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Hydrology and Earth System Sciences Discussions

Interactive comment on "Impact of bushfire and climate variability on streamflow from forested catchments in southeast Australia" *by* Y. Zhou et al.

Y. Zhou et al.

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We would like to thank the two reviewers' comments and suggestions for the improving the manuscript "hess-2013-102". A major revision has been done, and corresponding responses are provided below. A revised version has been provided in a separate pdf file as well.

Reviewer #2: General comments: 1. My most important comment is that the authors completely ignore the effects of fire on soil properties. Several studies have pointed out the impact of forest fires on the hydrological cycle, including reduced infiltration rates,

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reduced evapotranspiration rates and increased overland flow. Such impact is mainly attributed to the destruction of the vegetation cover and the consequent direct influence on interception, evapotranspiration and overland flow velocity. However, forest fires can also affect hydrological processes indirectly, altering the hydraulic properties of the soil. Fires destroy the top soil organic matter destabilizing the soil structure, they convert the organic ground cover to soluble ash, and they give rise to phenomena such as water repellency. The authors should mention the effects of fire on soil properties in the introduction of the paper and refer some related works. They may find more information on this issue along with many references in the following recent study: “Soulis K.X., Dercas N., Valiantzas J.D., 2012. Wildfires impact on hydrological response – the case of Lykorrema experimental watershed. Global NEST Journal, 14(3), 303-310.” They should also discuss and justify why the effects of fire on soil properties are not important for their case. Alternatively, the authors may include these effects in their calculations. E.g. they can replace "âŰşQveg" (âŰşQ caused by vegetation changes) with a more general term like "âŰşQfire" (âŰşQ caused by bushfire). In the latest case they should revise the discussion and conclusions sections accordingly to take into account these effects.

Response: Thanks for your insightful comments and constructive suggestions which have led to an improved manuscript. Please find below answers to your specific questions. (1) In the introduction part, the effects of fire on soil properties have been added. Lines 78-90: “A number of studies have found that bushfires impact on streamflow by destroying the vegetation cover and litter layer, and altering the soil properties (e.g. Brown, 1972; Scott, 1993, 1997; Shakesby and Doerr, 2006; Mataix-Solera, et al., 2011; Soulis, et al., 2012). On the one hand, bushfires cause a dramatic change in vegetation cover, and present potential for a distinct temporal change in evapotranspiration (ET) as the early loss of leaf area transitions into regrowth or recovering forest. Secondly, bushfires destroy the organic matter destabilizing the soil structure in top soils (Mataix-Solera, et al., 2002), produce ash (a mixture of black carbon, soot, charred material, charcoal and mineral material) (Moody et al., 2009), and enhance the

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impacts of water repellency (Debano, 2000). Therefore, soil infiltration capacity can be reduced due to surface pores sealed by fine soil and ash particles and the hydrophobic compounds on the soil surface (Shakesby & Doerr 2006; Sheridan et al. 2007). Cumulatively, these effects increase runoff, and peak flow magnitude (Soulis, et al., 2012)." (2) For the methodology section, we accepted your suggestions and replaced deltaQveg with deltaQfire. The discussion and conclusions section are revised as follows. Lines 701-716: "Finally, the other fire-related hydrologic processes that should be considered in modelling are changes to soil hydraulic properties and consequent runoff generation. Increases in surface runoff generation after fire have been widely reported in the literature (eg. White and Wells, 1979; Prosser and Williams, 1998; Moody and Martin, 2001; Robichaud, 2000, Johanson et al., 2001; Benavides-Solorio and MacDonald 2001; Onda et al., 2008). Development or enhancement of water repellency (eg.; Shakesby et al., 1993; Robichaud, 2000, Doerr et al., 2000; Martin and Moody, 2001), the effect of ash on infiltration (Campbell et al., 1977, Cerdà and Doerr, 2008; Onda et al., 2008; Woods and Balfour 2010; Ebel et al., 2012) or loss of roughness/detention storage from plant immolation (eg. Lavee et al., 1995 Scott, 1997; Inbar et al., 1998) have been invoked as the agent driving the process change. The implication is water is more efficiently routed to the stream network via infiltration-excess overland flow, and that peak flows in particular may increase markedly (eg. Campbell et al., 1977; Scott, 1993, Moody and Martin, 2001; Moody et al., 2009, Soulis et al, 2012). Some of these runoff generation studies have been at plot or small experimental catchment scales where scale effects may not be captured. "

