A response to “Interactive comment on ‘Which type of slope gradient should be used to determine flow-partition proportion in multiple-flow-direction algorithms – tangent or sine?’ by L.-J. Zhan et al.” by Anonymous Referee 1 (HESSD, 9, C3083-C3097, 2012)

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The authors thank the anonymous referee for the constructive comments and criticism which are helpful for improving the final version of this paper. Below we try to answer the issues raised by the referee. The comments by referee are in italic.

With regards to general comments:

- ***Multiple flow direction algorithms have been shown to produce improvements in the quantification of terrain attributes such as the specific drainage area over single flow direction algorithms, but they have never been shown to provide a reliable description of overland flows. As presently written, this paper contributes to generate confusion by failing to distinguish methods for the determination of terrain attributes and methods for the description of overland flows. The paper presented by the authors clearly focuses on overland flow modeling, and more specifically on the problem of determining how overland flow partitions along downslope directions. Under this perspective, however, the analysis done is inadequate and potentially misleading.***

MFD algorithms have been shown advantage to calculating the hydrologic land-surface parameters for quantifying water flow and related surface processes (Gruber and Peckham, 2009; Wilson, 2012). These hydrologic land-surface parameters include specific catchment area (SCA, a measure of surface or shallow subsurface runoff at a given point on the landscape (Moore et al., 1991)) and

SCA-based terrain attributes (e.g. topographic wetness index, and stream power index), which have been widely used in hydrological applications and other different areas (Hengl and Reuter, 2009). Howerer, there is few discussion on the hydrological basis of the general flow-partition function, Eq. (1), used in most current MFD algorithms (e.g., Quinn et al., 1991; Freeman, 1991; Holmgren, 1994; Quinn et al., 1995; Kim and Lee, 2004; Qin et al., 2007).

$$d_i = \frac{(\tan \beta_i)^p \times L_i}{\sum_{j=1}^{8}[(\tan \beta_j)^p \times L_j]}, \quad (1)$$

In this study we argue that the flow-partition function used in MFD algorithms should be designed based on a clear hydrological theory and revisit Eq. (1) from the perspective of hydrological theory. The deduction performed in this study based on hydrological theory gets a flow-partition function with the similar form as Eq. (1) but conceptually related to $\sin \beta$, instead of $\tan \beta$ as used currently. We will revise the manuscript to state this point.

With regards to specific comments:

- ***Page 6409, title. The specific question given in the title is not very relevant. In fundamental open channel hydraulics, "sin" is used in preference to "tan". However, the issue addressed in the paper is how overland flow partitions along downslope directions in multiple flow direction algorithms (page 6410, line 23). This is a complex issue that is not just determined by the use of "tan" or "sin".***

In this study we intend to question the use of $\tan \beta$ in Eq. (1) from the perspective of hydrological theory, rather than determine which specific flow-partition function should be applied to MFD algorithm. We will revised the manuscrip to state this point. In the final version of this paper, the title will be revised as "Revisit of the general flow-partition function in multiple-flow-direction algorithms".

- ***Page 6410, line 17. The D8 algorithm is not the best single flow direction algorithm available. It has been substantially improved by the D8-LTD method introduced in Orlandini et al. (2003). Another significant contribution to the determination of flow directions has been provided in Tarboton (1997). A more accurate analysis of the literature would probably help the authors to identify relevant problems and suitable solution methodologies.***

The MFD algorithms have grown in popularity over time (Wilson, 2012). In this study we focus on the MFD algorithms with the flow-partition function similar to Eq. (1). D8-LTD (Orlandini et al., 2003) and D-inf (Tarboton, 1997) algorithms will also be referred in the revised manuscript.

- ***Page 6410, lines 19–22. It is reported here that: "Generally, MFD performs better than SFD, especially when the flow-direction algorithm is used to derive the spatial pattern of hydrological parameters (such as specific catchment area and topographic wetness index) at a fine scale (Wolock and McCabe, 1995; Qin et al., 2011; Wilson, 2012)." This sentence is potentially very misleading. The MD8 multiple flow direction algorithm was introduced by Freeman (1991) and Quinn et al. (1991) to provide improved estimations of local terrain attributes such as specific catchment area with respect to those provided by the D8 single flow direction algorithm by O'Callaghan and Mark (1984). Gallant and Hutchinson (2011) have however shown that Tarboton's (1997) method outperform Freeman's (1991) and Quinn et al.'s (1991) method in the computation of specific drainage area. More importantly, the authors' sentence seems to imply that multiple flow direction algorithms outperform single flow direction algorithms in the prediction of surface flows while this may not be the case. The authors' paper clearly focuses on overland flow modeling and not on the determination of terrain attributes such as specific catchment area, and implicitly assumes that multiple flow direction algorithms can be suitably used for this task. However, there is at present no scientifically valid evidence that multiple flow direction algorithms consistently outperform single flow direction algorithms in the description of overland flows. The sentence reported on lines19–22 of the submitted manuscript is not adequately supported by results reported in the literature, and contributes therefore to generate confusion by***

failing to distinguish methods for the determination of terrain attributes and methods for the description of overland flows.

