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Hydrology and Earth System Sciences Discussions

Interactive comment on "Evaluating the impacts of land use changes on hydrologic responses in the agricultural regions of Michigan and Wisconsin" *by* A. P. Nejadhashemi et al.

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Responses to the Referee #3

We greatly appreciate the positive comments from the referee #3. We have addressed all the questions and concerns. In the following, we include the original comments along with our responses.

Comments for the Author *General comments* Summary: This paper uses a modelling approach to attempt to evaluate the changes in hydrology that have resulted from historic changes in land use, including deforestation, increased arable production and urbanisation, in the Great Lakes region of the US. The broader aim of the paper is to improve understanding of the underlying mechanisms determining hydrological change in order to support sustainable management of water resources. The paper relies heavily on the SWAT model and the physical basis of the processes coded within it in undertaking the assessment.

Comment: Unfortunately, the validity of the internal processing of the model is never evaluated for this study area with a validation procedure based on a single objective (simulation of stream flow at the watershed outlet) and an optimisation procedure that selects a single optimal solution.

Response: Thank you for your comment. However, the model was both calibrated and validated as it was shown in table 4 for all watersheds. Calibration and validation of the model based on observed stream flow data at the watershed outlet is a common and widely used/accepted practice in calibration/validation of hydrologic models. Authors can cite dozens of modeling papers demonstrating this procedure including the recent published article in the Hydrol. Earth Syst. Sci., 15, 807-818 by Betrie et al. (2011) titled “Sediment management modelling in the Blue Nile Basin using SWAT model”. More detailed discussion can be found under “Special Comments” section

Comment: This method fails to acknowledge the uncertainty in the model structure, input data and validation data.

Response: Thank you for your comment. Authors agree that there is a level of uncertainty present in any scientific work including modeling, field studies, monitoring, etc. Evaluating different aspects of uncertainty (model structure, inputs, and parameters) is beyond the scope of the study and can be discussed in a separate paper. In addition, output parameter uncertainty analysis cannot be performed for many hydrological parameters under current scenario and no parameter for pre-settlement scenarios because the true values are unknown. Additionally, as it was discussed by Yang et al. (2008) application of uncertainty analysis for complex hydrological models such as

SWAT are computationally too expensive for straightforward use. However, we agree with the reviewer about the important of uncertainty analysis. As a matter of fact, the first author of this manuscript has published a paper in 2003 discussing the uncertainty within the hydrologic and water quality models specifically SWAT (Sohrabi et al., 2003). Therefore, the following sentence was added to the manuscript to acknowledge the importance of model uncertainty in section 2.5 "In addition to calibration, uncertainty analysis is important for distributed watershed models such as SWAT. Sources of structural uncertainty for these types of models include unaccounted processes within the model and over-simplification of model processes. However, performing uncertainty analysis is computationally expensive and time consuming for complex hydrological models, and therefore is not within the scope of this research (Yang et al., 2008)."

We also added the following sentence to the "Conclusion" section "However, due to the important role of uncertainty analysis in the decision making process for water resources, it is recommended that future studies be performed to evaluate different sources of uncertainty to increase confidence in the model results."

Reference: Yang, J., Reichert, P., Abbaspour, K.C., Xia, J., Yang, H. Comparing uncertainty analysis techniques for a SWAT application to the Chaohe Basin in China. JHYDROL 358, 1-23, 2008.

Sohrabi, T.M., Shirmohammadi, A., Chu, T.W., Montas, H., Nejadhashemi, A.P. Uncertainty analysis of hydrologic and water quality predictions for a small watershed using SWAT2000. Environmental Forensics, 4:229–238, 2003

Comment: Results from a sensitivity analysis are presented but are impossible to interpret, as insufficient explanation of the procedure is included.