Lines 718-730:"Recent studies into post-fire soil hydraulic responses to fire in similar environments to the wet eucalypt catchments modelled here (Lane et al. 2004; Lane et al. 2006; Sheridan et al. 2007; Nyman et al. 2010) have found that although there is enhancement of water repellency (which is naturally occurring in summer) and generation of surface runoff, this does not translate into broadscale overland flow. The principal reason is the spatial heterogeneity in infiltration properties mainly controlled by macropore distribution and their suction characteristics (Nyman et al., 2010). As the background hydraulic conductivities can be in the order of metres per day, small patches of non-repellent soil can capture any generated flow. Lane et al. (2006) found all flow percentiles increased after fire, but no evidence of altered runoff generation processes. The net result is that it is unlikely these soil factors are important for streamflow analysis on an annual scale in the modelled catchments. However it is emerging that soils in drier eucalypt forests may respond differently (Nyman et al., 2011)." (3) In conclusion section, we have added the bushfire impacts on soil infiltration. See lines 763-765: "We hypothesise the flow increases were mainly caused by the loss of leaf area and tree morality because of the bushfires and associated reductions in interception, actual transpiration and soil infiltration rates."

2. A second important comment is that the bushfire impact on stream flow seems to be lower at the period soon after the fire incident, it significantly increases after this initial period (at least for the first two catchments), and then decreases again (Figs 3,4,5). Typically the effect of fire on streamflow should be more profound the first years after the fire and then it should be decreasing gradually. The authors refer as a possible effect the combined effect of fire and logging; however this behavior should be discussed and justified in more detail. In case that this behavior can't be justified, the authors should at least put some more emphasis on this issue.

Response: The discussion section has been added possible reasons for the lower streamflow response due to bushfire than expected. See lines 731-743: "The streamflow response to bushfire for the first couple of years, shown in Figs 3-5, is not as large as expected (Soulis, et al., 2012; Lane, et al., 2010; Cornish and Vertessy, 2001). First, the interaction of vegetation dynamic and hydrologic response may or may not be considered in the calibration. Second, hydrological response to bushfire is greatly related to fire severity. The more severely the catchments are burnt, the more significantly the vegetation and soil properties are disturbed. The severe destruction of vegetation cover can reduce catchment evapotranspiration rates in early post-bushfire period and changes in soil properties affect runoff generation mechanism (Scott et al., 1998). As

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discussed previously, we are not sure about the fire severity and the quantity of direct bushfire impact on streamflow using rainfall-runoff modelling. All of these factors contribute uncertainties to explain the modelling results."

Specific comments: 1. Title and abstract. As I can understand from the paper text, this study is dealing with the effect of bushfires on streamflow and not with the effect of climate variability. Thus I believe that the term "climate variability" should be removed from the title. The abstract should also be revised accordingly.

Response: We partly agree with the reviewer's comment. However, the modeling experiments described in this study uses climate data from two separate periods which have different climate characteristics (see Table 2). As such we need to keep "climate variability" in the paper title.

2. Introduction. In the conclusions section it is referred for the first time that the ability of the models to reproduce the climate variability was validated in four nearby similar catchments. I consider this as an important part of the study that significantly supports the accuracy of the obtained results. Therefore I suggest that the model validation should be also referred in the introduction and presented in the methodology sections.

