Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2020-570-AC2, 2021

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Are maps of nitrate reduction in groundwater altered by climate and land use changes?" *by* Ida Karlsson Seidenfaden et al.

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Received and published: 6 May 2021

Reply: Referee #2 General comments In the manuscript, the authors investigate the impact of changes in climate and land use on maps of nitrate reduction in groundwater in a Danish catchment. Such maps are important tools to support management strategies that deal with nitrate pollution. Therefore it is highly relevant to investigate the potential error made in current practices that use static maps and thus neglect the effect of changes in climate and land cover. This study compares maps of nitrate reduction in groundwater produced for different climate and land use scenarios within a modelling framework. I think that a number of point need to be clarified and examined

to ensure the robustness and reproducibility of the results. I provide here a summary of my main concerns:

1) More information on the data and methods used is needed. In particular, the manuscript refer to numerous past studies for the data and methodology, which makes it difficult for the reader to have a clear understanding of the data and methods. The authors should provide in the manuscript a summary description of all data and method used (they can then refer to past studies for more details). Thank you for this comment. We have added new information on the methodology and restructured the entire method section. We have also added more information on the data and the data sources in the data section (2. Study site).

2) The calibration includes a number of 'manual' adjustments to the parameter values and identify a single parameterization. I think that it would be valuable to account for the uncertainty in the model parameter values and to determine whether the changes observed in the nitrate reduction maps due to changes in the climate are appreciable given the uncertainty due to parameter values. Given the presumably large number of calibrated parameters, the issue of equifinality is likely to arise, i.e. combinations of different parameter values could lead to the same model performances, but produce different nitrate reduction maps. In particular, only groundwater parameters are adjusted to match the Nitrate Arrival Percentage (NAP), and the value of these groundwater parameters could compensate for deficiencies in the values of the soil parameters (in particular soil denitrification parameters). I think this should be at least discussed in more details in the manuscript and I refer e.g. to Wade et al. (2008). Thank you for this comment. Yes, the section was unfortunately somewhat unclear and it was not very well described the steps we took during the calibration to ensure equifinality. We have added some extra introductory sentences to the method section (L121-L137), as well as restructured the entire section and changed the headlines. We have also added more information on the calibration procedure in the section 3.1-3.3 and on the validation in section 4.1, and an additional figure (Figure S1) in the supplementary material

showing the stream hydrograph and performance.

The model was calibrated in 3 steps, the parameter-rich hydrological model (Mike She), was first calibrated by identifying five sensitive parameters (among these was a single soil parameter) through a sensitivity analysis of 28 free (and 43 tied) parameters. A global search engine (Shuffled Evolution Complex) was used. Thus, limiting the risk of equifinality. Secondly, the sensitive and calibrated soil parameter was thereafter transferred to Daisy. The Daisy model has previously been manually calibrated (a manual calibration is the only way to calibrate this model due to its 1D column formulation) to the catchment, and this setup was used in this study and performance was evaluated after changing the soil parameter calibrated by Mike She. First after the calibration of these two models, the redox interface location was calibrated as a final step, using the nitrate arrival percentage obtained at the downstream station.

3) From the manuscript, I understand that, in the model, tile drains can be located in non-agricultural areas, which I find surprising. Some explanation on this are required, since tile drains appear to have a large impact on the model results. Yes, this true. We did not explain this. We have added text on this issue in L145-149: The study is heavily tile drained, and it can be assumed that drainage will always be present when it is need in the agricultural areas. However, the actual site-specific location of tile drains are unknown and therefore drains are specified across the entire catchment at a depth of -0.5 meters . Drain flow is however only activated when groundwater level rise above drain level. Apart from representing tile drainage the drainage system also represents small ditches and stream, too small to incorporate into the river system following the approach of Troldborg et al. (2010).

Troldborg, L. et al., 2010. DK-model2009 - Modelopstilling og kalibrering for Fyn. GEUS Report.

I provide below detailed comments. ABSTRACT L20-22 'Th study, however, [...] in reduction capability: ' this sentence needs to be revised. 'complex interactions' is vague

and the analyses presented in the manuscript do not explore the effect of model formulations on the nitrate reduction maps. We have reformulated the sentence: The study, however, also showed that the reductions maps are products of a range of complex interactions between water fluxes, nitrate use and timing. What is also important to note, is that the choices made for future scenarios, model setup and assumptions may affect the resulting span in reduction capability.

