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Hydrology and Earth System Sciences
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Interactive comment on "Minimum forest cover for sustainable water flow regulation in a watershed under rapid expansion of oil palm and rubber plantations" *by* Suria Tarigan et al.

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Anonymous Referee #2

General comments: I found the topic and results described in this manuscript to be quite interesting. There is very limited information available in the literature to date regarding the potential effects of expanded production of rubber or oil palm trees, using SWAT model or any other modeling approach. Thus I think that the information reported in this manuscript will ultimately prove to be a useful contribution to Hydrology and Earth System Sciences (HESS) and the existing literature in general. However, I believe that the current manuscript suffers from several deficiencies including

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inadequate review of existing literature, insufficient description of SWAT and key input parameters (including coefficients used for rubber tree and oil palm tree in the crop parameter file), lack of in-depth description of SWAT calibration and validation results, and an inadequate description of the simulated watersheds. Specific comments regarding these issues are provided below.

We appreciate the referee's concerns. We have addressed all referees' concern in the respective comments below including: a) more comprehensive review of existing literature, b) in depth description of key crop parameters. In addition, we have restructured method section into several subsections as follows. Each subsection is described in the respective specific comment below.

2. Methods

2.1 Study area

2.1.1. Land use and soil characteristics

2.1.2 Watershed characteristics

1. Macro watersheds

2. Small watersheds

2.2 Flow simulation

2.2.1 SWAT model

1. Crop and Soil parameters

2. Input data

3. Model validation and calibration

2.2.2 Simulated C and BFI values

2.2.3 Observed C and BFI values

1. Observed C values
2. Observed BFI values

Specific comments

1) Abstract: The Abstract needs to be considerably revised to reflect more of the actual quantitative results of the study versus the “general discussion” that dominates much of the abstract between lines 9 to 24. The revised abstract should include a summary of the baseline calibration and validation results.

We agree with the referee’s suggestions, and have improved the abstract accordingly. (see the description in the following paragraphs)

Lines 9-24: In many tropical regions, rapid expansion of monoculture plantations has led to a sharp decline of forest cover potentially degraded the water flow regulation function of watersheds. In a watershed where expansion of agricultural plantations occurs rapidly, the regional planner need to know the minimum proportion of forest cover required to maintain proper water flow regulation function of a watershed. Research dealing with this issue is still rare, especially in the tropical area where oil palm expansion occurs at alarming rate. We investigated the impact of forest and monoculture plantations (oil palm and rubber plantations) on rainfall partitioning to direct runoff and subsurface flow for a humid tropical watershed in Indonesia. The results are based on streamflow as simulated by a calibrated SWAT model and observations across several watersheds and subsequently derived the direct runoff coefficient (C) and the baseflow index (BFI). The model gave satisfactory performance with the NSE values of 0.80-0.88 (baseline calibration) and 0.80 - 0.85 (validation); and the PBIAS values of -2.9 - 1.2 (calibration) and 7.0-11.9 (validation). The study exhibits a statistically significant correlation of percentage of forest covers in a watershed with C (negatively) and BFI (positively). On the other hand, the rubber and oil palm plantations showed flow regulation behavior contrary to forest covers. Finally the study suggests the minimum forest cover requirement in the study area (i.e. 30%) for sustainable ecosystem services. The new contribution of our study is the establishment of quantitative relation between forest cover and flow indicators in a watershed, which can be used as a guide for regional planners to determine the minimum proportion of forest conservation area to maintain a sustainable ecosystem service of water flow regulation in a watershed.

2) Lines 43-45: I would suggest you rewrite this sentence to read something like: “This vertical movement of water in the soil determines how much water flows as direct runoff and how much percolates to the water table where it sustains baseflow or groundwater (references).”

We agree with the referee’s suggestions, and have revised the sentence.

3) Lines 49-68: Please include citation and discussion of some “big picture” studies regarding the impacts of Palm Oil and/or Rubber Trees in the southeast Asia region such as those listed immediately below.

We thank the referee for this suggestion. We have substantially improved the citation and discussion of some studies regarding the impacts of palm oil and/or rubber trees in the Southeast Asia region.

Line 30-46 In Southeast Asia in particular, the land under oil palm and rubber have expanded considerably. In Indonesia, which is now the largest palm oil producer worldwide, the oil palm area increased from 0.7 million ha in 1990 to 11 million ha in 2015 (Ditjenbun, 2013; Tarigan et al., 2016). Projections of additional land demand for palm oil production in 2020-2050 ranges from 1 to 28 Mha in Indonesia (Wicke et al., 201, Afriyanti et al., 2016). The rapid increased of oil palm expansion is partly triggered by increased demand for biofuel production (Mukherjee and Sovacoo. 2014). While oil palm has improved farmer and regional economic, it has been subject to the environmental and social criticism. Oil palm expansion is often held responsible for deforestation (Wicke et al., 2011; Gatto et al., 2015; Vijay et al., 2016), biodiversity loss (Koh and Wilcove, 2008; Fitzherbert et al., 2008;Wilcove and Koh, 2010; Carlson et al., 2012; Krashevka et al., 2015), decreased soil carbon stock (Guillaume et al., 2015, 2016; Pransiska et al., 2016) and increased greenhouse gas emissions (Allen et al., 2015; Hassler et al., 2017). Apart from oil palm, another prevalent plantation crop in Southeast Asia is rubber plantation (Ziegler, et al., 2009). In Indonesia itself, the rubber plantation covers 3.5 million hectares of land (Ditjenbun, 2013). The land devoted for rubber in Southeast Asia could double or triple by the year 2050 (Ziegler, et al., 2009). Expansion of the rubber plantation reduces soil infiltration capacity, accelerates soil erosion, increases stream sediment load (Ziegler, et al., 2009; Tarigan, et al., 2016), increased evapotranspiration (Wangpimool et al., 2017) and decreases soil carbon stock (Ziegler et al., 2011).

Some newly added References:

Afriyanti, D., Kroeze, C., Saad A.2016. Indonesia palm oil production without deforestation and peat conversionby 2050. Science of the Total Environment 557–558 (2016) 562–570

Allen K, Corre MD, Tjoa A, Veldkamp E (2015) Soil nitrogen-cycling responses to conversion of lowland forests to oil palm and rubber plantations in Sumatra, Indonesia. PLoS ONE 10(7): e0133325. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0133325

Carlson, K.M., Curran, L.M., Ratnasari, D., Pittman, A.M., Soares, B.S., Asner, G.P., Trigg, S.N., Gaveau, D.A., Lawrence, D., Rodrigues, H.O.. 2012. Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. Proc Nat Acad Sci USA 109:7559–7564.

Fitzherbert, E. B., Struebig, M. J., Morel, A., Danielsen, F., BruÌĹhl, C. A., Donald, P. F., Phalan, B., 2008. How will oil palm expansion affect biodiversity? Trends in Ecology & Evolution 23 (10), 538–545.

Gatto M, Wollni M, Qaim M (2015) Oil palm boom and land-use dynamics in Indonesia: The role of policies and socioeconomic factors. Land Use Policy 46: 292-303. http://www.sciencedirect.com/science/article/pii/S0264837715000733

Guillaume T, Damris M, Kuzyakov Y (2015) Losses of soil carbon by converting tropical forest to plantations: Erosion and decomposition estimated by δ 13 C. Global Change Biology 21: 3548-3560. http://onlinelibrary.wiley.com/doi/10.1111/gcb.12907/abstract

Guillaume T, Holtkamp AM, Damris M, Brümmer B, Kuzyakov Y (2016) Soil degradation in oil palm and rubber plantations under land resource scarcity. Agriculture, Ecosystems & Environment 232: 110-118 http://www.sciencedirect.com/science/article/pii/S0167880916303619

Hassler E, Corre MD, Tjoa A, Damris M, Utami SR, Veldkamp E (2015) Soil fertility controls soil-atmosphere carbon dioxide and methane fluxes in a tropical landscape converted from lowland forest to rubber and oil palm plantations. Biogeosciences 12: 5831-5852. http://www.biogeosciences.net/12/5831/2015/bg-12-5831-2015.html

Koh, L.P., Wilcove, DS., 2008. Is oil palm agriculture really destroying tropical biodiversity? Conservation Letters 1 (2008) 60–64

Krashevska V, Klarner B, Widyastuti R, Maraun M, Scheu S (2015) Impact of tropical lowland rainforest conversion into rubber and oil palm plantations on soil microbial communities. Biology and Fertility of Soils 51: 697-705. http://link.springer.com/article/10.1007/s00374-015-1021-4

Mukherjeea, I., B.K. Sovacoo. 2014. Palm oil-based biofuels and sustainability in southeast Asia: A review of Indonesia, Malaysia, and Thailand. 37: 1-12. DOI: 10.1016/j.rser.2014.05.001.

