Authors' response to Anonymous Referee #1 on "Multiple runoff processes and multiple thresholds control agricultural runoff generation" by S. Saffarpour et al.

We appreciate the reviewer's comments and suggestions, which we found very useful. We have addressed each reviewer comment separately. In the following document the blue font indicates the reviewer's comment and the black font shows our reply.

General comment

This is a very interesting work that focuses on the analysis of runoff processes and the controls exerted by different thresholds on the hydrological mechanisms related to runoff generation in an agricultural Australian catchment. The research aims to understand how subsurface connectivity, saturation excess and rainfall intensity play a role in rainfall-runoff response at the seasonal and event time scale. The manuscript is well written, logically organized and with overall clear graphical presentations. Results are generally well supported by data and interpretation are overall sound. I particularly like the conceptual summary of hydrological processes and thresholds reported in Fig 1, and how this figure was referred to in the Introduction and in the discussion. However, I think that there are some confused points that deserve to be clarified and better explained. I have some comments and suggestions that can hopefully help this paper to have a greater impact on the hydrological community.

Thank you for these positive comments.

Specific comments

5, 24-26. As far as I understand, two different isotope laser analysers have been employed for the analysis of stable isotopes of water. This is a methodologically critical point: based on my experience, two different laser machines, even of the same model and calibrated using the same set of reference standards, could return quite different values of isotopic composition. Using a different sets of standards in different laboratories, as it seems that was the case here, could lead to differences that have the potentials to impact the resulting analysis of hydrograph separation. I think it is important for the paper to run some tests and report some comparison metrics between the measurements performed by the two machines in order to assess, and in case correct, potential deviations.

It is true that the two laser analyzers were systematically different, which we established by analyzing identical samples to both laboratories and should have discussed in the original paper. We developed and applied a correction between the two laboratories based on these samples. In the analyses presented here we actually only used samples analyzed at the Monash University laboratory and hence this difference between laboratories does not affect our results. We will edit the methods to reflect this.

6, 10-12. It is not clear how the soil water storage has been computed starting from ASI. A specification, perhaps including equations, would be really useful here. This is important because the soil water storage is addressed several times in the rest of the manuscript.

Fractional volumetric water content (VWC) was measured for the 0-30 cm and 30-60 cm layers using vertically installed 30 cm long Campbell Scientific (CS625) probes (Campbell Scientific, 2006), which were recorded hourly by the automatic weather station (AWS) logger. The VWC was temperature corrected using measured soil temperature and the manufacturers recommended temperature correction, as follows (Campbell Scientific, 2006).

$$\tau_{\mathrm{corrected}}(\mathrm{T}_{\mathrm{soil}}) = \tau_{\mathrm{uncorrected}} + (20 - \mathrm{T}_{\mathrm{soil}}) * (0.526 - 0.052 * \tau_{\mathrm{uncorrected}} + 0.00136 * \tau_{\mathrm{uncorrected}}{}^{2})$$

where $\tau_{uncorrectd}$ is the probe output period, T_{soil} is the soil temperature and $\tau_{corrected}$ is the corrected probe output. The *VWC* was then computed from $\tau_{corrected}$ using (Campbell Scientific, 2006):

$$VWC = -0.0663 - 0.0063 * period + 0.0007 * period^{2}$$

Soil water storage over the top 60 cm soil depth was computed by adding the VWC from the 0-30 cm and 30-60 cm layers and then multiplying by the 300 mm soil layer thickness.

Moreover, it's not clear how manual measurements of the saturated are have been carried out. Please explain.

Measurement of the saturated area is explained briefly in section 2.4. We will expand that explanation so that it is clearer. Specifically: The lateral boundary of the saturated area is constrained and field observations suggested it was stable over time, while the upstream boundary moved up and down the riparian zone. The saturated area was estimated by locating the upper boundary through field inspection and then measuring the distance from either well 2 or 3. The saturated area was then estimated from this information combined with the mapping of the riparian zone boundary (see Figure 2). These measurements were made between events.

8, 2. The statement that 'any rainfall depth could produce a response' seems to contradict what reported elsewhere in the manuscript (eg, 7, 4-5; 8, 14; 8, 26) about some rainfalls that did not produce runoff. This is confusing and should be clarified. 8, 6-16.

We will reword this sentence for clarity to "Acknowledging that we have excluded rainfall events below 5 mm total rainfall, essentially any rainfall depth could produce a response at the catchment outlet, provided the catchment is sufficiently wet. There was a wide variation in runoff coefficients (indicated by the scatter)."

