

# ***Interactive comment on “Modeling nitrate from land-surface to wells’ perforations under agricultural land: success, failure, and future scenarios in a Mediterranean case study” by Yehuda Levy et al.***

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Authors’ response to Referee #1 Comment

We thank the anonymous referee for his thoughtful review. We are sure the changes that will be made due to these comments will improve the manuscript significantly. The referee’s comments and our responses are listed herein one by one.

1) Title – consider revising to emphasize the main scientific issue (spatial variability of nitrate?). One option is to replace “success, failure” (which can be misunderstood) with “spatial variability.”

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Response 1 - We considered this comment for a long time (as well as before submission). The scientific issue in this work is not only spatial variability but also how can we model the fate of nitrogen from the agricultural fields to nitrate contamination in groundwater wells. Putting spatial variability in the title can raise an expectation that the paper focuses on heterogeneity and finds solutions in the stochastic-hydrology arena. Therefore we prefer not to use this term in the title. Nevertheless, we took the reviewers suggestion to put spatial variability up front at the beginning of the abstract (comment # 2). The terms success and failure may be misunderstood, yet, on the other hand they raise positive curiosity in the reader. Reading the abstract is enough to understand the title. Furthermore, we think the success in modeling large-scale while failing in point estimation and the reasons for that in this case, is a significant part of the scientific conclusions of this study.

2) Abstract - Consider stating the scientific problem early in the abstract (e.g. Can spatial variability of nitrate, be characterized on the basis of land use and standard agricultural practices?)

Response 2 – The reviewer’s suggestion was accepted the following will be added to the text in line 14 after the first sentence of the abstract: "Contaminated areas often show large spatial variability of nitrate concentration in wells. In this work we tried to assess whether this spatial variability, can be characterized on the basis of land use and standard agricultural practices."

3) 61 - Consider also mentioning that nitrate is discharged to streams or other surface water receptors, which can be a major concern.

Response 3 – The paper is about nitrate leaching to aquifers under Mediterranean climate in which permanent surface flow are rare. Nevertheless, we will add a sentence that mentions the ecological problem of accesses nitrogen from agricultural sources in surface water bodies.

4) 64 - Should this say “significant spatial variability”?

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Response 4 - We thank the reviewer very much for this rightful correction. We will change "distribution" to "variability" in the revised manuscript.

5) 75-80 - In the statement of objectives, consider making the scientific implications (e.g. explaining the spatial variability of nitrate) more prominent, and perhaps de-emphasize the model-specific and site-specific elements.

Response 5 - As mentioned above the spatial variability is one aspect of the scientific implications in this paper but not the only one. The term spatial distribution will be changed here to spatial variability, which will make it more prominent.

6) - Should "restore" be "estimate"?

Response 6 – We will change the text to "reconstruct the observed groundwater nitrate concentrations". The term "reconstruct" is used often to describe a model results that fit observations.

7) 100 - Consider defining aerial coefficient of variation mathematically

Response 7: The sentence will be changed to: "The coefficient of variation (standard deviation / Average) of nitrate concentration in the wells in Fig. 2 is 38%."

8) 145-150 - Are agricultural-chemical source of Cl important (e.g. KCl)? Are these accounted for in the mass balance?

Response 8 - Usually potassium fertilizers in this area are added according to soil or leaf analysis and most farmers use mixed type K fertilizers when needed (K<sub>3</sub>PO<sub>4</sub>, KCl, K<sub>2</sub>SO<sub>4</sub> etc.). Therefore, we couldn't estimate the Cl concentration from fertilizer properly and it was neglected. In the worst case scenario of high need for K and using only KCl, the Cl mass contributed from the fertilizer will not exceed 15% of the total Cl mass input at the soil surface (Citrus orchard data, irrigation water contain 140 mg/l chloride and are the dominant source of Cl). This small contribution and rareness of such worst-case scenario justify neglecting this source of chloride in the chloride mass balance.

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9) 227 - Consider spelling out "Israel Water Authority" here.

Response 9 - "IAW" will be changed to "Israel Water Authority".

10) 245 - Consider changing "strictly kept" to "kept constant" or something similar.

