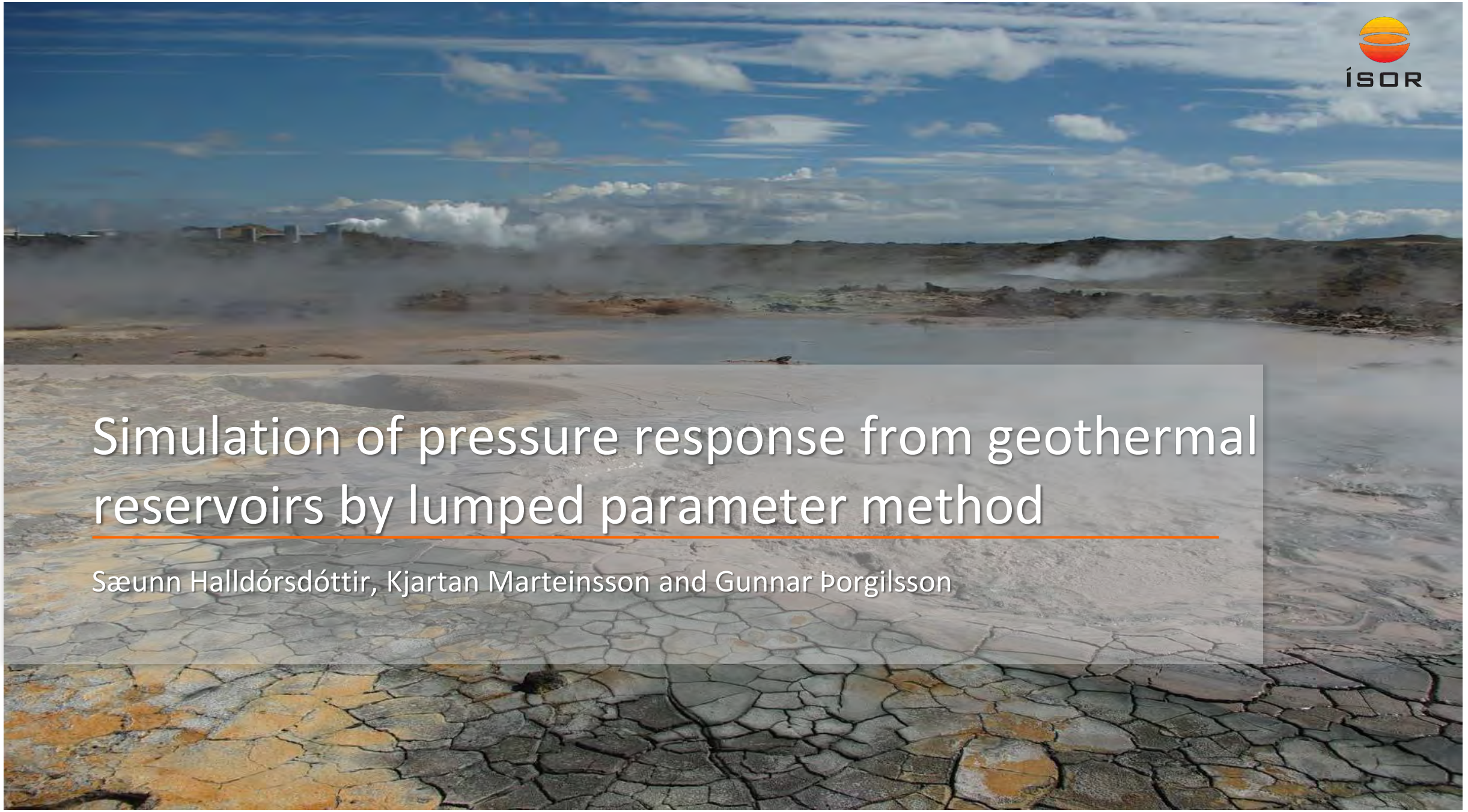


Simulation of pressure response from geothermal reservoirs by lumped parameter method

Sæunn Halldórsdóttir, Kjartan Marteinsson and Gunnar Þorgilsson

Production capacity of geothermal systems

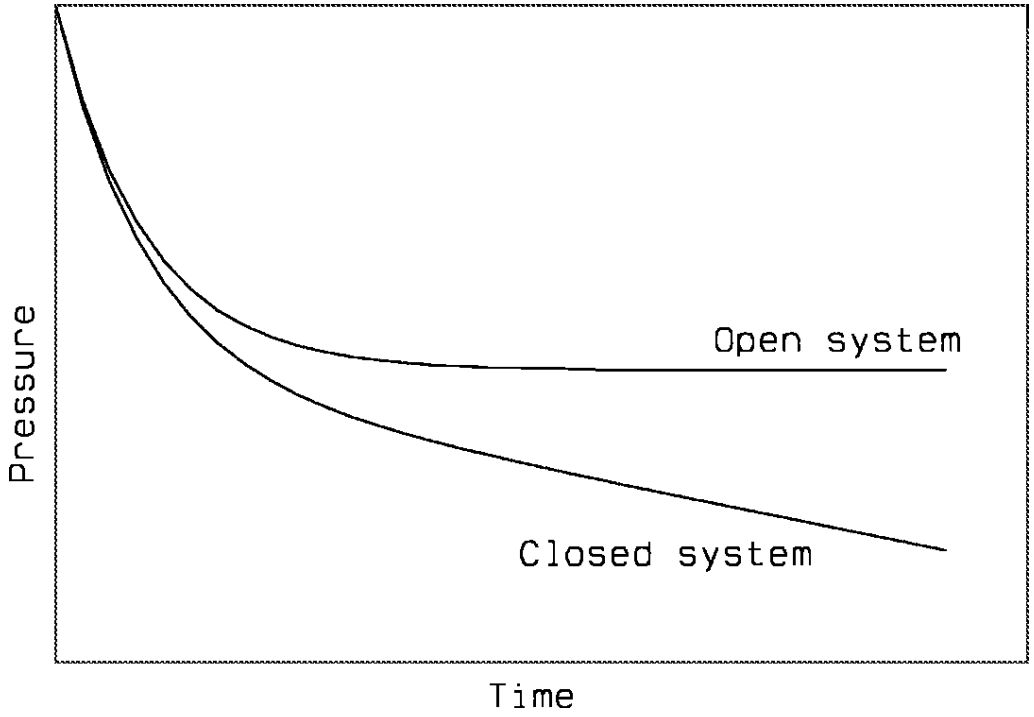
What controls production capacity?