Pransiska Y, Triadiati T, Tjitrosoedirjo S, Hertel D, Kotowska MM (2016) Forest conversion impacts on the fine and coarse root system, and soil organic matter in tropical lowlands of Sumatera (Indonesia). Forest Ecology and Management 379: 288-298 http://www.sciencedirect.com/science/article/pii/S0378112716303942

Vijay V, Pimm SL, Jenkins CN, Smith SJ. 2016. The Impacts of Oil Palm on Recent Deforestation and Biodiversity Loss. PLoS ONE 11 (7): e0159668. doi:10.1371/journal.pone.0159668

Wicke B, Sikkema R, Dornburg V, Faaij A. 2011. Exploring land use changes and the role of palm oil production in Indonesia and Malaysia. Land Use Policy 28 (2011):193–206

Wilcove DS, Koh LP. 2010 Addressing the threats tobiodiversity from oil-palm agriculture. Biodivers.Conserv. 19, 999–1007. (doi:10.1007/s10531-009-9760-x)

Wilcove et al. 2013. Navjot's nightmare revisited: logging, agriculture, and biodiversityin Southeast Asia. Trends in Ecology and Evolution 28(9): 531-540. DOI:10.1016/j.tree.2013.04.005.

Ziegler et al. 2009. The Rubber Juggernaut. Science 324: 1024–1025. DOI: 10.1126/science.1173833.

Ziegler et al. 2011. Recognizing Contemporary Roles of Swidden Agriculture in TransformingLandscapes of Southeast Asia. Conservation Biology 25(4): 846-848. Available at: http://www.jstor.org/stable/27976544.

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4) Lines 69-70: Please expand this discussion to provide a broader review of different modeling and other analysis methods, beyond the option of SWAT, available to assess the impacts of expanded rubber and oil palm plantations in the Southeast Asia region.

We thank the referee for this suggestion, and have expanded the discussion to provide a broader review of different modeling and other analysis methods, beyond the option of SWAT.

Lines 78-92: A number of approaches can be used to assess the impacts of expanded rubber and oil palm plantations on hydrological characteristics in the Southeast Asia region. The approaches can be categorized as empirically-based and process-based. Empirical-based approaches use long-term historical data to correlate the land use changes with the corresponding streamflow data (Adnan and Atkinson, 2010; Rientjes et al., 2011; Mwangi et al. 2016) or paired catchment studies (Bosch and Hewlett, 1982; Brown et al., 2005). Process-based method utilizes physically based hydrological models where the change impact is determined by varying land use/cover settings (Guo et al. 2016; Khoi et al. 2014; Zhang et al. 2016, Marhaento et al. 2017, Wangpimool et al. 2017). Process-based approach require more data as input and subject to high uncertainty in parameter estimation (Zhang et al. 2016; Xu et al. 2014). Due to the absence of long-term historical data in our study area, we used the second approach. The distributed hydrologic models such as the Soil and Water Assessment Tool (SWAT) eco-hydrological model (Arnold et al., 1998; 2012) are useful to understand the effects of land use changes on watershed flow regulation. It quantifies the water balance of a watershed on a daily basis (Neitsch et al., 2009) and has been recommended for the evaluation of hydrological ecosystem services of a watershed (Vigerstol et al., 2011). The SWAT modeling approach is one of the most widely used and scientifically accepted tools to assess the water management in a watershed (Gassman et al., 2007).

Some newly added References:

Adnan, N. A., Atkinson, P. M. 2011. Exploring the impact of climate and land use changes on streamflow trends in a monsoon catchment. International Journal of Climatology 31, 815–831.

Guo J, Su X, Singh VP, Jin J. 2016. Impacts of Climate and Land Use/Cover Change on Streamflow Using SWAT and a Separation Method for the Xiying River Basin in Northwestern China. Water 2016, 8, 192; doi:10.3390/w8050192.

Khoi DN, Suetsugi T. 2014. Impact of climate and land-use changes on hydrological processes andsediment yieldâĂŤa case study of the Be River catchment, Vietnam. Hydrological Sciences Journal–Journal des Sciences Hydrologiques, 59 (5) 2014.

Marhaento et al. 2017. Attribution of changes in the water balance of a tropical catchment to land use change using the SWAT model. Hydrological Processes. 31(11):2029–2040. DOI: 10.1002/hyp.11167.

Meijide A, Röll A, Fan Y, Herbst M, Niu F, Tiedemann F, June T, Rauf A, Hölscher D, Knohl A (2017) Controls of water and energy fluxes in oil palm plantations: Environmental variables and oil palm age. Agricultural and Forest Meteorology 239: 71-85 http://www.sciencedirect.com/science/article/pii/S0168192317300771

Rientjes, T. H. M., Haile, A. T., Kebede, E., Mannaerts, C. M. M., Habib, E., & Steenhuis, T. S. (2011). Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin–Ethiopia. Hydrology and Earth System Sciences, 15(6), 1979–1989.

Wangpimool et al. 2017. The impact of Para rubber expansion on streamflow and other water balance components of the Nam Loei River Basin, Thailand. Water. 9(1) DOI: 10.3390/w9010001.

Xu X, Yang D, Yang H, Lei H. 2014. Attribution analysis based on the Budyko hypothesis for detecting the dominant cause of runoff decline in Haihe basin. Journal of Hydrology 510 (2014) 530–540.

Zhang L, Nan Z Xu Yi, Li S. 2016. Hydrological Impacts of Land Use Change and Climate Variability in the Headwater Region of the Heihe River Basin, Northwest China. PLoS One. 2016; 11(6):e0158394. doi: 10.1371/journal.pone.0158394.

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5) The expanded paragraph noted in comment 3 should be followed by a specific paragraph about SWAT including relevant review studies about SWAT and a more in-depth

review of how SWAT has been used for land use change analyses. Note that the Zhang et al. (2013) article you cite in line 76 is not a very good choice regarding reviews of SWAT studies; please instead cite one or more of the studies listed on the webpage at http://swat.tamu.edu/publications/special-issues/ or in the “SWAT Publications box” in http://swat.tamu.edu/. Please also cite some relevant SWAT “land use change studies” (see the SWAT Literature Database that can again be accessed on the SWAT model homepage) such as those listed here:

Babel, M.S., B. Shrestha and S.R. Perret. 2011. Hydrological impact of biofuel production: A case study of the Khlong Phlo Watershed in Thailand. Agricultural Water Management. 101(1): 8-26. DOI: 10.1016/j.agwat.2011.08.019. Marhaento et al. 2017. Attribution of changes in the water balance of a tropical catchment to land use change using the SWAT model. Hydrological Processes. 31(11):2029–2040. DOI: 10.1002/hyp.11167. Tan et al. 2015. Impacts of land-use and climate variability on hydrological components in the Johor River basin, Malaysia. Hydrological Sciences Journal. 60(5): 873-889. DOI: 10.1080/02626667.2014.967246. Tarigan et al. 2016. Mitigation options for improving the ecosystem function of water flow regulation in a watershed with rapid expansion of oil palm plantations. Sustainability of Water Quality and Ecology . 8: 4-13. DOI: 10.1016/j.swaqe.2016.05.001. Wangpimool et al. 2017. The impact of Para rubber expansion on streamflow and other water balance components of the Nam Loei River Basin, Thailand. Water. 9(1) DOI: 10.3390/w9010001.

