCTION
2. LITERATURE REVIEW
3. MATERIALS AND METHODS INVESTIGATION
4. SITE DESCRIPTION
5. RESULTS
6. CONCLUSION



INTRODUCTION

Issue

To increase renewable energy for the balance of the global energy demand and supply without releasing pollution to the environment.

Challenge

Identify thermal behavior of the seasonal aquifer thermal energy storage (***ATES***) system.

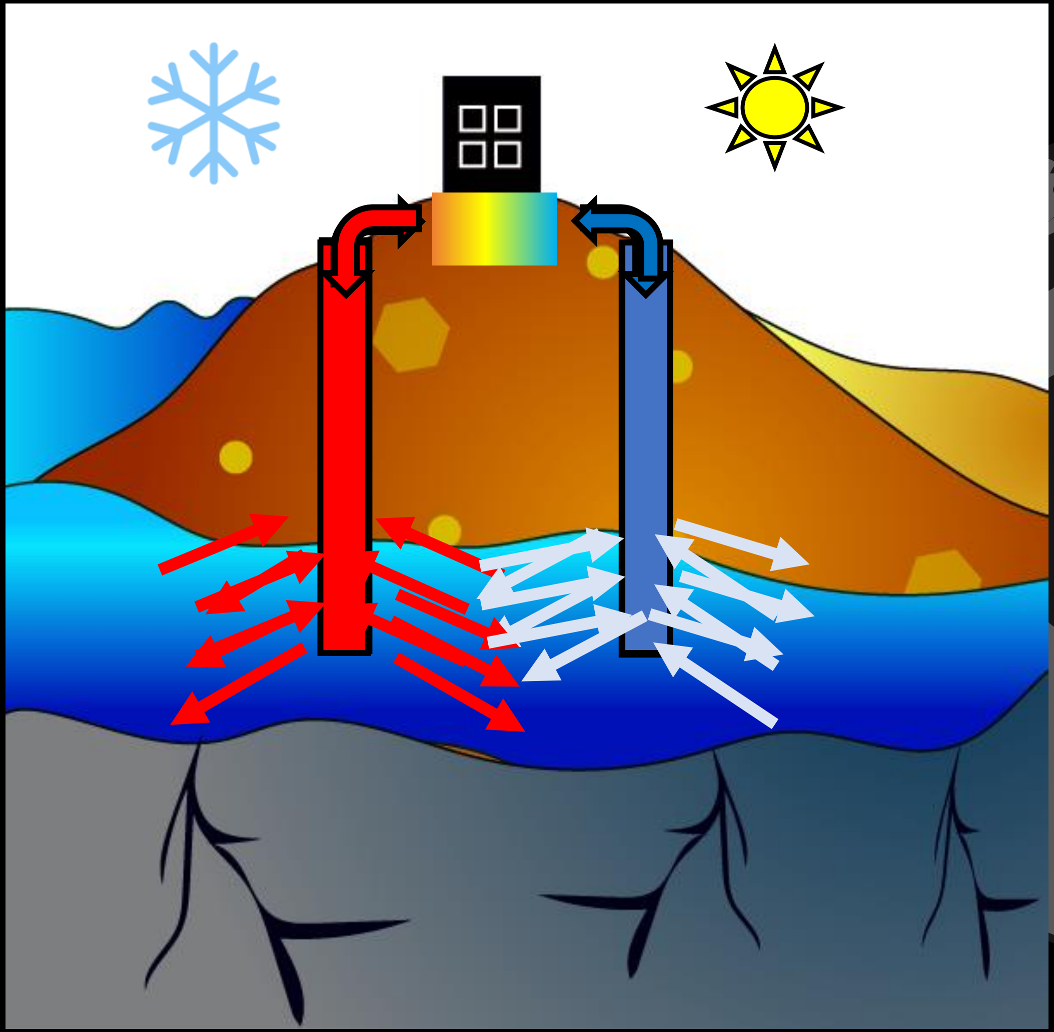
Process

A three-dimensional groundwater flow simulation program ***MODFLOW***, and a heat flow simulation by the multi-species mass transport simulation program ***MT3DMS***.

Objective

To analyze through potential geothermal energy of the ATES system for heat production energy supply for the domestic area.

LITERATURE REVIEW



Aquifer thermal energy storage (ATES)

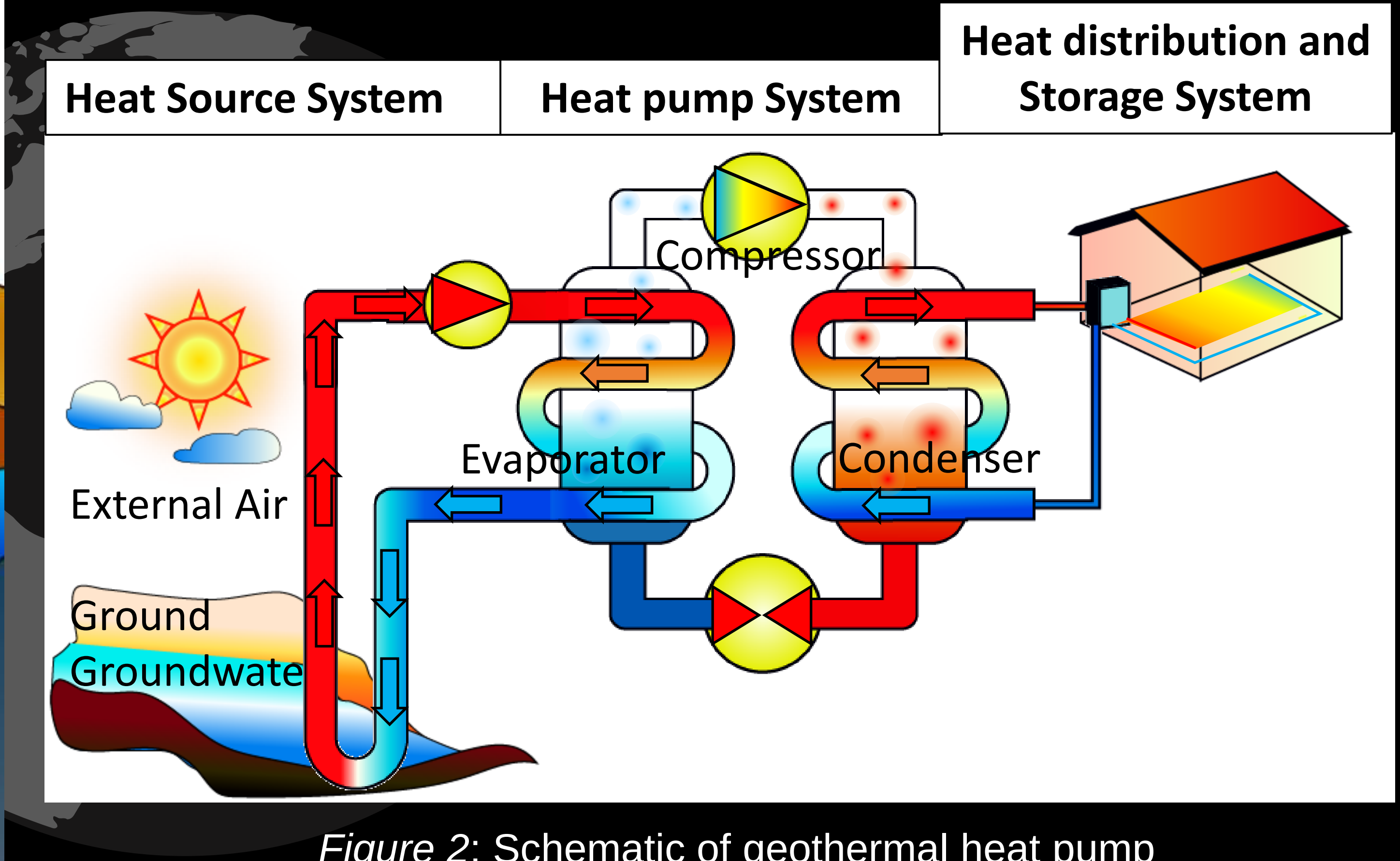


Figure 2; Schematic of geothermal heat pump
Image source; https://www.researchgate.net/publication/316919670 (Melissa, 2020).

Figure 1; Principle operation of an ATES doublet system in winter and summer
Image source; CHAPTER 7 Seasonal Thermal Energy Storage Technologies for Sustainability (S. Kalaiselvam and R. Parameshwaran, 2014).

SITE DESCRIPTION

2 major types of geothermal reservoirs in HUNGARY

1) Porous reservoirs are found between 700 to 1,800 m with temperature between 50 to 75 °C, and consisted of layers of coarse sand and gravel of the clastic basin deposits or called Upper Miocene-Pliocene "Pannonian" basin-fill sequence

2) Karstic thermal reservoirs are found at 2,000 m depth or more. The temperatures can be between 100 to 120 °C. as medium-enthalpy in the group of karstic rocks that are found in almost half of the hilly areas covering one-fifth of Hungary's territory.