Fig. 5b seems to be dense and informative. However, I think that is not straightforward to understand it. The different symbols are hard to distinguish and the scale of runoff coefficients is not very useful to understand their values. I suggest considering to replace it by another graphical way (eg,

cumulative distribution + bar plot or multiple panel boxplot). Moreover, I don't understand why ASI and ASI+rain have been plotted against rainfall intensity: the relation is obviously scattered (and so the sentence at 8, 12 is obvious too since rainfall is a stochastic process) because no relation is expected between these two variables and intensity of rainfall events. But if the authors used this representation to show how the different events plot in reference to these variable this should be clearly stated.

Figures 5b-d are used to examine thresholds leading to different rainfall-runoff behaviors. The reason for plotting ASI + rain against rainfall intensity is that runoff shows threshold behavior with respect to these two variables, not because we expect a relationship between the two variables. We will add the thresholds in both catchment wetness and rainfall intensity to these figures to make the interpretation clearer. A revised version of Figure 5 is below. A joint threshold involving intensity and water storage that correctly separates nearly all events into those that produce runoff and those that do not is also shown. This will be discussed in the first paragraph of section 3.3 where we mention interaction between intensity and wetness.

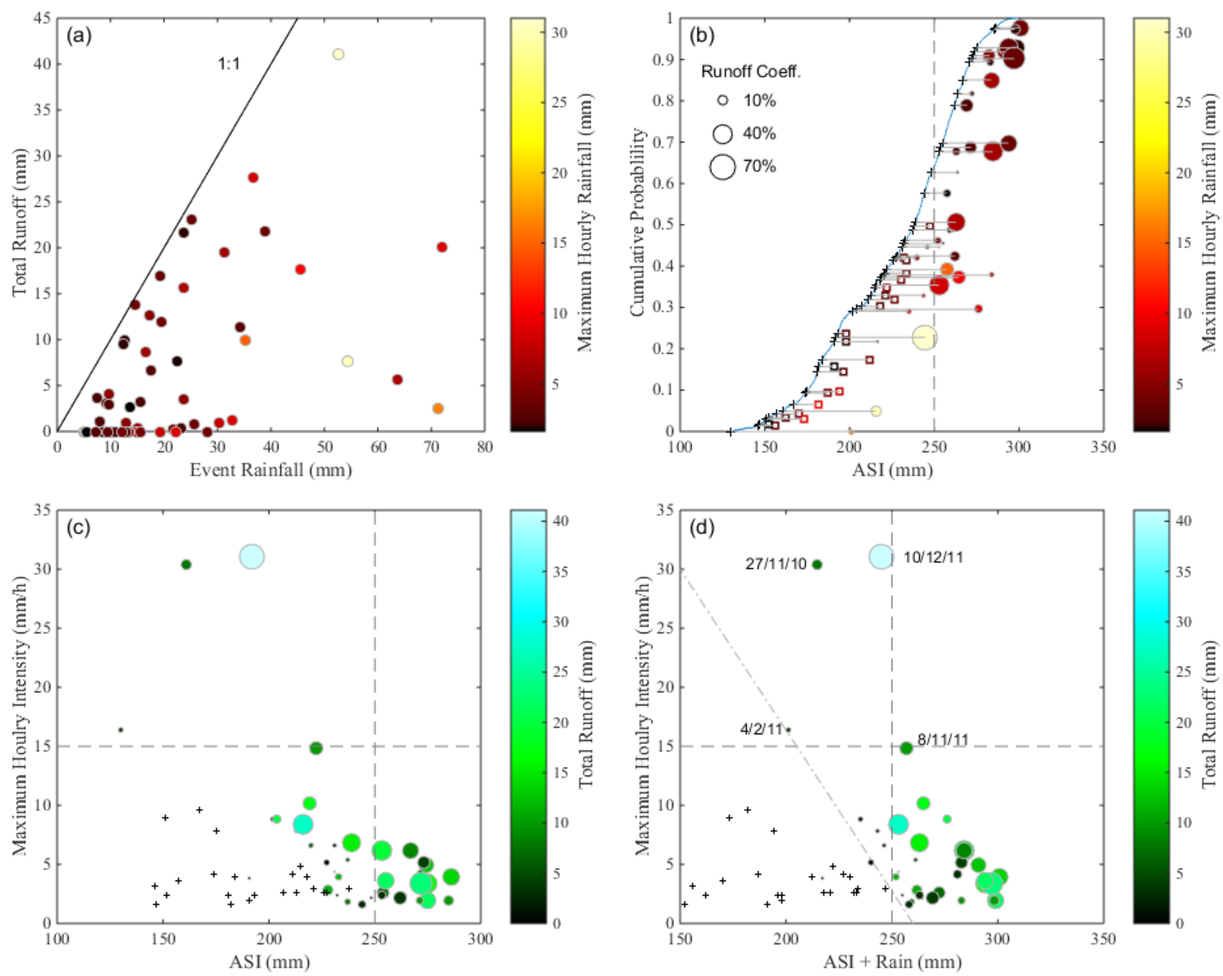


Figure 5. Thresholds of runoff mechanisms at RBF, a) event rainfall versus total event runoff, colours indicate the highest hourly rainfall intensity, b) the impact of five factors together including: cumulative curve of the distribution of soil water

storage as observed through the study period, ASI, ASI+rain, colour shows the peak hourly rainfall intensity (I_{peak}) and the size of the bubbles shows the quick flow runoff coefficient, c) ASI versus the peak hourly rainfall intensity (I_{peak}) and the size of the bubbles shows the quick flow runoff coefficient and colour shows event total runoff, and d) ASI+rain versus the peak hourly rainfall intensity (I_{peak}) and the size of the bubbles shows the quick flow runoff coefficient and colour shows event total runoff. The dashed lines in b), c) and d) show thresholds at ASI and ASI+rain = 250mm and I_{peak} = 15mm/h. The dot-dashed line in d) shows a threshold of 260 – 3/11*I_{peal}.

