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Thermal lift effect in geothermal wells

&

its impact on the calculation of hydraulic transmissivity of geothermal water reservoirs

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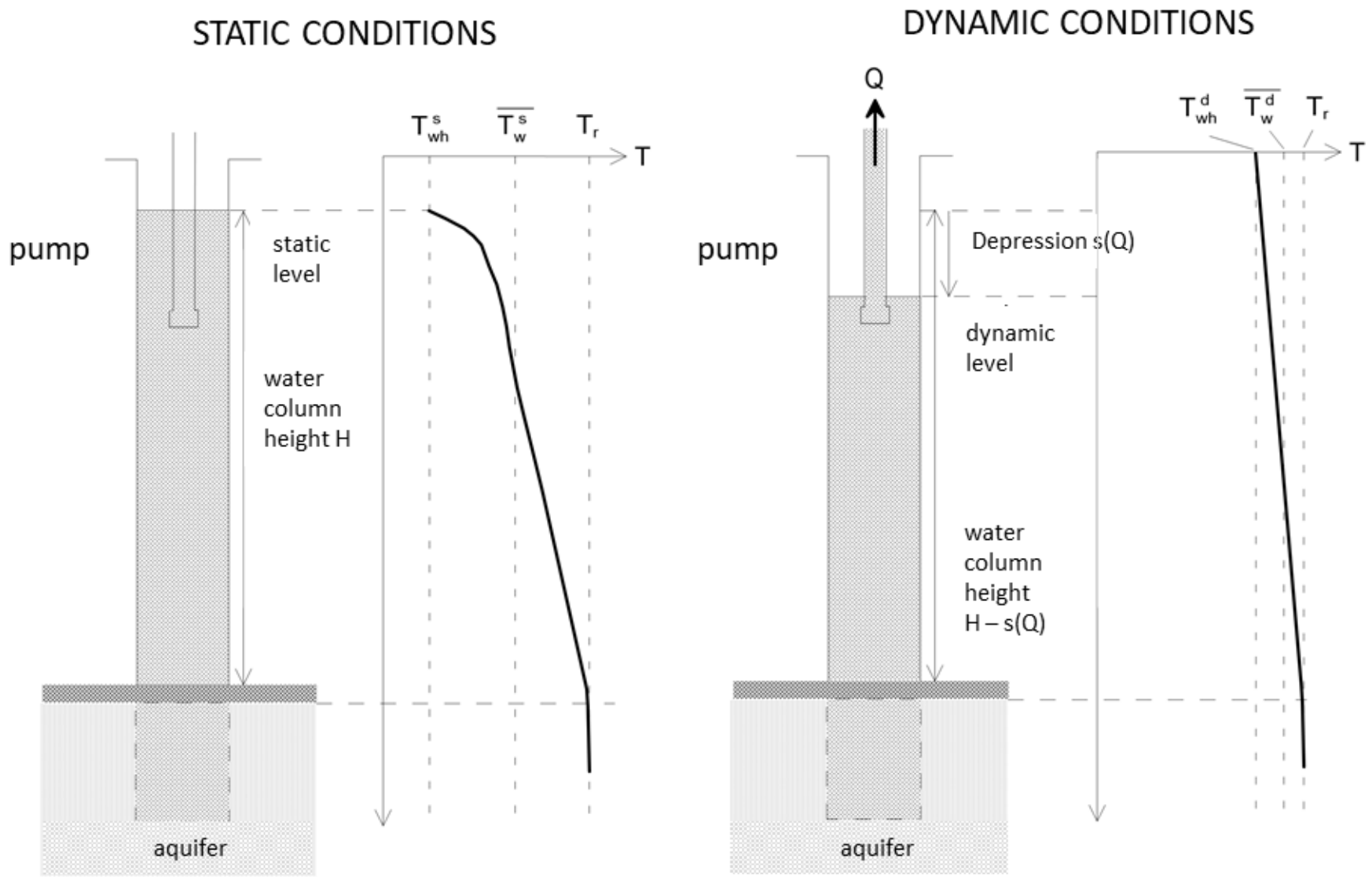
