Reply to the interactive comment by D. Milledge (referee #1)

We thank Dr. Milledge for his comments, which helped to clarify a number of points and improve significantly the revised version of the paper. The reviewer's comments are quoted above the author's responses.

General Comments:

"This paper applies and existing landslide model to a catchment with mapped land-slides, many of which were triggered by a single large storm. The model is applied to topographic data at 4 resolutions and the authors demonstrate that intermediate resolutions (4 & 10 m) outperform the highest (2 m) and lowest (20 m) resolutions. The authors explain this in terms of modification to the derived parameters (slope and effective upslope area), which are resolution dependent. The result is robust and confirms what others have already shown with other similar landslide models (Claessens et al.,2005, Tarolli and Tarboton, 2006). This result is valuable to those looking to apply this particular landslide model (QDSLAM) and of some interest more generally in con-firming the behaviour found elsewhere. The authors also demonstrate that the model performs significantly worse at predicting road failures, especially with high resolution topographic data. They suggest that this is due to diversion of the flowpaths by roads that are included in the DEM once the resolution becomes sufficiently fine. This may be a novel finding, it is relatively intuitive. Roads do divert flow paths but the resolution of the topographic data is never sufficient to represent these diversions. This makes sense since very minor changes in road topography or drainage could divert all the water flowing on a road onto the adjacent hillslope. However, this paper doesn't provide a way to predict road related landslides it tests the existing model's ability to predict road related landslides and shows that it cannot do so effectively. This is its contribution.

To go further with this the authors could ask: how does the model perform for failures upslope of roads versus downslope of roads? This would help to test their hypothesis, since only landslides downslope of roads would be affected by the road runoff."

This was exactly the purpose of this work. We have applied the model separately on the road-related landslides and on non road-related landslides, in order to quantify the decreasing model performances for road-related failures. We agree that this is relatively intuitive result; however, this is the first time these comparisons are reported.

Specific comments:

"L58-69: The discussion of the importance of landslides could be slightly shorter, and needs to remain relevant to shallow landslides."

We shortened this part by focusing the discussion on shallow landslides.

"L61: "the proportion of individual fatalities" I'm not clear what you mean by this."

We modified the sentence as follows: "..in terms of both the number of people affected globally and the proportion of fatalities on the affected population."

"L82: Freer et al., 2002 does not discuss landslide locations, what statement do these references relate to?"

We remove the reference.

"From "The effect of this: :" (L116) to ": : :receiving areas" (L119) is not needed."

We removed those two sentences.

"L138: what does "small scale" mean in the context of a landscape?"
We removed "small scale" that was unnecessary in the sentence.

"L173: your explanation of h is confusing, my understanding from equation 2 is that h is the height of the water table above an impeding layer, measured perpendicular to that layer but this is not clear from the sentence in which h is defined and it could be misinterpreted as the water table depth from the surface. You should also explain that you assume that: 1) there is an impeding layer at depth z (i.e. the impeding layer is the soil bedrock interface), 2) the layer is slope parallel, and 3) the failure plane for the landslide is on this impeding layer."
We thank Dr. Milledge for this important clarification that we integrated in the revised manuscript.

"L184: you should include a reference on the original authors of the infinite slope model"
Done; we added the reference: Hammond t al. (1992).
Hammond C, Hall D., Miller S., Swetik P., 1992. Level 1 Stability Analysis (LISA) documentation for version 2.0. *General Technical Report INT-285*, US Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT; 190 pp.

"L200: "many slides are actually triggered by the transient response of pore pressures to burst of intense rainfall, which may occur on short timescales of less than 1 day" you correctly identify this as a problem with the steady state approach, which will be addressed to some extent by your quasi-dynamic approach. However, Iverson (2000) and others since have argued that migration of the pressure wave vertically through the soil profile can take minutes to hours while the lateral subsurface flow contribution can take hours to days. This is relevant to your study because you assume that infiltration is instantaneous and you should justify this assumption. It is also relevant because you observe that landslides in your study area are triggered by short duration high intensity rainfall, (3 hours (L271) and 8 hours (L273)). However you do not use these durations in your model runs. Iverson (2000) would suggest that the pressure wave would take around 20minutes to travel 1m into the soil profile, and would argue that the observed landslides were triggered before pore pressures could be strongly influenced by lateral subsurface flow. Your Figure 4 shows that 3 hours of rainfall results in a maximum effective area of 16 m2/m. That said, Iverson (2000) and others recognise the importance of initial water table height in defining the pore pressure response to rainfall and lateral subsurface flow may play an important role in defining those initial conditions.
Reference
Iverson, R. M. (2000), Landslide triggering by rain infiltration, Water Resour. Res., 36,1897– 1910."