We thank you the referee for suggestions. We have added specific paragraph about SWAT and a more in-depth review of how SWAT has been used for land use change analyses.

Line 93-102 Marhaento et al. (2017) used the SWAT model to simulate impact of forest cover and agriculture land use on the runoff coefficient and the ratio of base flow to stream flow in Java Island Indonesia and found that forest cover change from 48.7% to 16.9% resulted in the increased of the runoff coefficient (C) to 44.6% and decrease of the ratio of base flow to stream flow to 31.1% showing similar trend with that of our results. Meanwhile, Wangpimool et al., (2017) found that annual reduction of the basin average water yield about 3% based on the SWAT model simulation due to the rubber expansion in Thailand from 2002 to 2009. Babel et al., (2011) simulated impact of oil palm expansion using SWAT in Thailand and reported increased nitrate loading (1.3 to 51.7%) to the surface water. The new contribution of our study is the establishment of quantitative relation between forest cover and flow indicators in a watershed, which can be used as a guide for the regional planners to determine the minimum proportion of forest conservation area to maintain a sustainable ecosystem service of water flow regulation in a watershed. Tarigan et al. (2016) used SWAT model to simulate impact of soil and water conservation practices on low flow in oil palm dominated watersheds in Jambi Provinces, Indonesia.

6) Lines 71-73: These two current sentences have grammatical problems. As a part of comment 4, I suggest that you revise the text as follows: “A useful tool to answer this question is the Soil and Water Assessment Tool (SWAT) ecohydrological model (Arnold et al., 1998; 2012), which quantifies the water balance of a watershed on a daily basis (Neitsch et al., 2009) and has been recommended for the evaluation of hydrological ecosystem services of a watershed (Vigerstol et al., 2011).”

We agree with the referee’s suggestions, and have improved the sentences accordingly.

Lines 71-73 Distributed hydrologic models such as the Soil and Water Assessment Tool (SWAT) eco-hydrological model (Arnold et al., 1998; 2012) are useful to understand the effects of land use changes on watershed flow regulation. It quantifies the water balance of a watershed on a daily basis (Neitsch et al., 2009) and has been recommended for the evaluation of hydrological ecosystem services of a watershed (Vigerstol et al., 2011).

7) Study area description: The two study watersheds should be described in depth in this subsection rather than being referenced later in subsection 2.2 (please describe the area of the watersheds in km2 rather than ha). More detailed land use information (percentages of each type of land use) for the two watersheds should be provided (rather than waiting until subsections 2.3.1 and 3.2 to describe some of that information), as well as more information about the natural vegetation, and rubber and oil palm plantations (growth cycles, management practices, time period of plantation development, etc.). Further details about the typical porosity and other characteristics of the soils in the study watersheds would also be useful.

We thank the referee for the suggestion. We have re-restructured and substantially improved the description of the whole subsections in the method section. We describe subsection 2.1.1:1 (Land use and soil characteristics) in this comment (nr. 7); subsection 2.1.2:1 (Watershed characteristics) in comment nr. 8; subsection 2.1.2:2 (Small watersheds) in comment nr. 9.

2. Methods

2.1 Study area

2.1.1. Land use and soil characteristics

2.1.2 Watershed characteristics

2.1 Study area The study area was situated in the Jambi Province of Sumatra with geographic location of 1o54’31.4”S, 103o16’7.9” E covering area of 31,868 sq km. The area is experiencing rapid development of plantations, mainly oil palm and rubber plantations (Drescher et al., 2016). The climate is tropical humid with average temperature of 27 °C and average rainfall of 2700 mm yr-1. Rainy season occurs during October until March. Flooding events occur normally in the months of January and February. A dry season with monthly precipitation less than 100 mm occurs from June until September. The soil types in the study area are dominated by clay Acrisols (Allen et al., 2015).

2.1.1. Land use and soil characteristics. Based on the land use map (Bappeda 2013; Ditjenbun 2013), the dominant land uses in BH and MT watersheds respectively are forest 50%, 30%; oil palm; 4%, 32% ; rubber 14%, 10%; (rubber) agroforest 6%, 9% and shrubland 11%, 10%. Oil palm and rubber are the most important plantation crops in this area. Both crops are planted in rows with planting distance 8 m and 4 m respectively. The weeds in the plantation were regularly eradicated with herbicides. Pruning, i.e. cutting of oil palm fronds, is common practice in oil palm cultivation. The pruned leaf fronds are stacked in the middle of the row between two trees forming frond piles. The width of frond piles is normally ∼2 m. Based on our field measurement in the study area, oil palm and rubber plantation soils showed significantly higher bulk densities than soils in forest (Figure 1). Higher bulk density in monoculture plantation can be explained by compaction due to frequent harvest activities taking place at least 2 times per month under oil palm and several days a week in rubber plantations. Similar to our findings, Sunarti et al. (2008) found that bulk density in forest soil (0.81 gr cm-3) was significantly lower than in oil palm (1.05 gr cm-3) and rubber plantation (1.14 gr cm-3) in Bungo District, Jambi. Tanaka et al. (2008) also found higher soil bulk density in oil palm plantations compared to secondary forest in Sarawak, Malaysia.

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8) In relation to comment 7, some description of all six macro watersheds shown in Figure 1 should also be provided in the Study area description subsection. Who defined these six watersheds and why? It is clear that hydrologic data was collected for the watersheds but the current text is vague regarding the overall purpose of these six watersheds.

We agree with the referee's suggestions, and have described all six macro watersheds under subsection 2.1.2 (Macro watershed).

2. Methods

2.1 Study area

2.1.1. Land use and soil characteristics

2.1.2 Watershed characteristics

1. Macro watersheds

2. Small watersheds

2.1.2 Watershed characteristics The study watershed consists of 2 categories (Figure 2): 1) two macro watershed (BH and MT) used for flow simulation with SWAT model, and 2) six macro watershed (including BH and MT) for BFI field data observation. The area of BH and MT watersheds were 18,415 km2 and 13,452 km2, respectively. Both watersheds were chosen as representative of the rapid land use transformation from forest to plantation in Indonesia. Beside BH and MT watersheds used for SWAT modeling, we also collected time series streamflow data from four nearby watersheds. The streamflow data from these six watersheds (including from BH and MT watersheds) were used to determine observed BFI values and then correlated with forest cover proportion in the respective watersheds. This correlation was compared with that obtained from the SWAT simulation model to get qualitative impression whether the BFI values calculated form the SWAT model really reflects the field observation (despite good performance of the model in our study).

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9) Also in relation to comment 7, please describe the “small watersheds” referenced in lines 144-145 and 195-196 and shown in Figure 1 in the study area subsection, rather than waiting to describe those in current section 2.3.1 (and that information does not need to be repeated at the start of section 3.2). What other hydrologic data were collected for those small watersheds besides the C values?

We agree with the referee’s suggestions, and have described “small watersheds” in subsection 2.1.2 (Small watershed).

Parallel to the purpose of collecting observed BFI values from the six-macro watershed in the comment 8, we also collected data from two small watershed in the study area to determine observed C values. These values were compared with that obtained from the SWAT simulation model to get qualitative impression whether C values calculated form the SWAT model really reflects field observation (despite good NSE performance of the model).

The dominant land-use type in the first small watershed was oil palm (90%), meanwhile 80% of the second watershed was covered by rubber plantations and the rest by rubber agroforest. Both watersheds were instrumented with rectangular weirs and automatic water level recorders. The direct runoff components of the hydrographs were separated by using the straight line method described in (Blume et al., 2007). After hydrograph separation, we calculated the direct runoff coefficient (C). The direct runoff coefficient C is the percentage of rainfall that appears as surface runoff during a rainfall event, or directly following a rainfall event. We did not calculate BFI values along with C values in the small watershed experiments, because BFI calculation requires longer hydrograph records. The hydrograph records of the small watersheds were available in the time period 2013-2015.