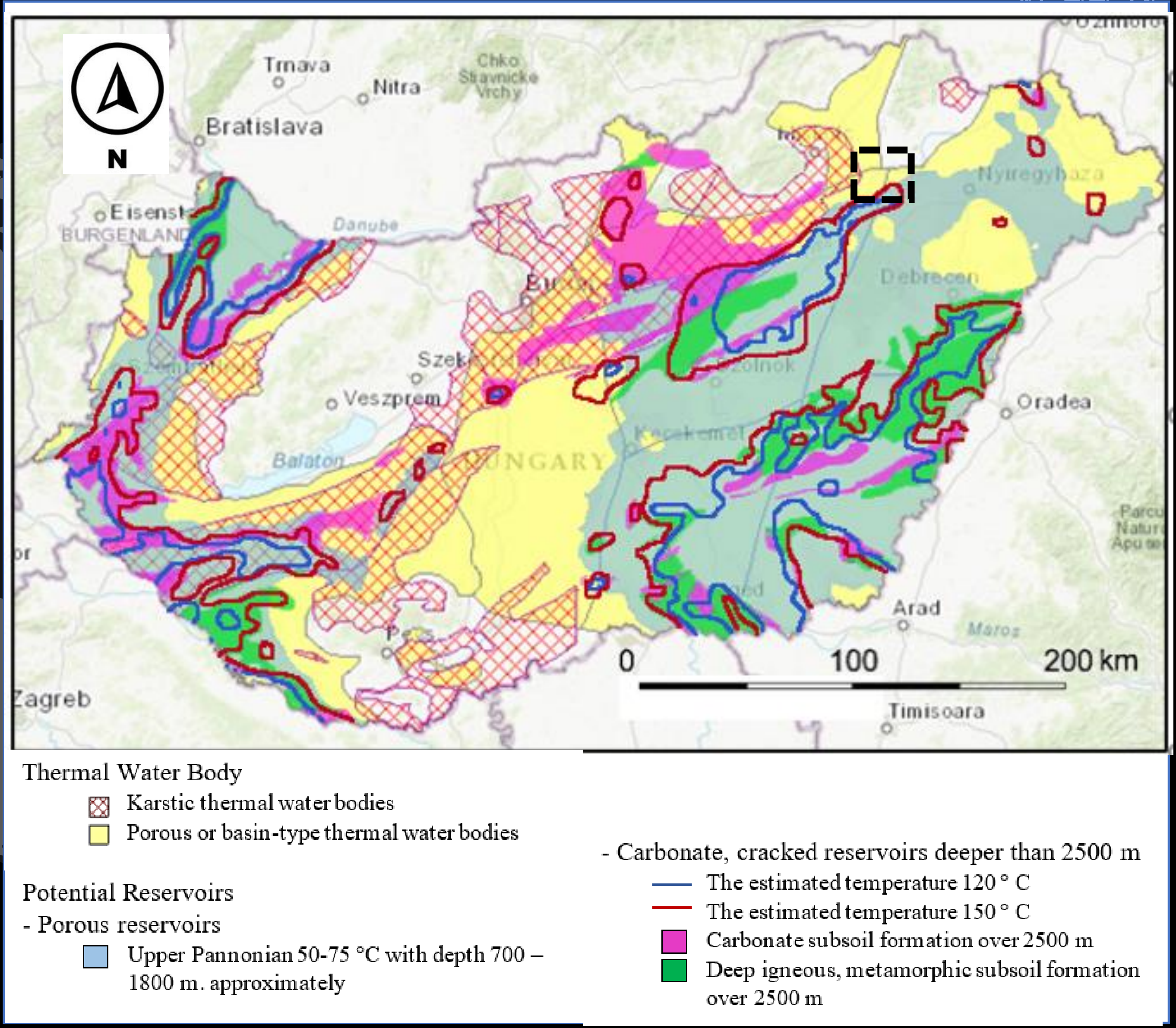


Figure 3; Thermal water body and potential reservoirs.

Image source; https://map.mbfsz.gov.hu/ogre_en/ (National Geothermal System (OGRe))

SITE DESCRIPTION

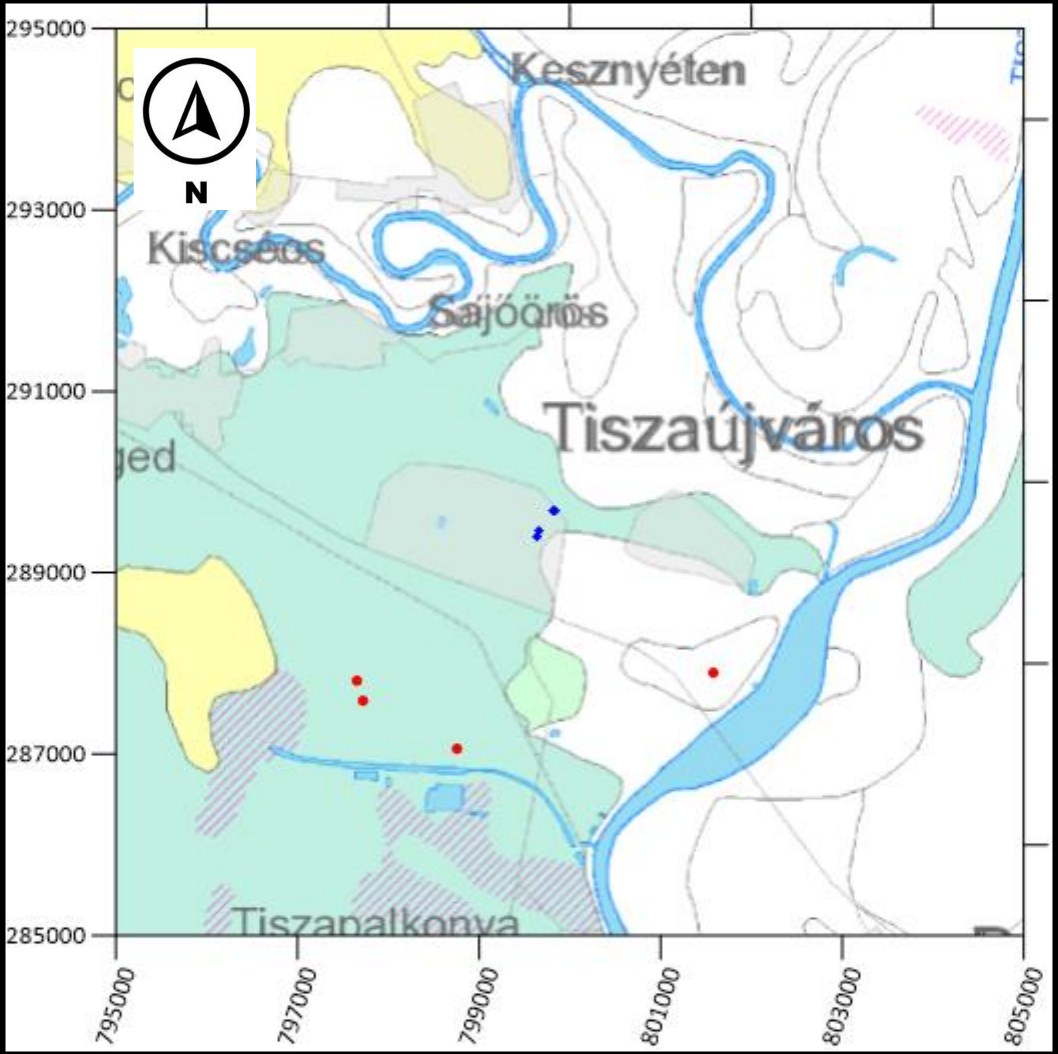


Figure 4; Site map of the Tiszaújváros

Image source; https://map.mbfsz.gov.hu/ogre_en/ (National Geothermal System (OGRe))

Tiszaújváros.

- ➢General information
- ➢Description of the wells

SITE DESCRIPTION

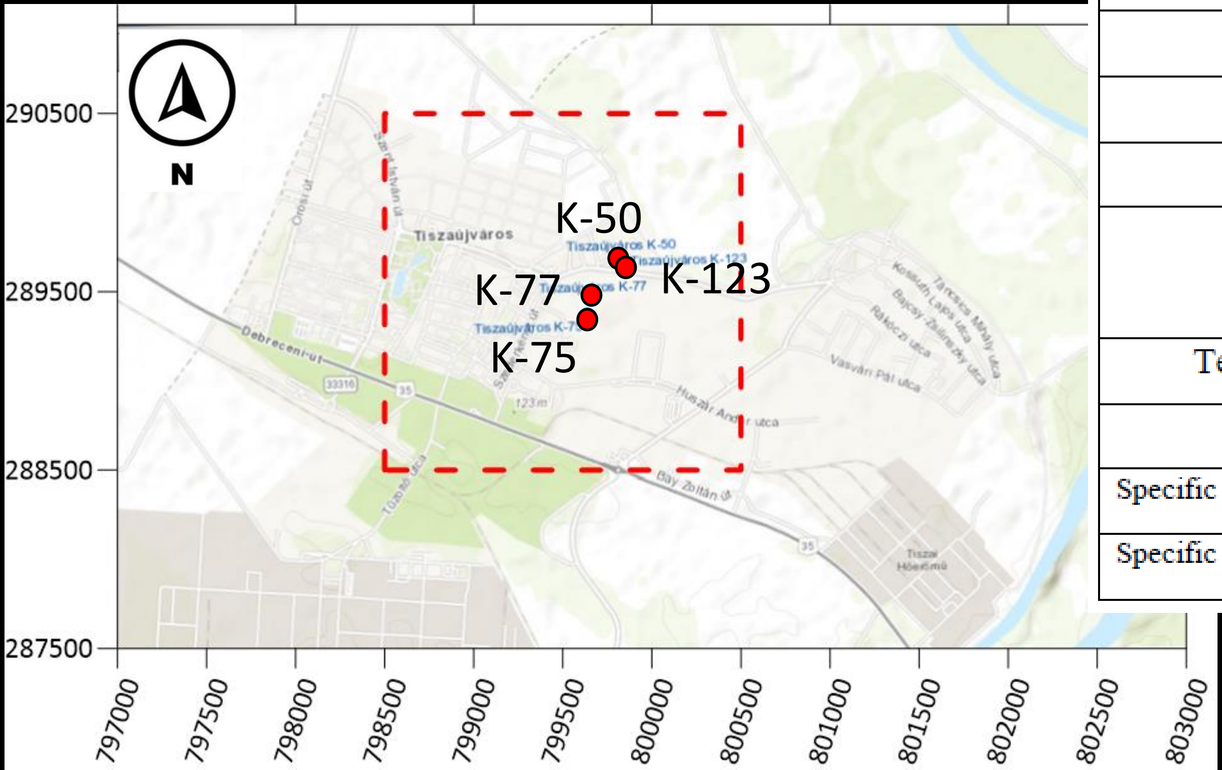


Figure 5;Location of the four thermal wells

Image source; https://map.mbfsz.gov.hu/ogre_en/ (National Geothermal System (OGRe))

