Transient dynamics in confined aquifers: Planning horizon impacts on sustainable yield estimations.

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Résumé

Confined aquifers challenge current groundwater sustainability concepts due to their long response time scales and the dampening potential of aquitards. Pumping introduces a perturbation that initiates a transient response, which propagates through the confining units towards adjacent aquifers and surface systems. As a result, the planning horizon, which refers to the timeframe over which management decisions are evaluated, becomes a critical factor in sustainability assessments. This work explores how sustainable yield estimations in confined systems are influenced by climatic conditions, the degree of confinement, and the chosen planning horizon.

To investigate this, a synthetic cross-section model of a multi-layer aquifer system was developed using MODFLOW6 and FloPy. The sustainable yield was estimated through a constrained optimization approach, by iteratively running a transient model with different constant pumping rates. This analysis was conducted under a range of scenarios, including contrasting recharge rates, varying degrees of confinement, and multiple planning horizons. Additionally, the effect of transient recharge rates was investigated to understand their relevance on the transient response of the system and the impact on estimated sustainable yields.

The modelled response times of this type of systems appear to be highly relevant for planning purposes given the typical human timeframes used for management and policy implementations. Our results reveal that sustainable yield is not a single, fixed value but a dynamic variable dependent on the chosen planning horizon. This analysis illustrates that what might

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be considered a sustainable withdrawal rate over a 25-year horizon could lead to unacceptable or undesirable impacts over a 50-year period, bringing an important question to the debate: which planning horizon to use?

We conclude that effective management of confined aquifers requires a paradigm shift away from steady-state thinking: what is considered sustainable fundamentally depends on when we decide to evaluate it. This demands an adaptive, time-dependent approach where sustainability is analysed within a context-specific planning horizon, acknowledging that our decisions today have consequences that might unfold over decades or even centuries. This introduces broader issues of intergenerational equity, emphasizing that sustainability cannot be determined solely by physical indicators and it must also address long-term governance and ethical considerations.

Mots-Clés: Hydrogeology, Numerical modelling, Confined aquifers, Sustainability, Hydrogéologie, Modélisation numérique, Aquifères captifs, Durabilité