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Comment on "Power law catchment-scale recessions arising from heterogeneous linear small-scale dynamics" by C. J. Harman, M. Sivapalan, and P. Kumar

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[1] It is demonstrated that a near-linear subsurface runoff response from a short and relatively steep slope segment and a nonlinear response at the watershed scale may primarily arise from geometry rather than from an assumed linear nature of the subsurface runoff response from the hillslope, as *Harman et al.* [2009] employed for the Panola Mountain Research (PMR) catchment in Georgia. The authors caution in their paper that hydraulic theory (exemplified by the study of *Brutsaert and Nieber* [1977]) cannot generally account for the heterogeneity in the watershed scale and therefore should be used with certain reservation when employing it for catchment-scale parameter estimation. They base this on observations [*Clark et al.*, 2009] that the PMR watershed in Georgia displays a near-linear (which Harman et al. accept to be linear) subsurface flow response at a short segment (~50 m) of the upper part of a hillslope, while the same response becomes increasingly nonlinear with scale. The authors employ linear reservoirs in parallel, with prescribed distributions (e.g., bounded power law (BPL)) of the storage coefficient and in the limit; when the number of reservoirs approaches infinity, they obtain the required degree of nonlinearity in their summed outflow. With the application of the BPL distribution, the shape of which changes significantly with scale, they can achieve the observed full range and temporally changing nature of the exponent of the recession flow equation. This way, they argue that the nonlinear subsurface flow response from the PMR watershed may emerge from a combination of linear responses similar to what is observed at the short upslope segment.

[2] The logic behind the parallel reservoir approach taken by *Harman et al.* [2009] is this: an observed near-linear subsurface runoff response from a short, relatively steep uphill portion of a hillslope leads to the assumption of a linear response for *all* hillslopes within the catchment. However, to my best knowledge such a general linear hillslope response in the PMR watershed was never observed, since hillslope runoff measurements were taken only at one particular short uphill slope segment. This then questions the suitability of employing a linear reservoir for the description of the general hillslope response and, consequently, that of the watershed.

[3] With the help of the 2-D combined Richards equation an alternative explanation of the seemingly different subsurface runoff response between the short uphill segment and the watershed is presented here, acknowledging that reality is certainly much richer than what is captured in the ensuing brief and highly simplified modeling. As described by *Freer et al.* [2002], subsurface flow response at the hillslope was obtained in a trench running perpendicular to the slope gradient and dug down to the rock surface. This latter property is important because, this way, the slope section (and its subsurface flow dynamics) uphill of the trench is cut off from the rest of the slope downhill and the trench acts as a drain. Therefore, in comparison with the typical watershed hillslope, one has a short, relatively steep hillslope with relatively thin soil, and, because it is an uphill segment, it receives relatively little support from surface and subsurface flow from above. In addition, the resulting subsurface outflow is collected and removed, thus creating zero water levels in the trench, which is also somewhat different from the case of the typical slope of the catchment that is drained at least intermittently by a stream with nonzero water depth. This last difference from the ensuing modeling point of view is, however, minor since, having no information of whether the streams at the catchment are fully or partially incised, they will be assumed to be fully penetrating here with zero stream water depth ($h = 0$) for the trench and a constant nonzero depth for the typical watershed.

[4] Having a look at the map of the watershed [*Clark et al.*, 2009], it is safe to assume a magnitude difference of the specific hillslope segment length mentioned above and that of the average hillslope of the catchment. Let us then consider two slopes now, one with a base length of 20 m, a slope of 1:2, and a soil thickness of 0.5 m, drained by a fully incised stream with zero stream levels. Let the other slope have a base length of 200 m, a slope of 1:10, and a soil thickness of 1 m, drained by a fully incised stream with $h = 0.1$ m (Figure 1). Let both slopes be covered by soils of a loam-type physical texture as described by *Szilagyi et al.* [2008]. Because the shorter slope is steeper and because it has less moisture support from above (in the form of, for example, interflow and/or preferential flow and surface runoff with the ensuing enhanced infiltration) than the longer one, let it have full saturation up to a unit height from its base only, while the longer one will have saturation up to 10 m (Figure 1), before drainage simulations start.

