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Discussions

Interactive comment on "Impacts of climate and forest changes on streamflow and water balance in a mountainous headwater stream in Southern Alberta" *by* V. Mahat and A. Anderson

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We thank you for your helpful comments on our paper. Please find below our response to the comments.

Comment: General Comments In this manuscript, the authors present a study evaluating the impacts of environmental change on streamïňĆow and water balance components (speciïňĄcally Et and SWE) in an Alberta Canada headwater catchments using the HBV model constrained by forecasted precipitation and air temperature generated under 3 IPCC (AR 4) emission scenarios. In general I believe this manuscript

contributes important progress concerning the impacts of environmental change on water resources. While the experimental approach, analyses, and results are sound, speciïňĄc and important details are absent from the manuscript that should be included to strengthen the manuscript. SpeciïňĄc shortcoming are introduced here and further discussed below: the authors suggest the use of GLUE for uncertainty analyses in the abstract but based on section 3.3.4, uncertainty analysis was little more than a Monte Carlo analysis with an unstated number of simulations; the study explores the individual and combined effect of forest cover change (in perpetuity or recovery?) and climate change on hydrology yet how forest cover was treated in HBV-EC is not discussed. The paper is well written with clear objectives but for the shortcoming addressed above and those detailed below, I believe this paper requires revision to meet the expectations of the readers of HESS.

Reply: We will add the following detail in section 3.3.4 in the revised manuscript to explain the guided GLUE approach that we have used in the analysis.

Multiple acceptable models with combination of different model parameters sets can be obtained as a representation of hydrological behavior (equifinality). Equifinality introduces uncertainty into the model estimates. Usually uncertainty is addressed generating random samples and picking up the parameters set that produces the best result (Stahl et al., 2008). But in the high dimensional parameter space, random sampling may not guarantee that best parameters set can be found even with the large numbers of model runs (Jost et al., 2012). The Generalized Likelihood Uncertainty Estimation (GLUE) methodology can provide model evaluation and model uncertainly when equifinality exists with the high dimensional parameter space (Beven and Freer, 2001). For this analysis we followed a guided GLUE approach used by Jost et al. (2012), which is a simplified version of the original GLUE approach presented by Beven and Freer (2001) and Freer et al. (1996). First, we define expended bounds for the parameters to be calibrated. Next we used GENOUD (Mebane and Sekhon, 2011), an optimization algorithm in R, to calibrate and produce a model with the Nash-Sutcliffe efficiency, E or the generalized likelihood measure. GENOUD combines an evolutionary algorithm method with a steepest gradient descent algorithm to solve difficult optimization problems (Jost et al., 2012). Following the calibration, if optimal parameters are sampled near the preselect bounds, the prior parameter bound are widen and GENOUD function re-run. Once an optimal parameter set is identified, model is set to run 10,000 runs using the Latin Hypercube Search (LHS) technique to produce 100 most efficient model parameters that result in E values higher the optimal less. The optimal less value is selected as E minus 0.1.

In the Genoud functions thousands of simulations are done automatically until the problem is solved and the parameters are optimized. In our case, it took more than 15,000 runs to get the parameters optimized.

Comment: the study explores the individual and combined effect of forest cover change (in perpetuity or recovery?) and climate change on hydrology yet how forest cover was treated in HBV-EC is not discussed.

Reply: We will include more detail on the methods used to simulate forest removal as: This project parallels another project investigating the effects of a 2003 wildfire and some salvage harvesting on the hydrology of the headwater catchments following methodology presented by Seibert et al. (2010). Here the objective is to investigate a plausible worst case scenario of changes to the hydrology at larger scales following a large catastrophic forest change (such as wildfire) under present and possible future climates by simulating the removal of forests. Using a relatively simple conceptual model (e.g. HBC-EC) to simulates streamflow with simple precipitation and temperature input data does limit the ability to describe detailed forest processes (e.g. interception, transpiration, changed to radiation, and sensible and latent heat fluxes etc.) using physical processes. However, HBV-EC parameters such as interception factor and MRF (Ratio between melt factor in forest to melt factor in open) (see table in supplement) allow the simulation of different land covers by calibrating the differences in precipitation interception and snowmelt processes between the forest and the

open areas. Under our scenario of catastrophic change and no forest regrowth, the parameters controlling interception and snowmelt process are likely the most important process in the mountainous regions where catchment hydrology is dominated by the snowmelt.

We also found that many parameters interacted causing the possibility of unrealistic calibration parameters RFCF (Rainfall correction factor) and SFCF (Snowfall correction factor) values (see table in supplement). For example, calibration of interception in addition to the parameters RFCF and SFCF results in a negative number when rain/snow gauge catch deficiency is larger than the forest snow interception loss. So, we fixed the interception parameters based on some available data and focused our efforts on the calibration of the MRF parameter for the watershed in reference condition. To investigate the importance of the forest in the hydrology of the region and how it interacts with changing climate, the forest was completely removed from the watershed by substituting the parameter set of open areas to approximate the effect of a catastrophic forest wildfire.

Comment: SpeciïňĄc Comments Pg 8509 - A single GCM model, CGCM3) was used in this analysis. An ensemble GCM modeling approach would contribute to uncertainty in future climate projections. While a single GCM is justiïňĄable, discussion is required to address the limitation of a single GCM with respect to uncertainty in climate projections and hence hydrologic prediction;

Reply: We will add additional detail about the GCM uncertainty in the revised manuscript.