Response: Thank you for your comment. Additional explanations of the procedure were added. The sentence was rewritten to explain that mean and median are corresponding to rankings of watershed parameters. Please see section 3.1. Read as "Two criteria (mean ranking and median ranking for each watershed parameter) were selected to identify the most influential parameters, which affect daily flow rates." The following sentence was also added earlier in section 2.4, "In these tables, the overall rankings for each watershed parameter were calculated based off the median and mean of individual rankings for all watersheds."

In response to selection of both median and mean, the following was added to the manuscript to justify the use of the two above criteria (section 3.1). "In the case that mean of two watershed parameters' rankings are the same, the median value was used in determining the overall ranking."

Comment: In general, the paper is very difficult to understand as the structure is poor, with confusion between presentation of methodology and results. Insufficient detail of the methodology is included with regard to application of the model and sensitivity analysis, the meaning of parameters and identification of their values for the study area. Overall, there are two many unexplained aspects of the modelling and processes in the paper to generate a belief in the reader in the validity of the results from the model application.

Response: Thank you for your comment. Authors tried to address your comments and concerns by explaining different aspects of modeling a process more clearly and addressing the specific comments below.

Specific Comments

Comment: P3426 - please explain what is meant by "6 digit" and "8 digit" watersheds for an international readership

Response: Thank you for your comment. The following sentence has been added to the manuscript in section 2.1 "The US Geological Survey used surface hydrological features to divide the continental United States into 352 accounting units, which are also known as hydrologic unit code (HUC) 6-digit watersheds.

Additionally, based on referee 2's comments, the sentence containing HUC 8 digit was removed. Therefore, we did not describe it in the above sentence.

Comment: why are 2 of the watersheds combined in Table 1 ?

Response: Thank you for your comment. Due to similarity in physiographic and climatologic characteristics of watersheds 040400 and 040301, they were combined in Table 1.

Comment: provide an inset of the location in the USA in Figure 1

Response: Thank you for your comment. Figure 1 was modified to include an inset of the USA.

Comment: refer to Figure 2 for land use

Response: Thank you for your comment. We referred to figure 2 at the end of the following sentence in section 2.1"Based on pre-settlement land use data obtained from Michigan Natural Features Inventory, Original Vegetation Cover of Wisconsin, and Land Cover of Illinois for the early 1800's, the area of interest has gone though a significant land use changes in the past 200 years (Fig. 2)."

Comment: define somewhere what you mean by sub-basin, watershed and river basin (the latter two mean the same thing to me) and what sort of catchment areas each define (e.g. 10s km2, 100s km2, or 1000s km2)

Response: Thank you for your comment. Subbasin was defined in the manuscript under section 2.2 as "In SWAT, a watershed is divided into subbasins," We also added the definition of the watershed and the basin in section 2.1 in the following sentences "In this study, watersheds (HUC 6-digit) in nine accounting units were selected, which include 070700 (Wisconsin), 040301 (Northwestern Lake Michigan), 040400 (Southwestern Lake Michigan), 040302 (Fox), 70900 (Wisconsin portion of Rock), 040500 (Southeastern Lake Michigan), 040900 (St. Clair-Detroit), 040801 (Southwestern Lake Huron), and 040802 (Saginaw). The study area (basin) is shown in Fig. 1."

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Interactive Comment

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Comment: occasional words are missing from sentences throughout the paper (e.g. p3426, l25 should read “the” water budget)

Response: Thank you for your comment. Authors have attempted to correct any small errors within manuscript, including the one mentioned above.

Comment: the overview of processes in the SWAT model is not very helpful as it is very simplistic and leaves more open questions than answered ones (e.g. why was the SCS method chosen in this application?, which ET calculation method was chosen and why?, how is the soil profile defined ? etc.). It would be more useful to include a discussion of processes occurring within the study area, how these relate to the SWAT model structure, and especially how the parameterisation is undertaken.