The systems **response to production**, predominantly controlled by reservoir pressure decline; technical limit to how great pressure decline can be

Also controlled by energy content, which is determined by temperature
and reservoir size

Fluid recharge plays a role

Dependent on boundary conditions and reinjection



- Production Response (Pressure Decline)

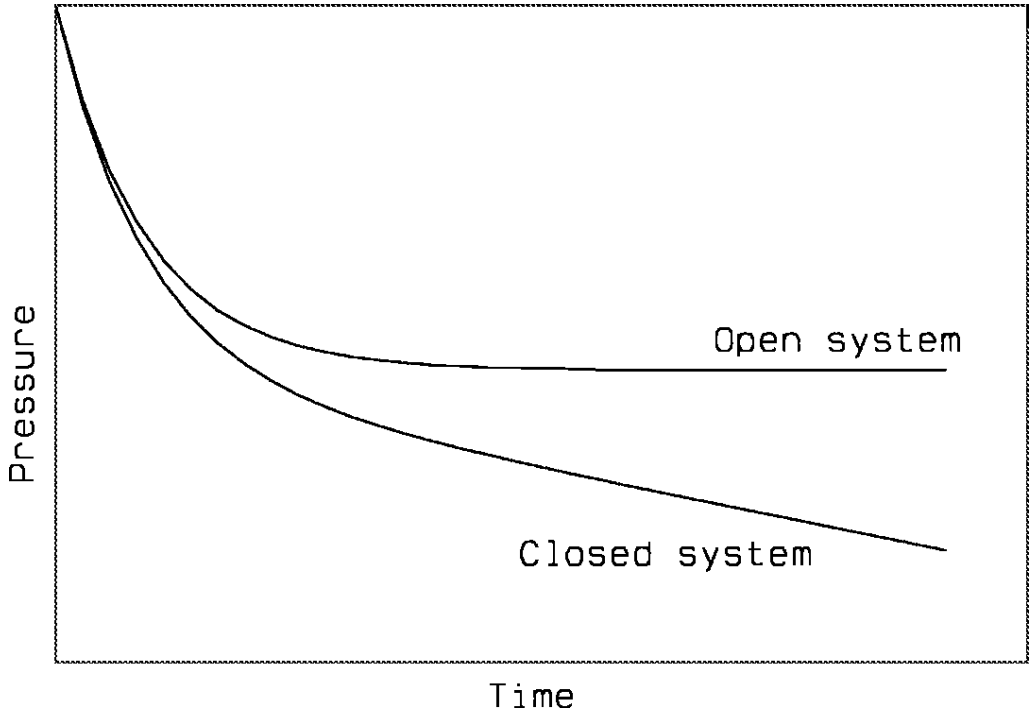
- Controlled by:
  - Size of geothermal reservoir
  - Reservoir rock permeability
  - Reservoir storage capacity (porosity + nature)
  - Water recharge (i.e. boundary conditions)
  - Geological structure (fractures + main permeable volumes)

- Types of Systems

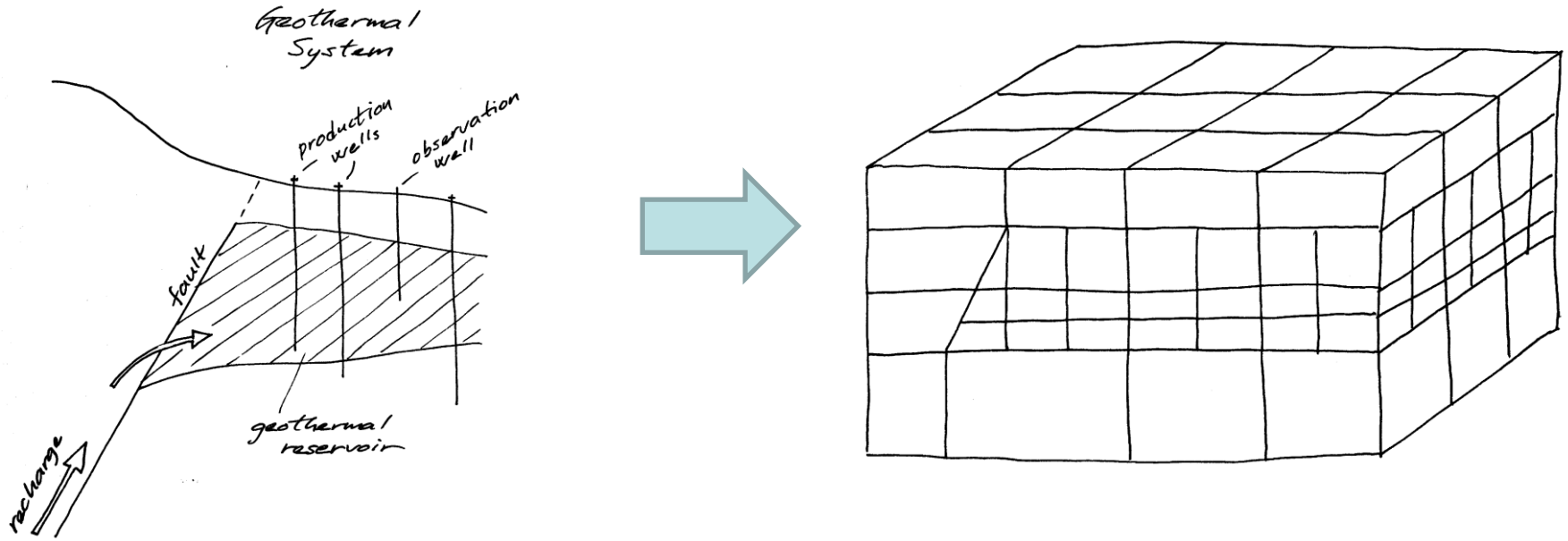
Geothermal systems can in most cases be classified as either:

(A) **closed systems** with limited or no recharge or

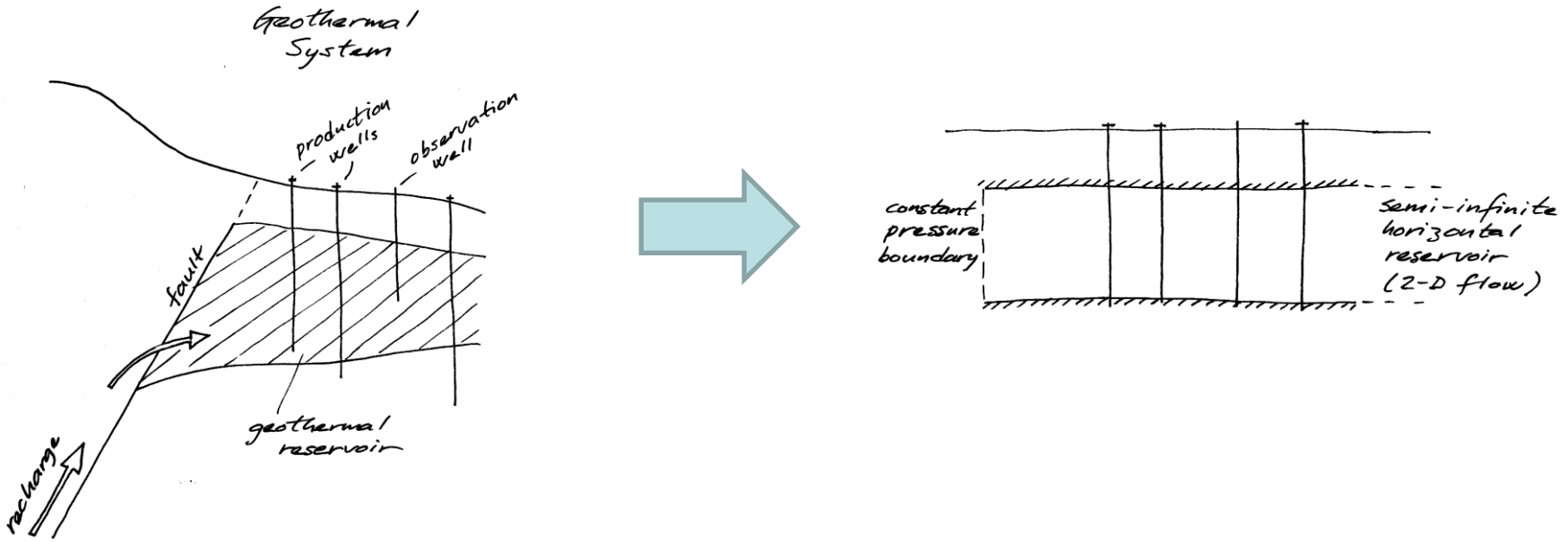
(B) **open systems** where recharge equilibrates with the mass extraction



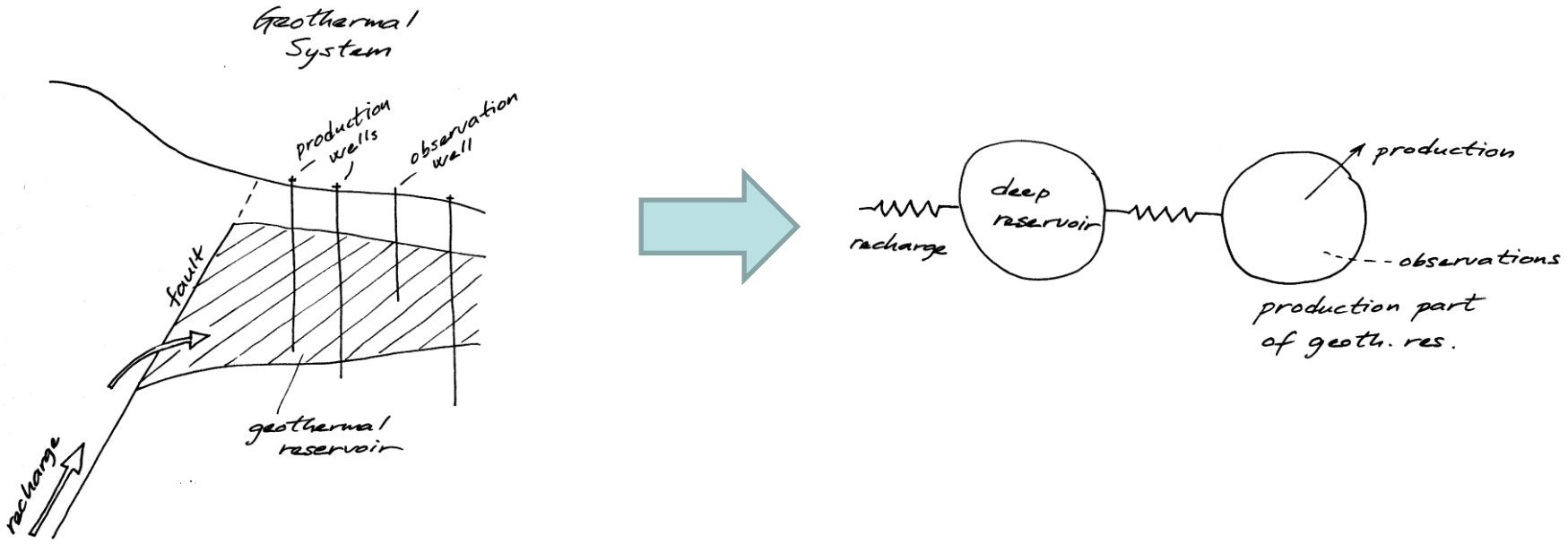
DETAILED NUMERICAL MODELS: These can accurately simulate complex geometry and structure, also variable properties. Response must be calculated by powerful computers. Such models can simulate pressure, temperature (enthalpy) and chemistry, simultaneously



SIMPLE ANALYTICAL MODELS: Geometry and structure greatly simplified; properties assumed constant. Analytical expressions describing response can be derived. Such models usually simulate either pressure, temperature or chemistry



LUMPED NUMERICAL MODELS: Geometry (mostly) ignored; properties integrated into lumped values. Response given by analytical functions