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10) Please rewrite “C&BFI” as “C and BFI” throughout the text.

Revision made

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11) A SWAT Description subsection needs to be added to the manuscript. This should note the specific version of the model used for the study (including the Revision number) and provide a succinct overview of the model, especially regarding components that were particularly important for the study you conducted. A description of the crop parameters used for the rubber and oil palm trees, and other vegetation in the watersheds, should also be provided (those parameters could be described later in the

methods if more appropriate). See the Wangpimool et al. article listed in comment 4 above regarding revised rubber tree crop parameters they used in their study.

We agree with the referee's suggestions, and have described the SWAT model and crop parameter in subsection 2.2.1.

2.2.1 SWAT model

We used the SWAT model version 2012 (Arnold et al., 2012). The SWAT model is a continuous model, i.e. a long-term yield model. The model was developed to simulate the impact of land cover/management practices on the streamflow in complex watersheds with varying soil, land use and management condition over long periods of time. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, and land management (Arnold et al., 2012; Neitsch et al., 2009). Delineation ofwatersheds and their sub-watersheds in our study area was carried out automatically by the SWAT model and was based on a digital elevation model (DEM) with a 30-m resolution. During the automatic delineation we pre-defined an area of 50.000 ha as a threshold for a minimum sub-watershed area. Based on this threshold, both study watersheds in our study area were further sub-divided into 25 and 23 sub-watersheds, respectively. The sub-watershed is further sub-divided into hydrological response units (HRUs) with homogeneous hydrological unit defined by topography, soil, and land use characteristics. Hydrological outputs are then calculated in the HRUs based on the water balance equation. Output of the SWAT model include total stream flow, surface flow and base flow. These output were used to calculate the C and BFI values for each sub-watershed. For this simulation, the SWAT model required other inputs such as climate data, as well as soil and land-use maps for each sub-watershed (Table 1).

We also carried out field data collection on several important parameters including hydraulic conductivity (SOL_K), bulk density (SOL_BD), available water content (SOL_AWC) and texture for SWAT model input.

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Digital Elevation Model with 30 m pixel resolution is available from the National Aeronautics and Space Agency. Rainfall and climate date are available from the Meteorology and Geophysics Agency. The streamflow data of the six macro watersheds were provided by the Ministry for Public work. The land use data are available from the Regional Planning office. All these data are freely available for research purposes by official request to the corresponding institutions. The time series streamflow and the rainfall records for the small catchments, the resampled soil hydraulic conductivity, bulk density, available water content and texture are deposited by the first author office at Bogor Agricultural University and EFForTS Database (https://efforts-is.uni-goettingen.de). The land-use and soil map for the study area was obtained from Jambi Province Regional Planning (BAPEDA, 2013) and Agricultural Plantation offices (Ditjenbun, 2013). Soils in our study area are dominated by two soil types, namely Tropodult and Dystropept (Figure 3).

Crop parameter

According to Griensven et al. (2014), the SWAT is designed for temperate regions so that it is necessary to adapt the crop parameters for application in a tropical region. In this respect, we adjusted the crop parameters, directly related to the flow component such as CANMX and CN. To adapt these values we carried out field measurement on several important hydrological component including interception, infiltration, and overland flow (Figure 4).

Canopy Storage (CANMX)

Interception reduces the amount of water reaching the ground and consequently reduces streamflow. We measured interception in oil palm, rubber, agroforest, and forest trees at the plot between November 2012 and February 2013. In total there were 30 rainfall events during this time, representing light to heavy rain. In oil palm, rainfall is not only intercepted by leaves and branches but also by hollow spaces between fronds and trunk. This type of interception is called trunk storage and may have led to the

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slightly increased interception in oil palm. Interception in oil palm was rather similar to interception in the forest (Figure 5).

The measured interception values were used as an estimate of (CANMX), which serves as an input parameter for the SWAT model. The CANMX is the maximum amount of water that can be trapped in the canopy and trunks when they are fully developed. Higher CANMX values reduce potential runoff during heavy rains. Beside CANMX we also adapted other crop parameters such as OV_N, BLAI. CHTMX, T_BASE and T_OPT (Table 2).

Adapted CN values for oil palm and rubber land uses.

One important parameter of the SWAT model related to surface runoff modeling is SCS curve number (CN, Arnold et al., 2012). It determines proportion of rainfall becoming surface runoff. Its value range from 0-100. The bigger the value the higher the proportion of surface run of on a particular rainfall event. The SCS curve number (CN) is differentiated into Hydrologic Soil Groups (HSG) A,B,C, and D which are a function soil's infiltration. We measured soil infiltration and surface runoff in the typical land use types in our study area i.e. oil palm, rubber, and forest. Infiltration was measured using a double-ring infiltrometer. No infiltration measurement was carried out under agroforest as infiltration in agroforest is likely similar to infiltration in secondary forest. Infiltration measurements in different land-use types from the study area showed the following order: oil palm harvest path (3 cm h-1) < rubber (7-7.8 cm h-1) < forest (47 cm h-1). The infiltration in the oil palm, rubber plantations were markedly lower than those at the forest. The surface runoff in oil palm and rubber plantation were significantly higher than those in agroforest and forest (Figure 6). Low infiltration capacity in oil palm and rubber plantations was one reason for higher surface the plantation land use (Tarigan et al. 2016).

Due to the high surface runoff and the infiltration rate, we adopted HSG-D category for all HRUs in oil palm and rubber land uses irrespective of soil types (Table 3). For forest and agroforest, we assumed that the CN value was similar to those of forest evergreen (FRSE) and forest mixed (FRST) values in the SWAT crop database respectively.

a) An expanded description of the SWAT calibration and validation procedures is needed, which again should be in a separate subsection. This should include a description of the calibration parameters used in the study, including the default value (or initial value range) and the final calibrated values. Please also provide a description of any sensitivity analyses that was performed and provide a description of the specific baseflow separation techniques that were used in the calibration process. A description of measured baseflow data, or proxy baseflow data obtained via literature sources or expert opinion, is also important in relation to the use of the BFI indicator in your study.

We agree with the referee's suggestions, and have expanded the description of the SWAT calibration and validation procedures in subsection 2.2.1.

Model validation and calibration We calibrated the model using the Latin hypercube sampling approach from the Sequential Uncertainty Fitting version 2 in the SWAT Calibration and Uncertainty Procedure (SWATâĂŘCUP) package. First parameter ranges were determined based on minimum and maximum values allowed in SWAT. The SWATâĂŘCUP is an interface for auto-calibration that was developed for SWAT. The interface links any calibration/uncertainty or sensitivity program to SWAT (Abbaspour, 2015). The discharge data of BH and MT watersheds used for calibration and validation were available for the period of 2005-2014. The calibration was carried out in year 2007-2009 and the validation in year 2012-2014. We evaluated the model using Nash-Sutcliff efficiency (NSE) and Percent Bias (PBIAS). The NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). The PBIAS measures the average tendency of the simulated data to be larger or smaller than the observations Gupta et al., (1999). The optimum value is zero, and low magnitude values indicate better simulations. Positive values of PBIAS indicate model underestimation and negative values indicate model overestimation. The model input parameters that were used for the calibration process and their fitted values after calibration are shown in Table 4.

The ALPHA_BF (baseflow recession constant) was calculated from daily streamflow hydrograph plotted on semi-log paper. The calculation was based on the average ALPHA_BF values derived from several selected individual rainfall events. Based on several study in Indonesia, the ALPHA-BF ranges from 0.9 to 0.95.

b) I suggest you then introduce a third subsection that describes the specific C and BFI methods that were used in your analyses.