Response: Revised as you suggested. In the introduction section, the model validation has been referred in lines 181-188: "However, it is essential to calibrate and validate the rainfall-runoff models to get an optimum simulation result (Beven, 1989). Model calibration is an iterative process to refine model parameters by comparing simulated and observed data to satisfy the criterion of accuracy; model validation is to evaluate the ability of model predicting streamflow outside the calibration with the calibrated parameters (Refsgaard and Henriksen, 2004). This model validation exercise makes sure that a rainfall-runoff model can simulate runoff time series for an independent period or under different climatic conditions." In the methodology section, "3.3.3 Cross-validation" has been added. See lines 398-406: "Validation is to determine the suitability of the calibrated models for predicting streamflow over any period outside the calibration period with the same catchment characteristics (Vaze et al., 2012). However, the study catchments in this paper suffered from significant changes in vegetation cover and soil properties due to the 1983 bushfires. There was also a prolonged drought in the mid-1990s. As such, it was necessary to evaluate whether the models are able to adequately reproduce catchment hydrology behavior in post-bushfire period. Therefore, four unregulated (unburnt) forested catchments around the three study catchments are selected for cross-validation (Table 1)." See lines 408-414: "For the four selected catchments, the pre-bushfire period (1975-1982) is used for model calibration and three post-bushfire periods, 1983-2009, 1983-1998 and 1999-2009, are used for model validation (Table 6). The calibrated parameter sets from pre-bushfire period are used to simulate the streamflow in post-bushfire period. The NSE and WBE in the validation period are compared to those in the calibration period to assess whether the model calibrated in the pre-bushfire period can reproduce the hydrological behavior in the post-bushfire period."

3. Page 4403. Study catchments. There is very little information about important characteristics of the studied catchments except for land cover. E.g. there is no information about geomorphology, soil properties, geology, Base flow (BFI), etc. The above information may have an important role in the response of the catchment and the effect of wildfires.

Response: The characteristics of the studied catchments are added in lines 205-211: "Elevations range from 112-901 m (Yarra River), 207-1126 m (Latrobe), and 320-940m (Starvation Creek). The geology of the catchments is dominated by Devonian granites with smaller areas of Devonian metamorphics (mainly hornfels), and some sandstones. They are characterised by deep, well structured and highly conductive soils (eg. Davis et al., 1999, Lane et al, 2004), mainly red or brown ferrosols or dermosols (red or brown earths). These soils can be more than 5 m deep and have large storage capacities. "

4. Page 4403. Study catchments. It would be useful to have here some information about the four catchments used for validation. For example the validation catchments

could be included in the map.

Response: The four catchments used for validation are included in Fig.1 (I and II) and the introduction to these four catchments is provided in lines 243-248: “The four median-size forested catchments around the three bushfire impacted catchments are selected for model validation. These four catchments are unregulated and they were not affected by the bushfires (Fig.1 (II), catchments (1) – (4) named 405205, 405209, 405227 and 227202). All these four catchments have long term reliable streamflow records spanning from pre-bushfire to post-bushfire period. Therefore, they can be used for investigating the transposability of calibrated model parameters in time.” And lines 250-253: “The catchment area for the four catchments varies from 109 to 1080 km2 (Table 1). The four catchments are largely covered by eucalypt forest, with a forest ratio varying from 0.86 to 1.0. Mean elevations for catchments 405205, 405209, 405227, and 227202 are 670.5m, 604.4m, 751.4m, and 155.3m, respectively.”

5. Page 4406, Line 8: “considers hydrological response units (HRUs) for each grid or catchment”. This phrase is confusing.

Response: Revised in lines 319-322 “The main feature for the AWRA-L model is grid based , and includes flexible land cover types described at sub-grid scale (tall deep-rooted vegetation and short shallow-rooted vegetation are included in this study).”

6. Hydrological modeling. After the calibration section it could be added a section describing the validation of the models (see specific comment 1).

Response: “3.3.3 Cross-validation ” has been added. See lines 398-406: “Validation is to determine the suitability of the calibrated models for predicting streamflow over any period outside the calibration period with the same catchment characteristics (Vaze et al., 2012). However, the study catchments in this paper suffered from significant changes in vegetation cover and soil properties due to the 1983 bushfires. There was also a prolonged drought in the mid-1990s. As such, it was necessary to evaluate whether the models are able to adequately reproduce catchment hydrology behavior in post-bushfire period. Therefore, four unregulated (unburnt) forested catchments around the three study catchments are selected for cross-validation (Table 1)." And lines 408-414: "For the four selected catchments, the pre-bushfire period (1975-1982) is used for model calibration and three post-bushfire periods, 1983-2009, 1983-1998 and 1999-2009, are used for model validation (Table 6). The calibrated parameter sets from pre-bushfire period are used to simulate the streamflow in post-bushfire period. The NSE and WBE in the validation period are compared to those in the calibration period to assess whether the model calibrated in the pre-bushfire period can reproduce the hydrological behavior in the post-bushfire period."

