Reviewer 1

Considering the long timescales required for peatland restoration and rehabilitation, modeling is critical for planning restoration and analyzing potential environmental impacts. This topic of this review is highly relevant for Biogeosciences. This review provides a comprehensive assessment of the current status of application of ecohydrological models on restoration of bogs and fens in northern regions considering a wide variety of potential environmental impacts. The authors clearly state their approach to identifying suitable studies and synthesize the results of these studies in a very useful manner. The results are based on 234 unique study sites which represents a substantial dataset. The authors identify the most widely used models, including LPJ, ecosys, and DigiBog. Much of the emphasis of the modeling exercises is on GHG emissions. The review highlights the emergence of remote sensing and machine learning to assess the progress of restoration with minimal intervention at sites. The figures and summaries provided in the review are very informative. This is an important review to provide context for peatland restoration.

This review is very timely as there are increasing efforts to restore and rehabilitate peatlands. The review synthesizes the models that have been applied to assess peatland restoration using several different categories. The conclusions are significant and important to understand the current and evolving status of this field of process-based modeling applied to peatlands in northern regions. The interpretations and conclusions are supported by the results of the review. The authors include detailed descriptions of some representative studies. The title is informative and reflects what is presented in the review. The abstract is excellent and summarizes the study clearly. The paper is clearly written. The review is concise and should not be shortened.

[Changes made: emphasis on GHG emissions acknowledged especially in methods section when explaining the search string used. Additional mentions of the evident lack of water quality modelling research on peatlands also included, to reflect the statement made in lines 53-62.]

Reviewer 2

The paper by Silva et al. provides a timely and much needed review of global modelling efforts as applied to peatland ecohydrology in a restoration context. This has the potential to be an excellent resource for future peatland modellers. While the abstract, introduction, methodology, and results are well-written, concise, and valuable, the discussion section offers little of value and is unfocused. The discussion section is rife with speculative statements, which as far as I can tell are unsupported assertions by the authors on the “likelihood” of future model developments and work that will be conducted. I personally do not feel that the discussion adds substance to the article, and should be reorganized and rewritten.

[Changes made: As of now I have retained the current presentation and content of the discussion section. See below.]

Two of the six figures are related to the spatial relationship between published peatland restoration studies and the Köppen-Geiger climate regions, while this has the potential to be an interesting feature of this review, it is not mentioned at all in the discussion section. The authors do not attempt to explain the patterns that the see, which perhaps are a spatial reflection of peatland prevalence, historical degradation, and being located within countries with a legacy of environmental stewardship and scientific funding. However, it is unclear what meaningful relationships can be derived from this analysis when the authors state that they deliberately placed an emphasis on NW Europe, as it is of particular interest to them. The remaining four figures are not well-integrated into the manuscript and do not contribute anything of substance. I would recommend that they be removed and perhaps replaced with a compressed version of Table S1.

[Changes made: I have added more detail to Figure 1 to improve the connection between location-based data and models included in the review. Some additional reflection on location-based data has been added in the discussion to add balance. Figure 2 is currently retained but could still be moved to supplementary material if deemed necessary. So far, figures 3-7 are retained in the manuscript to "break up" the text and provide visual context for models highlighted in the discussion. If it would be preferred by the editors, this can still be removed.]

Arguably, the key themes that the authors identified as "emerging" reflect those that have already been established and firmly rooted in the contemporary scientific zeitgeist, and do not reflect truly emerging trends. The exception to this is the discussion on machine learning techniques. This does not represent a critical flaw but rather a missed opportunity to talk about where peatland science and modelling will go over the next decade.

[Changes made: the term "emerg*" was searched for in the manuscript and wording was changed to more accurately represent established trends without speculating on new trends, excepting machine learning techniques.]

My suggestion for the discussion section would be to categorize models by level of process complexity, and not restrict the discussion to (largely) ecosys, CoupModel, and DigiBog. The models HYDRUS, Hydrogeosphere, and MODFLOW (SURFACT) incorporate the equations governing unsaturated flow and transport. While this has the potential to reveal detailed process-based insights into peatland function and recovery, they tend to have prohibitive data requirements for most projects. In contrast, DigiBog has strengths that these complex finite-difference/element models lack being able to simulate peatland development on a far longer time scale (centuries-millennia). By organizing the discussion section along the spectrum of process complexity I think this review will be more valuable and integrate a larger number of studies and approaches, each with their own strengths and weaknesses. While I feel that this paper aligns with the aims and scope of Biogeosciences, the discussion section should be improved before the manuscript is accepted.

[Changes made: this suggestion was not heeded as I believe that an overhaul of the discussion's structure is not needed. Instead, I was able to retain the structure of much of the discussion/results by removing the more speculative 'high potential' wording and instead highlighting the fact that these models highlighted did actually exist most frequently in the database within/across thematic categories (see line 250 and new Table 3). This means that while the review still does not enter into process-specific detail for a large number of studies, and process complexity is instead mentioned throughout the discussion within different thematic categories, there is increased justification for "restricting" the discussion to the few models highlighted.]