We agree with the referee's suggestions, and have added subsection 2.2.2 to describes the specific C and BFI methods.

2.2 Flow simulation

2.2.1 SWAT model

2.2.2 Simulated C and BFI values

SWAT model simulated daily flow components including total stream flow, surface flow and base flow in all 48 sub-watersheds of BH and MT watersheds (Figure 7). We calculate the daily average ratio of the surface flow to the rainfall and the baseflow to the total streamflow as a proxy to C value (direct runoff coefficient) and BFI value (baseflow index) for each sub-watershed.

13) Please expand on your discussion of the calibration and validation results. This should include showing hydrograph comparisons between the simulated and measured

outputs and discussion of your results in the context of model evaluation criteria suggested in the two Moriasi et al. studies.

We agree with the referee's suggestions. We have expanded our discussion of the calibration and validation in a new subsection (Subsection 3.1 – Simulated flow) including NSE and PBIAS as suggested in the two Moriasi et al. (2007, 2012) Moriasi et al. (2007, 2012) recommend three quantitative statistics, Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of measured data (RSR) be used in model evaluation.

A visual comparison between the best-fit simulations and observed data is depicted in Figure 8. Overall, the model performance was satisfactory with the Nash-Sutcliff efficiency values of 0.80-0.88, (calibration) and 0.84 - 0.85, (validation); and the PBIAS values of -2.9 - 1.2, (calibration) and 7.0-11.9 (validation) for the BH and MT watersheds respectively.

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14) Line 131: I think the word "was" should be "were". Why were simulated values that were within an "order of magnitude" of the measured values considered acceptable? It appears that the average measured and simulated C values reported in Tables 5 versus 6 were almost identical; that would indicate that the "order of magnitude" criteria is unnecessary?

We thank the referee for pointing this out. We have revised the entire sentence:

Line 131-132 In addition to the SWAT model calibration and validation procedure, we also compared the simulated C and BFI values with those obtained from the field measurement in selected watersheds.

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15) Sentence in lines 184-185: The phrase "as acceptable for a good watershed service" in this sentence sounds odd. A suggested revision is: "The Ministry of Forestry

of Indonesia considers C values < 0.35 to be adequate to support required ecosystem services for Indonesian watersheds (citation)."

We agree with the referee's suggestions, and have revised the sentence accordingly.

Line 184-185 The Ministry of Forestry of Indonesia considers C values < 0.35 to be adequate to support required ecosystem services for Indonesian watersheds (Ministry of Forestry Decree, 2013)

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16) Conclusions: Some expansion of your Conclusions section is warranted. Please include additional quantitative information from both the baseline testing results as well as the C and BFI analyses.

We agree with the referee's suggestions and have included additional quantitative information in the conclusion.

Line 230-239 Overall, the SWAT model performance was satisfactory with the Nash-Sutcliff efficiency values of 0.80-0.88, (calibration) and 0.80 - 0.85, (validation); and the PBIAS values of -2.9 - 1.2, (calibration) and 7.0-11.9 (validation). The study exhibits a statistically significant correlation of percentage of forest covers in a watershed with C (negatively) and BFI (positively). On the other hand, the rubber and oil palm plantations showed flow regulation behavior contrary to forest covers. Finally the study suggests the minimum forest cover requirement in the study area (i.e. 30%) for sustainable ecosystem services. The quantitative relation between forest cover and flow indicators derived in this study can be used as a guide for the regional planners to determine the minimum proportion of forest conservation area to maintain a sustainable ecosystem service of water flow regulation in a watershed.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-116, 2017.

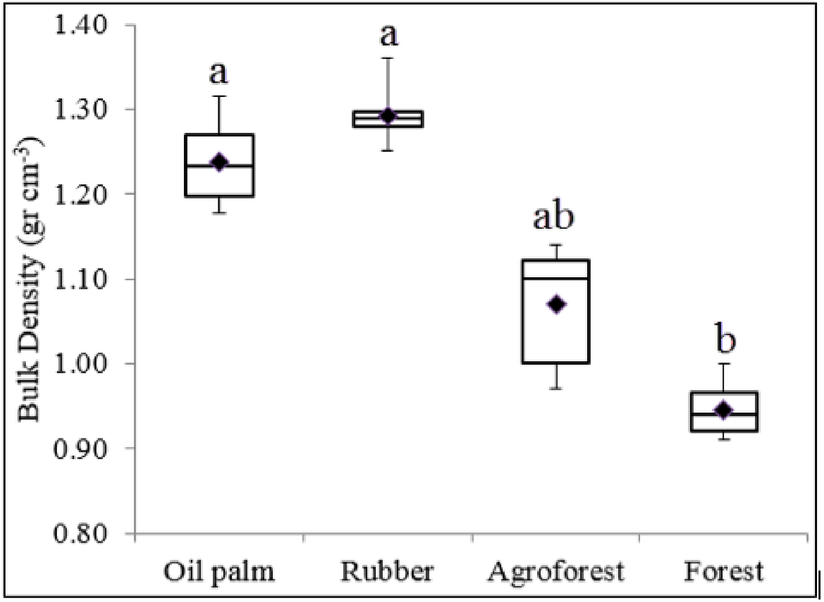

Figure 1. Bulk density in the study area under different land use types. Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA ($p < 0.05$)

Fig. 1.

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Discussion paper

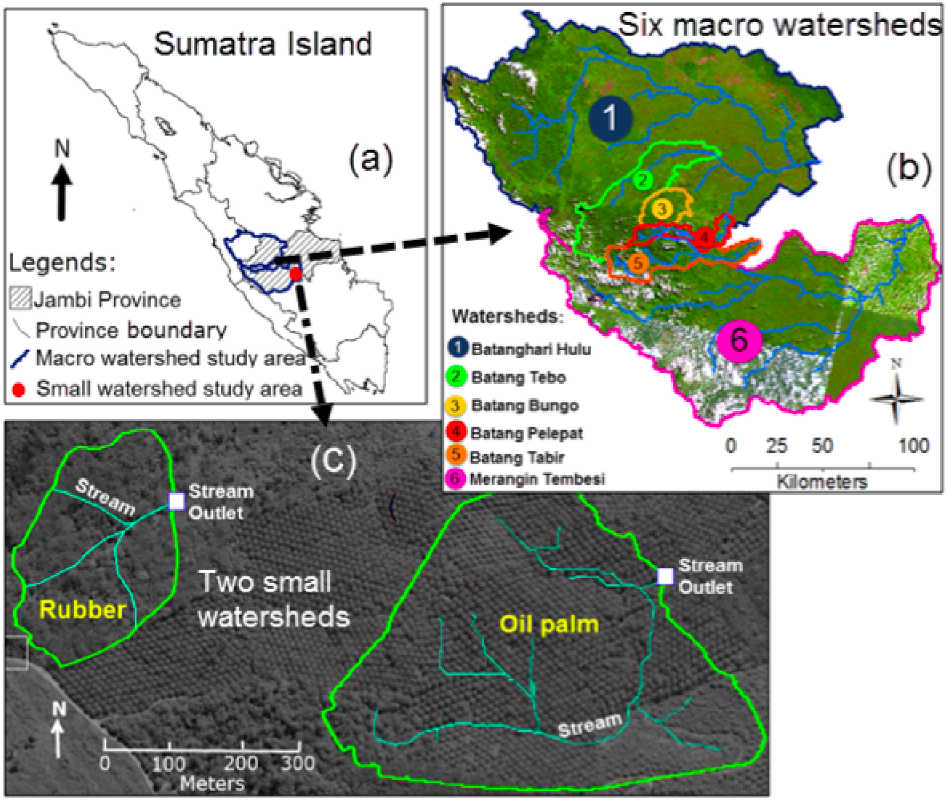

Figure 2. Study area in the Jambi Province, Sumatra Island, Indonesia (a) macro watershed (b) small watershed (c).

Fig. 2.