7. Page 4413. In Yarra River at Little Yarra catchment there is no obvious increment in the stream flow (figs 3,4,5). For comparison reasons, it would be interesting to calculate and include in the results the deltaQ for the pre fire period (calculated with the same methodology as for the post fire period) to have an idea of the magnitude of the impact of the model related uncertainty. Response: The differences between observed and simulated streamflow in pre-bushfire period (deltaQ) for the three catchments are small and their percentages relative to pre-bushfire period are no greater than 5%. Since observed streamflow and the water balance error (B) are shown in Tables 2 and 3, respectively, it is not necessary to show an extra table.

8. Figs 3,4,5. It would be helpful for the reader if the rainfall data were depicted in the figures.

Response: The rainfall data have been added into Figs 3, 4 and 5.

9. The possible effect of the big gap in the validation period of the Starvation Creek catchment to the obtained results should be discussed.

Response: There is only one year of data missing for the Starvation Creek catchment (out of total 22 years of test period, 1983-2004) and this is expected to have very little impact on the overall results presented and discussed in this paper.

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10. There are some minor grammatical errors.

Response: Revised.

Conclusively, I suggest that the paper should be accepted for publication in HESS if the authors adequately address the above issues. In my opinion a minor to moderate revision is needed for this purpose.

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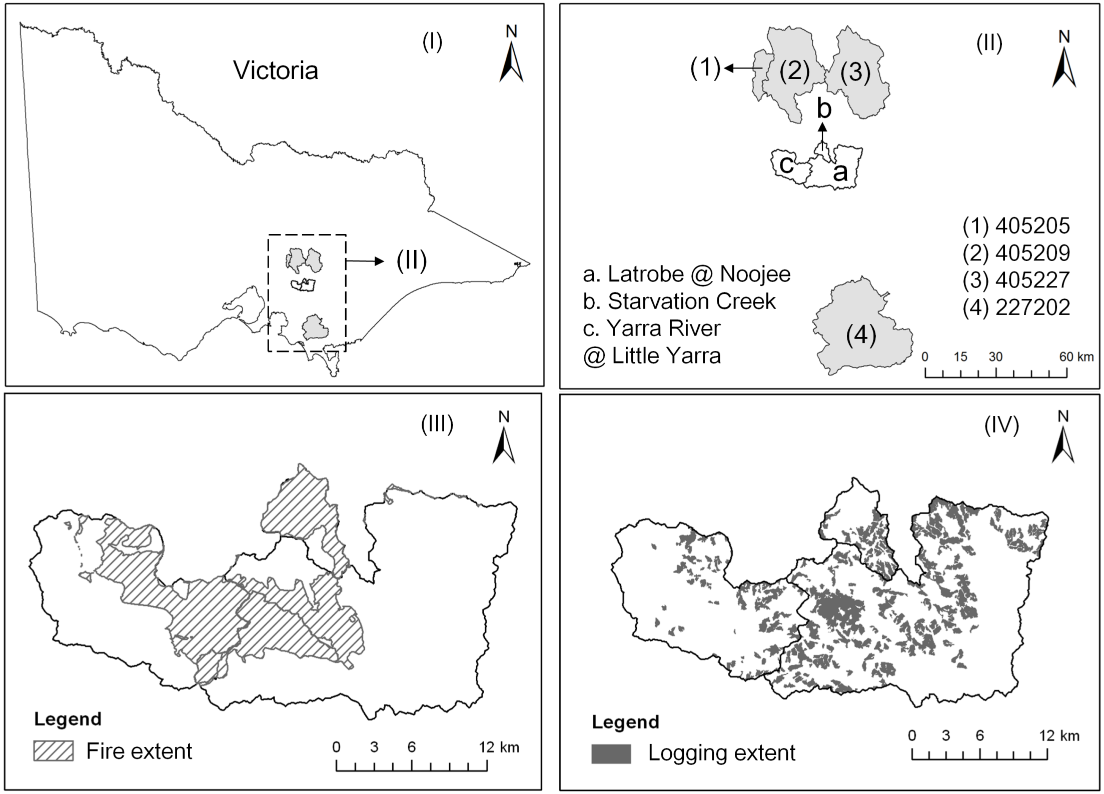