Description		K50	K75	K77	K123	Unit
Location: EOV coordinate	X	799824.44	799632.76	799644.83	799844.97	
	Y	289693.53	289389.15	289459.79	289677.27	
Top Elevation		94.155	94.155	94.59	93.94	mBsl.
Depth		1,177	686.00	1,268.0	1,177.8	m.
Water Table		111.16	96.16	78.69	69.88	Bsl.
Floor heat		1,173.8	658.0	1,253.0	1,170.6	m
		64.5	41	72	65.61	°C
Temperature of water		58	35	64	57.50	°C
pH		7.70	8	7.6	7.7	
Specific total Gas Content, GVV		472.56	87.47	257.2	309.85	l/m^3
Specific total methane content, MVV		295.43	27.28	97.06	125.8	l/m^3

Table 1; Description of the wells

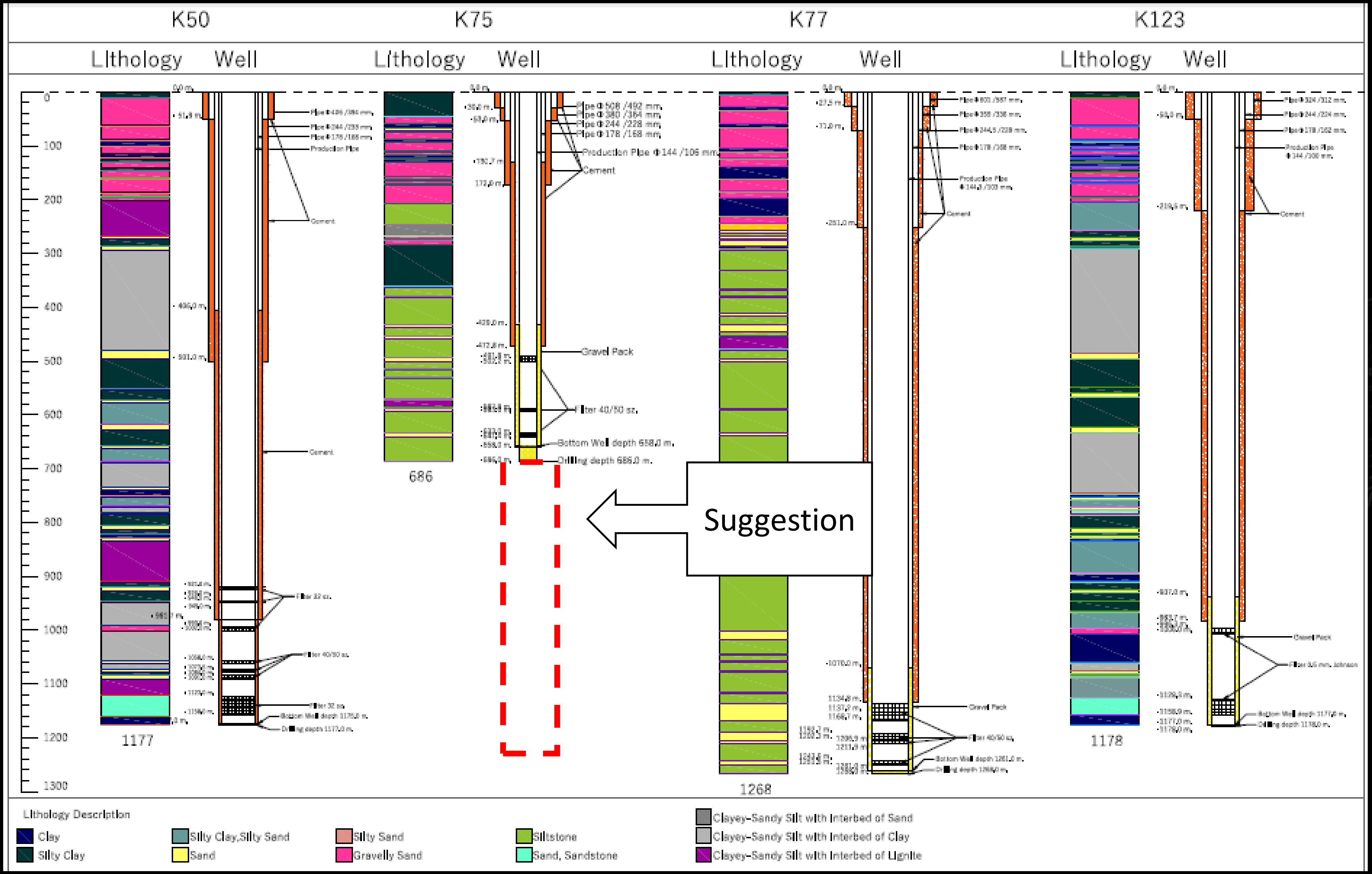


Figure 6; Lithology and well construction of the four thermal wells

MATERIALS AND METHODS INVESTIGATION

Modelling of ATES system

1) ***Groundwater flow modelling MODFLOW***

- using the numerical equation:

  finite difference method (FDM)

- specified head boundaries
- specified flow boundaries
- head-dependent flow

Table 2; Aquifer hydraulic input parameters

Layer	Layer Material Description	Hydraulic properties			
		K (m/d)	Ss	Sy	Porosity
1	Top Soil, Silty clay, Clay, and layer of sand	1.78×10^{-4}	1.2×10^{-6}	0.10	0.18
2	Pebbly coarse-sand	432	1×10^{-4}	0.32	0.36
3	Clayey-Sandy Silt with interbed of Lignite	1.78×10^{-3}	1.4×10^{-5}	0.18	0.20
4*	Sand, sandstone	43.2	1×10^{-4}	0.27	0.32
5	Clay	8.64×10^{-10}	2.4×10^{-4}	0.20	0.20