Methods in applied geophysics

TABLE I

ANALOGIES FOR PARABOLIC DIFFERENTIAL EQUATIONS

Model	*Potential variable*	*Flow variable*	*Parameters*	
			conductivity	*capacitivity*
MR-rod	velocity	force	spec. dashpot conductance	spec. mass
electric CR-line	voltage	current	spec. conductance	spec. capacitance
Magneto-telluric model	magnetic field intensity	electric field intensity	resistivity	permeability
thermal model	temperature	heat flow	heat conductivity	density by heat capacity
hydrological model, free surface	water level	flow	water conductivity	density by porosity
hydrological model, confined	pressure	flow	water conductivity	density by expansibility

(Bodvarsson, 1966)

https://doi.org/10.1016/0016-7142(66)90001-9

Lumped parameter modelling of geothermal systems

- Lumped parameter modelling may be used to simulate water level/pressure change data. Can simulate long and detailed data-sets very accurately
- A method has been developed that automatically simulates data through a non-linear iterative least-squares technique

Tank (capacitor) simulates storage in a reservoir, mass storage coefficient (capacitance) $\kappa = m/p$ (m = mass increase, p = pressure increase)

Resistor (conductor) simulates flow resistance (permeability) in a reservoir, conductance $\sigma = q/\Delta p$ (q = mass flow, Δp = pressure differential)

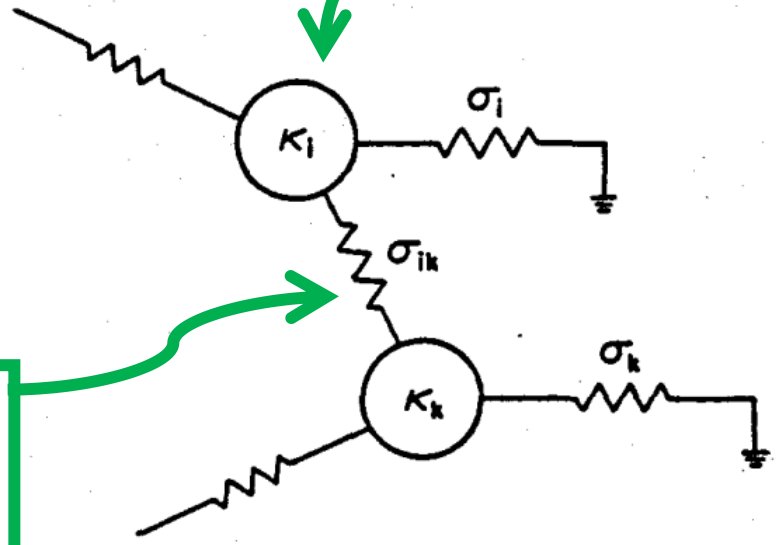


Figure 1. *General lumped capacitor/conductor network.*

Axelsson, G., 1989: Simulation of pressure response data from geothermal reservoirs by lumped parameter models. Proceedings 14th Workshop on Geothermal Reservoir Engineering, Stanford University, USA, 257-263

Key tool for resource assessment

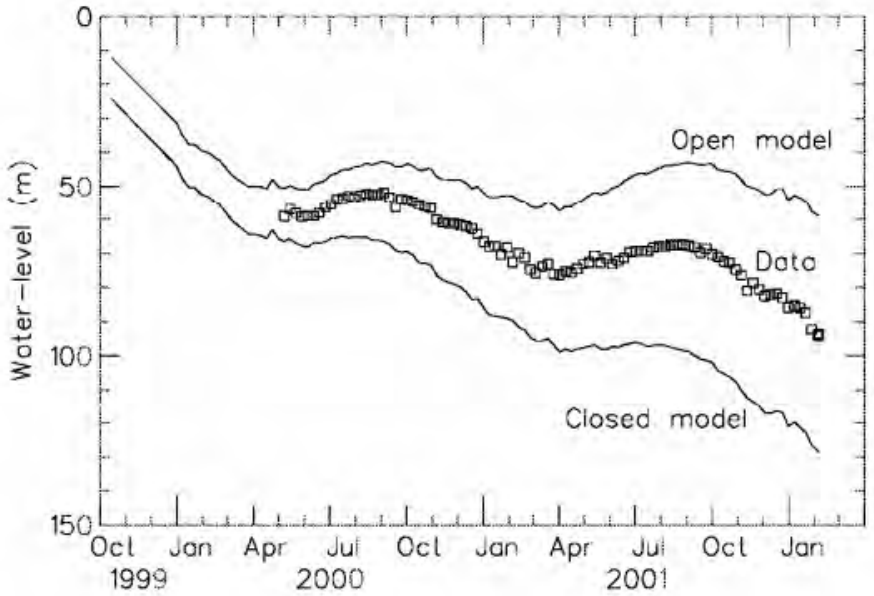


Figure 8: Water level history of the Hofstadir geothermal system, from late 1999 up to early 2002, simulated by a lumped parameter model developed in 1997 on the basis of data from a 5-month production test conducted that same year. The simulation is based on water level data collected during the 1997 test and production data up to early 2002. The simulated data are calculated by open and closed versions of the lumped model.