Response 10 - No, the recharge fluxes are not constant they are transient. They were calculated by the unsaturated zone flow models, and were not changed during calibration of the groundwater model.

11) 248 - Section 2.3.3. – This is quite brief and readers will have additional questions, e.g. about initial conditions and boundary conditions for NO<sub>3</sub>- concentrations.

Response 11- We accept the reviewers comment that this section is too brief and details on initial and boundary conditions are missing. Lines 256-258 will be changed to: "In the groundwater transport model the initial condition was the measured nitrate concentration at 2012. The transient nitrate-concentration boundary conditions were modified to account for similar reductions in nitrogen fertilization outside of the model domain. This was done by two steps: (1) run the model to the future with constant boundary condition and looking on the trends of the nitrate concentration of the wells inside the model domain; (2) adjusting these trends to the boundary condition and run the model to the future again with transient boundary conditions."

12) 297 - Table 3 – Spell out "Crop Mass Balance" or define CMB in caption or table footnote.

Response 12 –"Chloride Mass Balance" will be spelled out in the Table caption

13) 306 – spell out MAE (mean absolute error).

Response 13 – mean absolute error was defined as MAE in line 243.

14) 307 - It is not clear what is meant by "the improvement in the calibration ceased when...". Is the meaning that calibration efforts were stopped when MAE <0.5 and bias <0.1? And/or that it was difficult to improve results beyond those cutoff values?

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Response 14 – The meaning is that the calibration efforts were stopped when the conditions of average MAE  $<0.5$  m and bias  $<0.1$  m, were achieved. It was assessed that in the framework of this research this target is appropriate. The hydraulic head gradient in the research area is relatively linear from east to west, with a magnitude of about 2.5 m/ 1 km, hence, the target of 0.5m is reasonable. We also do not want to elaborate further on the flow system in this paper because the main issue is the nitrogen transport and fate. Due to the reviewer’s comment “met” in line 308 will be changed to “achieved”

15) 314 - Should this say “initial transport parameters”? (is this 500m value the one referred to in the previous sentence?)

Response 15 – No, this value of longitudinal dispersivity is the fitted value after the first stage of calibration. To emphasize this point we will change the text to: "The final transport parameters used in the calibrated model ..."

16) 316 – Consider revising to “mean nitrate concentration for the entire modeled area”

Response 16 - We thank the reviewer for this good suggestion: "nitrate concentrations over the entire modeled area" will be changed to: “mean nitrate concentration for the entire modeled area”.

17) 318-319 - “The model reconstructed. . .” This seems repetitive and can be omitted.

Response 17 – We thank the reviewer for this comment. Nevertheless, although there is redundancy in this text we prefer to leave it because the first sentence describes the goodness of fit measures, while the second is the mechanistic interpretation of this result. The words “This means. . .” will be added to the beginning of the second sentence to emphasize the point.

18) 326 and onward – It seems that the need for “multipliers” is a key result of the paper, because it indicates that nitrate variability is greater than can be explained by variation of crop-specific agricultural practices and physical processes, to the extent that they

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are simulated here. I suggest revising to emphasize this scientific significance, and to put less emphasis on the technical role of multipliers as an ad-hoc solution to a modeling problem. In other words, consider revising the language so that readers can see that the two models (with and without multipliers) address the scientific question of whether nitrate variability can be explained by general crop-type practices and the other factors considered in the numerical models. Also, it would be helpful to further emphasize in the discussion how this result fits into the existing literature. For example, homogeneous NO<sub>3</sub><sup>-</sup> input functions have been used with some success in local-scale (e.g.. single field) studies to explain spatially varying NO<sub>3</sub><sup>-</sup> concentrations (e.g. Liao et al., 2012 <http://onlinelibrary.wiley.com/doi/10.1029/2011WR011008/full> ; Alikhani et al., 2016 <http://www.sciencedirect.com/science/article/pii/S0022169416302098>). In regional scale studies, it has been established that a homogeneous input function typically does not suffice, and multipliers similar to those of this study have been implemented (e.g. Green et al., 2016 <http://www.sciencedirect.com/science/article/pii/S0022169416302852>). This current study can be seen as a logical extension of the previous studies because it tests the extent to which the input function of NO<sub>3</sub><sup>-</sup> can be improved, or even directly estimated from general agricultural practices and vadose zone characteristics. So in combining the current and previous studies, perhaps the authors could comment further on typical scales of variability (e.g. if intra-field variability of fertilizer applications were an issue, would the previous field-scale studies with homogeneous N-inputs have succeeded as well as they did?), the factors that may account for the variability (some already included in discussion), and/or related topics to inspire future research directions.