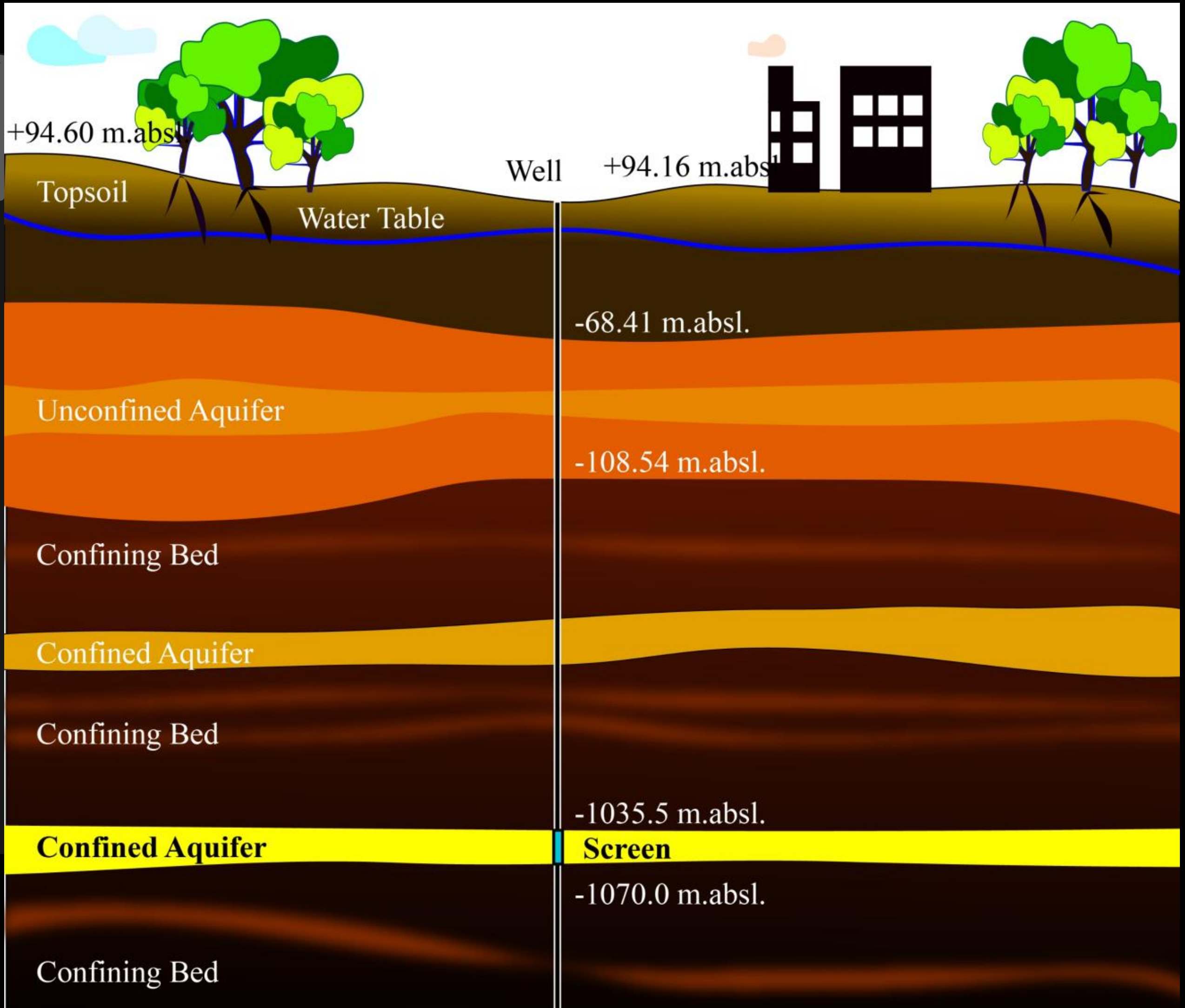


Figure 7; Aquifers main properties in the study area

MATERIALS AND METHODS INVESTIGATION

Modelling of ATES system

Model parameter	Symbol	Value	Unit
Temperature of injecting constant hot water	-	333.15 K (60 °C)	
Effective thermal conductivity of the porous media	λ_b	2.7	W/m/K
Volumetric heat capacity of the water	$\rho_w C_w$	4.19 x10^6	J/(m3/C)
Thermal distribution coefficient	K_d	2.10x10^{-4}	m^3/kg
Thermal diffusivity	D_T	1.64x10^{-6}	m^3/s
Longitudinal dispersivity	α_L	0.5	m
Horizontal transverse dispersivity	α_{TH}	0.05	m
Vertical transverse dispersivity	α_{TV}	0.05	m
Dry bulk density	ρ_b	1961.0	kg/m^3
Specific heat capacity of the soil	C_s	880	J/kg/K
Retardation factor	R	2.37	-
Sorption Method	-	Linear Isothermal	
Geothermal gradient;	-	50°C/1000 m	

Table 3; Thermal input parameters

2) Heat transport modelling MT3DMS

- basic transport package (BTN),
- advection package (ADV),
- dispersion package (DSP),
- sink & source mixing package (SSM),
- chemical reactions package (RCT).

By the iterative solver called generalized conjugate gradient solver (GCG).

MATERIALS AND METHODS TO MODELLING

Model construction

A MODFLOW simulation in GMS is used for the groundwater flow model with model domain extension 2000 x 2000 m^2 with a 10 x 10 m^2 cell grids. And 5 horizontal layer with various thickness

Initial condition

The water table and elevation of stratigraphy of layers were interpolated by Kriging method.
The temperature of the model is incresing with the depth respect to geothermal gradient 50°C per 1000 m

Boundary condition

A flow model, northern and southern borders are assumed as no-flow boundaries.
A transport model, the northern and southern boundaries of the domain are no mass flux

Operation conditions

A cyclic mode of the seasonal ATES system using four wells in total is simulated. Injection flow rate 1500 m^3/day for 6 months and production flow rate 2000 m^3/day for 6 months each year, and the cycle is repeated for 25 years

Model assumptions

- the model domain is a homogenous, isotropic, and confined aquifer;
- if any between the aquifer and the confining bed, fluid exchange is negligible;
- the hydraulic and thermal properties of the wells and aquifers are always constant;

Model Experimental scenarios

- A unique well with double function
- A doublet of wells system

MATERIALS AND METHODS TO MODELLING

Model construction

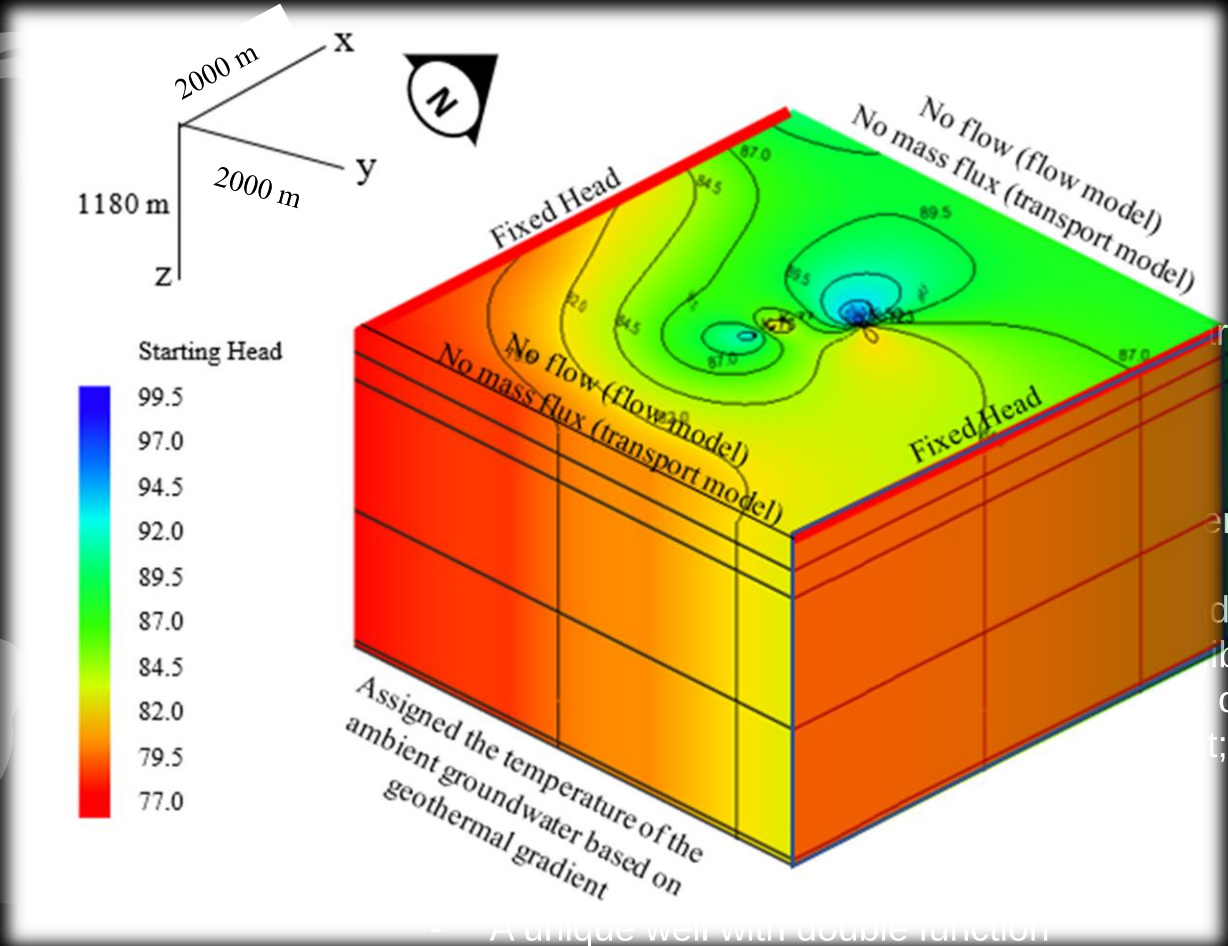
A MODFLOW simulation in GMS is used for the groundwater flow model with model domain extension 2000 x 2000 m^2 with a 10 x 10 m^2 cell grids. And 5 horizontal layer with various thickness

Initial condition

The water table and elevation of stratigraphy of layers were interpolated by Kriging method.
The temperature of the model is incresing with the depth respect to geothermal gradient 50°C per 1000 m

Boundary condition

A flow model, northern and southern borders are assumed as no-flow boundaries.
A transport model, the northern and southern boundaries of the domain are no mass flux



- A doublet of wells system

Figure 8; The model grid showing the initial boundary conditions assigned to the model