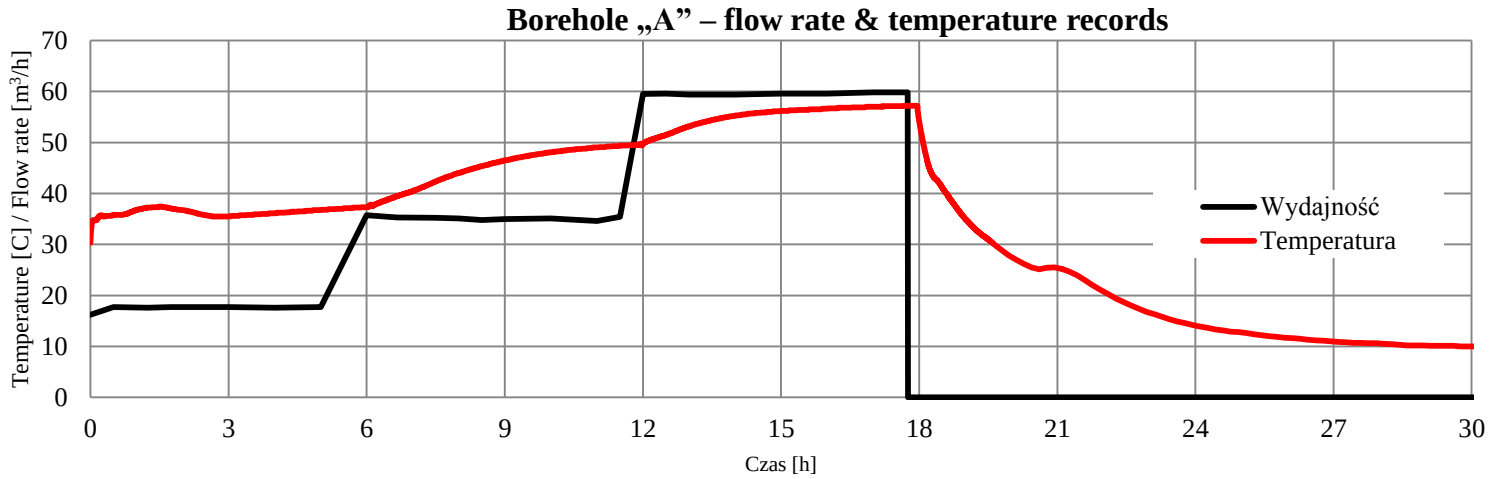
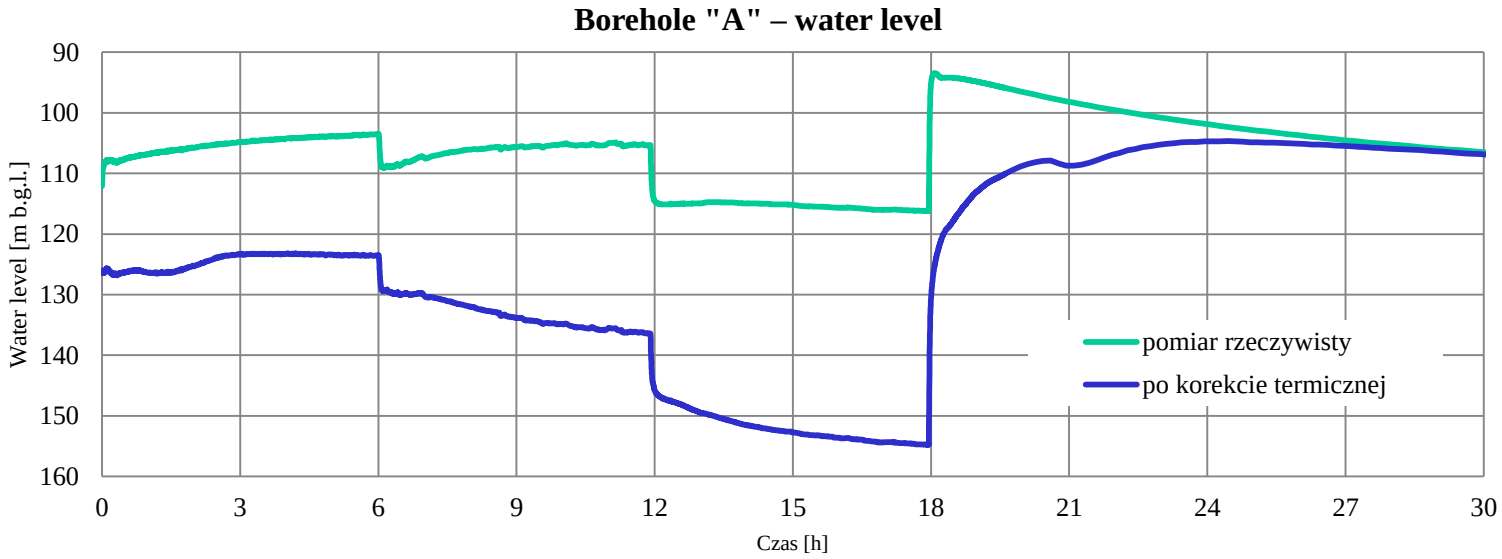
Temperature profile in static & flowing well



Example – „raw” data from the pumping test





Why this effect is so important?