Response: Thank you for your comment. The goal of this section of the paper is to briefly define hydrologic components of the very comprehensive SWAT model. Further information and detailed descriptions of each component can be found in SWAT2005 Theoretical Documentation available at http://swatmodel.tamu.edu/documentation

However, the following sentences were added to section 2.2 to address the specific concerns raised above including “In this study, the SCS method was used because only daily precipitation data was available.” “Since observed PET values were not available, daily PET values were estimated using the Penman-Monteith method, which is recommended for the study area.”

Meanwhile, soil profile is an input to the SWAT model and is provided by the Natural Resources Conservation Service’s State Soil Geographic (STATSGO) database. This sentence was added to section 2.3. “In addition, the Natural Resources Conservation Service’s State Soil Geographic (STATSGO) database was used in the model.”

The goal of using models in this study is to try to understand the processes occurring within the study area. Therefore, discussion of the processes and parameterization in advanced is not possible at this section of the paper.

Comment: P3429 - l 21-23: don't understand these statistics on elevation or their relevance in the context of the modelling

Response: As explained in the next sentence "These differences may have significant impacts on watershed hydrologic responses such as stream flow and evaporation in two regions (Mohamoud, 2004)." These statistics could later help to explain results and observed differences obtained from the modeling.

Comment: l 24: what kinds of impacts on stream flow – rates of runoff, peak flows, or total runoff volumes (driven by differences in the overall water balance)?

Response: Mohamoud (2004) discussed the significance of elevation differences on stream flow, however, more specific impacts on runoff, peak flow, and total runoff volume is site specific and difficult to drive general conclusions. Therefore, additional discussion on more specific impacts of elevation differences on hydrological elements was avoided.

Comment: P3431 - no explanation is given for the sensitivity analysis methodology. This is important.

Response: Thank you for your comment. The following sentence was added to the manuscript "In this study the sensitivity analysis concerning daily flow rate was performed on 42 different SWAT parameters. One-factor-At-a-Time (LH-OAT) technique developed (van Griensven et al., 2006) is embedded in SWAT and was used to perform sensitivity analysis."

Comment: L4-5: "Senistivity analysis: : :calibration" I don't understand the meaning of this sentence. It suggests a sequential parameter calibration approach but this fails to acknowledge the effect of interactions between model parameters.

Response: Thank you for your comment. However, it is not clear how the reviewer come to this conclusion that a sequential parameter calibration approach fails to acknowledge the effect of interactions between model parameters. In this section we did

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not talk about the calibration procedure. However, in calibration procedure, regardless of performing sensitivity analysis a sequential parameter calibration approach will be adopted. This is the general practice for a manual model calibration.

Comment: l3: Shouldn't refer to the results until the results section. This section should be about the method.

Response: Thank you for your comment. The following sentence was removed from section 2.4 "and results are summarized in Tables 3a and 3b"

Comment: l20-21: Why were sensitive parameters not altered? What were their values based on? Why were other parameters altered instead ? You need to explain the rationale for the method.

Response: Thank you for your comment. The following paragraph in section 2.5 was revised to address these concerns:

"The following parameters were used for the model calibrations in different watersheds: Alpha_Bf (baseflow recession constant), Cn2 (moisture condition II curve number), EPCO (plant uptake compensation factor), ESCO (soil evaporation compensation coefficient), Rchrg_Dp (deep aquifer percolation fraction), Surlag (surface runoff lag coefficient), TIMP (snow coefficient lag factor). Some parameters identified as sensitive (Sol_Z, Sol_Awc, Canmx, Gwqmn, Ch_K2) were not modified during calibration, while others that were not identified during sensitivity analysis were modified during calibration. Sensitive parameters that were not used for calibration were identified as not attributing to variation in model output. Parameters that were not identified as sensitive but used in calibration were applied to match the model with naturally occurring processes in the watershed. Additionally, parameters not identified as sensitive in the sensitivity analysis must be adjusted due to error observed in predicted variables. Parameters chosen other than those identified by the sensitivity analysis were based on calibration parameters identified in other published results (White and Chaubey, 2005)."

