**Hydrology and
Earth System
Sciences
Discussions**

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Interactive comment on "Impacts of ditch cleaning on hydrological processes in a drained peatland forest" *by* H. Koivusalo et al.

H. Koivusalo et al.

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General response to reviewer comments

The reviewers recognise the importance of the issues that are related to the ditch network maintenance in forested peatlands and to the potential impacts of the maintenance on receiving lakes and rives in large areas in the boreal zone. In addition, the reviewers appreciate the long term measurements and earnest data collection efforts behind the 11-year dataset from a remote district in Scandinavia.

All three reviewers raise similar criticism about the modelling approach adopted in the submitted paper. The poor performance of the hydrological model against measured water table and runoff data, which is clearly visible from the presented results, is stated to be an indication of serious deficiencies in the model and its structure. According to

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the reviewers, poor validation results call for a rejection of the model and render the analysis based on model results as pointless. Inferences from a mathematical model are deemed to be justified only in cases where the model can yield a satisfactory reproduction of reality. Even though one internal variable, such as water table level, was simulated successfully (which was not the case in our study), the modelled separation of water balance into its components may be in failure. It is valuable for us that the reviewers did not present only these opinions in their reports. Instead, all three reviewers shared their thoughtful and constructive ideas for viewing the Tilanjoki dataset from different directions.

A clear recommendation arises from the feedback of the reviewers: Water table and runoff measurements need to be given more weight and be analysed separately from the model application. Concrete suggestions were provided for the rebuilding of the model application. Main comments were related to the needs to clarify the model calibration procedure, to account for parameter equifinality, to consider uncertainty in the model and data, and to focus either on the occasions when the model fails or on the occasions when the model succeeds. A tempting advice was given to apply the model alone in a numerical experiment, which demonstrates the main relationships embedded in the model structure and sensitivity of the model to parameters relevant from the point of view of drainage and vegetation controls.

In response to the reviewer suggestions we divide the study into three parts: 1) data analysis, 2) application of a hydrological model to assess data quality and experimental setup, and 3) a numerical experiment.

We note that the purpose of the original experimental arrangement in Tilanjoki was to set up two pairs of artificially delineated catchments including control and treated catchments side-by-side. The catchments were monitored for the periods preceding and following the ditch cleaning to support a paired-catchment analysis of the data (e.g. Watson et al., 2001). Firstly, we classify the water table measurement sites according to the type of subsoil (peat, till, or sand). Based on the data alone, one can

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detect no water table response to ditch cleaning in sites with a deep peat formation, some response in sites with till subsoil, and a clear response in sites with sandy subsoil. After viewing the water table data, a paired catchment analysis is conducted to quantify the ditch cleaning effect on annual runoff volumes for the two catchment pairs. Annual runoff from the treated catchments is shown to increase with respect to the control catchments.

The model application is started with a short review of the snow model results. The snow model is not calibrated against the snow measurements and it is shown to produce similar behaviour against the snow data for the time periods preceding and following the ditch cleaning. This assures that the meteorological data affecting snow processes do not contain trends leading to any increasing bias with time. The model application is then continued with calibration of the model against water table and runoff data by using the GLUE (Generalised Likelihood Uncertainty Estimation) methodology of Beven and Binley (1992). A section is added to briefly summarise the GLUE approach, the selection of parameter ranges, and the likelihood function. The calibration procedure allows us to identify the equifinality of the calibration parameters and to estimate uncertainty propagation from calibration parameters to model predictions. Prior and posterior distributions of six calibration parameters are presented and discussed to point out three calibration parameters that show equifinality. The 'behavioral' parameter set is used to produce the 5th and 95th percentiles of water table levels. Some of the water table measurements fall outside the 90% uncertainty limit suggesting a rejection of the model. Rejection of the model indicates that there are deficiencies in the model structure, data, or experimental setup. The runoff results are then investigated to obtain a clearer picture of the implication of the model rejection.

The paired catchment analysis is repeated to detect how measured runoff in each study catchment behaves between the periods preceding and following the ditch cleaning when compared against a reference. The reference is the modelled runoff in the control catchment. Comparison of the measured annual runoff against the reference that

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is produced from the meteorological forcing indicates that runoff volumes from both treated and control catchments change after the ditch cleaning. It is concluded that the artificial catchments delineated side-by-side with shallow ditches are not independent from each other. There is a hydrological connection between the catchments that can occur through underlying groundwater aquifer, and possibly through drain flow divergence between the catchments or their surrounding area during the highest peaks. The connection between the catchments is not described in the model and therefore, the model structure becomes rejected. Rejection of the model means that the assumptions behind the paired catchment analysis do not hold for the Tilanjoki catchment pairs.