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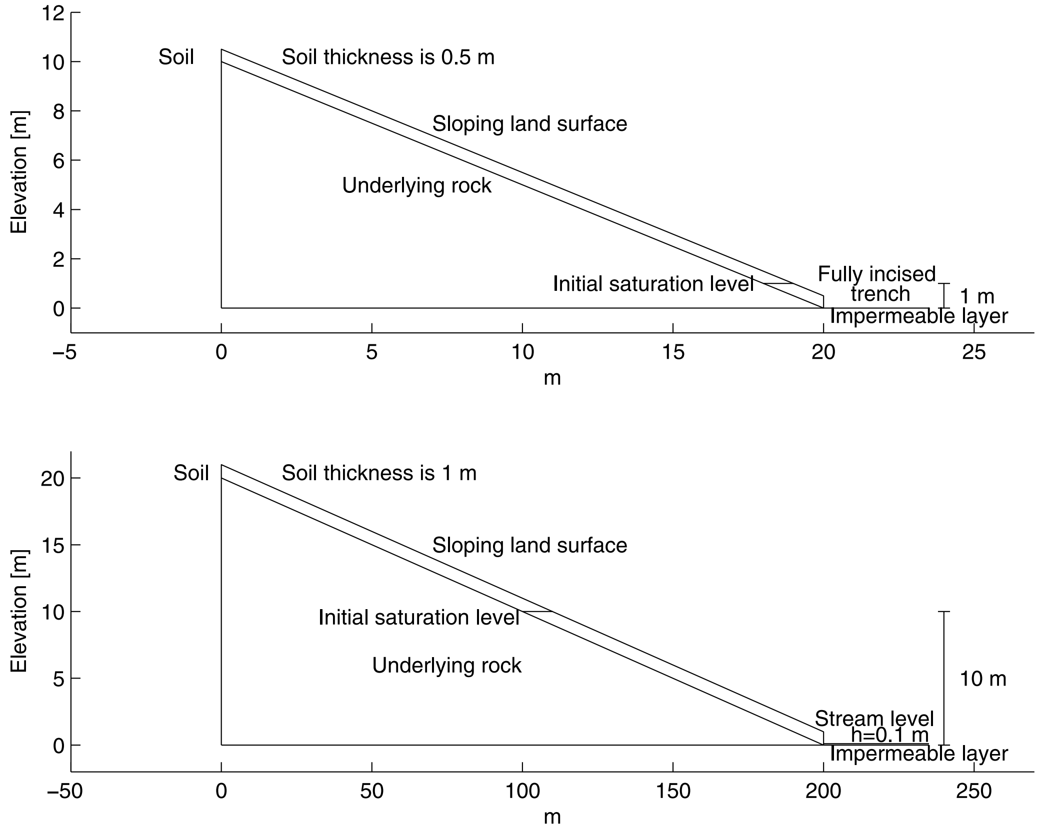

Figure 1. Schematic representation of the hillslopes.

Drainage simulation of the two slopes was carried out for 4 days. The reasons for not keeping the original length of the slopes observed in the PMR catchment are that (1) numerical integration becomes cumbersome when the domain's dimensions differ significantly, i.e., 0.5 versus 20 m and 1 versus 200 m, being already at the limit, and (2) the exact true dimensions are not important now because of the unknown hydraulic properties (i.e., water retention and hydraulic conductivity curves) of the soils at the watershed.

[5] Soil moisture and groundwater dynamics have been modeled by a combined version of the 2-D Richards equation [*Lam et al.*, 1987] that treats saturated and unsaturated flow in one equation. For further details of the model in a hillslope setting, see *Szilagyi* [2006] or *Szilagyi et al.* [2008].

[6] Figure 2 depicts the resulting subsurface flux rates as a function of time as well as the flux versus time rate of change in the flux values in a double-logarithmic graph. As can be seen in the double-logarithmic graphs, the outflow of both hillslopes behaves highly nonlinearly at early times of the drawdown (slope much larger than unity) while turning into a near-linear response (slope of about unity) at later times only for the short slope during the 4 days of drainage modeled. The 4 day period was chosen because *Clark et al.* [2009] mentions that measurements were taken only for a few days after individual storm events. With an increase in drainage time, one would naturally see the same near-linear response (omitted in the graph) for the longer slope, as can be seen for the shorter one preceded in time by a steeper slope section for early drawdown.