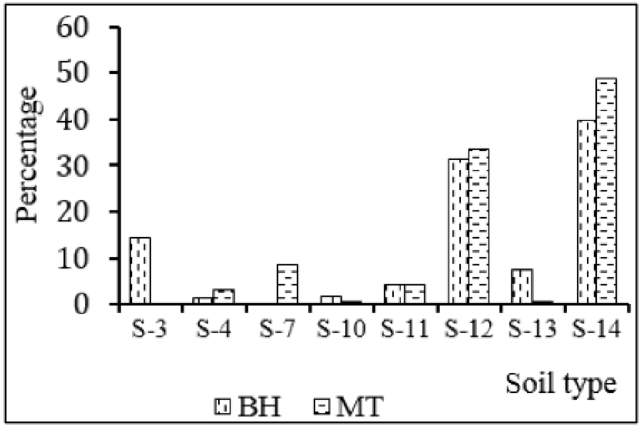

Figure 3. Soil type in BH and MT watersheds. Soil types respresent Fluvaquents (S-3), Humitropepts (S-4), Paleudults (S-7), Tropofluvents (S-10), Troposaprist (S-11), Tropodults (S-12), Dystrandepts (S-13), Dystropepts (S-14).

Fig. 3.

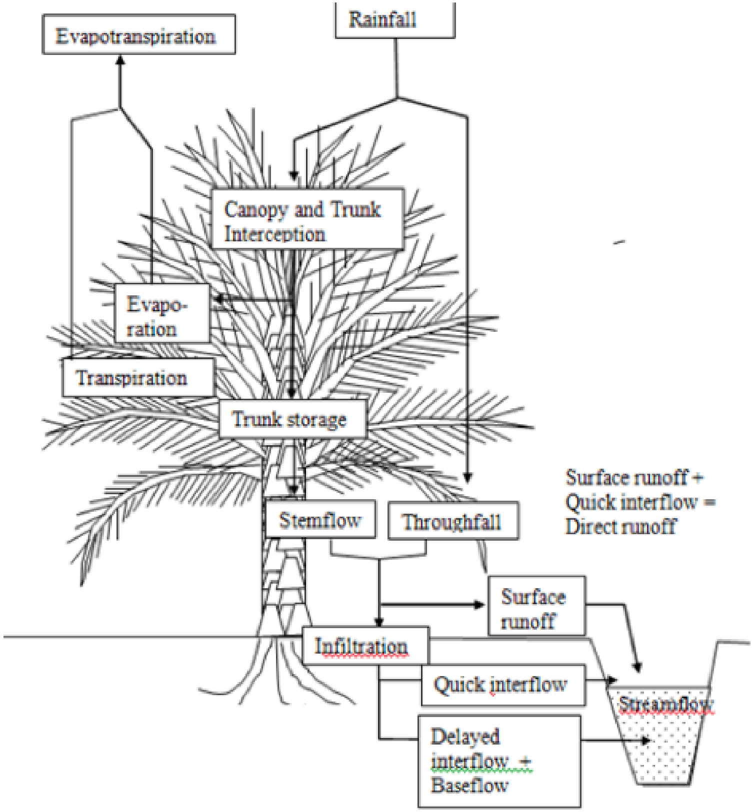

Figure 4. Oil palm hydrological components

Fig. 4.

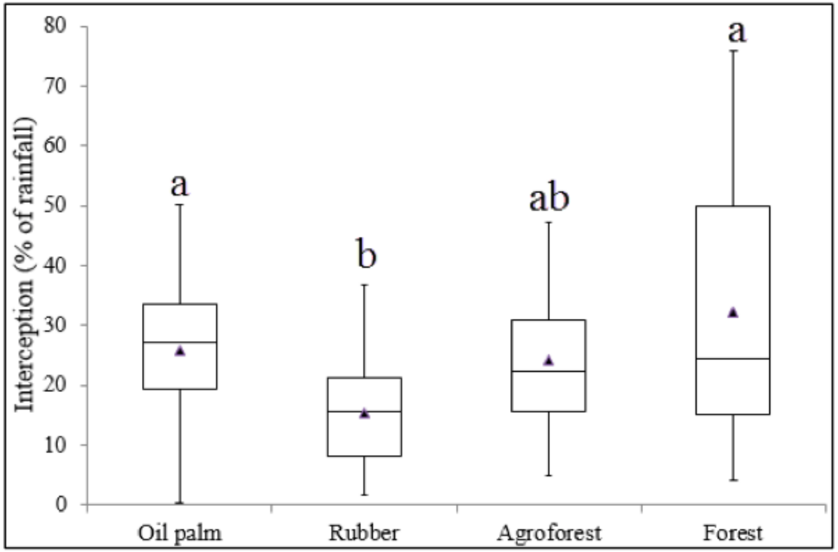

Figure 5. Interception of different plantation crops and forest. Different letters indicate significant differences of averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA ($p < 0.05$)

Fig. 5.

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Discussion paper

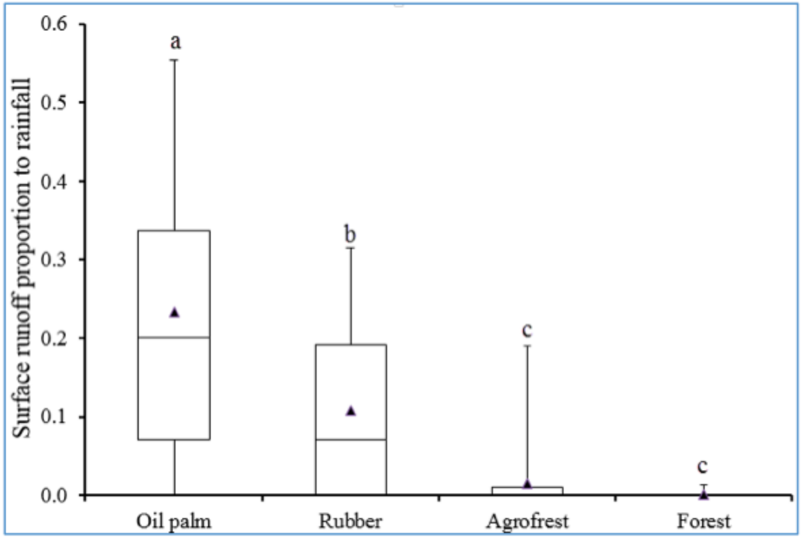

Figure 6. Surface runoff of different land use types in the study area. The different letters indicate significant differences among averages according to a Bonferroni-corrected posthoc t-test based on an ANOVA (p< 0.05).

Fig. 6.

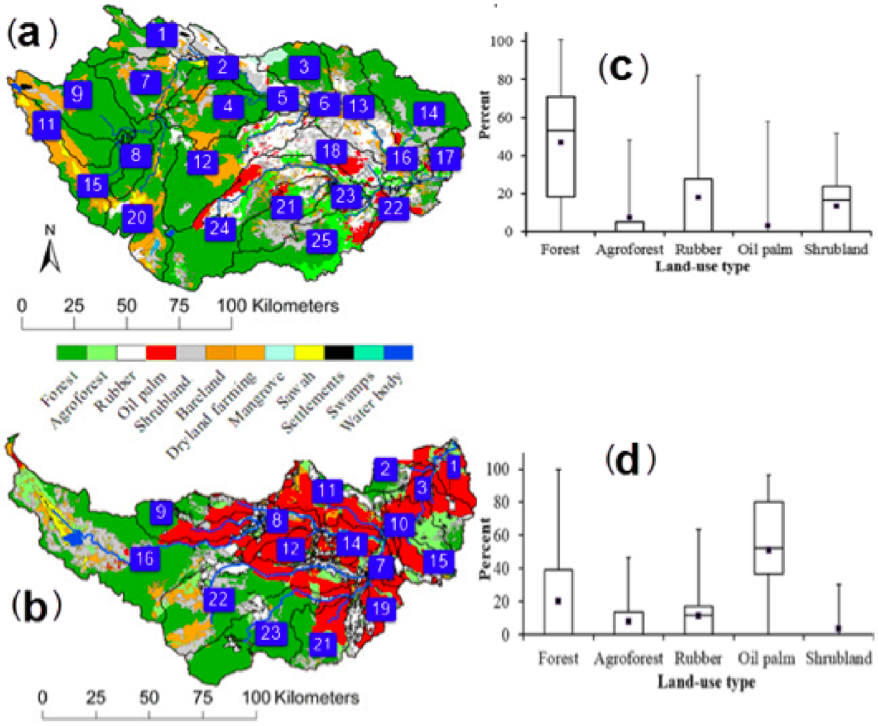

Figure 7. Land-use types and the sub-watershed numbering of the BH (a) and MT (b) watersheds. The box whisker plots (c and d) represent the distribution of the proportion of the land-use types in all sub-watersheds in both watersheds.