10, 25-26. Here a two-component mixing model is mentioned but no details are given in the Materials and Method section. I'm not suggesting to report the well-known equations (a simple citation to the suggested references 5 and 6 below is enough) but some methodological/conceptual information are needed, eg: which sample(s) has been considered as pre-event for the application of the hydrograph separation technique? Why only deuterium data have been used since both 18-oxygen and deuterium data have been measured? How many samples for isotopes have been collected and which ones were used? How many events have been sampled? More importantly: why has the separation been carried out only for the 12 August event showed in Fig. 9? Or was it also performed for other events? In this case, what are the results? Are they similar so that they corroborate the proposed conceptualization? Or did they provide much different estimates? Can the author report the results of all sampled events in a Table? This would be useful. All this information should be reported and these points well addressed in the revised version of the manuscript.

Another major point related to this is the lack of uncertainty analysis of the estimated fractions of pre-event water and event water (I prefer these terms instead of old and new water) in streamflow. This is particularly critical since these estimates have been used to build some conceptualization (eg, 17% of event water corresponding to 5% of rainfall amount..but what is the uncertainty of that 17%?). And is the result about 5% of rainfall based only on the 12 August event? In that case this is not robust. The traditional method of uncertainty estimation proposed in reference 2 below is suggested.

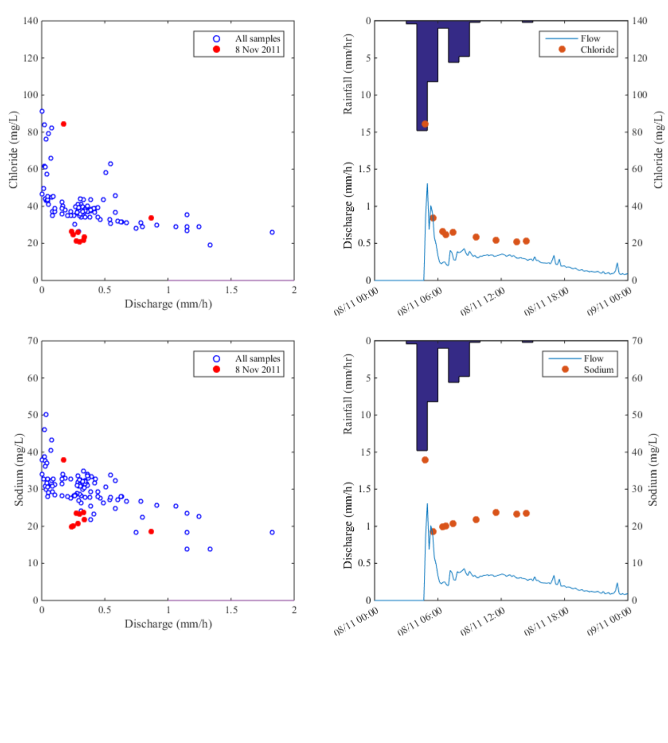
We will update the methods so that the above questions are clarified, including citing the well- known one tracer, two component model of hydrograph separation approach (Pinder and Jones, 1969; Sklash and Farvolden, 1979) and clarifying how each end-member was identified and the overall estimation of event and pre-event water volume. We will also report uncertainties following Genereux (1998).