In the end, a numerical experiment based on the model simulations alone is conducted to explain how the assumed relationship between soil moisture and transpiration is reflected in the modelled runoff response to the ditch cleaning. The numerical experiment demonstrates the situations when the ditch cleaning does not improve evapotranspiration condition and becomes unnecessary.

The comments of the reviewers lead to a substantial revision of the manuscript. In the revised manuscript we aim to keep the hydrological analysis simple without presenting any detailed separation of water balance components. Instead we focus on explaining the main reasons behind the mismatch between the data and the model simulation. The finding that the paired catchment setup in our case study was affected by unexpected problems can lead to improvements in the implementation of hydrological experiments in wetlands: It would be most useful to bind hydrometeorological measurements together through a model application and produce a holistic analysis of data during early stages of the experiments to detect possible inconsistencies in the experimental setup and to detect unexpected responses in different measurements. Another issue that in our opinion deserves to be communicated to water authorities and forest practitioners is the suggestion from the numerical experiment that the cleaning of the drainage ditches in forested peatlands is not necessary in certain situations. Avoidance of unnecessary treatments would be beneficial from the water protection

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point of view.

Response to the major and minor comments by Reviewer 1

See also our general response to all three reviewers.

Major comment (1) We agree that the model must be rejected due to the poor performance against measurements. In the revised manuscript, we carry through the model case study and identify the main deficiencies of the model structure that prevent successful comparison against the Tilanjoki data.

Major comment (2) We follow the suggestion of the reviewer and make an independent analysis of the water table and runoff data. In the model application, we aim to explain the reasons for the failure of the model. The main reason for the poor model performance is the model assumption that the study catchments are independent and hydrologically disconnected from each other. The control catchments are found to respond to the ditch cleaning, which suggests that the study catchments are not independent from each other.

Major comment (3) We agree that ditch spacing is one important parameter relevant for the design of drainage. However, the current study focuses on hydrological effects of ditch cleaning in a situation, when ditch spacing is not changing. Therefore, changing ditch spacing was not included in the main themes that we want to address in the study. In the numerical experiment, the ditch spacing is fixed to a value of 40 m, which is commonly applied in Finnish drained peatlands. The main relationships pointed out in the numerical experiment do not change, when the spacing is varied within the limits observed in Tilanjoki.

Major comment (4) Production of a detailed picture of the ditch cleaning impacts on hydrology during different seasons would be a desirable goal. Unfortunately, our data do not support a detailed analysis of the ditch cleaning impacts. We avoid carrying out a detailed analysis of seasonal ditch cleaning impacts or a detailed analysis of

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impacts on water balance components. Straightforward assessment of the data and experimental setup in terms of total annual runoff volumes is given the primary focus in the manuscript.

Major comment (5) The reviewer is correct in stating that there are no direct links between the ditch cleaning and snow processes other than vegetation growth. Snow modelling is necessary to facilitate continuous hydrological simulation. In the revised manuscript discussion about the ditch cleaning impacts on snow processes is removed, and weight of the snow model application is reduced.

Minor comment (a) We refine the model calibration procedure following the GLUE methodology of Beven and Binley (1992). The calibration of the model is documented more clearly in the revised manuscript.

Minor comment (b) It is stated more clearly in the revised manuscript that a snow model application is an efficient test for the consistency of wintertime meteorological data. Large errors in precipitation and air temperature become highlighted as mismatches between measured and modelled snow accumulation and snow ablation, respectively. Because of clear mismatch between snow data and model simulation during 1989-1992, temperature during this period was from the nearby weather stations.

Minor comment (c) The reviewer is correct in noting that the model fails in the simulation of both spring and autumn runoff peaks, and that simulation of autumns peaks is not affected by snow simulation. Spring flood in the calibration catchment was measured during 9 years and the maximum daily runoff occurred during the spring in 8 of these years. The efficiency coefficient (Nash and Sutcliffe, 1970) for runoff is prone to errors in simulating the largest event (spring flood). In the model calibration, the performance of the lower peaks during autumn becomes sacrificed for the reproduction of spring high peaks. Those parameters that affect both spring and autumn peaks (e.g., minimum stomatal resistance) attain their calibration value based mainly on performance against the largest events.

