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Discussions

Interactive comment on “Irrigation return flow causing a nitrate hot spot and denitrification imprints in groundwater at Tinwald, New Zealand” *by* Michael Kilgour Stewart and Philippa Lauren Aitchison-Earl

Michael Kilgour Stewart and Philippa Lauren Aitchison-Earl

m.stewart@gns.cri.nz

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Reply to Anonymous Referee #2 (R2)

R2: This paper looks at the impact of irrigation return waters in areas of intensive agriculture on nitrate concentrations and considers more broadly how we track the sources of nitrate via dual isotopes. The study itself is scientifically sound although I struggled in places with the text. Some of the sections are not very clearly written and the structure could be improved. Specifically, both the introduction and discussion

alternate between local and more global observations and the descriptions in parts of sections 4 & 5 are long. A few clearer statements around the global importance of the work would also improve its impact. I have made several comments below that I hope are useful in revising this paper.

Authors: We thank Referee #2 for helpful and constructive comments on our work.

R2: SpeciïňĄc comments: Abstract. The abstract is well-written and intelligible without having to refer to the rest of the paper. Having said this, it could be improved by: 1) Adding a sentence at the start to outline the motivation for the study 2) Adding a few key values (there are a fair number of qualitative terms here – high, low, relatively etc). A few speciïňĄc values would convey more meaning.

Authors: We will add sentences to the beginning of the abstract to address points 1) and 2) as follows: “Nitrate concentrations in groundwater have been historically high (N $\geq$ 11.3 mg/L) in an area surrounding Tinwald, Ashburton since at least the mid-1980s. The local community are interested in methods to remediate the high nitrate in groundwater. To do this they need to know where the nitrate is coming from.”

R2: Introduction The introduction sets the scene for the study. For a paper in an international journal such as HESS, it would be appropriate to add a few comments about how New Zealand compares to other intensive agricultural areas globally in terms of the scale of the problem. High nutrient loads are of global interest and this research will have broader interest, so some more comments here are warranted. The structure could be improved as it alternates between general and area-speciïňĄc statements. Try to group these more. Some of the description of the issues around Tinwald could be in section 2.

Authors: We will refer to OECD reports (2013 and 2017), which place New Zealand’s intensive agricultural area management in the context of those of OECD member countries: “Eutrophication causing hypoxia and algal blooms, due primarily to agricultural runoff of excess nutrients, is considered the most prevalent water quality problem globally (OECD, 2017). In New Zealand the N balance worsened (i.e. became more positive) more than in any other OECD member country between 1998 and 2009, almost entirely because of expansion and intensification of farming in New Zealand (OECD, 2013). (The N balance is the difference between N inputs to farming systems (fertiliser and livestock manure) and N outputs (crop and pasture production) - a positive N balance indicates increased potential for N pollution of soil, water and air. In fact, the increase of the positive N balance matched the increase of dairy farming in New Zealand.)"

R2: Lines39-43. What are the concentrations of nitrate in the groundwater and the river water?

Authors: Groundwater (N $\geq$ 11.3 mg/L) and alpine river water (N < 1 mg/L). These numbers will be added to the text.

R2: Lines 44-48. This seems out of place in the description of the local setting. It would be better earlier where you discuss the general importance (especially as it refers to contaminants other than nitrate).

Authors: We will move this to later in the paper, but it can't go earlier because the term 'irrigation return flow' needs to be defined first.

R2: Lines 68-62. These references are a little dated. Can you point to some key recent studies, especially those that deal with the issues of irrigation return ïňĆows?

Authors: More recent references including two dealing with irrigation return flow as well as nitrate isotopes have been added (i.e. Wexler et al., 2014, Park et al., 2018, Spalding et al., 2019).

R2: Background As mentioned above, some of the detail from the introduction (eg the high nitrate, which is also covered in section 2.4) would be better here. This section is also long for the information it contains and probably it could be written more succinctly.

Authors: We will make these changes.

R2: Lines 91-95 (and elsewhere). It would be preferable to use "residence times" not "ages". Also, here and throughout suggest referring to the groundwater not the well (the well's age is when it was installed, which is not what you mean).

Authors: Agreed

R2: Line 125. MAV not deïňĄned (I think that it is the maximum WHO limit for nitrate in drinking water?). Is this the best value to use of should the lower NZ limit be used?

Authors: MAV is now defined in the introduction. We prefer to use MAV, but either limit could be used.

R2: Line 126-136. Adding values to the text would get the message across better (rather than the reader having to ïňĄnd them for their self).

Authors: Agreed, will add values. (This problem is partly due to HESS's requirement that the figures be placed at the end, instead of at the right places in the text.)

R2: Methods Section 3.1 could use a few more details. a) Somewhere, the screened intervals should be notes as geochemical data from long screened production wells conveys different information to that from short-screened monitoring wells. b) In Table 1, is the depth the mid-screen? c) Were the wells purged or was sampling done from ïňĆowing wells? d) The Comments on groundwater levels and river flows is not very clear.

Authors: a) Agreed, we will add screened intervals to Table 1 (52% of wells had short screens (average 2 m length), 21% had long screens (average 10 m length) and 27% had no screens). b) The depths given were total depths, but we will use mid-screen depths instead where there were screens and total depths where there were no screens. c) Field measurements had stabilised before sampling for all wells. 25 wells were purged of at least three well casing volumes before sampling, the 8 remaining wells were sampled by low flow methods (pumps were lowered into the wells and water was sampled after pipes were purged by three pipe volumes). d) This has been rephrased.