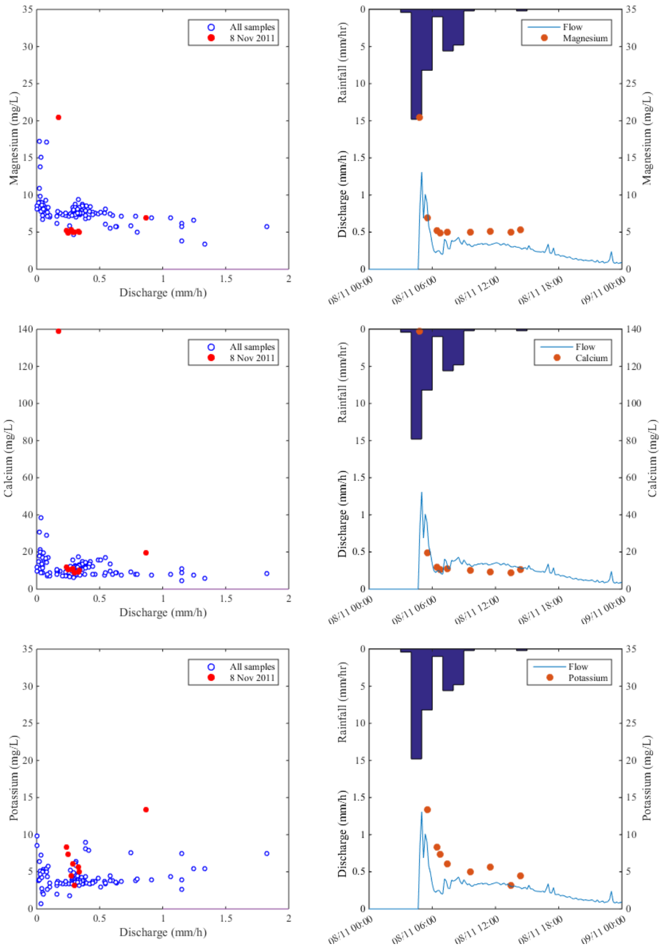
In terms of events considered, we collected multiple stream water samples from five events. Two events were missing rainfall samples and for two events the rainfall isotope signature was quite close to the typical low flow signature. Uncertainty estimates showed standard deviations for pre-event and event fractions being over 50% for these two events. For the event on 12/8/2010, the standard deviations were approximately 12% and 9% for ^{18}O and D respectively. Given that the event on 12/8/2010 was the only one for which we had a clear differentiation between rainfall and streamflow isotope signatures, we have just analysed that event. We will modify the methods to indicate that only a selection of events were sampled for isotopes and that only one analyzable event was sampled.

We have repeated the analysis using the O18 data and changed the method to estimate the rainfall end member slightly so that the mean of the rainfall samples during the event is used (rather than using the rainfall sample corresponding to the timing of the stream sample). We used a pre-event low-flow sample from ~2days before the analysed event as the pre-event end member. To estimate the overall event water contribution we interpolated the fraction of event water between stream water sampling times and combined this with the flow hydrograph to calculate the overall volume of event water. In the uncertainty analysis the pre-event end member standard deviation was estimated as the low flow sample standard deviation across the study period and the standard deviation of rainfall samples for the event was used for the event water end member standard deviation. The stream sample standard deviation was taken from the analysis precision as reported by the laboratory. This analysis suggests that the percentage of rain becoming runoff is 4.4% (3.4-5.4%) and 3.6% (3.0-4.2%) using ^{18}O and D respectively, where the figures in the brackets are 95% confidence intervals for uncertainty based on the hydrograph separation only.

11, 1-11. It is mentioned that the concentration of major ions is available for the 8 November event but only chloride has been selected and showed (Fig. 10). What is the reason behind this choice? Moreover, where does the estimate of 5% of the rainfall come from, that agrees surprisingly well with the estimate of the 12 August event (10, 26)? From a two-component hydrograph separation based on chloride? On isotopes? Please, explain in detail.