[7] What likely conclusions follow from this?

[8] 1. The instrumented hillslope of the PMR catchment tends to behave near linearly because of its uphill position (reduced support of moisture from above, thus reduced ability for becoming saturated), thin soil, relatively steep slope, and short length and because of the fact that it is cut off from the rest of the slope by an artificial trench speeding its drainage (i.e, compared to being connected to the rest of the slope). Note that hydraulic theory does not predict a true linear recession, as the observed recession is not truly linear either; that is, the slope is somewhat larger than unity [see *Harman et al.*, 2009, Figure 7; *Clark et al.*, 2009].

[9] 2. The longer hillslopes of the catchment behave nonlinearly because of reasons opposite to what were listed before; that is, they are milder in slope, have thicker soil, and receive abundant moisture support from uphill to keep their lower segments closer to saturation at all times. Compare the shape of the modeled recession curve with that of *Harman et al.* [2009, Figure 7] or *Clark et al.* [2009, Figure 2].

[10] 3. The nonlinear behavior attributed to the watershed by *Harman et al.* [2009] thus emerges not from a collection of linearly responding hillslopes but rather as the inherently nonlinear drainage response of the hillslope itself. This is fundamentally different from the conclusion of *Harman et al.* [2009].

[11] *Harman et al.* [2009], however, are right when cautioning the potential user of hydraulic theory for estimating watershed-scale hydraulic characteristics. For instance, the hydraulic theory approach by *Brutsaert and Nieber* [1977] yields effective parameter sets but does not