Fig. 7.

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Discussion paper

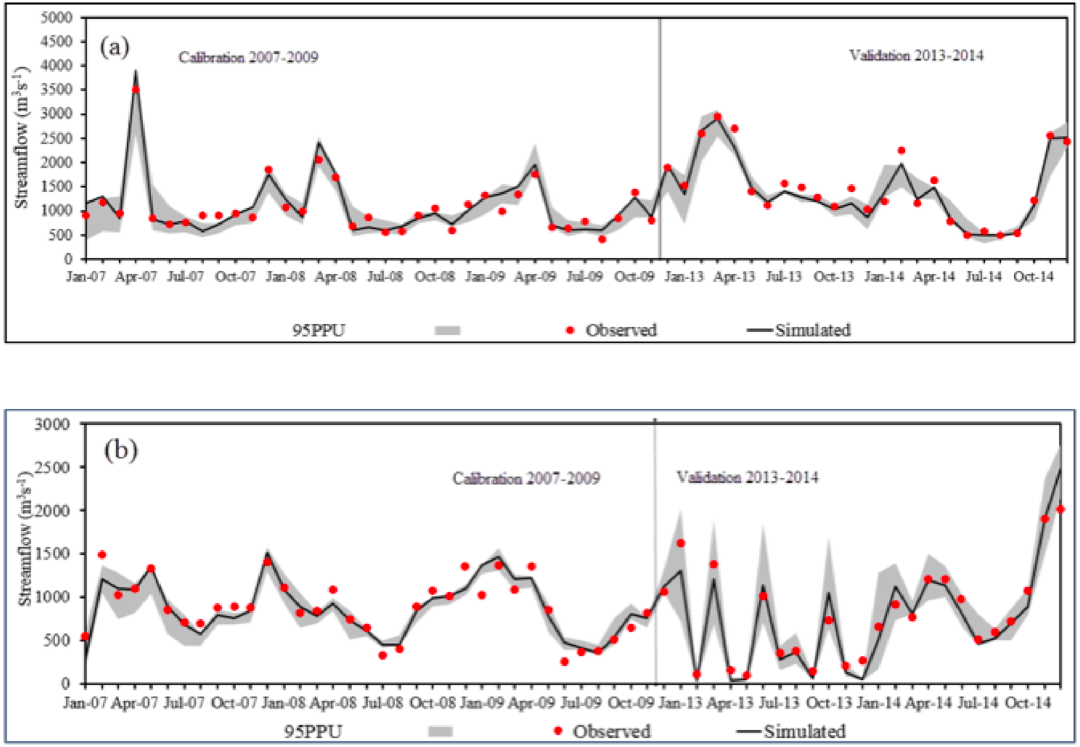

Figure 8. Observed vs. simulated streamflow and 95% uncertainty interval (95PPU) of behavioral simulations over time (defined as simulations with Nash-Sutcliff efficiency NSE > 0.5) for the BH (a) and MT (b) watersheds respectively.

Fig. 8.

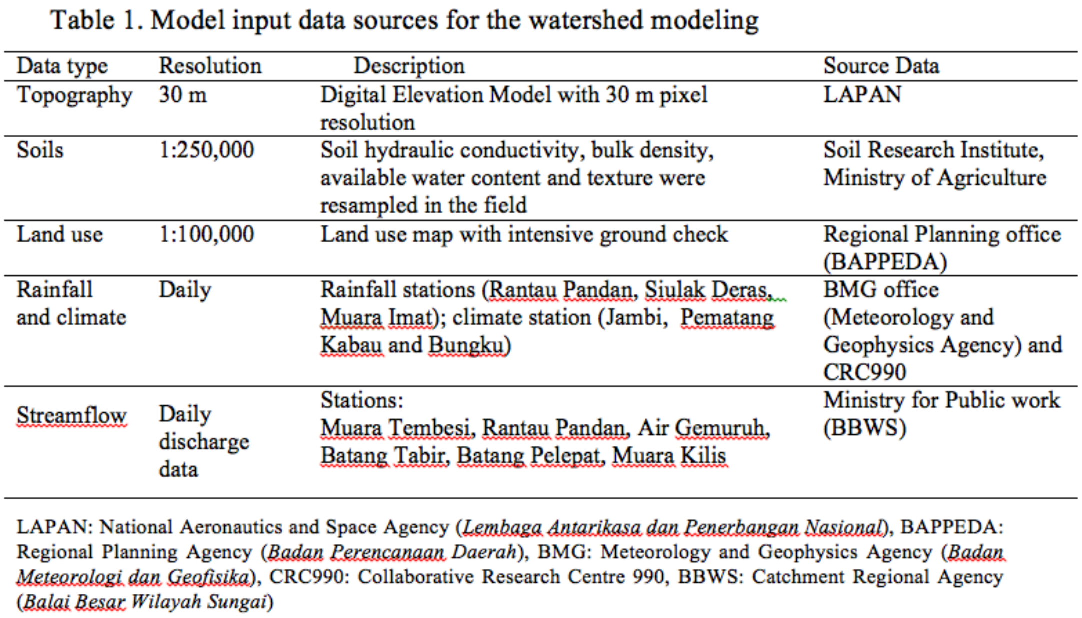

Table 1. Model input data sources for the watershed modeling

Data type	Resolution	Description	Source Data
Topography	30 m	Digital Elevation Model with 30 m pixel resolution	LAPAN
Soils	1:250,000	Soil hydraulic conductivity, bulk density, available water content and texture were resampled in the field	Soil Research Institute, Ministry of Agriculture
Land use	1:100,000	Land use map with intensive ground check	Regional Planning office (BAPPEDA)
Rainfall and climate	Daily	Rainfall stations (Rantau Pandan, Siulak Deras, Muara Imat); climate station (Jambi, Pematang Kabau and Bungku)	BMG office (Meteorology and Geophysics Agency) and CRC990
Streamflow	Daily discharge data	Stations: Muara Tembesi, Rantau Pandan, Air Gemuruh, Batang Tabir, Batang Pelepat, Muara Kilis	Ministry for Public work (BBWS)

LAPAN: National Aeronautics and Space Agency (*Lembaga Antarikasa dan Penerbangan Nasional*), BAPPEDA: Regional Planning Agency (*Badan Perencanaan Daerah*), BMG: Meteorology and Geophysics Agency (*Badan Meteorologi dan Geofisika*), CRC990: Collaborative Research Centre 990, BBWS: Catchment Regional Agency (*Balai Besar Wilayah Sungai*)

Fig. 9.