The applicable conditions (e.g., terrain condition of study area, grid size of DEM, and the practical purpose) of different flow direction algorithms are different (e.g., Tarboton, 1997; Gruber and Peckham, 2009; Qin et al., 2011). We will revise the manuscript to avoid misleading the readers.

- ***Page 6410, line 23. It is reported here that: "The key issue in MFD is how to partition the flow into multiple downslope cells." I agree, but this problem needs to be addressed in a sounder manner than reported in the paper. See the other comments reported in the present review.***

The various flow-partition functions used in MFD can result in differnet patterns of SCA for a hillslope or watershed (Wilson, 2012). We will revised the manuscript to clarify this point.

- ***Page 6411, lines 18–20. It is reported here that: "In this paper, the general flow partition function is deduced based on hydrological theory, and approximation of the hydraulic gradient using tan to determine the flow-partition proportions in existing MFD algorithms is found to be questionable." Yes, the use of "tan" is questionable, but the use of "sin" does not suffice to determine a sound partitioning of flow based on hydrological theory. Perhaps, the use of "sin" in preference to "tan" provides some improvement, but this should be tested in some way. Stating that a technically sound flow partitioning is obtained by simply using "sin" in preference to "tan" in equation (1) is technically misleading.***

We agree with the reviewer. In this study we intend to question the use of $\tan\beta$ in Eq. (1) from the perspective of hydrological theory, rather than determine which specific flow-partition function should be applied to MFD algorithm. Please also see the response to the first specific comment from reviewer above.

- ***Page 6412, lines 15–21. The authors find here that the sine of the terrain inclination angle at the power 1/2 has to be used to provide a technically sound solution to the problem of overland flow partitioning. However, the theoretical analysis reported here is not technically sound for several reasons. The Manning equation is commonly accepted to describe surface flows in regular, low-gradient channels. I sympathize with the authors in their attempt to use the Manning equation to describe high-gradient channel flows and overland flows. However, there is field evidence that the Manning resistance coefficient (n) significantly depends on terrain slope under these circumstances (e.g., Jarrett, 1984; Jarrett, 1990). In addition, the assumption that the hydraulic radius is constant over all the downslope directions is not very realistic. For large surface flows the hydraulic radius is essentially equal to the flow depth. How can be assumed that the mean overland flow depth along different downslope directions is the same? One may think that the consistency between the structures of equations (1) and (5) is supportive. However, the ability of equation (1) to describe overland flows has never been tested and this needs to be considered. I feel that field data are needed to support models of flow partitioning along downslope cells.***

As a complex issue, the movement of water on the landscape is primarily driven by gravity and to some degree modified by the properties of the material it flows through or over (Gruber and Peckham, 2009). The effect of gravity can be estimated with DEM while the surface and subsurface properties and conditions are cumbersome to be described and treated quantitatively (Wilson, 2012). For simplifying this issue, flow direction algorithms normally determine the flow partitioning with a function of terrain attributes (e.g. slope, aspect). This is generally accepted in geomorphometry (Hengl and Reuter, 2009; Wilson, 2012).

In this study we revisit Eq. (1) used in most current MFD algorithms, from the perspective of hydrological theory. For simplicity, we used Manning's equation and Darcy's equation to describe the outflow of surface and subsurface respectively from a given cell distributed to neighbouring downslope cells.

We agree with the reviewer that Manning resistance coefficient significantly depends on slope, and the hydraulic radius should be different in different downslope directions. Therefore, we rebuilt Eq. (4) in the original manuscript according to the Manning resistance coefficient (n) proposed by Jarrett (1990):

$$n = 0.32 S^{0.30} R^{-0.16} \tag{2}$$

where S is slope, and R is hydraulic radius. The new deduction draws the same conclusion as in the original manuscript. We will revise the manuscript to include the new deduction.

In this study we intend to question the use of $\tan\beta$ in Eq. (1) from the perspective of hydrological theory, rather than determine which specific flow-partition function should be applied to MFD algorithm. It still needs additional work to evaluate which one among possible flow-partion functions is best or what is the applicable conditions for a specific flow-partition function. The test with the field data is beyond this paper. We will revised the manuscript to clarify this point.

- ***Page 6415, lines 11–17. The conclusions reported here are not supported by a sound theoretical analysis or by field data. On the basis of fundamental open channel hydraulics, one can think that "sin" is potentially more suitable than "tan". On the basis of experimental terrain analysis, one can think that "tan" is potentially better than "sin". The fact is that the flow partitioning provided by equation (5) — as well as that provided by equation (1) — has not been adequately tested and thus it should not be reported in a scientific paper as a technically sound means for describing overland flows.***

We agree with the reviewer. Again, in this study we intend to question the use of $\tan\beta$ in Eq. (1) from the perspective of hydrological theory, rather than determine which specific flow-partition function should be applied to MFD algorithm. It still needs additional work to evaluate which one among possible flow-partion functions is best or what are the applicable conditions for a specific flow-partition function. This is beyond this paper. We will revised the manuscript to clarify this point.

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