Fig. 1.

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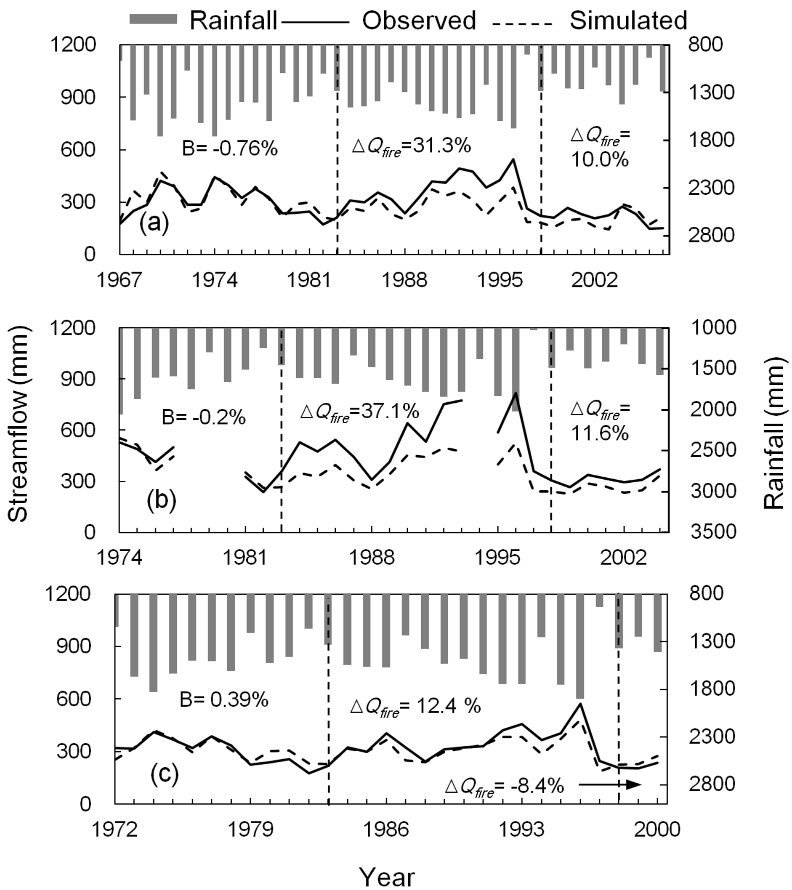

Fig. 2.

