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Discussions

Interactive comment on "Consequences and mitigation of saltwater intrusion induced by short-circuiting during aquifer storage and recovery (ASR) in a coastal subsurface" *by* Koen Gerardus Zuurbier and Pieter Jan Stuyfzand

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Final author comments on behalf of all co-authors

Referee #1: David Pyne General: This paper presents an excellent and thorough evaluation of potential mechanisms for salinization of recovered water from ASR storage in brackish aquifers and, in particular, the reduction in recovery efficiency (RE) due to short-circuiting through existing wells open to deeper aquifers. Effective mitigating measures such as the new Freshkeeper technology are of great potential value.

Land use and water quality constraints, and competing uses of coastal aquifer systems

to meet diverse objectives are common to many coastal areas globally. The relatively shallow depths of ASR storage aquifers in the coastal dune sands of the Netherlands are much shallower and more saline than coastal plain alluvial aquifer systems in many other parts of the world. The Dutch ASR experience and associated research therefore extends and deepens the understanding of solutions to similar challenges for ASR wells in other parts of the world. General: It may be helpful to present why the RE was defined for this site by a chloride below 50 mg/l. This makes sense for the Coastal Dunes and greenhouses of the Netherlands, but many readers will wonder why so low compared to drinking water standards, and may tend to be unimpressed by the reported ASR RE values. Author's response: The authors agree that these keywords can be added and are willing to do so. We propose to do is in the current Section 2.1

Page Line 1 26 Key words might also include "upconing" and "downconing," both of which describe "short-circuiting" as referred to in this paper, and as experienced at several operating ASR sites. Author's response: The authors agree that these keywords can be added and are willing to do so.

2 16 While the impact of short-circuiting may not have been evaluated in the research literature, it has been experienced in the field at many ASR locations in brackish and saline aquifers, resulting in recognition that adequate confinement is usually needed in order to achieve acceptable recovery efficiency (RE). Upconing through underlying confining layers and downconing through overlying confining layers can adversely and rapidly impact RE, whether through an open borehole or through a leaky confining layer. Author's response: The authors agree with the referee that there is more evaluation of the confinement of target aquifers for ASR. This study, however, focuses on short-circuiting only (for the sake of clarity). The authors are willing to further emphasize this focus in the introduction and mention the earlier work on confinement for ASR, as stated by the reviewer.

6 15 For ASR storage of fresh water in a brackish aquifer, with or without the potential for short-circuiting, we would normally provide for initial formation and then mainte-

nance of a buffer zone (BZ) to separate the stored fresh water from the surrounding (and underlying or overlying) brackish water. An adequate buffer zone addresses not only blending issues but also geochemical issues such as arsenic attenuation. A typical BZ in an aquifer like this might comprise 30% to 50% of the Target Storage Volume (TSV) that is needed for recovery, however the BZ is a one-time addition of water to the well. Formation of the BZ does not count against recovery efficiency. Instead, it is considered to be a final step in well construction. This typically works....except in situations with short-circuiting where often the BZ volume cannot overcome upconing or downconing of saline water through adjacent open boreholes. Where semi-permeable confining layers overly or underlie the storage aquifer, we may over time freshen the overlying or underlying adjacent aquifers, thereby steadily improving recovery efficiency. This paper sets the RE bar very high initially by aiming to recover all of the stored water (60,000 CM). This may be scientifically defensible and convenient however it is effectively counterproductive. Those who provide funds for ASR implementation are more likely to approve projects that achieve higher RE, even if they do not really understand the science. The buffer zone is one of the keys to achieving high RE, and the cost of the water comprising the buffer zone is usually rather small, especially if amortized over the life of the well. Drawing RE conclusions based on conducting and/or modeling 2 or 3 cycles, without prior formation of a buffer zone, really stacks the deck against achieving satisfactory RE in moderately brackish aquifers. Without short-circuiting, you may be able to achieve a satisfactory RE after maybe 5 to 15 cycles, or with a single cycle following prior development of a buffer zone. The volume of water forming the buffer zone depends on several factors, including leakance of the storage aquifer, lithology and associated dispersion, density differential, aquifer thickness and porosity. We have successfully stored drinking water in a seawater aquifer that had appropriate storage characteristics. Author's response: The authors recognize the potential additional value of introducing a buffer zone for particular settings, especially when short-circuiting and strong buoyancy effects are absent. Its evaluation was however not the scope of this study, so it cannot be stated what the potential benefit may be

in this case. However, the authors wish to state that given target aquifer characteristics and relatively small scale of the scheme, the (especially long-term) benefits of a buffer zone will be limited due to severe buoyancy effects, which causes the buffer zone to move to the top of the target aquifer, allowing salinization at the aquifer's base. Furthermore, the greenhouse ASR systems do not have any extra water to form a buffer zone: the available rainfall is infiltrated, the water demand is recovered. This study explores this maximum demand in the first cycles, in which the biggest performance increase occurs (Bakker, 2010). For the international perception of ASR, it is very important to note to properly sketch these conditions in order to manage performance expectations of the public. This is a very valid point of the referee. A section on this should be added in the discussion.

19 4 Consider adding a sentence or two near the beginning of the paper explaining why this site was selected for testing. People would not normally locate an ASR well 3 m from an ATES well that is known to short circuit the lower confining layer....except for the opportunity to conduct research on short circuit mechanisms and associated mitigating measures. Author's response: In fact, there was no other location available and the short-circuiting was not known at the time of the realization of the ASR wells. This information should be added to the methods section.

19 25 One bar injection pressure is not very high. We typically limit ASR well injection pressures to about two bars, primarily to avoid wellhead transducer seal failures. Author's response: For relatively shallow (50 m below surface level) injection wells in an area where pressure head are near the land's surface, 1 bar actually already high. Higher injection pressures than 1 bar can already result in failure of the sealing (Olsthoorn, 1981). No amendments suggested.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/hess-2016-343/hess-2016-343-AC1-supplement.pdf

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