SECT. 1 (INTRODUCTION) L42: I suggest citing and discussing the study by Knoll et al. (2020), that establishes a map of groundwater redox conditions for Germany through machine learning, and the study by Tesoriero (Tesoriero et al., 2015), that investigates the redox conditions in groundwater in the Chesapeake Bay watershed in the USA. Thank you, we have added these references. L49-54: Heterogeneities in geology and drainage systems are responsible for substantial local spatial variations in nitrate reduction. However, the spatial variation of nitrate reduction in the groundwater system has so far only been investigated in a handful of studies (e.g. Højberg et al., 2015a; Knoll et al., 2020; Kunkel et al., 2008; Merz et al., 2009; Tesoriero et al., 2015; Wriedt and Rode, 2006). Different approaches have been used in these studies from nitrate groundwater modelling (Højberg et al., 2015b; Merz et al., 2009; Wriedt and Rode, 2006), data driven machine learning (Knoll et al., 2020) or statistical modelling (Tesoriero et al., 2015).

L59-60: 'A severe problem [. . ..] resulting flow pathways.': This statement should be better explained and supported by some reference. We have reformulated this sentence and added a reference: A severe problem in this respect is, however, that the nitrate reduction maps may not be constant in time as the reduction taking place at a given location depend on resulting flow pathways (Hansen et al., 2014b).

SECT. 2 (STUDY SITE) L 75: Please add further details on the type, characteristics (such as frequency) of the nutrient data. Thank you, this has been added in L98-L104: The discharge station at Kratholm has one of the best nutrient time series in Denmark starting in the 1980s, with near-daily sampling from 1989 (Windolf et al., 2016). The station, therefore, provides a long and near-complete data set for nutrient modelling as well as an extensive water discharge time series (Trolle et al., 2019). In 2005-2009, the average discharge amounts to 4.6m3/s and the load is approximately 14 kg NO3-N/ha/year. A decreasing trend in nitrate loads has been observed previously during 2000-2013 by Windolf et al. (2016), possibly due to implementation of mitigation measures in the catchment.

Trolle, D. et al., 2019. Effects of changes in land use and climate on aquatic ecosystems: Coupling of models and decomposition of uncertainties. Science of The Total Environment, 657: 627-633. DOI:https://doi.org/10.1016/j.scitotenv.2018.12.055 Windolf, J. et al., 2016. Successful reduction of diffuse nitrogen emissions at catchment scale: example from the pilot River Odense, Denmark. Water science and technology : a journal of the International Association on Water Pollution Research, 73(11): 2583-9. DOI:10.2166/wst.2016.067

L81: A definition of the criteria to identify the redox depth (i.e. to separate aerobic from anaerobic conditions) is missing. This information has been added, L105-106: 226 measurements of the redox depth are available from boreholes in the area, the redox depths were mainly interpretated based on sediment colour as described by e.g. Ernstsen and Mørup (1992), and a few by measurements of reduced compounds.

Ernstsen, V., Mørup, S., 1992. Nitrate reduction in clayey till by Fe(II) in clay minerals. Hyperfine Interactions, 70(1): 1001-1004. DOI:10.1007/BF02397497

SECT. 3 (METHODS) - The authors need to justify their choice of coupling the Daisy and MIKE SHE model. Why not using one model or the other? Why Daisy/MIKE SHE are particularly appropriate for this study? Thank you for this comment. We have added some reflections on this in L 124-130: Both Mike She and Daisy have been used extensively in the danish area, and Mike She forms the basis of the national nitrate and groundwater model (Bruun et al., 2003; Hoang et al., 2010; Højberg et al., 2015a; Højberg et al., 2010; Højberg et al., 2013; Højberg et al., 2015b; Troldborg et al.,

2010). Mike She is a fully coupled integrated groundwater-surface water model and this integration is important for assessing the feedback between unsaturated and saturated zone, especially under changing climate. However, Mike She does not simulate crops development and nitrate leaching from the root zone, and therefore information from an agrological model, like Daisy, is necessary.