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Minor comment (d) The estimation of effective saturated hydraulic conductivity above the drain is now more clearly explained in the methods- Section: The effective saturated hydraulic conductivity is computed by dividing the total transmissivity above the drain depth with the depth of the corresponding saturated layer. Hooghoudt's drainage equation is widely applied in hydrological models. We tried to conduct simulations with the other methods as well, but the results were not affected by the drainage equation. Our experience from Tilanjoki suggests that the challenges of the model application are not related to the choice of the drainage equation.

Minor comment (e) Snow energy balance model is selected instead of a degree-day snowmelt model, because the model includes canopy description and simulates effect of forest cover on snow accumulation and melt. We agree that a degree-day snowmelt model is efficient for the simulation of snow mass balance, but the degree-day model requires calibration against snow data from all sites with different canopy characteristics.

Response to the comments by Reviewer 2

See also our general response to all three reviewers.

We agree that the Tilanjoki dataset, even when it was accurate, does not support holistic assessment of the ditch cleaning effects on all water balance components. We have revised the analysis and now there are separate data analysis and model application sections. The model application focuses on two purposes: 1) assurance of data quality and experimental setup and 2) numerical experiment about the role of vegetation and ditch cleaning on the runoff volumes in changing soil structure. The model calibration is now more clearly documented. We use the approach of the Generalised Likelihood Uncertainty Estimation (GLUE) to calibrate the model, assess the equifinality of calibrated parameters, and produce uncertainty limits in the modelled water table level and runoff.

It is noted in the revised manuscript that the experimental setup in Tilanjoki is de-

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signed to support a paired catchment analysis of treated and control catchments. The assumption behind such data analysis is that the hydrological response of the catchments is independent from each other. In the model application, where the catchments are assumed to act as hydrologically independent units, the comparison between the model results and measurements is found to be unsuccessful. Modelled runoff that is a reflection of meteorological conditions is, however, used as a reference for assessing the time periods before and after the ditch cleaning. When measured runoff is viewed against the reference, the control catchments, where no ditch cleaning occurred, show a response to the ditch cleaning, suggesting that the study catchments are not independent of each other. The rejection of the model in this case implies that the assumptions related to the paired catchment analysis do not hold for the Tilanjoki dataset. We suggest that application of a model that binds the measurements together is a useful aid for assessing the conformity of data and experimental setup.

The structure of the manuscript has been changed and the calibration parameters can now be detected from a Table and graphs presenting the GLUE results. Since the data do not support a detailed model application, examination of individual modelled water balance components is removed from the revised manuscript.

We are grateful for the advice to focus on a numerical experiment that is separated from the data analysis. The model is now applied in a numerical experiment to identify the role of vegetation growth and ditch cleaning on annual runoff volume in sites with different soil structure.

Response to the general and specific comments by Reviewer 3

See also our general response to all three reviewers.

General comment (A) We set more weight to the analysis of experimental data alone as suggested by the reviewer. A data analysis focussing on the measured ditch cleaning impacts on water table level and runoff is presented in a separate section. The model is then applied to assess the data quality and the experimental setup.

General comment (B) The calibration methodology is revised following the approach of the Generalised Likelihood Uncertainty Estimation (GLUE) (Beven and Binley, 1992). There is a separate Section for explaining how the model is calibrated and what the calibration parameters are. The equifinality of the calibration parameters is studied and the propagation of parameter uncertainty to the simulation results is presented. In the assessment of the model results, we identify the reasons for the poor performance of the model and explain why the model structure becomes rejected in the Tilanjoki case study. In the end, a numerical experiment is included to demonstrate the ditch cleaning impact on total annual runoff in sites with different vegetation and soil structural characteristics. Detailed separation of water balance components is removed from the revised manuscript, because it is not supported by available data.

Specific Comment (Introduction) Introduction-Section has been shortened.

Specific Comment (Methods) The Methods-Section is reorganised, when data analysis, model calibration, and numerical experiment are added to the Section. We also made an attempt to simplify the presentation of model parameterisation in the Methods-Section.

Specific Comment (Page 156/ lines 18/19) The model does not include a hydraulic channel flow routine. The elevation of the water level in the ditches is not measured or simulated. Therefore, the boundary condition of the water level in the ditch is set to the level of the ditch bottom, which is assumed to be sufficiently accurate for most of the time and most of the sites. This assumption may not hold during the spring flood, when there can be ice blocking flow in the ditches. It is now stated in the revised manuscript that the channel flow processes are not modelled.