Response 18 – We thank the reviewer for this important comment. The significant conclusion concerning aquifer-nitrate spatial variability and land use spatial variability is written in lines 324-325 in the results section. We tried to separate results from discussion in this paper, nevertheless the reviewer's suggestion to further discuss the scientific (and practical) meaning here is accepted for improving reading flow. In line 325 the fol-

lowing text will be added: "The meaning of this, is that nitrate spatial variability cannot be explained only by physical process of agricultural practice and land-use variability on surface. Other factors that are local and arbitrary, significantly affect nitrate concentration in some wells and therefore the measured spatial variability of nitrate in the aquifer. These factors were introduced into the numerical model as will be explained hereafter." As of the discussion, we accept the comment and will include more references in the revised version to better fit to existing literature, as suggested (e.g. Alikhani et al., 2016; Kourakos et al., 2012; Spalding and Exner., 1993; Liao et al., 2012; Green et al., 2016 etc.).

19) 335 – Consider adding a sentence to note that the physical significance of the multipliers will be addressed in the discussion section.

Response 19 – A sentence before, the reader is directed to the discussion section (line 333). The term "physical significance" will be used as suggested

20) 349 – Change "on average for" to "as an average of". Consider clarifying/acknowledging that even though the average is less than 70 mg/L, there would still be some wells exceeding that limit.

Response 20 – "on average for" will be changed to: "as an average of" as suggested. We thank the reviewer for the second remark. A sentence will be added saying: "Even in this case about half of the wells will still exceed the standard concentration."

21) 362 – Consider changing "coarse" to "approximate" or "first-order" or something similar

Response 21 – "Coarse" will be changed to "first-order"

22) 368 – I suggest not using the word "failure", as it can be misinterpreted as referring to the model itself, rather than to the relative smoothness of NO<sub>3</sub>- spatial gradients in the model as compared to measurements – a result which successfully addresses the scientific objectives of the study.

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Response 22 - The strait-forward mechanistic modeling scheme that was used failed to reproduce the spatial variability in wells. Nevertheless, this result and modeling scheme led to the proof that unrealistic nitrate fluxes (much higher than application rates) are needed to support the most contaminated wells.

23) 370 – The specific explanation here (intra-field variability) seems to be given without consideration of additional possibilities that are discussed later in this section (E.g. rapid transport in bore hole annulus)

Response 23 - High fluxes of nitrate can be a consequence of high fluxes of water (hole annulus, leaks of irrigation system etc.) and/or high concentrations of nitrate (fertilizer tank leakage, compost pile forgotten to be distributed etc.). In line 369-370 we will add a clarification on possible reasons for high nitrate inputs close to the well: ". . .and are a result of random failure of even fertilizer distribution in the field that can be due to one or more of the following reasons."

24) 376-378 – I don't follow the logic of this text.

Response 24 – We understand the paragraph is somewhat unclear and will be clarified in the revised paper. The first sentence argues that heterogeneity of the porous medium may also cause local very high nitrate fluxes. The second sentence shows how data from this study supports such possibility. The text will be changed to the following: "Heterogeneity of the porous medium may cause extremely high nitrate fluxes likewise well failure discussed previously, and may be a source for local high contamination. The field survey reported here support this statement. Of the nine deep profiles reported here (Figure 6, Table 1), one showed extreme nitrate concentrations and calculated nitrate fluxes that were 4- to 5-fold higher than in the other profiles extracted from the same orchard (Persimmon A, Table 1). "

25) 378 – I suggest changing "non-physical" to "heuristic"

Response 25 - We accept the comment. "non-physical" will be changed to "heuristic"

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