Bruun, S., Christensen, B.T., Hansen, E.M., Magid, J., Jensen, L.S., 2003. Calibration and validation of the soil organic matter dynamics of the Daisy model with data from the Askov long-term experiments. Soil Biology and Biochemistry, 35(1): 67-76. DOI:http://dx.doi.org/10.1016/S0038-0717(02)00237-7 Hoang, L. et al., 2010. Comparison of the SWAT model versus DAISY-MIKE SHE model for simulating the flow and nitrogen processes. In: conference, T.I.S. (Ed.). Højberg, A.L. et al., 2015a. En ny kvælstofmodel. Oplandsmodel til belastning og virkemidler. Metode rapport (A new nitrogen model. Catchment model for loads and measures. Methodology Report – In Danish). DOI:Available from http://www.geus.dk/DK/water-soil/water-cycle/Documents/national_kvaelstofmodel_metoderapport.pdf Højberg, A.L. et al., 2010. DK-model2009 – Sammenfatning af opdateringen 2005-2009, Geological Survey of Denmark and Greenland. Højberg, A.L., Troldborg, L., Stisen, S., Christensen, B.B.S., Henriksen, H.J., 2013. Stakeholder driven update and improvement of a national water resources model. Environmental Modelling & Software, 40(0): 202-213. DOI:http://dx.doi.org/10.1016/j.envsoft.2012.09.010 Højberg, A.L. et al., 2015b. National kvælstofmodel - Oplandsmodel til belastning og virkemidler. Metode rapport, revideret udgave september 2015 (National nitrogenmodel - Catchment model for load and measures. Method report, revised version September 2015). DOI:ISBN 978-87-7871-418-3 Troldborg, L. et al., 2010. DK-model2009 - Modelopstilling og kalibrering for Fyn. GEUS Report .

- It is also not clear which parameters are calibrated and for this I think that a table that summarizes the model parameters and their calibrated value should be added (in the main text or in the supplementary information). Thank you for this comment.

The calibration and parameters have already been reported in detail elsewhere and we would therefore like to avoid going into detail with the parameters, so the the paper do not get too long. We, however, do acknowledge that some information is needed here. We have therefore added a general statement of the parameter types included in the calibration at L157: After a sensitive analysis on 28 free parameters with 43 tied parameters; a total of five parameters were chosen for calibration, of these, one soil parameter in the unsaturated zone, one drainage parameter and three saturated zone parameters.

- What are the nitrogen inputs to the system? From L124 I understand that in cropland areas mineral fertilizers only are considered, is this correct? What about the N input for the areas with other land uses such as grass or forest? What about nitrogen biological fixation and nitrogen atmospheric deposition which can also be important inputs of nitrogen to soils? Thank you for the comment, yes that was indeed not clear. We have expanded this explanation in L199-208: Daisy also simulates nitrate leaching for each soil column that represents a unique combination of soil type, climate, crop rotation and groundwater depth. Crops are fertilized with mineral and organic nitrogen dependent on the farm type and soiltype. The crop recommended nitrogen rate for the years 2004-2007 was used to setup the fertilization scheme. Nitrate leaching input are simulated on daily basis based on the leaching from the permutated crop rotations simulated for the dominating soil type within a 200m x 200 m square grid (Karlsson et al., 2016). Because of the close feedback mechanism between nitrogen yields and nitrate leaching, the simulated mean nitrogen yields were recalibrated to observed annual mean nitrogen yields on Funen (Statistikbanken, 2015) for the dominating soil type for the period 2004-2007. The calibration is conducted by adjusting the crop parameters, following the methodology of Styczen et al. (2004). Nitrogen concentrations of yields were extracted from table values of mean nitrogen contents for different crops (Møller et al., 2005). For crop rotations including clover grass and peas nitrogen biological fixation is calculated using Høgh-Jensen et al. (2004) and nitrogen atmospheric deposition is included as input to the soil using standard Daisy settings for dry

and wet deposition (Hansen et al., 2012). Hansen, S., Abrahamsen, P., T. Petersen, C., Styczen, M., 2012. Daisy: Model Use, Calibration, and Validation. Transactions of the ASABE, 55(4): 1317. DOI:https://doi.org/10.13031/2013.42244 Høgh-Jensen, H., Loges, R., Jørgensen, F.V., Vinther, F.P., Jensen, E.S., 2004. An empirical model for quantification of symbiotic nitrogen fixation in grass-clover mixtures. Agricultural Systems, 82(2): 181-194. DOI:https://doi.org/10.1016/j.agsy.2003.12.003 Karlsson, I.B. et al., 2016. Combined effects of climate models, hydrological model structures and land use scenarios on hydrological impacts of climate change. Journal of Hydrology, 535: 301-317. DOI:http://dx.doi.org/10.1016/j.jhydrol.2016.01.069 Møller, J. et al., 2005. Fodermiddeltabel - Sammensætning og foderværdi af fodermidler til kvæg. 64. Statistikbanken, 2015. Statistical regional registrated annual mean yields. (In Danish) https://www.statistikbanken.dk/jord3. Styczen, M. et al., 2004. Standardopstillinger til Daisy-modellen. Vejledning og baggrund, Institut for Vand og Miljø, DHI.