We thank Dr. Milledge for the comment and the opportunity this provides to clarify the relevance of timescales based on the work of Iverson (2000). The timescales derived in the work of Iverson (2000) are based on the assumptions of homogeneous isotropic soil properties. Actually, the presence of macropore and/or pipe flow, and the influence of preferential flow, may have a considerable impact on the response timescale of vertical infiltration and lateral groundwater. Decades of work (see the recent review by Beven and Germann, 2013, and reference therein) have shown the significance of vertical and lateral flow through soils containing macropores under unsaturated soil conditions. The importance of preferential flow in the triggering of landslides has been analysed in detail by Krzeminska (2012). Saturated flow in fractures resulting in excess pressure was thought to be important in the Coos Bay slope failure (Montgomery et al., 2002) and might be a common feature of many landslides and debris flows (Uchida et al., 2001; Hencher, 2010). The hydrological response of soils in the study area is dominated by the presence of

pipeflow, macropores and fissures. This is the motivation for our assumptions of instantaneous infiltration and for the use of locally-calibrated lateral saturated hydraulic conductivity.

Beven, K., Germann, P., 2013. Macropores and water flow in soils revisited, Water Resour. Res., 49, 3071–3092, doi:10.1002/wrcr.20156.
Hencher, S.R., 2010. Preferential flow paths through soil and rock and their association with landslides. Hydrological Processes, 24 (12), 1610-1630.
Krzeminska, D., 2013: The influence of fissures on landslide hydrology. PhD Thesis, University of Delft.
Montgomery, D.R., W.E. Dietrich, and J.T. Heffner, 2002. Piezometric response in shallow bedrock at CB1: Implications for runoff generation and landsliding, Water Resour. Res., 38(12), 1274, doi:10.1029/ 2002WR001429.
Uchida, T., K. Kosugi, and T. Mizuyama, 2001. Effects of pipeflow on hydrological process and its relation to landslide: A review of pipeflow studies in forested headwater catchments, Hydrol. Process., 15, 2151–2174.

"L221: the language that you use for rainfall intensities here is confusing; I think that you are using rainfall intensity, rainfall depth, and rainfall rate interchangeably. If they are the same thing use a single term if not you need to define each term."
We thank Dr Milledge for this comment. We revised the rainfall-relevant terminology used in the work.

"L264 "road cuts truncate colluvial fills in topographic hollows and weathered bedrock in noses" this suggests that while you don't have hard data on soil depth in the study area it does varying consistently and is correlated with topography. A decline in root strength with depth and spatial variability in soil depth in space may be a large part of the explanation for soil observed in many locations that are unconditionally unstable according to the model."
We agree with the Reviewer that the spatial variability in soil depth may be explain the fraction of landscape assessed as unconditionally unstable according to the model. We added this possible explanation to Section 4.4.

"L283: Why are some of the landslides intersecting the road network classed as non-road related?"
The details of landslide locations are not accurately portrayed in Fig. 1, owing to its size. In that figure, a number of landslides which appear to intersect the road network are classified as "natural landslides". Actually, the initiation point of these landslides are either located a few meters upslope the road or 10-20m far downslope the road. As discussed in the paper, we classified landslides being 'road related' primarily based on distance downslope the road.

"L293: is this really the total landslide area? I count >130 landslides, in which case the mean landslide size is 0.5 m2. That could be something like 1 m long by 0.5 m wide, this would need to be <4 cm deep to have a length depth ratio >25. However you are using 1 m depth in the model and the photos look like the failure plane is on that order. I think something is wrong here."
The use of a fullstop to separate the integer part from the fractional number in this sentence was a source of confusion. In the revised version we fix the problem by using a comma, as follows: "The total landslide area is 67,593 m^2; this means a mean landslide in the order of 520 m^2." We thank the Reviewer for noticing this.

"L294: when you say "conventional wisdom" you should include references."
OK. We included the following reference: Gucinski t al., 2001

Gucinski, H., Furniss M.J., Ziemer R.R., Brookes M.H., 2001. Forest roads: A synthesis of scientific information, Gen. Tech. Rep. PNW-GTR-509, U.S. Dept. of Agric. For. Serv. Pac. Northwest Res. Stat., Portland, Oreg., 103 pp.