Comment: l23: isn't this an apriori requirement for all modelling exercises to assess suitable values for parameters to represent the catchment processes? Otherwise you are liable to end up with the "right" answer for the "wrong" reason, the internal functioning of the model will be "wrong" and the model is therefore liable to give the "wrong" answer when scenarios such as land use change are applied.

Response: Thank you for your comment. Authors agree. The sentence that was referred to emphasizes the concept that you discuss.

Comment: P3432 - l 9-10: this is totally dependent on the parameters representing different land uses being correctly parameterised and differentiated within the model. Single objective validation of a model on watersheds with mixed land use will be inadequate to validate the differences in land use parameters, due to the multiple degrees of freedom of a complex model such as this.

Response: Authors agree with your statement that "this is totally dependent on the parameters representing different land uses being correctly parameterised and differentiated within the model." And this is exactly what was done. As it was discussed in previous response calibration and validation of the model based on observed stream flow data at the watershed outlet is a common and widely used/accepted practice in calibration/validation of hydrologic models. Authors can cite dozens of modeling papers demonstrating this procedure including the recent published article in the Hydrol. Earth Syst. Sci., 15, 807-818 by Betrie et al. (2011) titled "Sediment management modelling in the Blue Nile Basin using SWAT model". Calibration at the outlet of the watershed captures overall hydrological processes, which is the goal of this study. Even in the case that additional monitoring sites are available within a watershed, this will not ensure that each monitoring site will capture localized impact of a single landuse change. Therefore capturing localized impact of landuse change can only be accomplished at the field scale. This level of uncertainty is acceptable in modeling practice; otherwise no model can be used to study any hydrological processes beyond a homogenous site.

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Comment: L14-19: I don't understand these statements.

Response: The sentence was rewritten to make it clearer "However, models such as SWAT are designed to evaluate hydrologic impacts of landuse change regardless of type, amount, and nature of landuse conversation. However it is worth acknowledging that the uncertainty in the model results will increase as larger areas of the watershed experience landuse conversion."

Comment: l 23-yes – exactly! Yet these processes are totally essential to understanding the impacts of land use change on hydrology, so one wonders what value can be expected to come out of the study.

Response: Authors agree and it was acknowledged in the manuscript. The issue of uncertainty does exist in any scientific work and is not only limited to modeling studies. However, the science community accepts some level of uncertainty as far as it can be explained and effects are minimal. As it was mentioned in this section collecting and incorporating information such as drainage system, irrigation, type of crop, crop rotation, etc. is very difficult and in some cases impossible due to the lack of datasets. However, this type of problem did not stop scientist from performing large scale hydrological studies and hundreds of papers can be found to attempt to explain hydrological fluxes in the large scale despite the fact that the majority of them, if not all, do not have detailed field by field information.

Comment: P3433 - need to define what you mean by "regional" and "local" scales.

Response: Thank you for your comment. The sentence was rewritten as follows "In the following section, we will study the hydrologic effects of land use change at both a regional (entire study area) and a local scale (subbasins)"

Comment: L 7-9 what is the difference between (1) and (2) ?

Response: Thank you for noticing the error. The sentence was revised as follows "(1) performing a hydrologic sensitivity assessment based on pre-settlement and current

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landuse scenarios (2) quantifying the magnitudes of hydrologic response to land use changes using the SWAT model."

Comment: was the sensitivity analysis done parameter by parameter, or investigating multiple parameters together ? Must describe the methodology in the previous section

Response: Thank you for your comment. As described in previous comment, the following sentences were added to the sensitivity analysis methodology section "In this study the sensitivity analysis concerning daily flow rate was performed on 42 different SWAT parameters. One-factor-At-a-Time (LH-OAT) technique developed (van Griensven et al., 2006) is embedded in SWAT and was used to perform sensitivity analysis."

Comment: l 12-13: why and how ?

Response: Thank you for your comment. This was explained in the manuscript in section 3.1 in the following sentence "These parameters directly or indirectly influence the daily flow rate and ranked higher than others."