Water expands when its temperature rises

↓

this results in higher wellhead pressure / water level during pumping

↓

observer is recording smaller pressure / water level drop compared to situation without this phenomenon

↓

smaller pressure / water level drop can be used to inaccurately estimate hydraulic properties of the reservoir

↓

overestimation of hydraulic properties of the reservoir, i.e. transmissivity, can lead to overexploitation

Procedure to calculate the thermal lift effect (1)

The hydrostatic pressure exerted by the water column is:

$$p = g \int_0^{H_{TVD}} \rho_w(z) dz \tag{1}$$

where:

- p – hydrostatic pressure,
- g – Earth's gravitational acceleration,
- ρ_w – the density of the water column in the borehole,
- H_{TVD} – vertical depth of the borehole,
- z – integration variable (depth).

Procedure to calculate the thermal lift effect (2)

Since the pressure at the bottom of the well is independent of the temperature of the liquid inside it, the multiplication of the height of the liquid column and its density will be the same for the cold well as for the heated one:

$$H_d\overline{\rho_w^d} = H_s\overline{\rho_w^s} \tag{2}$$

where:

- H_d – height of the water column in dynamic conditions,
- H_s – height of the water column in static conditions,
- $\overline{\rho_w^d}$ – average density of the water column under dynamic conditions,
- $\overline{\rho_w^s}$ – average density of the water column under static conditions.

Procedure to calculate the thermal lift effect (3)

Although in general the density of water is a non-linear function of temperature, in the temperature range from 40 to 95°C (typical temperature of geothermal water in liquid systems) the approximation by a linear function can be considered sufficiently accurate. By omitting some transformations of Equation 3, one obtains a relation that says that the average density of the water column is the density of water for the average (weighted) temperature of the water column:

$$\overline{\rho_w} = \rho_w\left(\overline{T_w}\right) \tag{4}$$

By inserting Equation 4 into Equation 2, the following relation is obtained:

$$H_d \rho_w \left(\overline{T_w^d}\right) = H_s \rho_w \left(\overline{T_w^s}\right) \tag{5}$$

where:

$\overline{T_w^d}$ – average water column temperature under dynamic conditions,

$\overline{T_w^s}$ – average water column temperature under static conditions.

Procedure to calculate the thermal lift effect (4)

The pressure measured at the bottom of the borehole under static conditions is as follows:

$$p_{r,0} = \rho_w \left(\overline{T_w^s}\right) H_{TVD} g + p_{wh,0} \tag{6}$$

where:

$p_{r,0}$ – pressure at the bottom of the well under static conditions (no extraction),

$p_{wh,0}$ – wellhead pressure under static conditions.

The bottomhole pressure during operation can be expressed in the form of Equation 7, which is analogous to Equation 6:

$$p_r = \rho_w \left(\overline{T_w^d}\right) H_{TVD} g + p_{wh} \tag{7}$$

where:

p_r – bottomhole pressure under dynamic conditions,

p_{wh} – wellhead pressure under dynamic conditions.

Procedure to calculate the thermal lift effect (5)

The value of the depression $s\left(\overline{T_w^s}\right)$ in a borehole is the difference between the static and dynamic bottom pressures:

$$s\left(\overline{T_w^s}\right) = \frac{p_{r,0} - p_r}{\rho_w\left(\overline{T_w^s}\right) g} \tag{8}$$

By substituting Equations 6 and 7 into Equation 8, one obtains a formula that allows to calculate the actual depression excluding the influence of the borehole thermal heating effect (also known as thermal lift) knowing only the static and dynamic wellhead pressure and the average water column temperature under static and dynamic conditions:

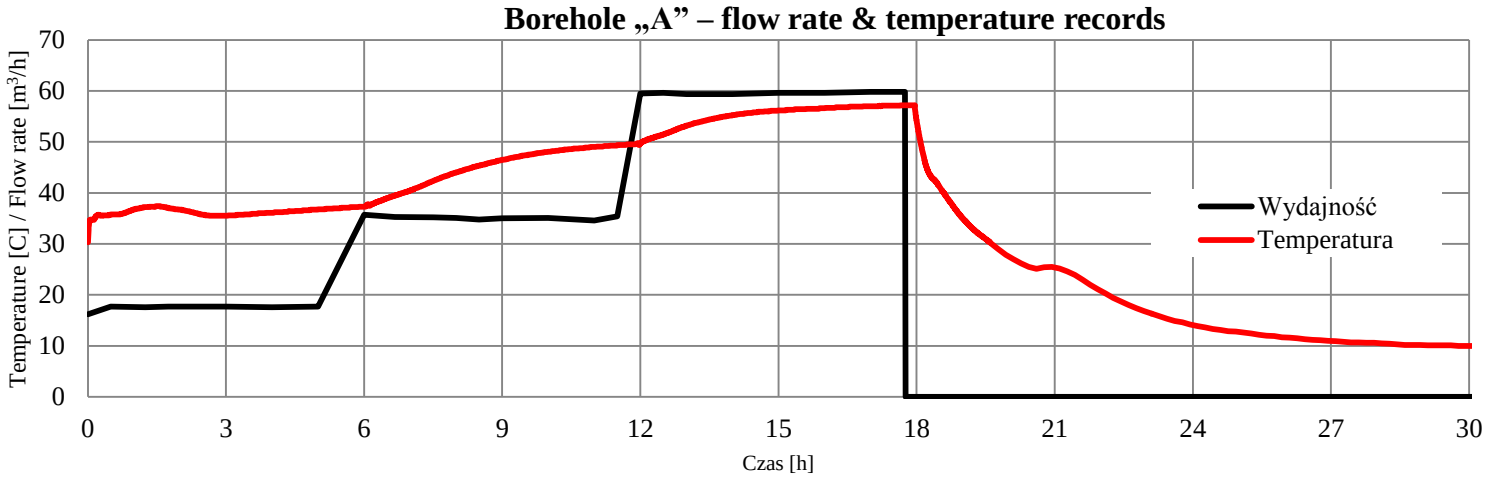
$$s\left(\overline{T_w^s}\right) = \frac{p_{wh,0} - p_{wh}}{\rho_w\left(\overline{T_w^s}\right) g} + \left[1 - \frac{\rho_w\left(\overline{T_w^d}\right)}{\rho_w\left(\overline{T_w^s}\right)}\right] H_{TVD} \tag{9}$$

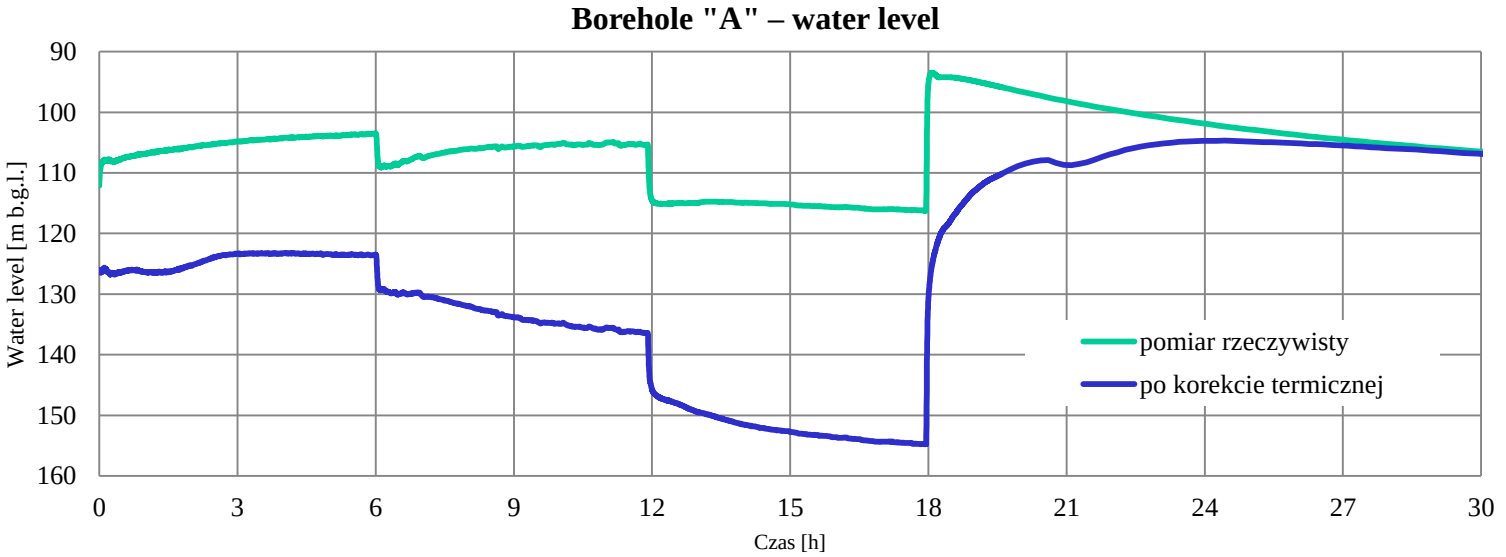
Procedure to calculate the thermal lift effect (6)

