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Confined aquifers: a need for an adaptation of sustainability concepts

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Confined aquifers, distinguished by their large storage and long-term flow dynamics, are often overlooked in groundwater sustainability assessments and rely on frameworks developed for unconfined systems. Unlike unconfined aquifers, confined systems release water through the compressibility of the porous medium, without pore drainage. These properties lead to lower storativity and higher hydraulic diffusivity, resulting in different responses to hydraulic perturbations, such as pumping or recharge temporal variations. Addressing these differences is essential to develop tailored approaches for the sustainable management of confined aquifers, particularly in the context of balancing water supply for different competing demands with the environmental and socioeconomic impacts of abstraction.

We develop a framework for the sustainable management of confined aquifers based on numerical models over synthetic cross sections of multi-layer flow systems. We explore the fundamental differences between confined and unconfined aquifers, particularly in terms of their hydraulic behaviour, response time to hydraulic perturbations, and the interactions with surrounding hydrogeological units. This modelling study also illustrates how confined aquifers indirectly interact with unconfined systems and surface water systems, through their connection via confining layers.

A critical aspect of this work involves understanding the transient response of aquifers, which is governed by their hydraulic diffusivity and described by the concept of response time. Diffusivity governs the rate at which hydraulic disturbances propagate, and the response time describes the time required for the aquifer to reach a new equilibrium. Existing analytical formulations highlight the distinct behaviour of confined aquifers, particularly their faster response times compared to unconfined systems. However, for large-scale confined or mixed systems, response time scales may approach or even exceed those of unconfined aquifers with similar hydraulic properties and, generally, smaller extension. This underscores the importance of a proper delimitation of aquifer boundaries in the assessment of their response times.

In practice, water sustainability policies are inherently scoped within site-specific areas and timeframes. Today, these policies must address increasing pressures from population growth, climate change, surface water quality issues, and other contributing factors. Groundwater models, which support management decisions, should include these factors through accurate conceptualizations of hydrogeological systems, evaluations of their response times, and scenario analyses. Through the adaptation of sustainability concepts for confined and mixed aquifer systems, this study contributes to the development of a framework that will support groundwater management strategies for confined aquifers and highlights their role as a valuable resource for long-term adaptation, emphasizing the need to protect and optimize their use in response to environmental and societal challenges.