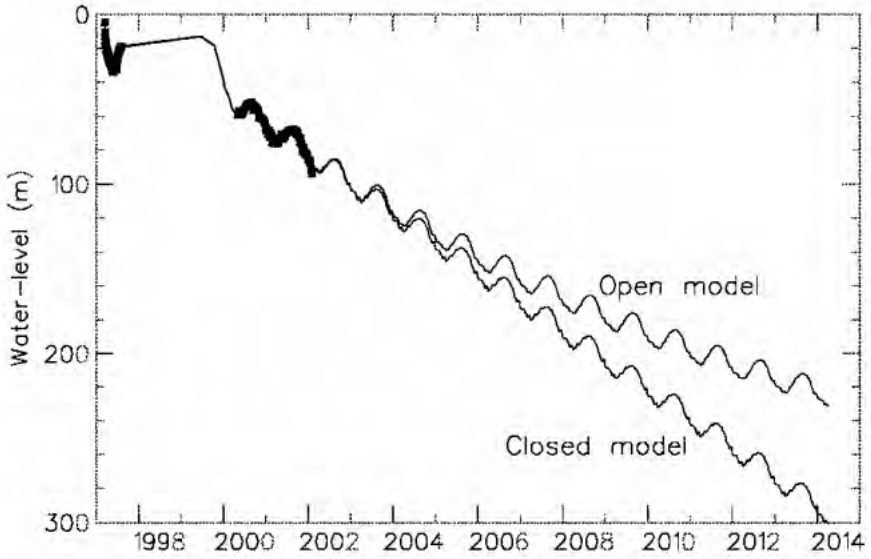
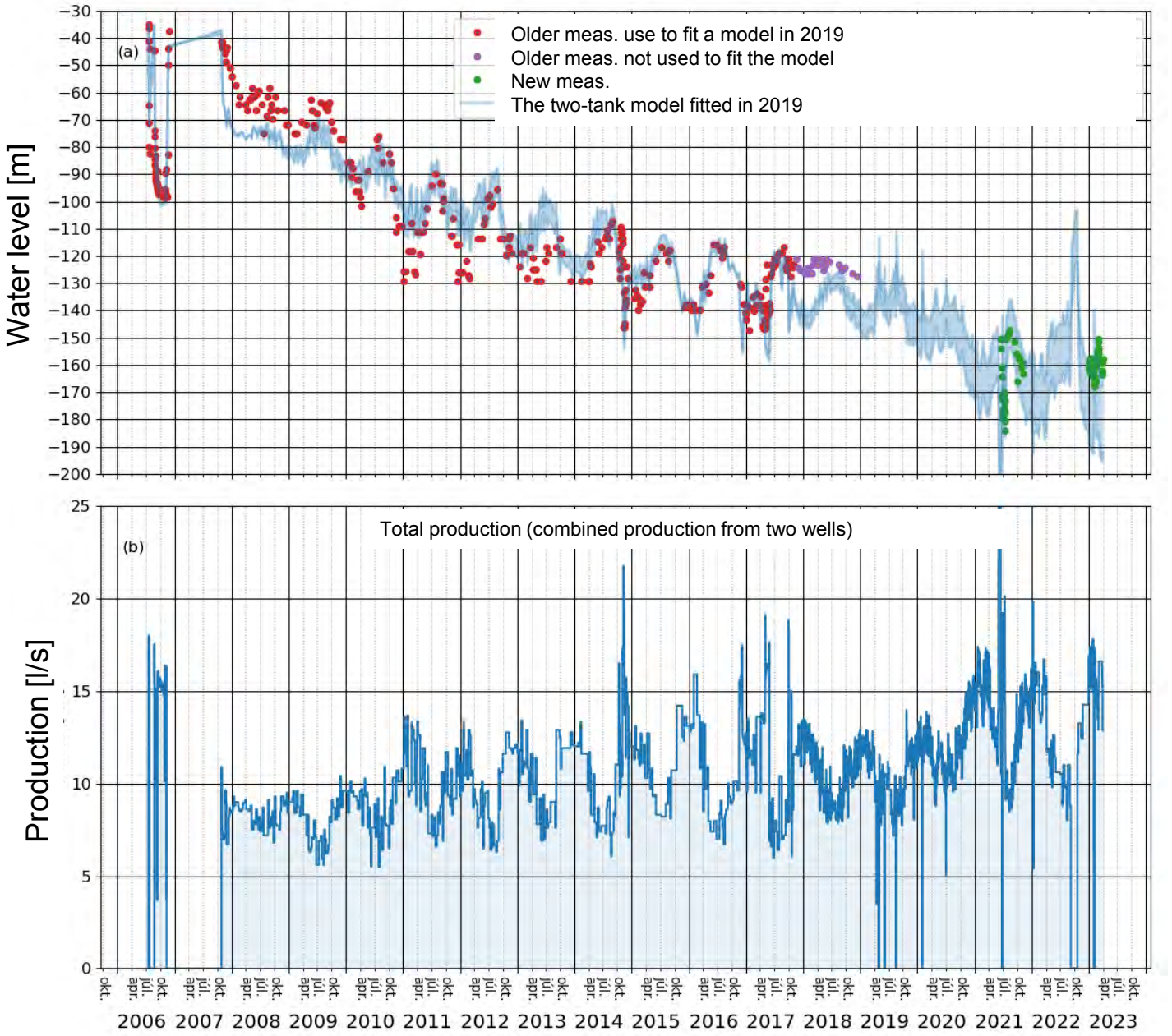


Figure 9: Predicted water level changes in the Hofsstadir geothermal system for a 10-year prediction period calculated by a lumped parameter model based on data up to 2002 (revision of the model of Fig. 8). Predictions by an open (optimistic) and a closed (pessimistic) version of the model, for a yearly production pattern as in 2001, are presented.

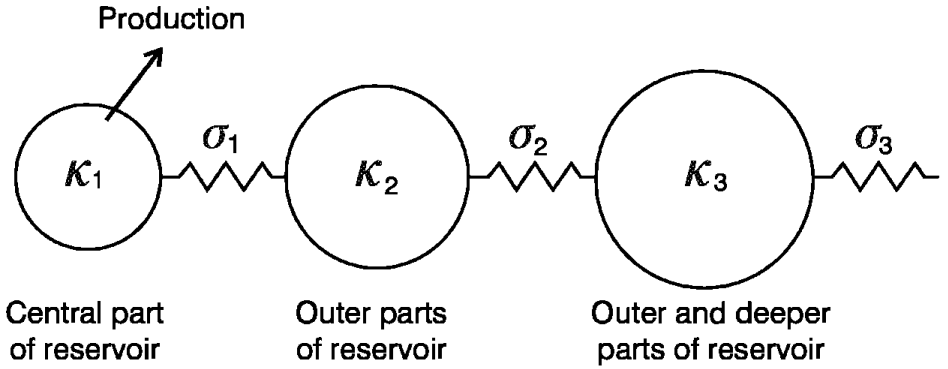
Axelsson, Gudni & Bjornsson, Grimur & Quijano, Julio. (2005).
Reliability of Lumped Parameter Modeling of Pressure Changes in Geothermal Reservoirs.