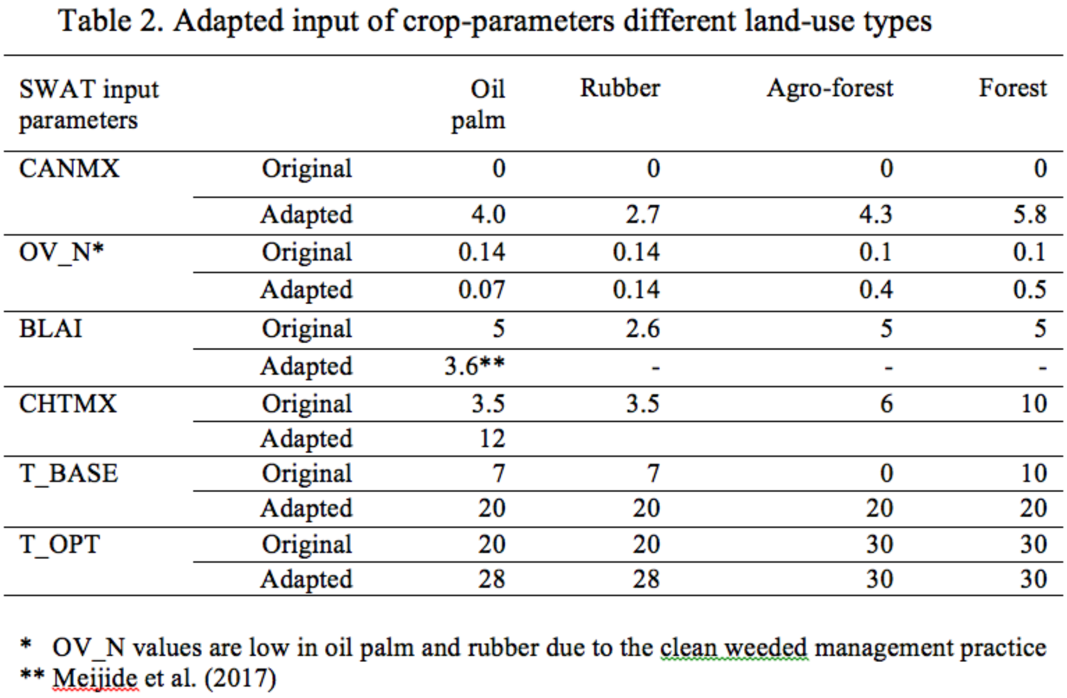

Table 2. Adapted input of crop-parameters different land-use types

SWAT input parameters		Oil palm	Rubber	Agro-forest	Forest
CANMX	Original	0	0	0	0
	Adapted	4.0	2.7	4.3	5.8
OV_N*	Original	0.14	0.14	0.1	0.1
	Adapted	0.07	0.14	0.4	0.5
BLAI	Original	5	2.6	5	5
	Adapted	3.6**	-	-	-
CHTMX	Original	3.5	3.5	6	10
	Adapted	12			
T_BASE	Original	7	7	0	10
	Adapted	20	20	20	20
T_OPT	Original	20	20	30	30
	Adapted	28	28	30	30

* OV_N values are low in oil palm and rubber due to the clean weeded management practice

** Meijide et al. (2017)

Fig. 10.

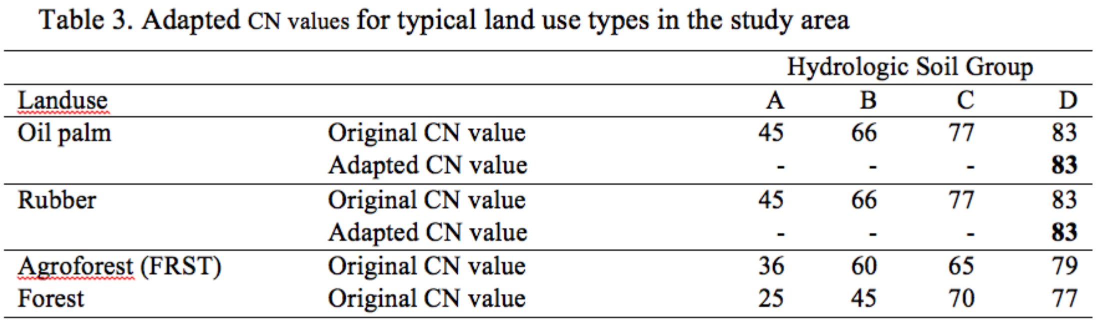

Table 3. Adapted CN values for typical land use types in the study area

		Hydrologic Soil Group			
Landuse		A	B	C	D
Oil palm	Original CN value	45	66	77	83
	Adapted CN value	-	-	-	**83**
Rubber	Original CN value	45	66	77	83
	Adapted CN value	-	-	-	**83**
Agroforest (FRST)	Original CN value	36	60	65	79
Forest	Original CN value	25	45	70	77

Fig. 11.

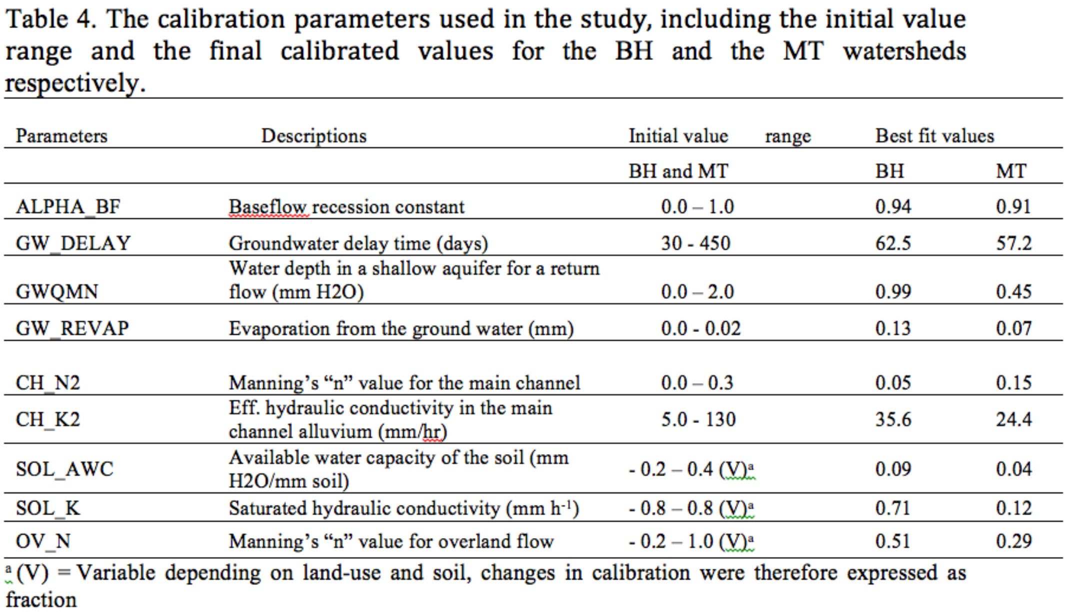

Table 4. The calibration parameters used in the study, including the initial value range and the final calibrated values for the BH and the MT watersheds respectively.

Parameters	Descriptions	Initial value range	Best fit values	
		BH and MT	BH	MT
ALPHA_BF	Baseflow recession constant	0.0 – 1.0	0.94	0.91
GW_DELAY	Groundwater delay time (days)	30 - 450	62.5	57.2
GWQMN	Water depth in a shallow aquifer for a return flow (mm H2O)	0.0 – 2.0	0.99	0.45
GW_REVAP	Evaporation from the ground water (mm)	0.0 - 0.02	0.13	0.07
CH_N2	Manning's "n" value for the main channel	0.0 – 0.3	0.05	0.15
CH_K2	Eff. hydraulic conductivity in the main channel alluvium (mm/hr)	5.0 - 130	35.6	24.4
SOL_AWC	Available water capacity of the soil (mm H2O/mm soil)	- 0.2 – 0.4 (V)[a]	0.09	0.04
SOL_K	Saturated hydraulic conductivity (mm h^{-1})	- 0.8 – 0.8 (V)[a]	0.71	0.12
OV_N	Manning's "n" value for overland flow	- 0.2 – 1.0 (V)[a]	0.51	0.29

[a] (V) = Variable depending on land-use and soil, changes in calibration were therefore expressed as fraction

Fig. 12.