Specific comments:

L33: What is a "governmental scale"? That covers everything from an individual municipality to a national effort.

[Change made: the word "scales" was replaced with "spheres" to help clarify my point here.]

L78: Two decades on from Belyea and Baird, the representation of feedbacks across spatiotemporal scales still proves a challenge – although some progress has been made, see Waddington et al. (2015)

Waddington, J. M., Morris, P. J., Kettridge, N., Granath, G., Thompson, D. K., & Moore, P. A. (2015). Hydrological feedbacks in northern peatlands. Ecohydrology 8(1), 113-127.

[Change made: an additional note about progress was added to ensure accurate context, citing the reviewer's suggestion.]

L232 The rationale for claiming some of these models have more applicability to northern peatland restoration is not clear to me. Furthermore, I'm not sure that I agree that some models have more or less relevance in this regard, they are simply used to understand different things.

[Change made: statement changed to focusing on specific capabilities that may .]

L244 "most natural" as in the largest number of processes?

[Change made: clarification made replacing "most natural" with a phrase about the largest number of processes governing living organisms.]

L245 According to S1, Putra et al. (2022) is a 2D model developed in DigiBog. Although I can see in Figure 7 that it is in fact 3D, however the model presented in Putra et al. (2022) is nearly axisymmetric and is not the most illustrative example of the value and capabilities of 3D modelling. Sutton and Price (2022), and Zi et al. (2016) are 3D.

[Changes made: error rectified. An additional clarification including the reviewer's suggested citations was included.]

L256 Although excellent models, the Melaku et al. (2022) paper seems to have only tangential relevance to restoration, similar to Hwang et al. (2018).

[Change made: the example is retained, and I have included a disclaimer that this model's current applicability is only in the theoretical stage.]

L261 Is direct coding required for anything other than process modification? Please expand on the "etc."

[Change made: sentence was restructured, and additional context/reflection added (now beginning on line 288).]

L268 This is incorrect and not the definition of the acrotelm. Besides being a potentially outdated conceptual framework (see Morris et al., 2011), the acrotelm comprises more than the "living layer" in bogs and includes partially and moderately decomposed plant matter (although plant roots can traverse the boundary between acrotelm and catotelm - as there is often more than just Sphagnum mosses living in peatlands). Furthermore, while the catotelm may comprise more well-decomposed peat with typically lower hydraulic conductivity, it is not hydrologically inactive and performs crucial hydrological functions in peatlands.

Morris, P. J., Waddington, J. M., Benscoter, B. W., & Turetsky, M. R. (2011). Conceptual frameworks in peatland ecohydrology: looking beyond the two-layered (acrotelm–catotelm) model. Ecohydrology 4(1), 1-11.

[Changes made: I referenced the term as a way to show where models are progressing from (retaining the words "changes occurring in" and adding "past designations of …"), citing Clymo in 1978 and Morris et al. in 2011 for comparison.]

L272-274 This is just my opinion, but I think more restraint should be exercised when recommending the use of models to practitioners that may not be aware of the myriad assumptions, limitations, and caveats that can apply to a model. That has the potential to cause more harm than good.

[Change made: Rephrased the sentence to focus more on the ease of execution (with fewer inputs and access to source code for greater context) rather than claiming no background knowledge is needed, and removed identification of potential target audiences.]

L277 This may not be germane to the overall paper, but it should be noted that fen-bog transitions can also be instigated quickly due to sudden drops in water table.

[Changes made: added a discussion of this point in lines 305-309.]

L277-279 These two sentences are rather hypothetical/speculative and unnecessary.

[Changes made: combined with discussion mentioned above to become less speculative.]

L297-298 One of the consequences of the organization of the discussion section (and focus on the Digibog, CoupModel, and ecosys) is that important developments are portrayed as unanswered open questions. The work of McCarter and Price have investigated this in a peatland restoration context using models.

[Changes made: cited Gauthier, McCarter, and Price (2018) as well as Lehan et al. (2022) to provide additional context for peat hydraulic behaviour during restoration.]

L390 This is written as though this is unknowable information, but surely this is made clear within the paper, if not perhaps it is not the best example to use.

[Changes made: shortened information to only briefly acknowledge the oil sands mining context.]

L394 The concept of an HRU does not inherently limit the resolution that different wetlands could be represented, many semi-distributed hydrologic models (ex. Raven) can have an arbitrarily large number of HRU, such that they begin to more closely resemble a fully spatially-distributed model.

[Change made: rephrased "HRUs" to "the number of currently incorporated HRUs".]

L414-415 What makes it likely that a 13 year old paper will have further modelling occur if it has not already? Why speculate in this manner? There may be better examples to draw upon to describe the use of 3D modelling in a peatland restoration context.

[Response: included to highlight that it is still rare that simulations combine 3-D modelling with a specific restoration context like in Jaenicke et al. (2010), while disclaiming that the study is old.]

Technical corrections:

L142: Missing the word "is"

[Rectified.]