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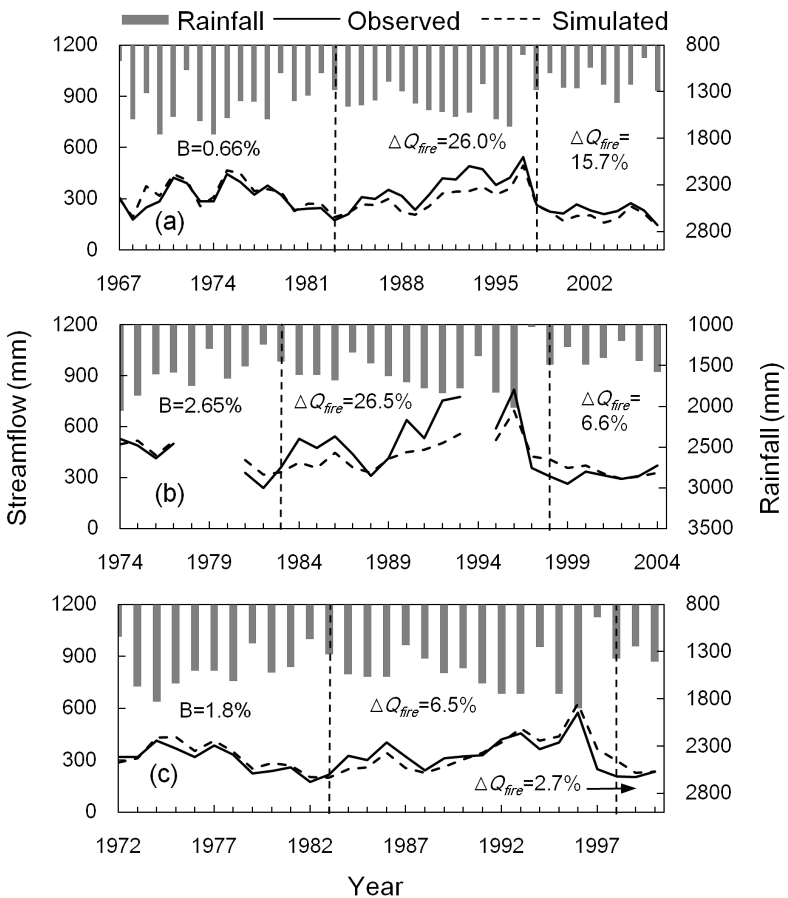

Fig. 3.

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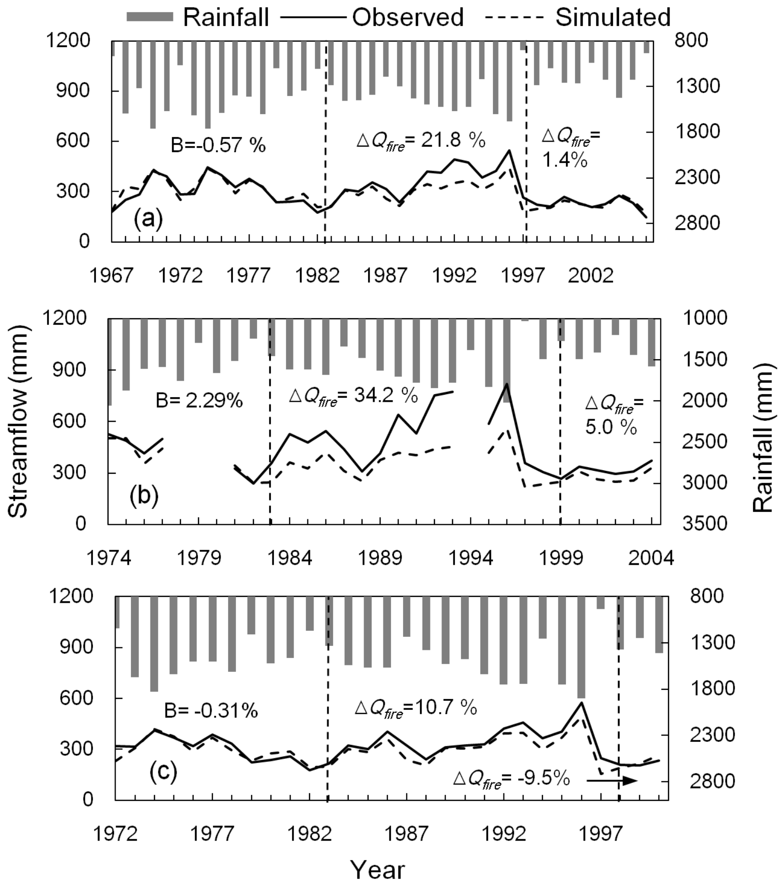
Rainfall
Observed
Simulated
B=-0.57 %
ΔQ_{fire}= 21.8 %
ΔQ_{fire}= 1.4%
(a)
B= 2.29%
ΔQ_{fire}= 34.2 %
ΔQ_{fire}= 5.0 %
(b)
B= -0.31%
ΔQ_{fire}=10.7 %
ΔQ_{fire}= -9.5%
(c)
Streamflow (mm)
Rainfall (mm)
Year

Fig. 4.