Comment: Pg 8510 – Authors state that daily observed climate is “perturbed” yet no further definition/description of the perturbation process. It would be impossible to reproduce without this information;

Reply: The paragraph (lines 4-8 of page 8510) will be re-written in the revised manuscript as: The relative changes in monthly climate means at the Coleman climate station are assumed to be equivalent to the changes in watershed averaged monthly climate means, ∆Tmax, ∆Tmin and ∆P that are obtained from Eqs. (1)–(3). Daily observed climate at Coleman is aggregated to a monthly scale to give reference condition Coleman climate means (TRmax, TRmin and PR) and future monthly climate means at the Coleman climate station (TFmax, TFmin and PF) are calculated by reverting Eqs (1)-(3).

Comment: Section 3.3.2 – My understanding is that the HBV-EC model was calibrated using climate data observed at the Coleman station to identify parameter set that is then used for hydrologic modeling (SS 3.3.3) using LARS-WG climate as input for reference period and future climate. While the authors justify the use of LARS-WG for reference and future hydrologic modeling, there is no comparison of HBV model results using observed climate forcing compared to LARS-WG climate forcing. A comparison of simulated streamïňĆow using different climate forcing would be helpful for understanding generated climate uncertainty. This sort of comparison was conducted for modeled vs observed climate in Table 2. Why not extend it to hydrologic modeling? Perhaps simply a 1:1 line (sim Q_obs climate vs. sim Q_LARS-WG climate) for comparison?

Reply: Figure 4 compares the sim Q_obs climate with actual measurements of Q, and Figure 5 compares the sim Q_LARS-WG climate with actual measurements of Q. So, there is an indirect comparison of sim Q_obs climate vs. sim Q_LARS-WG climate if we examine carefully Figures 4 and 5. However, we agree that there is no comparison in quantitative term. We will add 1:1 line (sim Q_obs climate vs. sim Q_LARS-WG climate) for comparison in the revised manuscript as reviewer requested.

Comment: Section 3.3.4 How many simulations were conducted to generate the 100 best parameter sets?

Reply: The model was set to run for 10,000 runs to generate 100 best parameters sets. We will clarify this in the revised manuscript. Please also see our previous response.

Comment: Section 3.3.5 – More detail to understand how you implemented change detection methods of Seibert and McDonnell 2010. SpeciïňĄcally Seibert and McDonnell 2010 used three methods for change detection: model residuals, comparison of parameter distributions, and comparisons of simulated hydrology different periods. It is unclear of your change detection approach.

Reply: We used one of the approaches that is ‘comparison of simulated hydrology different periods’. We will clarify this in the revised manuscript.

Comment: Pg 8516 – Again, how many simulations and what is the range on NSE. No ability to determine that “. . .NSE was not that great.”

Reply: 10,000 simulations were done. We will add and discussed the NSE values in the revised manuscript.

Comment: Section 4.4 presents the results of HBV-EC application using LARS-WG input data. Unlike section 4.3 that quantiïňĄes model error between observed and simulated Q, there is no such formal quantiïňĄcation of error in this section. Despite that this model application using the calibrated parameter set from observed data, it is important to quantify error for this model application as well. How well or poorly did the HBV-EC model perform (besides objective function evaluation)?

Reply: We will quantify and present the errors in the revised manuscript.

Comment: Section 4.6 – a major shortcoming of this study is how forest change was considered in the HBV-EC modeling framework. The forest parameters in HBV-EC determine the proportion (0-1) of precipitation, snow, and sunlight reaching the ground. It is unclear to me how the modelers treated forest change. Were the parameters for proportion of precipitation and sunlight ‘reaching’ the forest ïňĆoor adjusted to remove ‘interception’? Were these parameters ïňĄxed overtime for future scenarios implying no recovery of forest, i.e. a permanent removal of forests through the year 2100? How would Figure 9 differ based on forest change deïňĄnition? Given that the impact of forest change on streamïňĆow is a primary objective of the study, considerably more detail (methodology, assumptions, limitations, etc.) and therefore revision is required to understand how the parameterization of forest change is considered in the modeling endeavor.

Reply: Please see the previous response.

Comment: Pg 8520 – "Usually the removal of forest results in increased summer ïňĆow.."references to substantiate this?

Reply: We will add the references in the revised manuscript.

Comment: Section 6 Conclusions – The paper would be strengthened by understanding the implications of the results.

Reply: We will add and discuss the forest change impacts in the conclusions in the revised manuscript.

Comment: Table 1: "Relative" changes.. to what, to calibration/reference period? Also what are the annual and annual mean values at the end of the table? Please clarify/deïňĄne

Reply: The new heading would be "Relative changes in watershed averaged mean monthly GCM projections of precipitation and air temperature in comparison to reference period climates for A1B, A2 and B1 scenario for 2020s, 2050s, and 2080s time periods".

Annual means the relative changes in mean annual climate (precipitation and temperature) in future projections in relation to the reference condition climates. Annual mean is the mean of three annuals for the A1B, A2 and B1 scenarios. We will clarify this in the revised manuscript.

Comment: Figure 6: HBV-EC simulations based on LARS-WG? Please clarify in caption

Reply: We will correct the caption as: HBV-EC simulated mean monthly and mean annual streamïňĆows for the reference and nine future periods (for three different scenarios: A1B, A2 and B1 and for three different time periods: 2020s, 2050s and 2080s) at the watershed outlet at Crowsnest at Frank. Both reference and future periods input to the HBV-EC is the daily climate data generated by LARS-WG.

Comment: Technical Comments Pg 8513 – McDonnell misspelled in text. Require two "L's"

Reply: We will correct this.

References:

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Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/10/C5157/2013/hessd-10-C5157-2013-supplement.pdf

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