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Do tracer tests enable model-independent predictions of georeservoir output? two examples from Southern Germany, involving thermal drawdown and solute co-production

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For geothermal reservoirs operated by production/re-injection wells, thermal lifetime is usually defined in terms of a temperature drop threshold, and estimated as a function of fluid turnover time and heat exchange surface-area-per-volume,

$T_{heat} = R \cdot T_{fluid} + D \cdot \sigma^2 \cdot T_{fluid}^2$,

with T_{fluid} supposed to be measurable by means of a tracer test;
σ is rather difficult to infer from tracer signals alone.

For 'aquifer'-like reservoirs, the linear term prevails:

$R > (>>) 1$, $D \cdot \sigma^2 \cdot T_{fluid} << 1$

For fracture-dominated ('petrothermal') reservoirs, the quadratic term prevails:

$R \approx 1$, $D \cdot \sigma^2 \cdot T_{fluid} >> 1$

Deriving T_{fluid} from artificial-tracer signals looks 'model-independent', but is subject to large-time extrapolation uncertainty (which 'restores' model-dependence).

Unlike thermal forecasting, tracer-based prognosis of solute co-production (more precisely, of its lower-bound level, assuming conservative transport by fluid turnover only, non-'replenished' from adjacent rocks) isn't impeded by large-time extrapolation uncertainty, nor by reservoir model/parameter ambiguity, since mass output prediction as a function of time,

$$M_{out}(t) = (C_{ini} - C_{resid}) \left[VOL_{out}(t) - \int_o^t \int_o^{t'} Q(t') Q(t'') g(t'') dt'' dt' \right]$$

requires just knowledge of conservative-tracer fluxes within the forecasting time horizon.

Once a tracer test was conducted in accordance with the rules of the art [usually including observance of flux-type B.C. for tracer input and fluid sampling, cf. **Kreft_and_Zuber_1978**], the reservoir can be treated like a 'black box' with 'response function' (Green's kernel surrogate) g.

This approach is adequate for (conservative) solute co-production, but not for heat transport.

Tracer test results from a particular Upper-Jurassic (Malm) carbonate aquifer near Munich illustrate the issue with T_{heat} as a 'function' of T_{fluid}. Tracer signals available to date yield T_{fluid} in the range of months (still subject to extrapolation uncertainty), and are compatible with both fracture-dominated and 'aquifer'-like representations of reservoir structure; 'compatible' σ values span four(!) magnitude orders.

By contrast, tracer signals from a fractured-porous reservoir, Eastern side of the Upper Rhine rift could be used to predict 'geothermal lithium' output (and its gradual depletion in reservoir fluid turnover), irrespective of reservoir model availability/parametrization. The non-trivial challenge, however, is to foresee and quantify overall WRI effects of 'spent fluid' re-injection, the latter being depleted of its particular micro-constituent (albeit at trace levels only), but likely acidized / 'unreliably' buffered at major-ion levels. WRI cannot be told from conservative-tracer signals; hydrogeochemical modeling (**Kölbel_et_al._2020**, **Maier_et_al._2021**) becomes indispensable.

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