We will add figures (see below) showing Calcium, Magnesium, Sodium and Potassium to a supplement. The reason for choosing Chloride was that we expect less complication due to any ion exchange processes. Sodium and Magnesium show similar behavior to Chloride. Potassium also shows somewhat anomalous behavior but with higher concentrations. Calcium does not show anomalous behavior. The 5% was estimated directly from the hydrograph. Up until 0600 there had been 23.4mm of rainfall and 1.0mm of runoff. This is 4.3%. We will explain this more precisely in the paper.





All samples
8 Nov 2011
Magnesium (mg/L)
Discharge (mm/h)
Flow
Magnesium
Rainfall (mm/hr)
Discharge (mm/h)
Magnesium (mg/L)
Calcium (mg/L)
Calcium
Potassium (mg/L)
Potassium
08/11 00:00
08/11 06:00
08/11 12:00
08/11 18:00
09/11 00:00

11, 19. The saturation amount at the 5% of the catchment area is not shown and clearly presented, yet it is one of the most interesting results in terms of process interpretation. Please, provide a sound explanation.

As explained above, the lateral boundary of the saturated area is constrained and field observations suggested it was stable over time, while the upstream boundary moved up and down the riparian zone. The saturated area was estimated by locating the upper boundary through field inspection and then measuring the distance from either well 2 or 3. The saturated area was then estimated from this information combined with the mapping of the riparian zone boundary (see Figure 2). These measurements were made between events.

12, 29. I do not see such a clear threshold at 250 mm of ASI + rain. . .please, explain better, also in the results, where it derives from.

We will indicate the threshold on the relevant figures and describe the threshold more clearly in the paper.

Some relevant studies that I'm aware of and that are strictly linked to this research have not been cited. I think they should incorporated in the paper, particularly in the Discussion section (except the ones referring to methods, such as 2, 5 and 6):

1. Fu C, Cheng J, Jiang H, Dong L. 2013. Threshold behavior in a fissured granitic catchment in southern China: (1) analysis of field monitoring results. Water Resources Research 49: 1–17. DOI: 10.1002/wrcr.20191

2. Genereux D. 1998. Quantifying uncertainty in tracer-based hydrograph separations. Water Resources Research 34(4): 915–919. DOI: 10.1029/98WR00010

3. Penna, D., van Meerveld, H.J., Oliviero, O., Zuecco, G., Assendelft, R.S., Dalla Fontana, G., Borga, M., 2015. Seasonal changes in runoff generation in a small forested mountain catchment. Hydrological Processes 29, 2027–2042. doi:10.1002/hyp.10347

4. Penna, D., van Meerveld, H.J., Zuecco, G., Dalla Fontana, G., Borga, M., 2016. Hydrological response of an Alpine catchment to rainfall and snowmelt events. Journal of Hydrology 537, 382–397. doi:10.1016/j.jhydrol.2016.03.040

5. Pinder, G.F., Jones, J.F., 1969. Determination of ground-water com-ponent of peak discharge from chemistry of total runoff. Water Resour. Res. 5 (2), 438–445. http://dx.doi.org/10.1029/WR005i002p00438.

6. Sklash MG, Farvolden RN. 1979. Role of groundwater in storm runoff. Journal of Hydrology 43(1–4): 45–65. DOI: 10.1016/0022-1694(79)90164-1

We will incorporate these references .

Minor comments and technical corrections

We will address each of the following minor comments when we edit the final paper.

1, 10. The reference to individual research catchments makes the reader think that this paper focuses on the analysis of several catchments but this is not the case. I suggest to remove or reformulate.

We will rewrite as "However, to date, most attention has focused on single runoff response types"

2, 12. Here the suggested references 1 and 3 could be added.

Will add them.

3, 3-4. This sentence is not totally clear. Please, explain.

We will expand this paragraph to improve its clarity.

3, 22. Typo.

Will fix

3, 27. 'certain processes': too vague. Reformulate.

Will do

3, 30. Here the suggested references 1 and 4 could be added.

Will add them.

4, 9. It is a bit surprising to know that the study area is a hillslope after reading the Introduction that focuses almost exclusively on processes at the catchment scale!

It is really a small catchment. We will change our terminology.

4, 17. 'reasonably' is too vague. Specify.

The sentence will be revised as follows:

The study area has a humid climate and rainfall is uniformly distributed across the year.

5, 26. This can be misunderstood as the uncertainty in the presented results of hydrograph separation. I think it's clearer to use the term 'instrumental precision'.