Comment: l17: how is the sensitivity analysis ranking table deervied and what does it tell you ?

Response: Thank you for your comment. The following paragraph was revised to address the concern. "Mean and median were calculated for the top 15 parameters based on their position in the sensitivity analysis ranking table. In the case that the mean of two watershed parameters' rankings are the same, the median value was used in determining the overall ranking. Comparing tables 3a and 3b illustrates significant shifts in overall ranking of some parameters, while ranking of other parameters are slightly sensitive or insensitive to the land use changes."

The whole rest of section 3.1 discusses what the top ranked sensitive parameters explain and how the results of sensitivity analysis should be interpreted. The overall conclusion of the section was summarized in the last paragraph as "parameter sensitivity

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analysis may not always explain how the variation in model output can be attributed to different sources of variation in the model input. Therefore, attention should be taken to determine the true importance of sensitive parameters by considering their placement in model algorithms, since the most sensitive parameters may not always be appropriate for use in model calibration. It is recommended that in the future versions of SWAT, sensitivity analysis is redesigned to avoid this type of problem."

Comment: P3434 - l2-4: there is a lack of process interpretation of what the model is doing. Unclear what the value is of comparing the ranking analysis for pre- and post settlement situations.

Response: Thank you for your comment. The sentence was revised to include the process as follows "The aforementioned shift in ranking of Cn2 and Rchrg_Dp parameters can be explained by runoff-curve number values because in this study the SCS curve number was employed for calculating surface runoff and the SWAT model does not assign different Rchrg_Dp values to different land uses."

Regarding the comment "Unclear what the value is of comparing the ranking analysis for pre- and post settlement situations" please refer to the response of the previous comment.

Comment: P3437 - l25: A value of NS efficiency of 0.2 seems very low to be deemed as an acceptable simulation

Response: Thank you for your comment. The satisfactory model performances on daily basis was updated to ENS $\geq$ 0.40. As it was described in the paper "Moriasi et al. (2007) developed general evaluation guidelines based on a model performance rating. Based on these guidelines, a model performance can be evaluated as "satisfactory" for a monthly time step series if ENS > 0.50.". Further calculations on a monthly basis showed that for all studied watersheds the model performed satisfactory according to Moriasi et al. (2007) with an ENS > 0.50). Therefore, all eight watersheds were calibrated satisfactory. The following paragraph were revised to further address this concern.

“In general, shorter time steps have poorer model simulations than longer time steps (Moriasi et al., 2007). Performance ratings presented above for ENS statistics are for a monthly time steps and must be modified for a daily time step to be applicable in this study. In order to do so, a series of studies on SWAT model performance on daily basis were reviewed. For example Benham et al. (2006) ENS of 0.21 and Coffey et al. (2004) reported ENS of 0.15 for satisfactory SWAT calibration. Based on the above studies, a conservative criterion was considered to evaluate satisfactory model performances on daily basis: ENS $\geq$ 0.40. Further calculations on a monthly basis showed that for all studied watersheds the model performed satisfactory according to Moriasi et al. (2007) with an ENS > 0.50).”

Comment: P3438 - If you set acceptable criteria for your objective functions to exceed specific values, then you should end up with multiple sets of simulations which give satisfactory results. Why was only one parameter set selected from these ? What happens to the ranges of parameter values if you look at all acceptable simulations that achieve your performance criteria ? Does this affect the interpretation of results ? Are there any implications for evaluating the effects of land use change ?

Response: Streamflow is the only part of the hydrologic cycle that can be measured accurately. Therefore, almost all hydrologic modeling practices performing calibration and validation based on streamflow. Data and techniques do not exist within the large scale area to measure other hydrologic elements such baseflow. Therefore, we cannot comment on the ranges of parameter values and acceptable performance criteria of unmeasured elements of water budget. Availability of measured components of water budget can provide insight into effects of landuse changes and help in developing more accurate hydrological model.