MATERIALS AND METHODS TO MODELLING

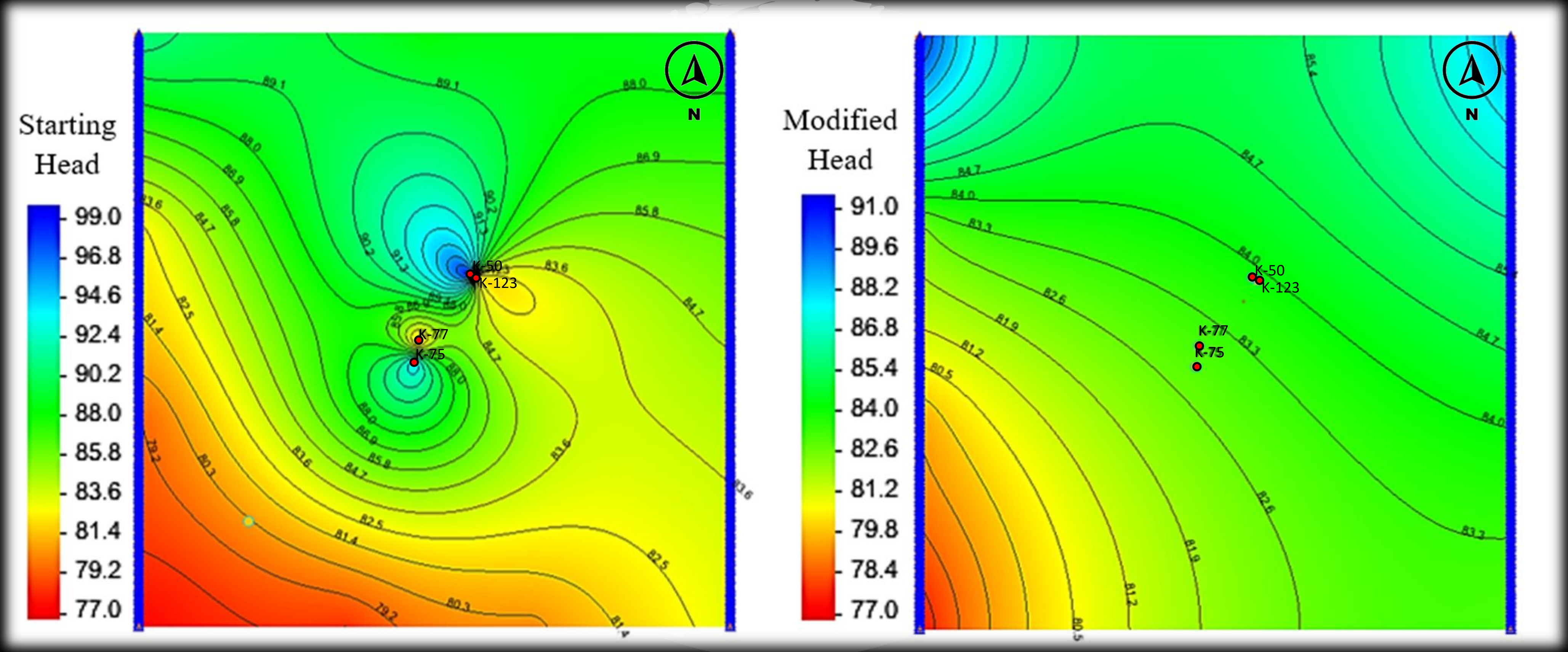
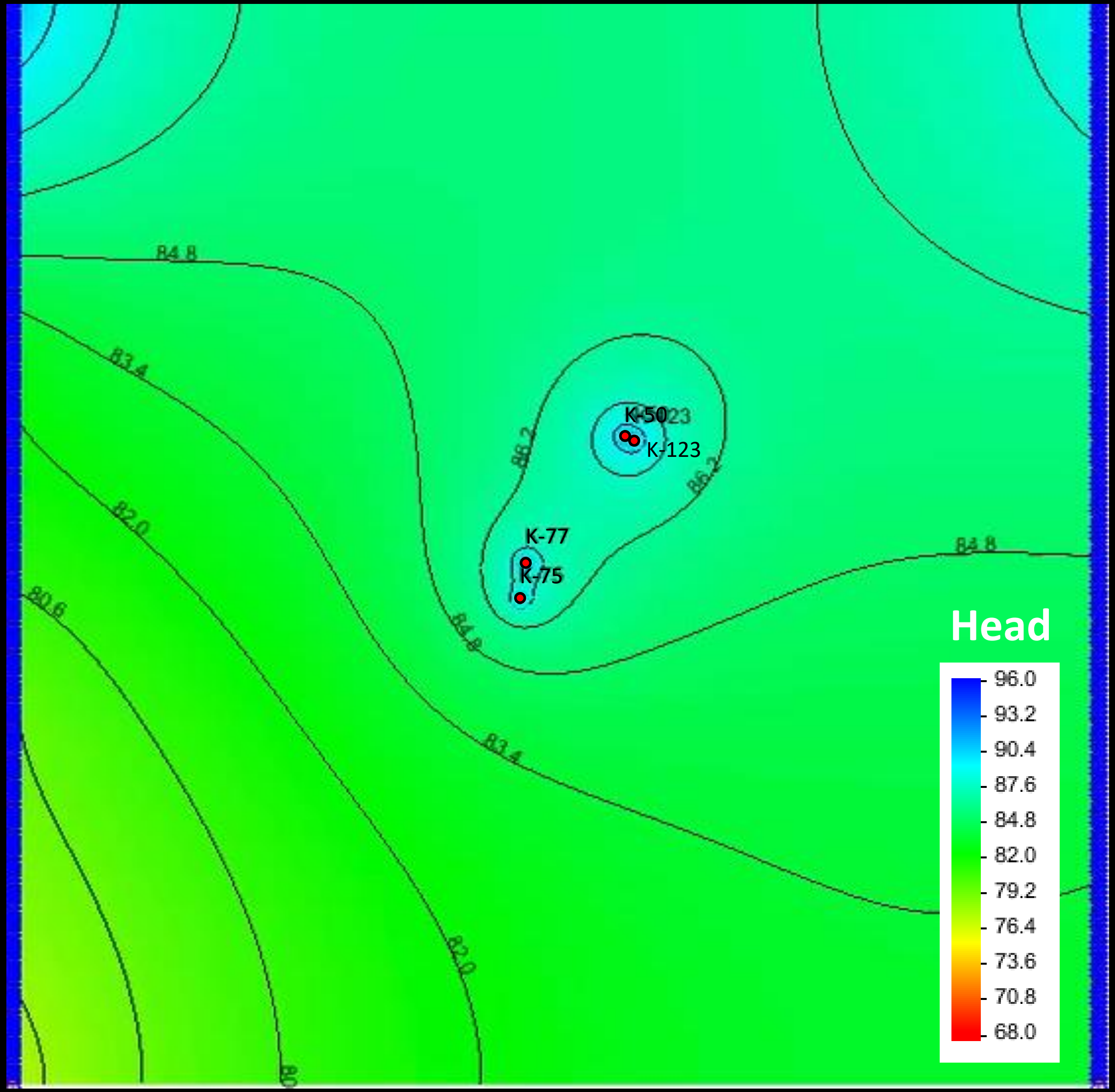
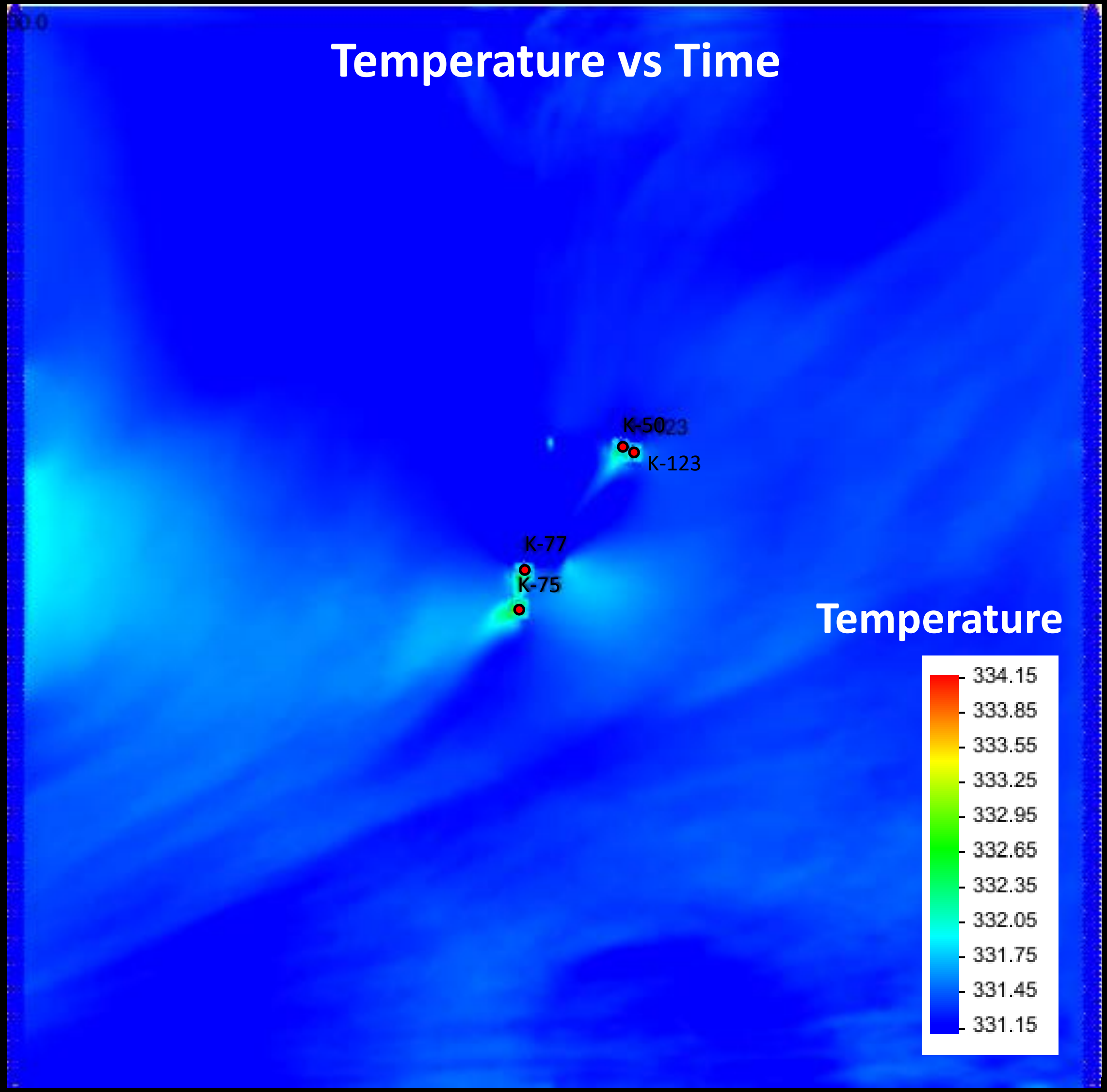