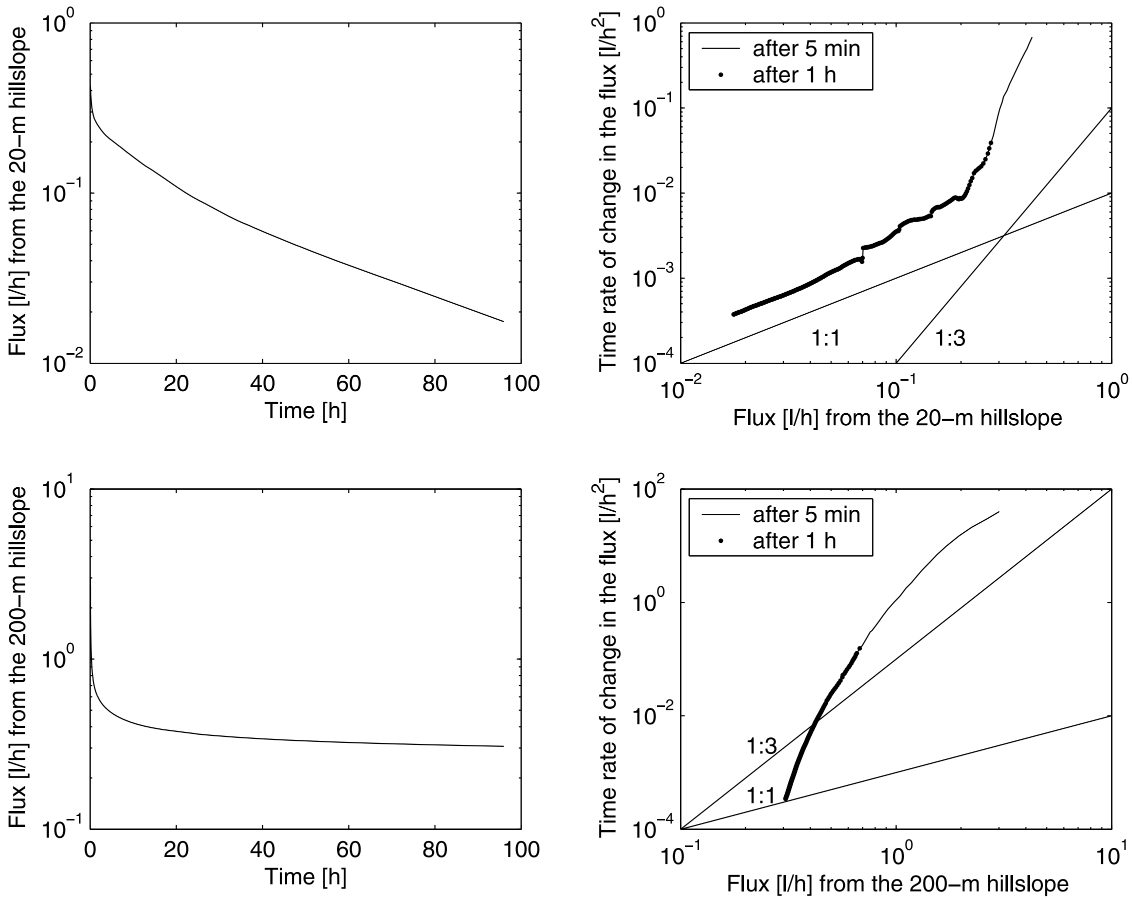

Figure 2. Flux rate versus time and flux rate versus time rate of change in the flux rate value from the hillslopes depicted in Figure 1, having a unit width. Flux is measured in liters per hour.

provide information about how the parameters might vary for individual subcatchments or hillslopes within the watershed; indeed, the catchment hydrograph may not contain sufficient information for that end, as *Harman et al.* [2009] point out.

[12] Certainly, there is room for further testing of the hydraulic theory for catchment-scale parameter estimation. Such an approach could be via the application of numerical models (as was demonstrated by *Szilagyi et al.* [1998]) with varying sophistication, in which arbitrarily complex aquifer heterogeneity can be prescribed, or via intensive field campaigns such as those reported by *Rupp et al.* [2004]. So far, both studies supported the applicability of the hydraulic theory for catchment-scale hydraulic parameter estimation.

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References

Brutsaert, W., and J. L. Nieber (1977), Regionalized drought flow hydrographs from a mature glaciated plateau, *Water Resour. Res.*, *13*(3), 637–644, doi:10.1029/WR013i003p00637.

Clark, M. P., D. E. Rupp, R. A. Woods, H. J. Tromp-van Meerveld, N. E. Peters, and J. E. Freer (2009), Consistency between hydrological models and field observations: Linking processes at the hillslope scale to hydrological responses at the watershed scale, *Hydrol. Processes*, *23*, 311–319, doi:10.1002/hyp.7154.

Freer, J., J. J. McDonnell, K. J. Beven, N. E. Peters, D. A. Burns, R. P. Hooper, B. Aulenbach, and C. Kendall (2002), The role of bedrock topography on subsurface storm flow, *Water Resour. Res.*, *38*(12), 1269, doi:10.1029/2001WR000872.

Harman, C. J., M. Sivapalan, and P. Kumar (2009), Power law catchment-scale recessions arising from heterogeneous linear small-scale dynamics, *Water Resour. Res.*, *45*, W09404, doi:10.1029/2008WR007392.

Lam, L., D. G. Fredlund, and S. L. Barbour (1987), Transient seepage model for saturated–unsaturated soil systems: A geotechnical engineering approach, *Can. Geotech. J.*, *24*, 565–580, doi:10.1139/t87-071.

Rupp, D. E., J. M. Owens, K. L. Warren, and J. S. Selker (2004), Analytical methods for estimating saturated hydraulic conductivity in a tile-drained field, *J. Hydrol.*, *289*, 111–127, doi:10.1016/j.jhydrol.2003.11.004.

Szilagyi, J. (2006), Comment on "Using numerical modeling to evaluate the capillary fringe groundwater ridging hypothesis of streamflow generation" by H. L. Cloke, et al., *J. Hydrol.*, *329*, 724–729, doi:10.1016/j.jhydrol.2006.03.020.

Szilagyi, J., M. B. Parlange, and J. D. Albertson (1998), Recession flow analysis for aquifer parameter determination, *Water Resour. Res.*, *34*(7), 1851–1857, doi:10.1029/98WR01009.

Szilagyi, J., Z. Gribovszki, P. Kalicz, and M. Kucsara (2008), On diurnal riparian zone groundwater-level and streamflow fluctuations, *J. Hydrol.*, *349*, 1–5, doi:10.1016/j.jhydrol.2007.09.014.

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