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Comment on hess-2021-594

Anonymous Referee #1

Referee comment on "Extreme precipitation events induce high fluxes of groundwater and associated nutrients to coastal ocean" by Marc Diego-Feliu et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2021-594-RC1, 2022

General Comments:

The manuscript is well written and well-illustrated. Whilst the proposed implications of the results sound exciting and significant in the context of land-ocean exchange processes, I have serious reservations about the numbers put forward for nutrient fluxes. These reservations fall into two categories that are related:

1. A clearer, less ambiguous definition of different SGD fractions being considered ('terrestrial and marine' vs 'fresh and recirculated' must be put forward – one that is underpinned by the mechanics of flow through porous media.
2. A mass balance approach (steady state one at that) that discriminates between different flow components, as well as different source functions for nutrients must be justified more clearly considering the known issues with non-conservative behavior of both isotopic tracers and transported solutes, the non-linearity of the mixing process for radioisotopes, the number of degrees of freedom available for potential solutions for the source functions into the mass balance, and the nature of subterranean estuaries as biogeochemical hotspots.

I go into more detail on this with 2 queries that I would like addressed, but fundamentally, the approach followed appears (I might be mistaken, and in that case would be happy to be educated on the issue) to ignore a well know aspect of chemical reactor engineering, which applies if we think of the subterranean estuary as a chemical reactor mixing different inputs: This is that the mean age of the outflow mixture does not correspond to the average residence time of water masses within the coastal aquifer, especially if there is a change in the mixing regime, which is very likely given the impact of extreme precipitation events on subterranean estuary dynamics, purely from a mechanistic point of view. If we then take radioisotope ratios as fingerprints of distinct mixture components, and simultaneously as an indicator of mean water age allowing us to determine flushing time within the water volume receiving the SGD inputs, while assuming conservative behavior within the reactor (e.g., the subterranean estuary) for both isotopes and solutes

being mixed, then the outcome of the budget trying to ascribe net nutrient transport into the coastal zone from both fresh and saline groundwater has to be uncertain.

Specific questions

Query 1: Definition of SGD source functions.

On Line 24: 'the flow of terrestrial and marine groundwater to the coastal ocean'.

The terrestrial and marine 'realms' are difficult to distinguish and define in a coastal aquifer. I would write fresh and saline (or salty) groundwater. However, it is unclear how this apparent distinction, made here, is reconciled with what is said in

Line 347: 'Whilst terrestrial SGD represents a net input of water to the ocean, marine SGD comprises disparate discharge processes solely involving the circulation of seawater through permeable sediments or the coastal aquifer', and

Line 358: "the study site, which are supplied via terrestrial (Combined discharge of meteoric groundwater and density-driven circulated seawater)".

Which is which: are the authors indicating that density driven circulation through the coastal aquifer is a net saline water input to the ocean? Are we separating inputs between fresh and saline, or are we distinguishing them based on Ra signatures, and therefore the need to include density driven circulation in the 'terrestrial' component?

But where is this density driven circulation happening? Is this in shallow sandy sediments, beach face, or is this the equivalent of return flow, and hence happening within the coastal aquifer at a larger spatial (but also temporal) scale?

These questions stem from the same issue: the definition of 'terrestrial' and 'marine' SGD is ambiguous. They are important, because any answer has consequences in terms of the way nutrient inputs to the coastal ocean are estimated and more importantly whether those estimates are valid: while fresh groundwater is a net input of water into the ocean, saline inputs are the result of a circulation cell of some type, so over the period of the circulation process, there is no net water input?

From Line 173: ‘Here, we define terrestrial groundwater discharge as the combined discharge of meteoric groundwater and density-driven circulated seawater, and marine groundwater discharge as those processes solely involving the circulation of seawater through permeable sediments (i.e., beach-face circulation, porewater exchange).’

I have reservations on the clarity of definitions presented throughout, as they translate into the mass balance approach (A1) and might affect the suitability of conclusions. It is clear to me that the authors are separating the components based on Ra signatures, more specifically the 224/228 ratios. How they then reconcile this separation made based on an isotope signature with the mechanics of water flow through the coastal aquifer, which defines origins, pathways and whether a net water input into the ocean exists impacts on the credibility of the conclusions.

Query 2. Appendix A: Mass balance.

See also comments on the definition of ‘terrestrial’ vs ‘marine’ SGD flows above.

FRA (Line 360) does not appear in equation A1.