"L321: What are the details of the rainfall data from which the GEV parameters have been estimated?"
The GEV parameters were based on a regional analysis by using the 1, 3, 6, 12 and 24 h duration annual maximum rainfall for a total of 388 station years in a homogeneous region defined accordingly with the L-moment procedures (Hosking an Wallis, 1997).
Hosking, J.R.M., Wallis, J.R., 1997. Regional Frequency Analysis. Cambridge University Press, p. 224.

"L344: more detail is required on the method of calculating local slope, which method did you use? Include a reference."
The local slope was estimated by a cell-to-cell computation, along the steepest-descended flow path according to the D8 flow direction method (O'Callaghan and Mark, 1984).

"L358: I don't think remarkably is a suitable word here, you could just say "increases with"."
Agree, done.

"L372: It is difficult to be sure what you mean by left and right tails on a box plot. My interpretation is that left tail refers to values above the median and right tail to values below. If this is the case though I am surprised that the left tails of the contributing area and QDWI distributions are most interesting, the right tail contains the highest values which should correspond to higher pore pressures."
The interpretation by Dr Milledge is correct. However, we disagree with the Reviewer on this specific point. Both left and right tails are of interest, depending on local conditions. Typically, left tail may be of interest because these are associated with high local slopes (even though pressure may be low).

"L367: "Grid size" previously you have talked in terms of resolution, you should be consistent in referring either to resolution or to grid size rather than using them interchangeably."
Done.

"L368: Areas that are predicted as unconditionally unstable should not be able to sustain a soil mantle (i.e. they should be bare rock). You should comment on whether this is what you observe here. If 10% of the catchment is unconditionally unstable and not bare rock then to me this suggests that one of the parameters is overly conservative. As I suggest above, my first thought would be that these are places where the soil is shallower than 1 m and / or basal root cohesion is greater than 1kPa. My second suggestion would be that the friction angle is a little low or perhaps if these areas are preferentially found in woodland that root cohesion is higher here allowing steeper slopes to be sustained."
The model describes a non-negligible portion of the basin as unconditionally unstable. Given this characterization, these sites should be continuously sliding; hence no soil could be found over there. There are two reasons for these results: the first is the assumption of a given soil depth exceeding the actual one; the second is the effect of legacy processes. One specific legacy processes can be recognised in this area, due to the presence of terraces. Terraces were built in some higher portions of the basin, which modified artificially the soil depth distribution – the

terraces are now abandoned, hence representing critical conditions for shallow landsliding triggering in unconditionally unstable terrain. We report these observations in the revised version of the paper.

"L407: "Larger QDWI values at the left tail" this is confusing since I expect large QDWI values to make up the right tail. Does it mean that there are now more high QDWI values? Or that the left tail has become heavier, i.e. more low QDWI values? This relates to my confusion on L372. I think both could be solved by clearly defining what you mean by left and right tails."
In this sentence, 'larger' is meant to indicate the effect of increasing grid size. We modified the sentence to make it more understandable. "*The effect of the decreasing DTM resolution is to increase the QDWI values at the left tail....*"

"L425: do these fractions include unconditionally unstable cells?"
These fractions apply only to the conditionally unstable fraction of the catchment. We clarified this aspect in the revised version of the manuscript.

"L459: It is difficult to compare performance since there are two metrics varying together: percentage of unstable cells in the catchment and percentage of landslides predicted. I think comparing the two as you do in Figure 7 is the best way to do this. You could easily present the same data for all 4 resolutions and I would find this helpful."
We agree with the Reviewer and report the distribution for all 4 resolutions in the revised Figure 7.

"L462: the percentage of cells that are either unconditionally unstable or fail with some rainfall return period is the most relevant metric here. These should be reported in one of the tables rather than just in the text. Fine scale variability in the topographic data is moving some cells from conditionally unstable at low return period to unconditionally unstable. Either way though, they are being predicted as unstable by the model so they should be included both in the percentage catchment area and percentage of landslides hit."
We have revised the Tables which provide now a more complete information on the percentages of landslide area and of catchment area that are included in the various stability classes.

"L466: "the general tendency of process based models" statement needs a reference."
We added the reference, as follows:
Huang, J.C, Kao, S.J., 2006: Optimal estimator for assessing landslide model performance. Hydrol. Earth Syst. Sci., 10, 957–965.

"L473: why only include 10 m results in Fig 7? If you are trying to compare different resolutions this looks like it might be the best way to compare all 4 and I don't think readability would suffer."
Done, we report the distribution for all 4 resolutions in the revised Figure 7.

"L484: I think you need to explain what you mean by "the QD-SLaM model does not incorporate the description required to predict road related failures". What would that description include?"
By this we mean that the model does not incorporate any module that takes road-related (or other man-related features) failures. We specified this in the revised text.