R2: Line 147. Field quality?

Authors: No, field quantity (quality means how good (the measurements) are, quantity means what the values are.)

R2: Lines 148-149. What are the criteria used for these groups? Results Section 4.1 is difïňĄcult to follow without some more details being reported in the text. At the moment, the reader has to keep looking at the data in the ïňĄgures or tables to see what is being referred to (especially lines 186-192 and 193 to 200).

Authors: Groups A and B have low DO values (< 4 mg/L) with A having high δ15N (> 15‰ and B moderate δ15N (7-9‰. Groups C and D have high DO (> 8.2 mg/L) with C having the highest and D the lowest Cl and SO4 concentrations. This description will be added to Section 3. The groups are clearly identified in Tables 1 and 2 and in many of the figures. (It is unfortunate that HESS requires that tables and figures be placed at the end of the paper, because it makes the reviewer's task so much more difficult and time-consuming.) Putting in so much detail that no reference to the tables and figures at all is needed would overburden the text.

R2: Lines 217-223. You do not need the detail of the GMWL as it is well known. You could move the deïňĄnition of the d excess to the methods.

Authors: This will be reduced.

R2: Lines 220-243. The description of the stable isotopes could be shorter (and clearer). There is a lot of text here to explain a relatively simple concept that samples with isotopic compositions to the right of the MWL are evaporated.

Authors: Ok

R2: Lines 243-250. There are probably a reasonable number of uncertainties in these calculations (having to estimate the initial isotopic composition of the rainfall that

recharges the groundwater, understanding the precise impacts of evaporation etc). Do you have any ideas of how those impact these calculations?

Authors: This calculation is considered approximate because some important quantities have been estimated rather than being measured. An estimate of error will be made.

R2: Section 4.3. Again, this description is long in places and could be rationalised. The Raleigh equation (line 261) is reported later in the section - it might be better to report how the calculations were done in the methods which would let this section focus on the results (at the very least try to group the descriptions of the calculations and the outcomes more).

Authors: Ok

R2: Section 5.1. Lines 330-364. Do you need all these calculations? It seems though the Cl mass balance together with the isotopic enrichment deïňĄnes the recharge % well enough (it is the basis of an often-used recharge rate calculation after all). Could you start off with that and then report the results of the water mass balance as support? Also, the inïňĄltration data look to be from a lysimeter, which may be less than total recharge (given that it is probably above the water table). Since you are interested in the chemistry of the recharging water it would be simpler to relate it to a recharge estimate based on the chemistry.

Authors: We will revise this section to simplify it in light of the referee's suggestions.

R2: Section 5.2. The other aspect that is often ignored is that the source has to be there (regardless of the isotopic composition). The points made on lines 398-404 are correct but there are a fair few studies where the isotopic compositions point to stores that are not locally present. This more general discussion would be better in the conclusions.

Authors: We will look at putting some of this into the Conclusions to emphasise some more general points.

R2: Lines 440-450. It is not clear whether these are general points or some things that may be related to your studies. If it is the latter, is there any evidence that they may apply? You make the point again in the next paragraph, so something to back it up would be good.

Authors: As pointed out by Referee #1, other studies have shown the presence of at least two pore sizes in Canterbury gravels (Dann et al., 2009).

R2: Conclusions The conclusions are reasonably area speciïňĄc; however, there are several general points made in the discussion. It is preferable to have the conclusions outline the more general points (after the area-speciïňĄc conclusions) – then the reader who skips the details gets the message!

Authors: We'll look at revising the conclusions

R2: Appendix I am not sure what the rationale is for where the equations are presented. At the moment they are scattered throughout the text and in an appendix. You could look at whether they would all be better in the appendix or split between the appendix and the methods.

Authors: Will do

R2: Are the calculations in the Appendix the same as those from GonïňĄantini (1986: Handbook of Environmental Isotope Geochemistry. Vol.2 the Terrestrial Environment. Elsevier, Amsterdam, 113-186) which are widely used?

Authors: The results would be very similar, but the calculations are based on the measurements and equations given by Stewart (1975), which also has been widely used and cited.

R2: Table 4. Standard deviations of the data would be useful

Authors: Ok

References Dann, R.L.; Close, M.E.; Flintoft, M.J.; Hector, R.; Barlow, H.; Thomas,

S; Francis, G.: Characterization and estimation of hydraulic properties in an alluvial gravel vadose zone. Vadose Zone Journal 8(3): 651-663, 2009. Park, Y., Kim, Y., Park, S-K., Shin, W-J., Lee, K-S.: Water quality impacts of irrigation return flow on stream and groundwater in an intensive agricultural watershed. Science of the Total Environment 630, 859–868, 2018. Spalding, R. F., Hirsh, A. J., Exner, M. E., Little, N. A., Kloppenborg, K. L.: Applicability of the dual isotopes δ15N and δ18O to identify nitrate in groundwater beneath irrigated cropland. Journal of Contaminant Hydrology 220, 128–135, 2019. Wexler, S. K., Goodale, C. L., McGuire, K. J., Bailey, S. W., and Groffman, P. M.: Isotopic signals of summer denitrification in a northern hardwood forested catchment, Proc. Natl. Acad. Sci. U. S. A.,111(46), 16,413–16,418, 2014.

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