- The grid resolution for Daisy/MIKE SHE needs to be clearly defined. Is it 200m x200m (L 126)? See comment above, we have added more information on this in the cited section (L203).

- L110-111 (and also L304-305): aren't tile drains usually located in agricultural areas? My understanding is that here tile drains are distributed uniformly independently of the land use. This is an important model assumption, since it appears that tile drainage has a large impact on the study results. See response to main comment 3)

- L115 '455 groundwater wells': Which data were derived from the groundwater wells? Thanks, we added L153: and 455 groundwater wells with hydraulic head measurements from the period 2004-2007

- L119-120 'following methods proposed by Allen et al. (1998) and Styczen et al. (2014)': it is required to add more explanation here (brief description of the methods, parameters that are calibrated with the methods). I also have the same comment regarding L128-129. Thank you. Yes, the section is very unclear. The complete section on Daisy modelling and calibration have been rewritten: The Daisy model setup for the Odense is contains on roughly 12,000 1D Daisy columns, and the water balance module is based on a previous calibration of the catchment (Børgesen et al., 2013), where root zone leaching and groundwater abstraction is compared with river discharge (Børgesen et al., 2013; Refsgaard et al., 2011). The model is setup so that each column represent unique combinations of soil type, climate, crop rotation and groundwater depth. The Daisy model uses the same climate input and soil parameter setup as MIKE SHE and the sensitive and calibrated unsaturated soil parameter from MIKE SHE were therefore transferred to Daisy. A more detailed description of the Daisy setup can be found in Karlsson et al. (2016). The water balance performance of Daisy was evaluated in the same calibration (2004-2007) and validation periods (2000-2003/2008-2009) as MIKE SHE.

Daisy also simulates nitrate leaching for each soil column that represents a unique combination of soil type, climate, crop rotation and groundwater depth. Crops are fertilized with mineral and organic nitrogen dependent on the farm type and soiltype. The crop recommended nitrogen rate for the years 2004-2007 was used to setup the fertilization scheme. Nitrate leaching input are simulated on daily basis based on the leaching from the permutated crop rotations simulated for the dominating soil type within a 200m x 200 m square grid (Karlsson et al., 2016). Because of the close feedback mechanism between nitrogen yields and nitrate leaching, the simulated mean nitrogen yields were recalibrated to observed annual mean nitrogen yields on Funen (Statistikbanken, 2015) for the dominating soil type for the period 2004-2007. The calibration is conducted by adjusting the crop parameters, following the methodology of Styczen et al. (2004). Nitrogen concentrations of yields were extracted from table values of mean nitrogen contents for different crops (Møller et al., 2005). For crop rotations including clover grass and peas nitrogen biological fixation is calculated using Høgh-Jensen et al. (2004) and nitrogen atmospheric deposition is included as input to the soil using standard Daisy settings for dry and wet deposition (Hansen et al., 2012). Børgesen, C.D. et al., 2013. Udviklingen i kvælstofudvaskn-

ing of næringsstofoverskud fra dansk landbrug for perioden 2007-2011. Evaluering af implementerede virkemidler til reduktion af kvælstofudvaskning samt en fremskrivning af planlagte virkemidlers effekt frem til 2015, DCA - Nationalt Center for Fødevarer og Jordbrug, Tjele, Denmark. Hansen, S., Abrahamsen, P., T. Petersen, C., Styczen, M., 2012. Daisy: Model Use, Calibration, and Validation. Transactions of the ASABE, 55(4): 1317. DOI:https://doi.org/10.13031/2013.42244 Høgh-Jensen, H., Loges, R., Jørgensen, F.V., Vinther, F.P., Jensen, E.S., 2004. An empirical model for quantification of symbiotic nitrogen fixation in grass-clover mixtures. Agricultural Systems, 82(2): 181-194. DOI:https://doi.org/10.1016/j.agsy.2003.12.003 Karlsson, I.B. et al., 2016. Combined effects of climate models, hydrological model structures and land use scenarios on hydrological impacts of climate change. Journal of Hydrology, 535: 301-317. DOI:http://dx.doi.org/10.1016/j.jhydrol.2016.01.069 Møller, J. et al., 2005. Fodermiddeltabel - Sammensætning og foderværdi af fodermidler til kvæg. 64. Refsgaard, J.C. et al., 2011. Vandbalance i Danmark - Vejledning i opgørelse af vandbalance ud fra hydrologiske data for perioden 1990-2010, Copenhagen, Denmark. Statistikbanken, 2015. Statistical regional registrated annual mean yields. (In Danish) https://www.statistikbanken.dk/jord3. Styczen, M. et al., 2004. Standardopstillinger til Daisy-modellen. Vejledning og baggrund, Institut for Vand og Miljø, DHI.