Testing the reliability of an existing model



data from Hrolleifsdalur

Linear model



Basic equations

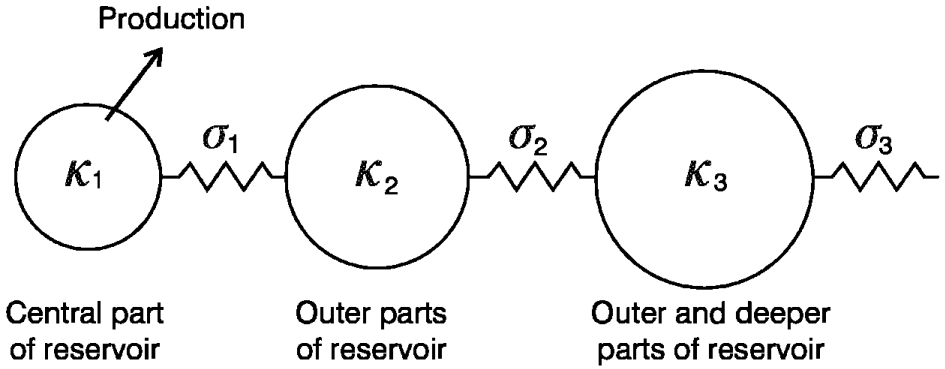
$$\text{Mass: } \kappa = \frac{m}{p} \quad \Rightarrow \quad m = \kappa p$$

$$\text{Flow: } \sigma = \frac{q}{\Delta \text{p}} \quad \Rightarrow \quad \text{q} = \sigma \Delta p$$

Conservation of mass:

Rate of change of **mass** in tank = Flow of **mass** in/out of tank + Sink/source of **mass** in tank

Linear model



Basic equations

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$$\text{Flow: } \sigma = \frac{q}{\Delta \text{p}} \quad \Rightarrow \quad \text{q} = \sigma \Delta p$$

Conservation of mass:

$$\kappa_i \frac{dp_i}{dt} = \sum_{k=1}^{N} q_{ik} - \sigma_i \left(p_i - p_0 \right) - Q_i$$

Flow between tanks:

$$q_{ik} = \sigma_{ik} \left(p_k - p_i \right)$$

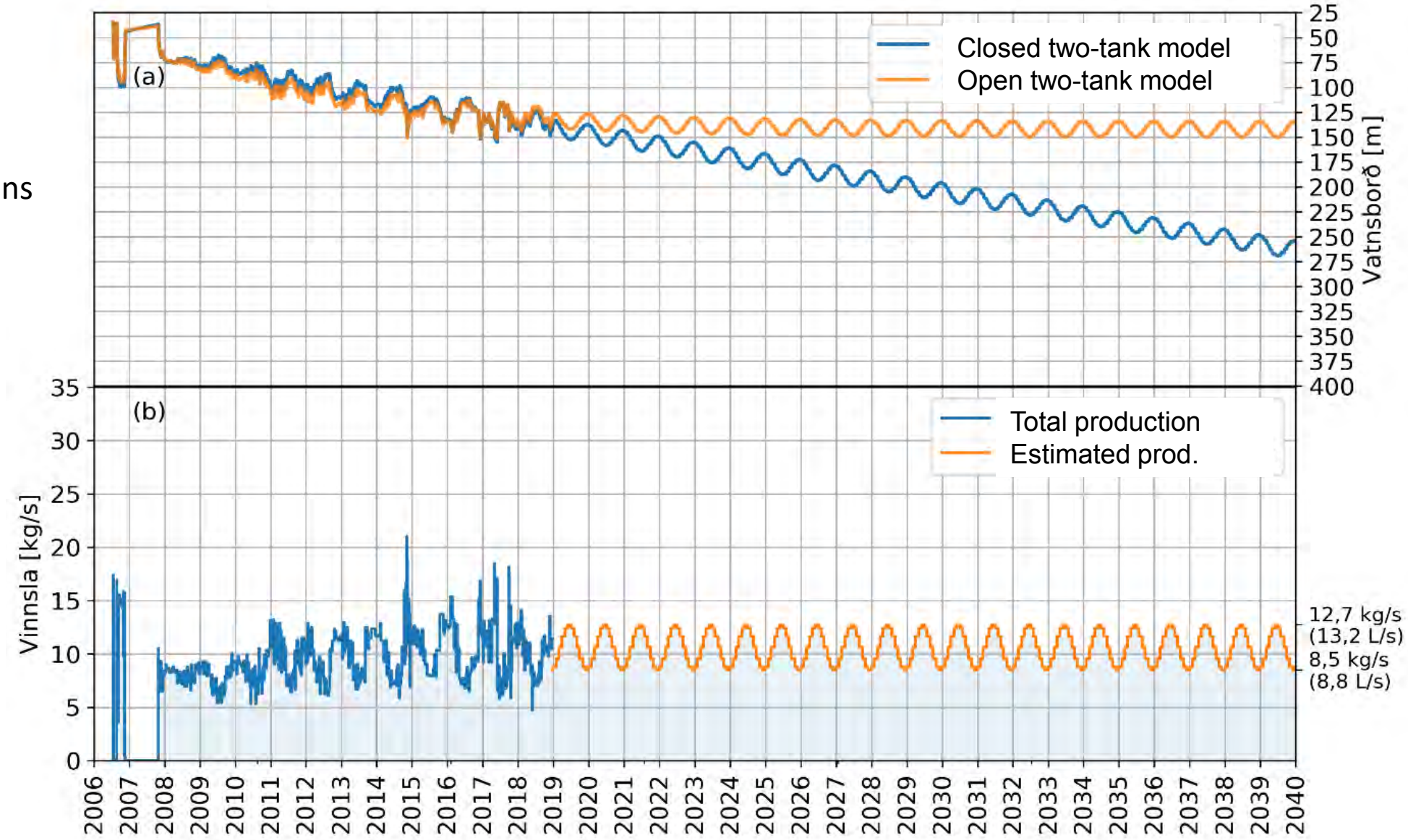
Updated method - Lumpfit++

- The previously implemented method was limited to a single source of production and had a limited number of connections between reservoir volumes.
- Increasing hot water consumption in Iceland over the last decades has led to increased production from geothermal fields, and an increased number of wells per field.
- The increased complexity of reservoir geometry calls for enhancement of the general lumped parameter method presented in 1989.