The sentence is revised to: the instrumental precision was δ18O=0.1‰ and δ2H =0.4‰.

6, 15. Do the authors mean 'conceptually separate' here, ie they are considering these processes, and not physically computing the fractions of return flow and SOF in stream- flow? Please, reformulate for clarity.

Will do so.

7, 6. Better to use 'stream' or 'streamflow' here instead of 'runoff'.

Will do so

7, 23. For the sake of clarity, indicate which events/panels.

Will do so.

8, 9. How was the quick flow runoff coefficient computed? In section 2.4 it was not defined. . .unless it's, as I think, the same than 'event runoff coefficient'. In the latter case, please be terminologically consistent.

We will edit the paper so that we use event runoff coefficient consistently.

8, 28-9, 4. This part could be condensed by pointing out at the Tables.

We will edit to condense.

10, 10. Although known and intuitive, the symbols of this equation should be explained. Moreover, it should be stated that the events falling into this period are 10 (as inferred from Fig. 8).

We will revise to:

To explore this, we calculated the recession constant, k (as in $Q_t = Q_0 e^{-kt}$, where Q_t is flow at time t during the recession period, Q_0 is the flow at the beginning of the recession and k is the recession constant), and plotted it against soil water storage at the start of the recession for individual events within this period (Figure 8). This period contained 10 events. K decreased as ….

10, 17. 'Clearly'. I think it would be more cautious to start this sentence stating the results and/or the figures that point at this.

We will begin this section as follows:

"The hydrometric results presented in Figures 6, 7 and 8 suggest that subsurface flow is important in this catchment. Given this, we would expect the hydrograph to be dominated by pre-event water; however, the saturated area….."

10, 24. 'different signature': ok, but the trend is similar and should be remarked.

We will reword to "…. very different isotopic concentration during the rising limb and peak of the hydrograph (-43‰) in comparison to antecedent low flow (-27‰). This change shows that the isotopic concentration moves significantly towards the rainfall sample concentrations."

10, 25. Here the suggested references 5 and 6 could be added.

Agreed.

11, 20. Please, explain what the 'field observations' are.

We will explain this in the methods section as discussed above.

11, 24. Here the suggested reference 4 could be added.

We will add the reference.

13, 7-13. This part is not very relevant to the observed results and could be skipped, in my opinion.

We will delete this paragraph.

Tables and Figures Table 1. Remove the first column, it's not useful. Don't use abbreviations in the column name.

We will amend this.

Fig. 1. The first 'Yes' on the top horizontal arrows should be moved more to the right close to the dashed arrow, in my opinion. And perhaps the second 'Yes' can be removed.

Agreed

Fig. 2. I suggest the terms lower, mid and upper hillslope (or slope) instead. Remove the notation and the arrow pointing to the wells and put them in a legend. Why has the DEM been cut before the stream. . .cannot be extended to it?

We will amend the figure as suggested

Fig. 4. Replace 'overview' with 'example'. I also suggest to include a no-flow event.

Agreed

Fig. 5. Please, see my comment above. Moreover, the difference between 'Soil Moisture Index' of panel b) and 'ASI' of panel c) is not clear and should be explained (or fixed if they are the same thing).

(I think 'soil moisture index' and 'ASI' are the same thing so we should change the title of X axis in panel b to 'ASI'.)

Soil moisture index in Figure 5 and ASI are the same thing. We will edit the figure so we use consistent labelling and check that we are also consistent throughout the text.

Fig. 6. Why are there values above zero? Explain or fix.

The soils are highly pugged in this area and water pooled on the surface in places leading to slightly positive water levels being recorded at site 2. We will explain this in the paper.

Fig. 7. Why have only these sites been shown and not also water table at the other locations? This should be explained in the text. Additionally, 'high intensity' is too vague and should quantified, possibly using thresholds presented in Fig. 5.

These sites were chosen because they show significant dynamics and we had logged records available. Other sites with loggers had limited dynamics or short records. We will explain this in the paper. We will define high intensity in the caption (>15mm/h).

Fig. 8. Add a mention to the period when these events have been selected. It would be interesting to see these results also for other events.

The following sentence is added to the caption of the Figure 8:

These events happened in the very wet period during August/September 2010. We will consider adding other events.

Fig. 9. The symbol '‰should be put in parenthesis. ´

Will do

Fig. 10. Please be consistent with the use of terms such as 'discharge' (as here) or 'flow' (as in Fig. 9).

We will edit the figures for consistency