Comment: L1-15 Unnecessary detail on reservoir management

Response: Thank you for your comment. The following section was removed from the

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manuscript. “Based on the Wisconsin River Reservoir System Operating Plan report (WVIC, 2010), maintaining uniform flow on the Wisconsin River and meteorological conditions (volume and timing of precipitation and snowmelt) are the factors considered in the reservoir operation cycle. In July 1996, four particular operating rules for the reservoir system are specified, including 1) maximum and minimum water levels in each reservoir; 2) minimum flow for each reservoir; 3) flow goals; and 4) storage balancing using index levels (WVIC, 2010), which alters the flow regime in the Wisconsin River after 1996.”

Comment: Section on sub-basin land use change – much of this should be presented in the methodology section. Results are poorly presented here.

Response: Thank you for your comment. The following paragraph was moved to the methodology section 2.6:

“2.6 Subbasin-Level Impacts of Land Use Changes The objective of this section is to understand whether land use conversion can explain hydrological behavior at the subbasin level. In order to estimate the percentage of land use conversion within each of the 2308 subbasins (Fig. 5), the pre-settlement and current land use maps were intersected. This allows partitioning of the subbasin to smaller units based on intersected area of pre-settlement and current landuse scenarios (Fig. 6). Then the top 14 land use conversion classes were identified and the percentage of landuse conversion within each of the 14 classes to the total subbasin area was calculated for all 2308 subbasins. In the next step, the degree of relationship (correlation) between percent of land use conversion within a subbasin and seven different hydrologic characteristics were assessed (actual evapotranspiration, soil water content, water percolation, surface runoff, baseflow, water yield, lateral subsurface flow).

In addition we relocated the following sections explaining methodology for watershed and basin level impacts of landuse change:

“2.7 Watershed-Level Impacts of Land Use Changes The objective in this analysis is to compare hydrological variables in pre-settlement and current land use at watershed level. The sample size for this analysis is rather low because only the means of eight HUC-6 digit watersheds are available, which makes difficult to test statistical assumptions (i.e. normality). In addition, the eight watersheds used for pre-settlement and current land use were the same, making this a paired dataset in which independence between subjects (i.e. watershed) is not found. A nonparametric test suitable for paired samples and small sample size is the Wilcoxon Signed Rank Sum, S test (Sprent and Smeeton, 2000).

2.8 Basin-Wide Impacts of Land Use Changes In general, the basin was divided into to three major classes. 1) positive high: if percent change in hydrologic characteristics is equal or more than 10% of the original value; 2) modest: if percent change in hydrologic characteristics is between -10% to 10% of the original value and; 3) negative high: if percent change in hydrologic characteristics is equal or less than -10% of the original value. ”

Comment: P3440 - Again, confusion between methods and results for the watershed level impacts

Response: Thank you for your comment. Please see response to the previous comment.

Comment: P3441 - Decreasing forest leads to a decrease in recharge compared with urban ? This is surprising as I would expect to see higher ET losses from forest leading to an increase in recharge and total runoff when deforestation occurs. Need to be clear about your definitions of “recharge” and “runoff”

Response: In general most hydrological behaviors are complex and site specific. Meanwhile, authors agree conversion of forestlands to urban increase surface runoff. However, in urban areas majority of the previous surfaces are converted to impervious areas, causing lower recharge to aquifers than forested land.

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Comment: P3442 - Define what you mean by “basin-wide”

Response: Thank you for your comment. This was responded to in a previous section and described as the entire study area.

Comment: l24 – what about the increase in urbanisation ? I would have expected this to be the main cause of an increase in overland runoff rather than agricultural land, which has most probably been drained.

Response: Thank you for your comment. The following sentence was revised to acknowledge the impact of urbanization. “This can be explained by the vast expansion of agricultural lands and urbanization in the region.”

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/8/C1801/2011/hessd-8-C1801-2011-supplement.pdf

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