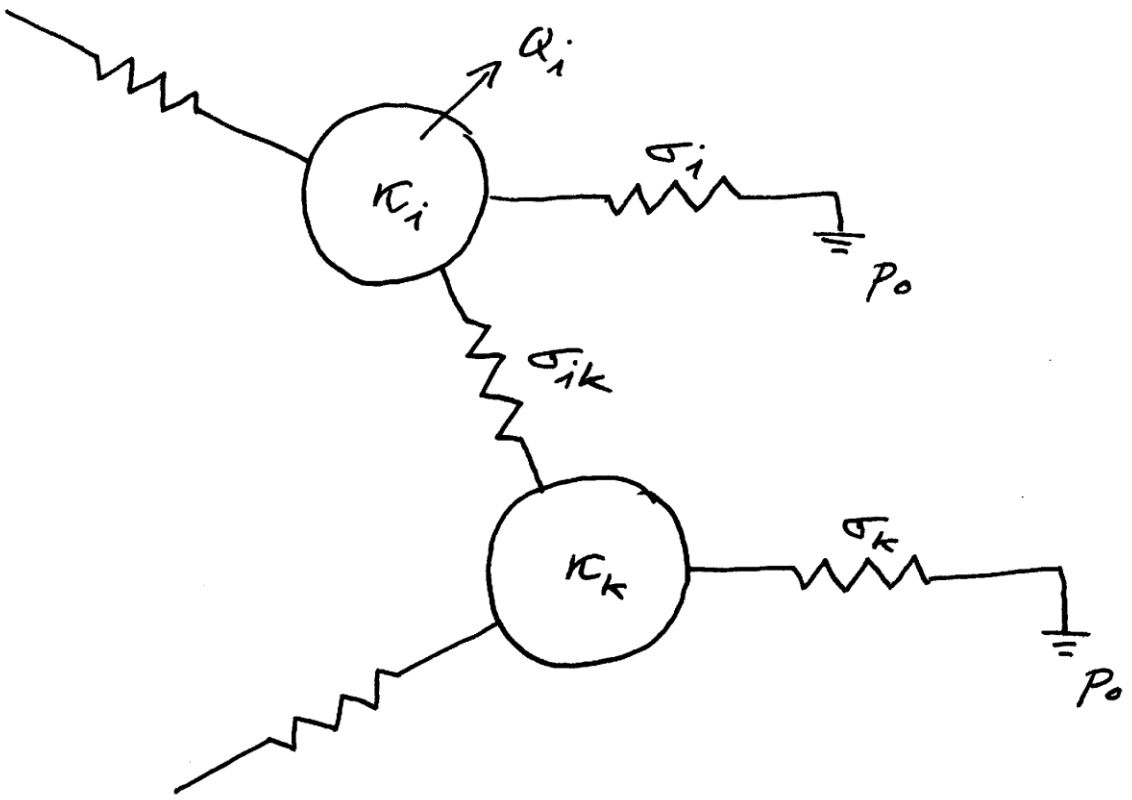
Water-level predictions by lumped parameter models

CLOSED MODEL = conservative predictions

OPEN MODEL = optimistic predictions



General Model



General problem $$\mathbf{K}\frac{d\vec{p}}{dt} + \mathbf{A}\vec{p} = \vec{f}$$

Storage $$\mathbf{K} = \begin{bmatrix} \kappa_1 & & \\ & \ddots & \\ & & \kappa_n \end{bmatrix}$$

Conduction

$$\mathbf{A} = \begin{bmatrix} \sum_j^N \sigma_{1j} + \sigma_1 & -\sigma_{12} & \dots & -\sigma_{1n} \\ -\sigma_{12} & \sum_j^N \sigma_{2j} + \sigma_2 & \dots & -\sigma_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ -\sigma_{1n} & -\sigma_{2n} & \dots & \sum_j^N \sigma_{nj} + \sigma_n \end{bmatrix}$$

Equivalent eigenvalue problem

$$\mathbf{A}\vec{\tau} = \lambda\mathbf{K}\vec{\tau}$$

Pressure Response

- Impulse production

$$\vec{f}_k(t) = \begin{cases} \delta(t) & \text{if } i = k \\ 0 & \text{else} \end{cases}$$