Subtracting the actual depression value $s\left(\overline{T_w^s}\right)$ from the static wellhead pressure, taking into account the thermal lift effect during extraction, the so-called reduced wellhead pressure value is obtained p_{wh}^{red}:

$$p_{wh}^{red} = p_{wh,0} - s\left(\overline{T_w^s}\right) \cdot \rho_w\left(\overline{T_w^s}\right) \cdot g = p_{wh} - \left[1 - \frac{\rho_w\left(\overline{T_w^d}\right)}{\rho_w\left(\overline{T_w^s}\right)}\right] \rho_w\left(\overline{T_w^s}\right) H_{TVD} g \qquad (10)$$

One more look at the example from the beginning of presentation:

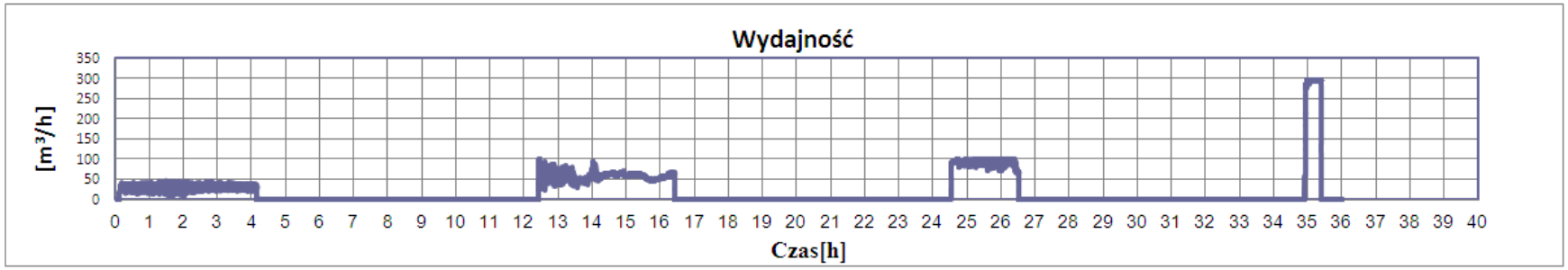


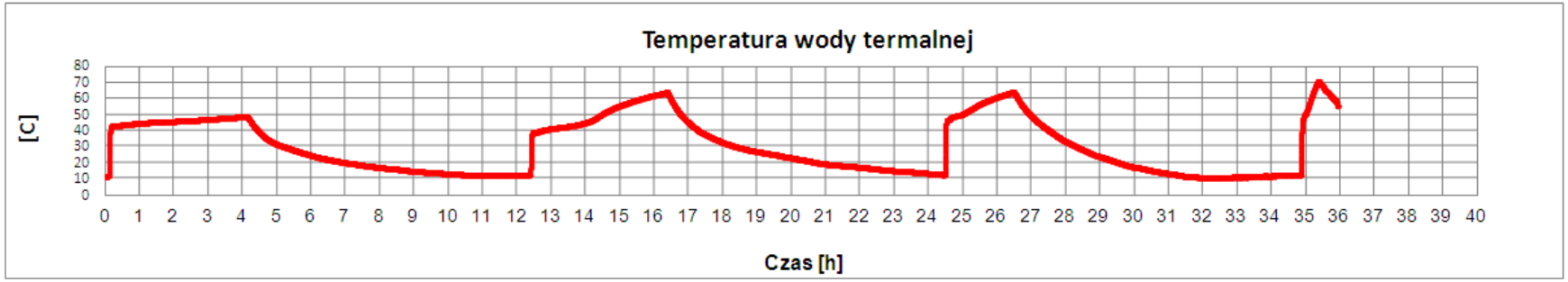


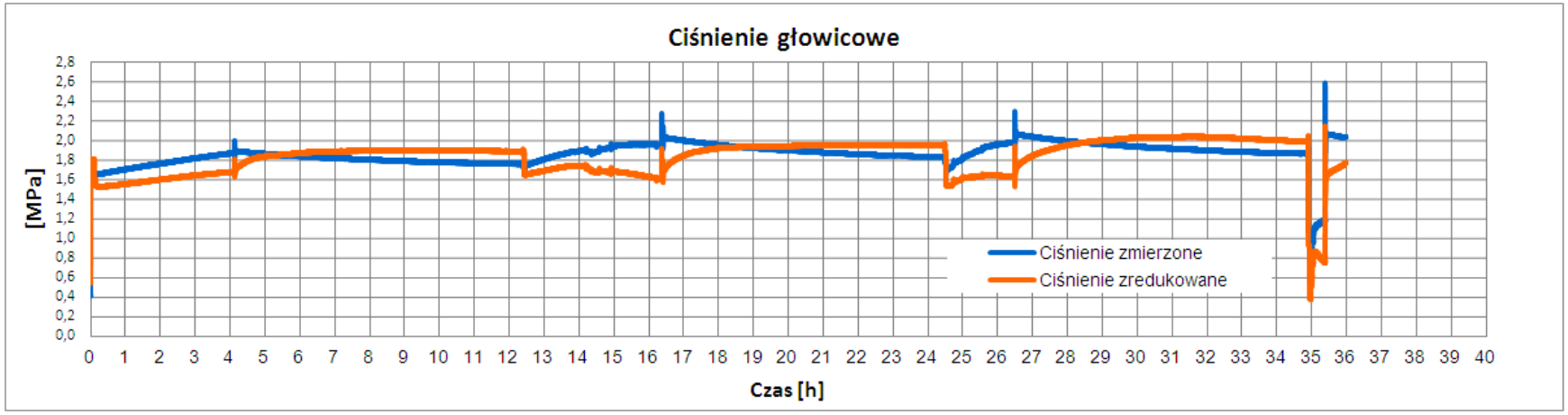
Without correction:
$k \cdot h = 1{,}86 \cdot 10^{-3}\ m^2/s$