Figure 9: the starting hydraulic head are interpolated from four water well reports, and the modified hydraulic head

RESULT

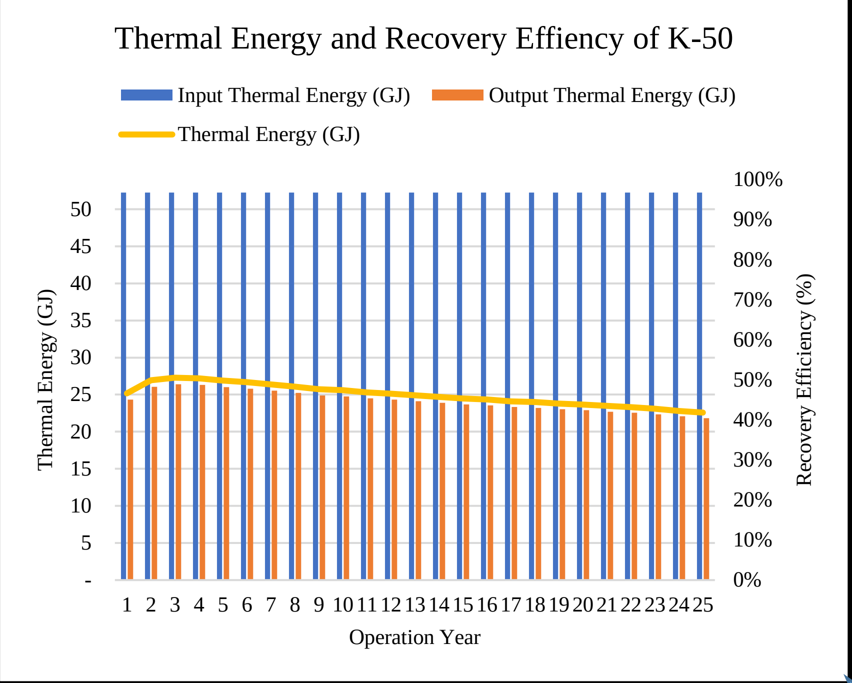
1) A unique well with double function, which alternates of injection period for 6 months, And production period for 6 months per year.

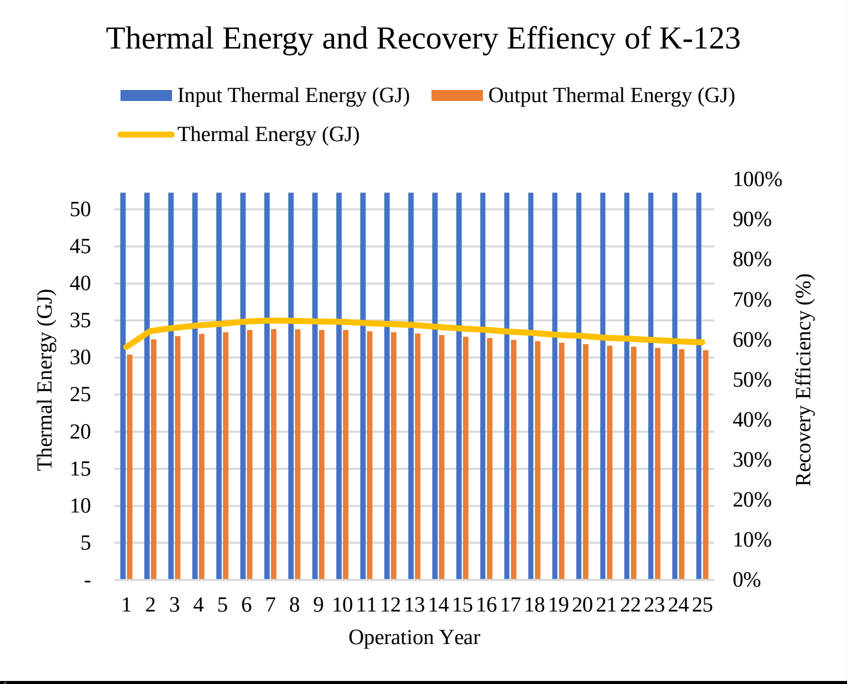




RESULT

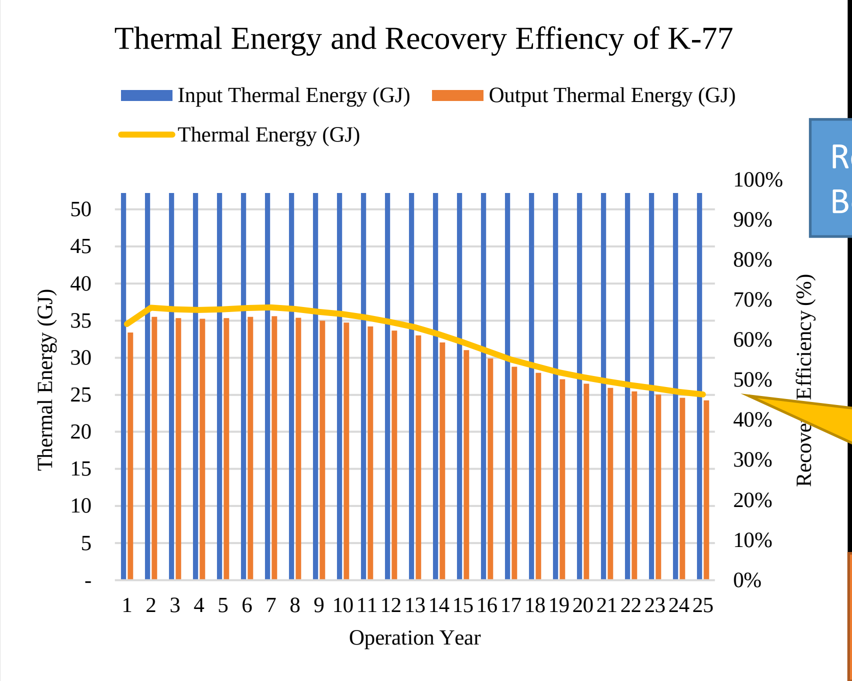
Figure; Input and output thermal energy and its recovery efficiency annually in ATES system for 25 years of the 1st scenario

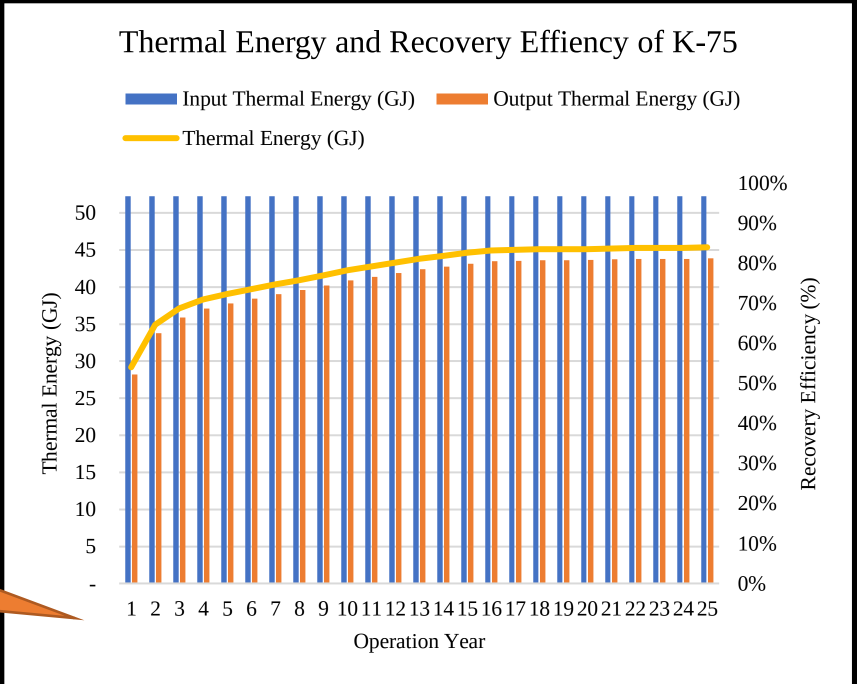




The heat transport has a strong influence by a thermal loss due to the different temperatures of the ambient groundwater flow in the ATES system.