- L121 ‘such that they produce similar actual evapotranspiration and stream flow for the simulation period’: a precise definition of what is meant by ‘similar’ is needed. See comment to L119-120

- L134 ‘the procedure described in [. . .]: Please summarize the procedure. See comment to L119-120

- L165 ‘compared with the measured redox depth in boreholes’: a description of this comparison is missing. Evt. Supmat. Thank you, yes this is unclear. We have added some more explanation (L226-239): As the calibration of these two parameters may result in non-uniqueness, all possible combinations (realisations) of the two parameters resulting in observed NAP, are identified. For all realisations the cumulative distribution of the redox depth is found at the location, where observations of redox depth are available from boreholes, as well as the cumulative distribution of the entire catchment. These two graphs are subsequently compared with the cumulative distribution of the actual measured redox depth in boreholes. The realization with the best representation of the fractional distribution of the observed redox depth for both on-site and especially catchment scale is chosen for the final redox depth parameters. The reason for comparing calculated redox depths to cumulative distributions for actual measurement locations and the entire catchment distribution is due to several issues. First, measured redox depths are very local point measurements, and large variations in space (within a few meters) are often reported (e.g. Ernstsen, 1996; Hansen et al., 2008), and a measurement may not be representable for the area or model scale, where numerous measurements together are more likely to represent to the correct fractional distributions in the catchment. Furthermore, the calculated redox depth may be applicable on catchment scale, on which scale it is also calibrated, but less trustworthy on location scale. Ernstsen, V., 1996. Reduction of Nitrate By Fe2+ in Clay Minerals. Clays and Clay Minerals, 44(5): 599-608. DOI:10.1346/CCMN.1996.0440503 Hansen, J.R., Ernstsen, V., Refsgaard, J.C., Hansen, S., 2008. Field scale heterogeneity of redox conditions in till-upscaling to a catchment nitrate model. Hydrogeology Journal, 16(7): 1251-1266. DOI:10.1007/s10040-008-0330-1 - L179-181: I do not understand this statement (in particular it is not clear to me what 'direct arrival percentage' means). We have reformulated this sentence to make it more clear: If this assumption is valid the calculation the reduction potential in each grid cell is the same with/without the stuck particles. Unfortunately, this assumption may not always be valid. Furthermore, the arrival percentage estimated by the two methods are not the same as not all particles are released in the complex particle arrival count, the data from which is the only way to calibrate the nitrate model. For the two methods to be comparable it is therefore necessary to exclude the particles that are stuck in the unsaturated zone.

- Table 1: Please define reference evapotranspiration and specify how it was calculated. The reference evapotranspiration (also sometimes denoted as potential evapo-

transpiration) as referred to in Table 1, is calculated based on variables from the climate models. We have added information on how it was calculated in L276-277: The reference evapotranspiration is calculated using FAO Penman– Monteith formula based on the climate model outputs for temperature, radiation, water vapour wind speed and water pressure.

- L215-216: I would suggest to briefly summarize how these scenarios were established and to refer to Oleson et al. (2014) and Karlsson et al. (2016) for more details as currently done. Thank you. This has been added in L289-293: The land use scenarios were created during workshops with researcher, farming industries, environmental protection agencies and government representatives. During the workshops, participants identified possible paths of developments for the land use in Denmark considering the balance of agricultural marked value on one side and priorities in the society on the other (e.g., environmental concerns or recreational use). From the workshop four scenarios that describe agricultural management in the period 2080-2099 was created,

- L222 '50 model simulations': In table 3 I see only 45 and not 50 scenarios, please clarify. Yes this is a mistake, it has been corrected to 45.