Specific Comment (Page 156/ lines 23ff) The comment about the groundwater recharge is relevant and this comment guided us to reconsider the success of experimental setup in Tilanjoki. We note in the revised manuscript that the original purpose of the study catchments was to support a paired-catchment analysis, where the treated

and control catchments are assumed to be independent of each other. This assumption is reflected in the model structure, where no interaction between a drained site and surrounding area (e.g., regional groundwater aquifer) is assumed. The data on groundwater levels, which are changing after the ditch cleaning in some of the wells in the control areas, suggest that isolation of artificial catchments has not fully succeeded in Tilanjoki. The problems related to a hydrological connection between the catchments and to the closure of the water balance become evident in the comparison of the measured and modelled runoff. Groundwater flow is likely to be one of the reasons explaining the odd behaviour of hydrological measurements in Tilanjoki. We make a statement that the formation of artificial catchments in wetlands by shallow ditch delineation contains uncertainty. When there is exchange of water between the catchments, assumptions behind a paired catchment analysis do not hold.

Specific Comment (Page 157/ lines 13ff) The flow delay caused by the channel network was estimated to be less than one day in the catchments with areas ranging from 28 to 99 ha. Such short term dynamics have only minor effect on water table and annual runoff. Therefore, channel flow processes were disregarded in the Tilanjoki study. The channel flow can affect the water balance in a case when water flow is blocked for several days in the channel network as mentioned earlier. This situation is not likely to occur frequently, because the drainage ditches were dug along the slope to assure efficient drainage in Tilanjoki. It is now stated in the Methods Section that the channel flow processes are not modelled.

Specific Comment (Page 159/ lines 2ff) A separate Section describing the model calibration was added to explain the calibration procedure and list the calibration parameters. The calibration parameters are also given in a Table and it is explained that the values of the hydraulic conductivities are calibrated.

Basic peat properties, such as the degree of humification and peat type, were measured in four locations in Tilanjoki. The selection of water retention characteristics of the peat layers from the data of Päivänen (1973) is more clearly explained in the

revised manuscript.

It is well known (e.g. Päivänen, 1973; Ahti, 1987) that the hydraulic conductivity of surface peat is high and it decreases rapidly with depth in forested peatlands. Since no direct information about depth of a highly conductivity top soil layer was available from Tilanjoki, the conductivity depth was estimated based on the behaviour of the water table level.

Only three water table measurement sites were included in the calibration of the model, because three different subsoil types were identified in the area. Addition of data from new sites into the calibration is not expected to change the main results of the analysis. The calibration procedure is explained more detailed in a separate Subsection of the Methods-Section. Water table data from site 7 with peat subsoil, site 26 with sandy subsoil, and site 27 with till subsoil, as well as runoff data from catchment C3 are now used in the model calibration. Site 7 is located in catchment C1, but it does not influence runoff computation in catchment C3 in the calibration. All three sites (7, 26, and 27) must be concurrently included in the calibration, because the hydraulic conductivity of top soil layer is assumed to be the same in each site.

Specific Comment (Page 161/ lines 23 ff) The aim of the model application is changed in the revised manuscript. We focus now on the identification of main causes behind the unsuccessful performance of the model. The assumption made about the conductivity structure of soil is not one of the main reasons explaining poor model performance.

Specific Comment (Page 162/ lines 3 ff) We make a critical re-assessment of the model to understand where the model assumptions do not meet with the reality of the experimental setup. Conclusions address the problems related to delineation of artificial catchments in wetlands. The GLUE methodology is applied to produce the 90% uncertainty limits of the calibration parameters, which helps the reader compare identifiability of hydraulic conductivities in different soil layers.

Specific Comment (Page 162/ lines 14 ff) A numerical experiment based on model sim-

ulations only is added to explain why ditch cleaning can increase or decrease annual runoff depending on the initial drainage condition. Available data cannot be used to isolate the ditch cleaning impact on the measured runoff, because the treated and control catchments are not independent of each other. We agree that the modelled effect of soil structure on the ditch cleaning impact on water table level may sound obvious in some cases. The combined effect of the soil structure and the ditch cleaning on runoff, however, is less obvious as shown in the numerical experiment.

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