"L484-7: I don't find this a persuasive explanation for why the model out performs the naïve case. While the over-prediction problem is recognised I don't think it explains why the model still does slightly better than random. Instead I would expect the explanation for this to be related to the

continued relevance of slope in defining failure likelihood. Since steeper slopes are more likely to be unstable both in the model and at road cuts I would expect that the model (which is strongly dependent on slope) would continue to perform a little better than a random classifier (i.e. the naïve case).”
We agree with the Reviewer and rephrased the sentence.

“L494-497: It is not clear what point you are making in this sentence or how it follows from your results. What are “external processes”?”
We changed the sentence as follows: “particularly when the terrain attributes may be themselves dependent on the resolution of the digital topography. “

“L531-533: As above, I don’t find this a persuasive explanation, why is there a general trend towards over-estimating unstable areas and why should this be true for road related failures just as it is for natural failures?”
See previous response at lines L484-7

“L545-550: These statements are comments rather than conclusions; they do not follow logically from the results that you have presented. I don’t think they should be included here.”
Done. In the revised text the sentences were removed.

“Tables 3, 4, 5 and 6: I think these could be more clearly expressed by combining tables 3 and 5 and doing the same with tables 4 and 6.”
We agree. Done.

“Table 7: I think it might be useful to include one sentence explanation of the efficiency index in the caption.”
Done.

“Figure 4: You should note in the caption that the y-axis changes between plots, the lettering for the plots is incorrect, repeating a-c.”
Unfortunately, Dr. Milledge has reviewed the version of the manuscript submitted to the HESS website without all the corrections implemented during the typesetting process. The version of the paper published on the HESSD and visible to the public looks fine.

“Figure 5: as far as I can see this is a copy of the top six panels in Figure 4, you should drop this figure.”
Please, see the response to the previous comment.

“Figure 6 is very hard to read beyond a very rough idea that variability increases at finer resolution. The maps are small and the white outlines of the landslides are hard to see against the pattern of the predictions.”
We agree with the reviewer. In the revised version of the work we revised the Fig. 6: in addition to the 4 large scale maps, 4 local scale example areas shown in 4 boxes for each map.

“Figure 7: I think that FL(q) and FB(q) should be defined in the caption and that you should also include the curves for the other 3 resolutions. It would be nice to see an additional Figure illustrating the diversion of specific catchment area that you suggest as an explanation for the poor prediction of road related failures.”
We modified the caption of Figure 7 accordingly with the comments by the reviewer.

Grammatical and Typographic errors

"L61: Replace "in debris flows" with "into debris flows". "
Done.

"L67: Replace "showed also" with "also showed".
Done.

"L88: Replace "is it" with "it is". "
Done.

"L94: Delete "kind of". "
Done.

"L96: Delete "configuration". "
Done.

"L104: Delete "degree of". "
Done.

"L106: "other error sources may add to this one" This doesn't make sense as a sentence on its own, I think you could combine it with the sentence below. "
We changed the sentence as follows: "Additionally, there might be other error sources".

"L106: Replace "networks, associated" with "networks, and their associated". "
Done.

"L110: Delete "at or near the earth's surface" I think this is implied."
Done.

"L113: Replace "than the one" with "that". "
Done.

"L114-116: this sentence doesn't make sense to me."
We changed it as follows: "Several road-related failures result from subsurface flow intercepted by road cut slopes"

"L127: the content of the brackets could be removed since this is repetition."
Done.

"L148: replace "interested" with "intersected". "
We changed it into "characterized"

"L149: replace "made available" with "provided", delete "were", replace "into" with "between". "
Done.

"L222: move "well" to the end of the sentence. "

Done.

“L266: replace “culvers” with “culverts’, replace “into valley” with “into the valley””
Done.

“L266: replace “width is ranging between 4 and 6 m” with “width ranges from 4 to 6 m”.”
Done.

“L267:replace “roads” with “road”.“
Done.

“L281: replace “within 6 km distance from the” with “within 6 km of the”.”
Done.

“L305: replace “Contrarily” with “Unlike”.
Done.

L308: replace “associated to” with “associated with".”
Done.

“L310: replace “owing to this reason” with “in-stead”.”
Done.

“L330: replace “affect” with “effect”.”
Done.

“L360: replace “contrarily to” with “unlike”.”
Done.

“L482: delete “as expected”.”
Done.

“L489: replace “to” with “with”, replace “thanks to the” with “for”.”
Done.

“L490: replace “roads” with “road”.”
Done.

“L521: delete “in simple terms”.”
Done.

“L541: replace “shows” with “show”.”