SECT. 4 (RESULTS) - L323: 'net precipitation' should be defined. This has been added in L413: Hence, the overall net precipitation (precipitation-actual evapotranspiration) may change slightly across the climate models,

- L453-455: It is not clear to me how these numbers are derived from Figure 9. Thank you, no this is unclear. We have specified in the text: Even though it is not possible to completely separate the signal of these three components, a cautious estimation can again be achieved by subtracting the blue bars with the red bar result from LU0 in the reference period, so that the signal from the climate model bias is tried to be removed.

SECT. 5 (DISCUSSION AND CONCLUSIONS) - L480: replace 'the full range' by 'a range' as a limited number of scenarios were used, which cannot comprehend all possible futures. This has been corrected as suggested.

- L515-516 'that should be addressed along with other known sources of uncertainty such as climate model projections, land use projections and hydrological model structure uncertainty.': This discussion needs to be expanded. In particular, uncertainty in model parameter values can also affect the results. We have expanded this section L710-719: The indication that errors can be up to 10% is based on only a single case study with one catchment, one model and a limited number of land use and climate change scenarios. While similar results may be found when applying the same approach for catchments governed by the same dominant flow processes and land use types, like the one investigated in this study. The error must be expected to be site and context specific and therefore causes projection uncertainties that should be addressed along with other known sources of uncertainty such as climate model projections, land use projections, parameter uncertainties, geological uncertainty, and hydrological model structural uncertainty (Hansen et al., 2014; Karlsson et al., 2016). Furthermore, during calibration and setup of the model assumptions must be made, adding to the uncertainty. Parameter estimation are here done in a stepwise fashion, and the catchment scale calibration of Daisy along with a particle tracking approach limits the evaluation of performance of the nitrate component to mean catchment figures, and the dynamic of the nitrate system is thus impossible to verify. To account for this a full solute transport solution would be necessary but was unfortunately not possible in the framework of this study; but would be a relevant next step in investigating uncertainties and improve model verification. Hansen, A.L., Gunderman, D., He, X., Refsgaard, J.C., 2014. Uncertainty assessment of spatially distributed nitrate reduction potential in groundwater using multiple geological realizations. Journal of Hydrology, 519, Part A: 225-237. DOI:http://dx.doi.org/10.1016/j.jhydrol.2014.07.013 Karlsson, I.B. et al., 2016. Combined effects of climate models, hydrological model structures and land use scenarios on hydrological impacts of climate change. Journal of Hydrology, 535: 301-317. DOI:http://dx.doi.org/10.1016/j.jhydrol.2016.01.069

MINOR EDITS: - L143 'section 0': please add the correct section number. This has been added

- L170 and in the figure captions: add 'cell' after grid. Corrected

- L230 'no 1': do the authors refer to scenario 1 in Table 3? Please clarify. Yes, it refers to scenario 1. We have added more explanation: Baseline: The term baseline refers to results from the specific model run combination (scenario number1, Table 3), where current land use scenario (LU0) is combined with the observational climate data.

- L236: replace 'm2/s' by 'm3/s'. This has been corrected.

- L345: remove 'impact' after 'change'. This has been corrected.

- L348: there is something wrong here. Maybe 'different' need to be removed? Some words are missing, we have added: different due to

- L364-365: Please correct by 'the change in the drain flow fraction' (two occurrences). This is corrected

- L397 'this is also found for one of the models': remove 'also' (possibly replace by 'indeed'). This is corrected

REFERENCES: Knoll, L., Breuer, L., & Bach, M. (2020). Nation-wide estimation of groundwater redox conditions and nitrate concentrations through machine learning. Environmental Research Letters, 15(6). https://doi.org/10.1088/1748-9326/ab7d5c Tesoriero, A. J., Terziotti, S., & Abrams, D. B. (2015). Predicting Redox Conditions in Groundwater at a Regional Scale. Environmental Science and Technology, 49(16), 9657–9664. https://doi.org/10.1021/acs.est.5b01869 Wade, A. J., Jackson, B. M., & Butterfield, D. (2008). Over-parameterised, uncertain "mathematical marionettes" - How can we best use catchment water quality models? An example of an 80-year catchment-scale nutrient balance. Science of the Total Environment, 400, 52–74. https://doi.org/10.1016/j.scitotenv.2008.04.030

Please also note the supplement to this comment:
https://hess.copernicus.org/preprints/hess-2020-570/hess-2020-570-AC2-

supplement.pdf

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2020-570, 2020.