- The heat transport velocity is 50 m/day





Recovery efficiency values of **K-50**
Between 62.57% reducing to 51.79%

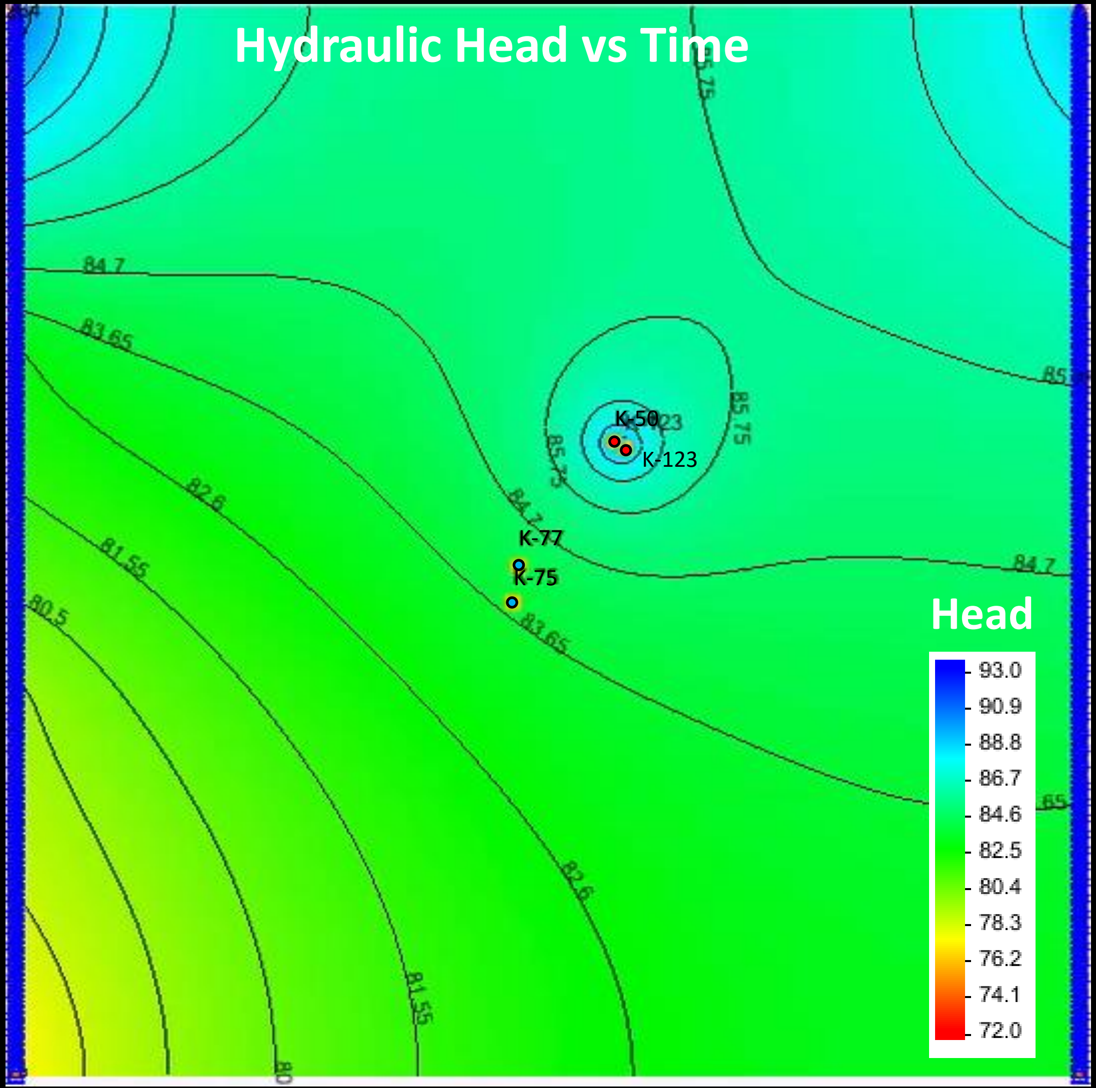
Recovery efficiency values of **K-123**
Between 80.24% decreasing to 72.08%

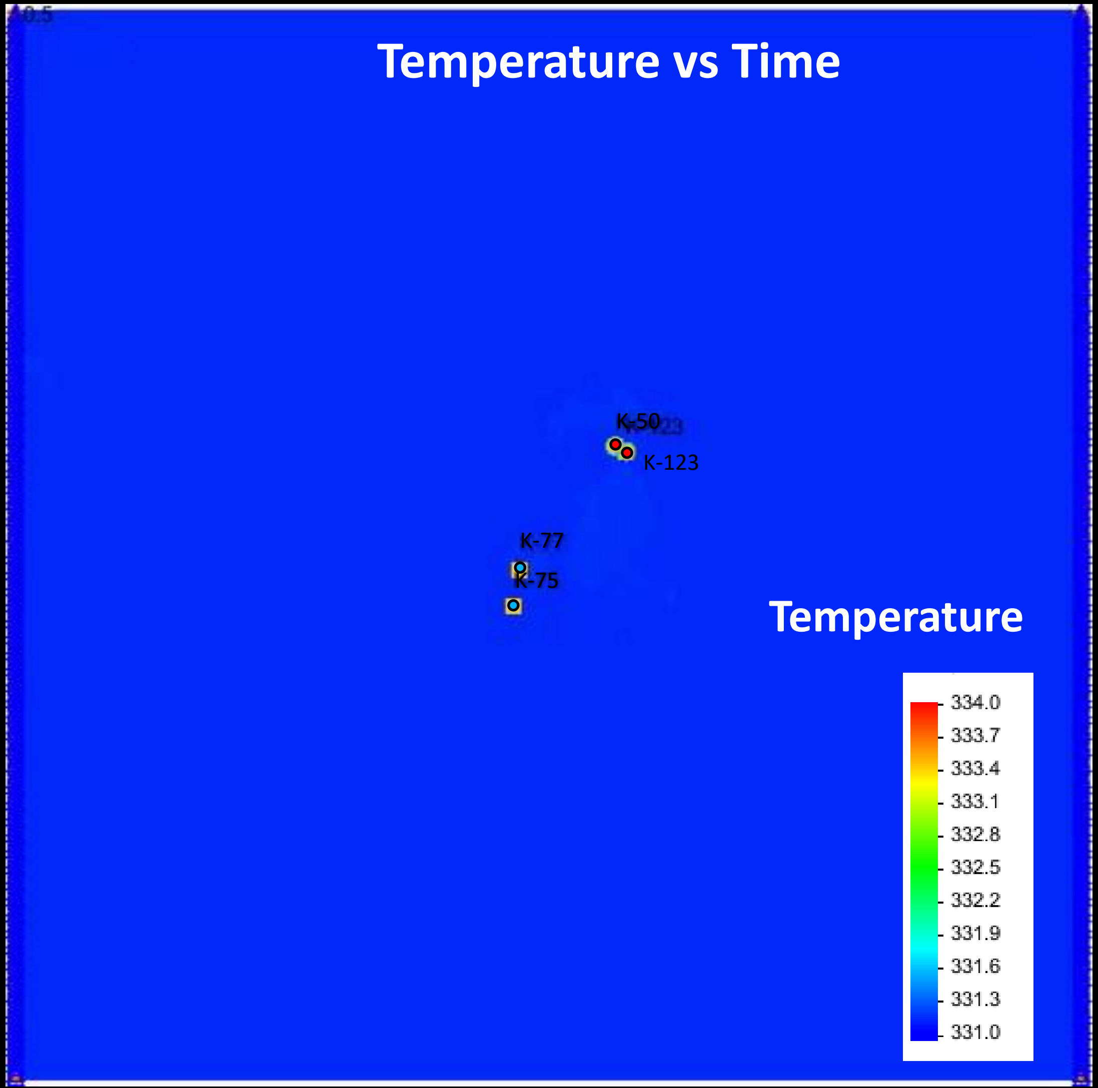
Recovery efficiency values of **K-75**
continuously improving yearly from 54.20% to 84.30 %

Recovery efficiency values of **K-77**
Between 69.11% increasing in 7 years to 73.58% then get lower to 50.14%