Likewise, FFSGD and FRSGD in Table A1 do not appear in the mass balance (equation A1). Please clarify how are they calculated.

Again, how do these relate to ‘terrestrial’ and ‘marine’ end members for what is clearly a brackish water mass, as already mentioned? Here it appears that SGD is broken into two components: fresh groundwater (FFSGD) and saline groundwater (this is the recycled portion, FRSGD). How do these components of the mixture square with the definitions already questioned in Query 1?

The ’terrestrial component’ is a brackish water mass, including both fresh groundwater and saline groundwater. It is not a net input of water into the ocean. Only part of it is. Which part it is not clear – but for the calculation of nutrient flows into the sea, the net input of water matters the most, and importantly, the fact that the composition of the flows is changed by the mixing, the circulation path, and the timing of the process. We have two components of that mixture: one that is circulating through the coastal aquifer and is therefore characterized by a spectrum of groundwater residence times and biogeochemical histories, and the other that is dragged along and/or forced by the hydraulic gradient and is fresher, but is also characterized by a distribution of residence times. To extract a net flux of nutrients into the ocean arising from the first process, one would need to determine the difference between the concentration at the beginning of the loop (what goes into the coastal aquifer from the sea) and the one at the end of the loop (what comes out after residing in the coastal aquifer), as well as the discharge corresponding to the circulation flow. This is not done.

For the second process, one would then have to determine the discharge associated with the net amount of water (fresh) incoming to the ocean, as well as the concentration of nutrients within that water mass. Even so, this would ignore the fact that the two components mix, and hence the chemical makeup of the solution that comes out cannot easily be reconstructed, and certainly not by assuming linear bi-component mixing. Regardless, we are also assuming here that the nutrients themselves are conservative through all the process and hence the two water masses can be distinguished not only by their isotopic composition, but also by their nutrient composition. It is not clear to me how this is done.

The authors try to ascribe different isotopic signatures to both components, as per Line 187: 'Both trends may indicate that the relative contribution of the terrestrial component of SGD, which is characterized by 224Ra/228Ra ARs close to the equilibrium value (1.0 to 2.2; Diego-Feliu et al., 2021), increased during the occurrence of the EPE.' End-member selection is explained in section A.2.4., but are the two components separable? If they are, then it should be clearly explained how this was done, since there are multiple solutions explaining the measured isotopic ratios in the coastal volume that was sampled. So, fluxes cannot be calculated tout-court by multiplying an apparent water mass flux (FFSGD and FRSGD above, however they are calculated) by the 'end-member' nutrient concentration. This approach not only assumes that the transported radioisotopes are a) conservative, b) mix linearly across the domain and this can therefore be treated like a bi-component mixture, but also that c) nutrients are conservative, and d) it is possible to ascribe a unique source composition to each endmember, which is difficult because a) and b) are not verified.

The recognition that this is the case appears between lines 237 and 243. This then begs the question of what exactly is the study proposing, since there isn't a clear, unambiguous result discriminating SGD pathways, and therefore their associated nutrient contributions to coastal budgets?

Technical edits

Abstract:

Line 17: 'Results indicate that the groundwater flows of terrestrial and marine SGD after the extreme precipitation event were 1 order of magnitude higher than those in baseflow conditions.'

I fail to see a mechanism explaining here how the saltwater (marine) SGD flows increased driven by an EPE. The classifications of 'terrestrial' and 'marine' are ambiguous in the context of SGD and should be clearly grounded on the mechanics of groundwater flow. See also specific queries.

Line 50: ‘Infiltrated water displaces groundwater stored in the aquifer towards the sea, enhancing mixing processes in the coastal aquifer’

This is not entirely correct. The fact that precipitation percolates through soil does not guarantee it reaches the local water table, thus adding its mass to the freshwater body in the aquifer; this is when the second part of the sentence would apply. The role of interflow is not well understood, and the timing of flow through the unsaturated zone varies tremendously (well beyond the scale of EPEs anyway), depending on geology, soil type, land cover, surface gradient, accumulated precipitation, and degree of clogging as well as precipitation rate – so this sentence must be rewritten. What fraction of ‘terrestrial’ SGD is interflow?

Methods

Line 106: ‘as well as seawater samples’ – clarification needed. Temperature and salinity measured in samples taken at sea as well? The sentence is not clear.

Line 125: ‘Polyethylene vials’ – clarify. HDPE is the standard for nutrient analysis. Was this used, or simple polyethylene vials?