- Impulse solution

$$\vec{h}(t) = \mathbf{T} e^{-t\mathbf{\Lambda}} \mathbf{T}^{\intercal}$$

- General production

$$\vec{f}_s(t) = \sum_{j=1}^{M} (\vec{Q}_j - \vec{Q}_{j-1}) H(t - t_j)$$

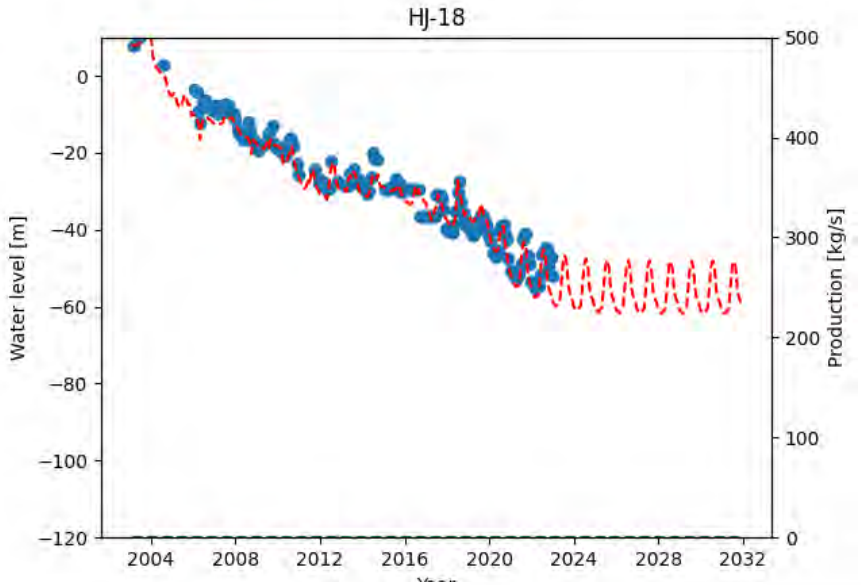
- General pressure response

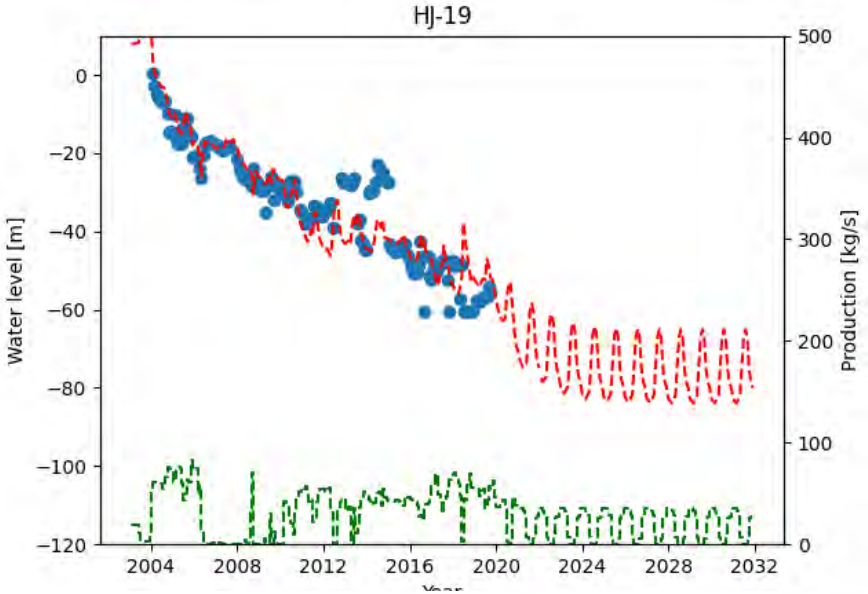
$$\vec{p}(t) = \int_0^t \vec{h}(t-\tau)\vec{f}(\tau)d\tau$$

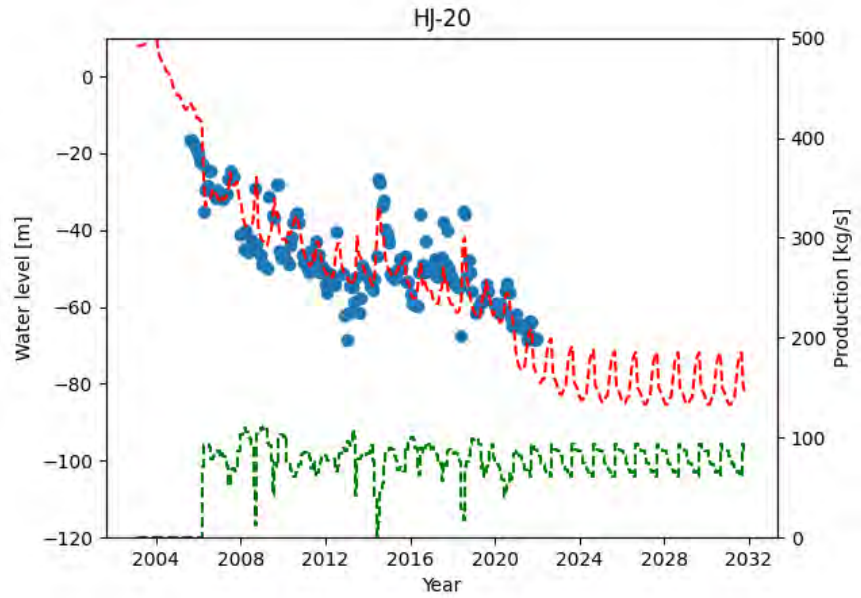
$$\vec{p}(t) = \mathbf{T} \sum_{j=1}^{M} \left[\mathbf{I} - e^{-(t-t_j)\mathbf{\Lambda}}\right] \mathbf{\Lambda}^{-1} \mathbf{T}^{\intercal} (\vec{Q}_j - \vec{Q}_{j-1})$$

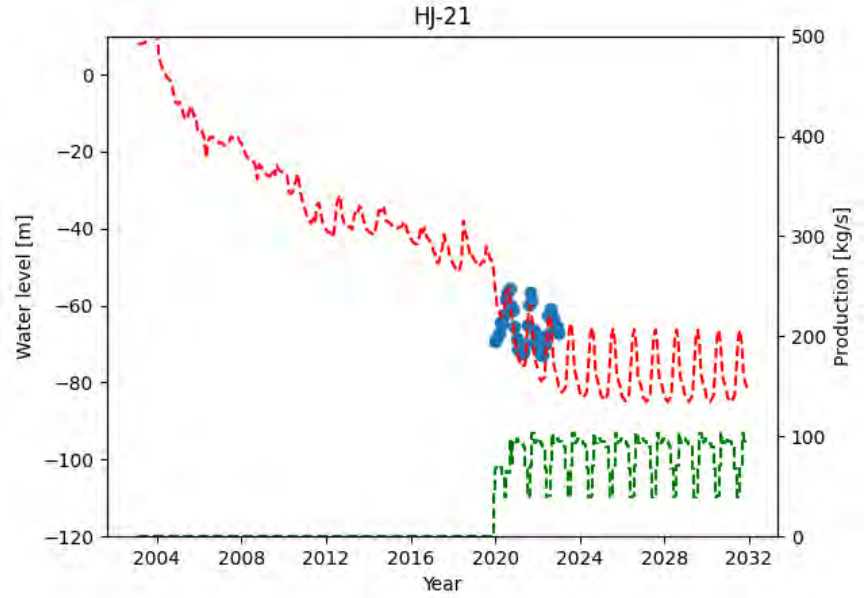
(Axelsson, 1989)

Water level prediction with Lumpfit++









GeoModel: Lumpfit++

- GeoModel project (www.geomodel.pl) aims to improve the management of low-temperature geothermal fields, by providing free access to useful computational tools for reservoir engineers, geothermal fields operators and students.
- One of they key outputs of GeoModel project is the upgraded version of Lumpfit, now called Lumpfit++.
- The new software significantly increases the ability to calibrate reservoir model and create pressure/water level predictions for multiple production wells.
- The tool should be reliable, accessible and easy to use.

Iceland Liechtenstein Norway grants

Norway grants

Acknowledgements

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geomodel.pl

Iceland Liechtenstein Norway grants

Norway grants

Thank you for your kind attention!

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