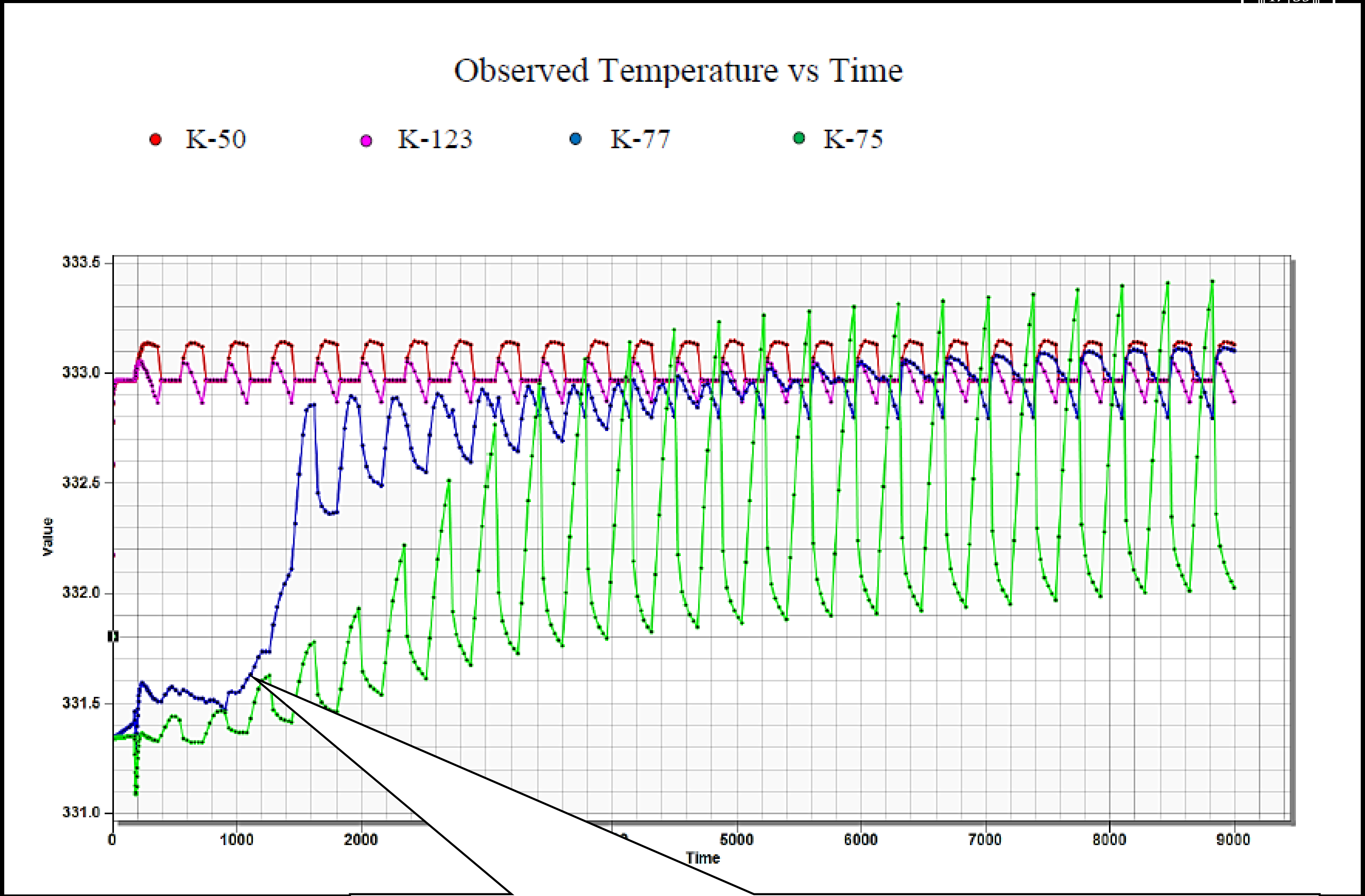
RESULT

2) A doublet wells system,K-50 and K-123 are injection well working for injection period for 6 months, and K-75 and K-77 are production well working for 6 months per year.





RESULT

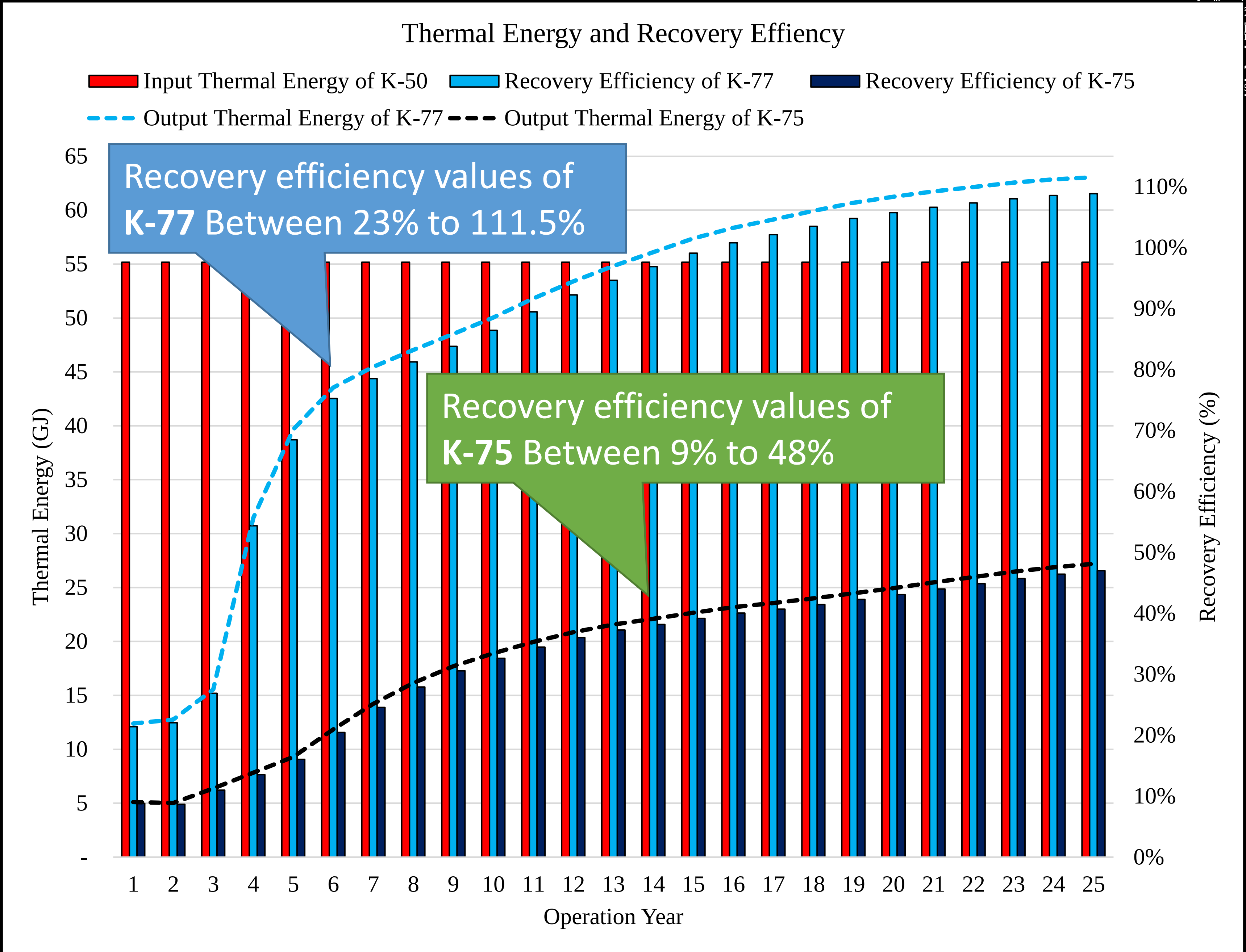


Figure; Timeline of observed temperature variableness at the four wells in ATES system for 25 years of the 2nd scenario

At K-77 receives mitigating warm water after 1000 days

RESULT

Figure; Input and output thermal energy and its recovery efficiency annually in ATES system for 25 years of the 2nd scenario



Injection wells K-50 and K-123 are in the upstream, production wells K-75 and K-77 are in the downstream.

K-77 receives the mitigating warmwater from the injection wells earlier than K-77 due to the smaller distance.

CONCLUSION AND DISCUSSION

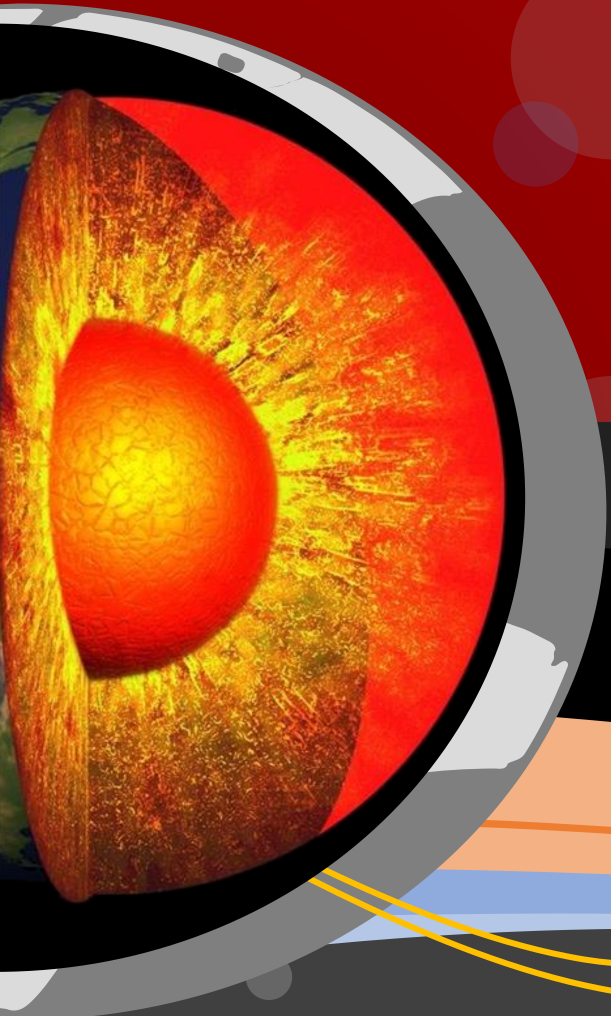
The influence of the thermal behavior in the ATES systems with main 3 parameters

1. The location and distance between the injection well and production wells
2. The volume of warmwater and its temperature as well as the injection time period
3. The hydraulic and thermal parameters

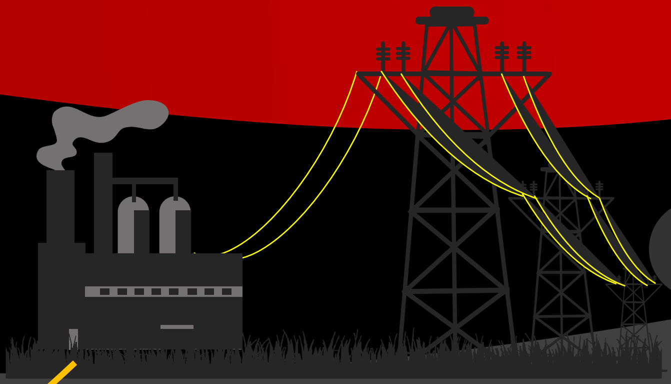
The model confirms that the hydrogeological mechanism in the Tiszaújváros conditions is considerably satisfied with great thermal recovery efficiency overtime.

According to the small-scale differences of the temperature, the model is still able to evaluate the effectiveness of storing and offering a great thermal energy production of ATES systems.

Therefore, there is possible to apply ATES system in shallow depth approximately 500 m if there is a good amount and high temperature of the energy source injection.



THANK YOU



Udomporn TUPBUCHA