After correction:
$k \cdot h = 4{,}12 \cdot 10^{-4}\ m^2/s$

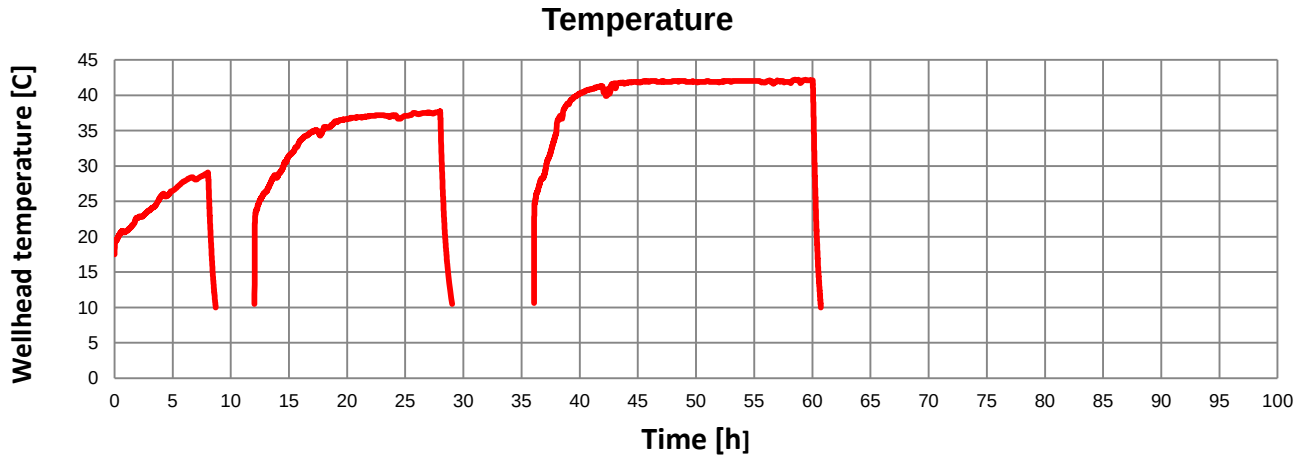
Another example:

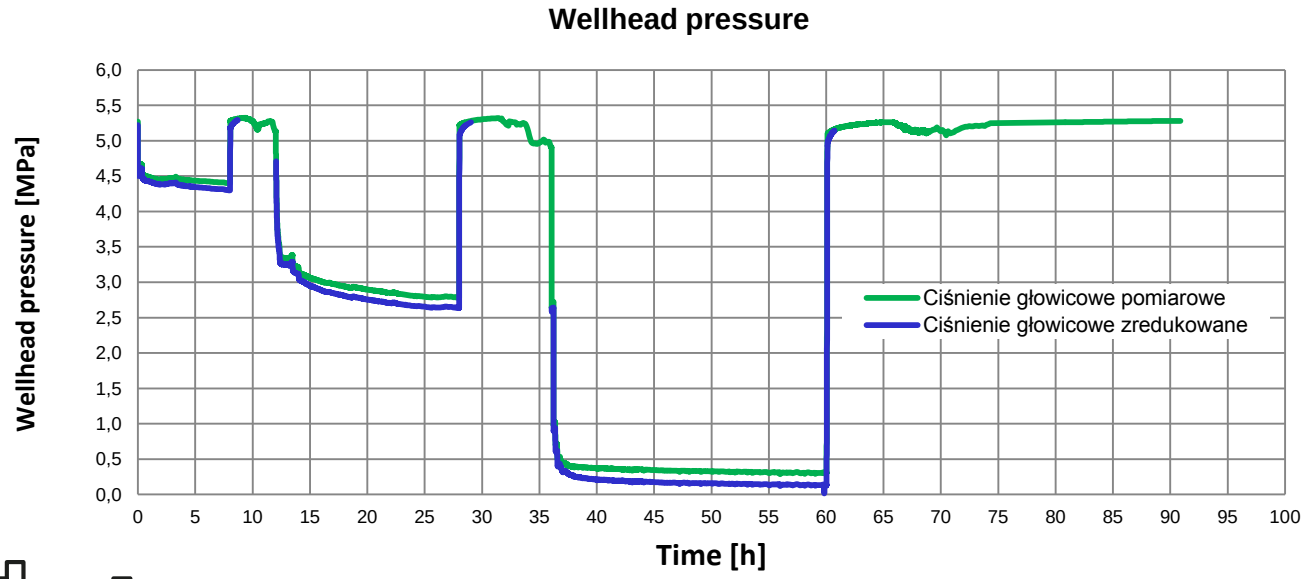






Yet another example:

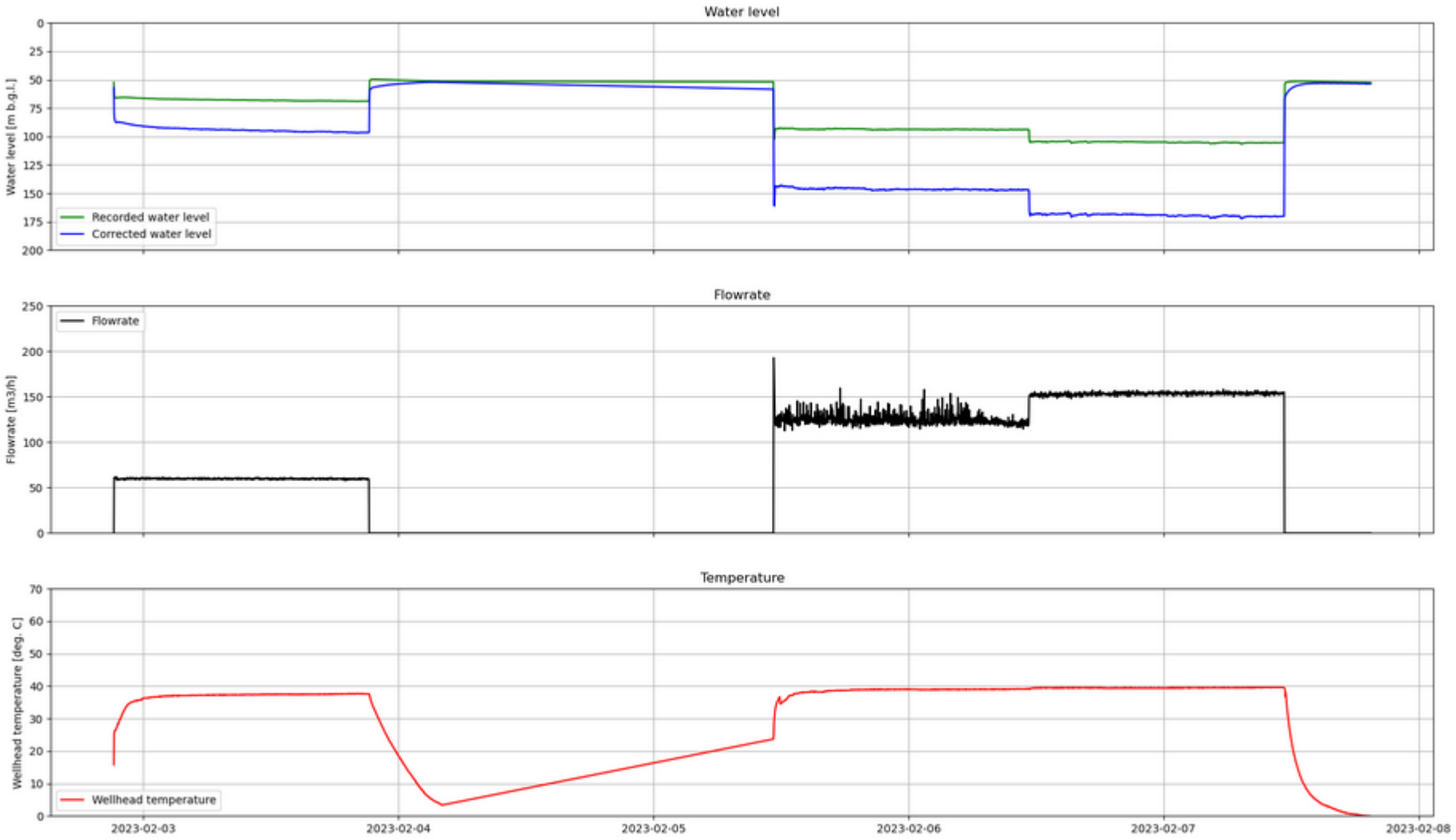




Without correction:
$k \cdot h = 7{,}67 \cdot 10^{-5}\ m^2/s$

After correction:
$k \cdot h = 3{,}54 \cdot 10^{-5}\ m^2/s$

And one more example…



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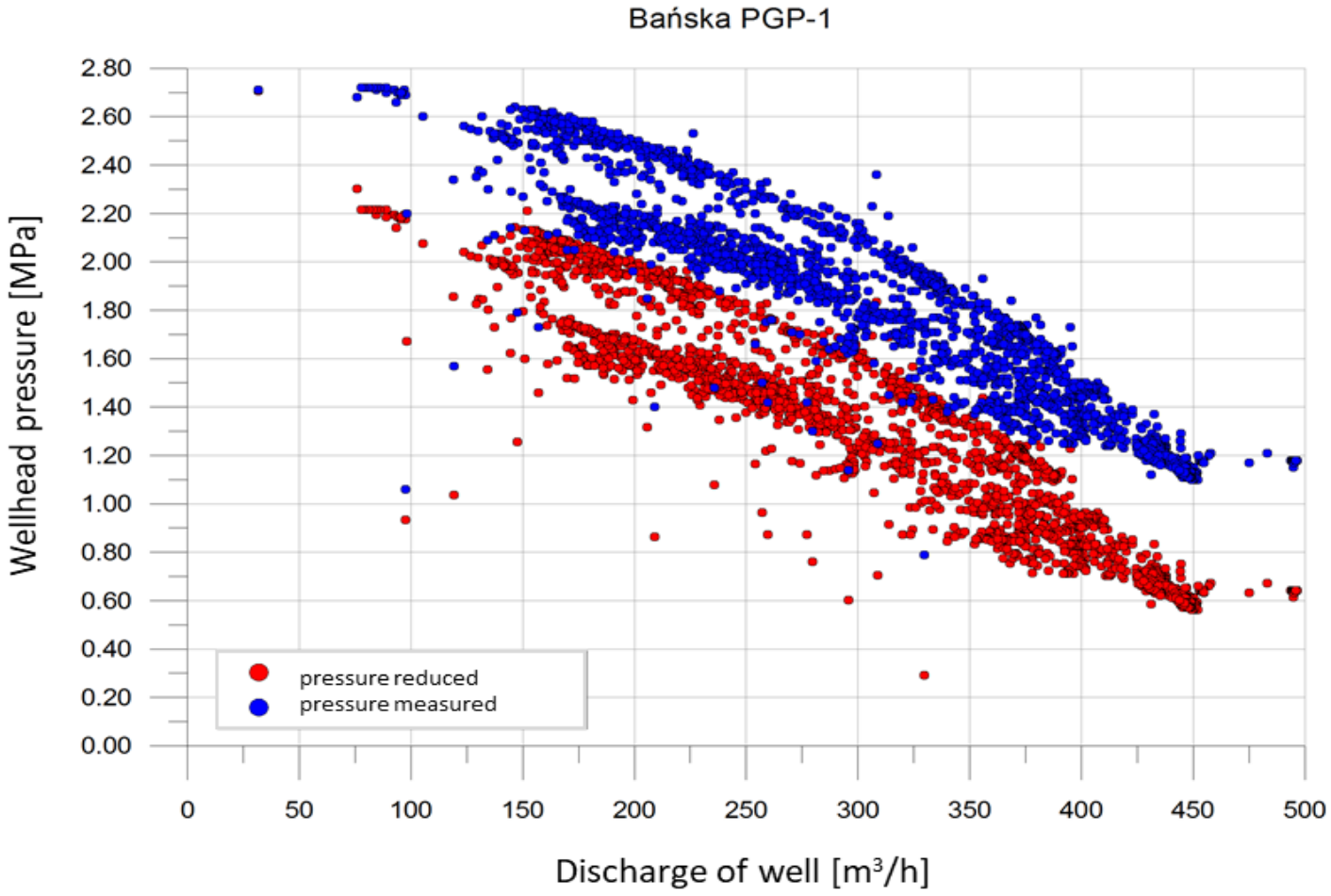

Recorded wellhead pressure and calculated reduced wellhead pressure for the Bańska PGP-1 production well (data from 2001-2015). Source: Miecznik 2017, based on data provided by PEC Geotermia Podhalanska S.A.

GeoModel goals in this regard:

- Provide free, easy to use Python library / example stripts for performing „thermal lift effect” calculation
- Implement density calculation for high range of salinities
- For vertical and deviated wells
- Automatic completing missing data
- Automatic date & time recognition from text files
- Plot graphs before and after correction procedure
- Export calculated values to disk files