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Interactive comment on "The Landlab OverlandFlow component: a Python library for computing shallow-water flow across watersheds" *by* Jordan M. Adams et al.

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Dear Dr. Michaelides,

Thank you for taking the time to review our manuscript. We appreciate the detail you have put into your comments and believe your suggestions have strengthened the manuscript. Below we have replied to each comment, addressing the concerns regarding the original manuscript.

Many thanks again,

Jordan (on behalf of all authors)

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Discussion paper

This paper presents a new component of the Landlab model that simulates runoff generation and surface-water flows in watersheds. The novelty of this component in the context of landscape evolution models is that: (i) it represents non-steady state runoff (in contrast to other models that typically assume steady state, i.e. Q = PA) and (ii) it implements a two-dimensional hydrodynamic algorithm, the formulation of which allows for computational efficiency and stability on steep and shallow terrains. After presenting details of the algorithms and methods, the paper outlines some example simulations of the performance of the overland flow component on synthetic and real watersheds and compares against the steady-state runoff assumptions of other landscape evolution models (LEMs). Finally, the paper presents fluvial erosion simulations by coupling the flow and incision components in Landlab. I'm excited to see this new component developed and implemented in Landlab and I can see many potential applications and future developments based on it. Technically, I think it is sound and the algorithm developments are quite clearly explained. Overall, this paper will make a nice contribution to GMD and I look forward to seeing it published soon. However, in my opinion the paper requires some restructuring and editing to make it clearer, more focused and to improve the flow.

We thank Dr. Michaelides for her comments.

There are few aspects of the paper that need to be more clearly explained up front. For me these are:

General comments:

1) What are the intended timescales of application of OverlandFlow (event, year, decade, 10ËĘ3y, 10ËĘ4y, 10ËĘ5y etc.)? If is intended to be flexible, then some discussion is needed as to how the various modes can be implemented (especially the long timescales which are not addressed in the paper). Given the myriad of watershed hydrological models out there that can do what OverlandFlow does and much more for event to decadal scales, I feel that the novelty of this component within Landlab would

be better pitched as an improved flow component within an LEM.

We have tested from event to 10,000 year scales on a desktop machine. We have added specific language to both the abstract and future applications sections to reflect these timescales. In this updated text, we also added some discussion about the flexibility of the different timescale opportunities, and how high-performance computing can extend this model even further.

2) As a hillslope person, I get easily confused with phrases “throughout the watershed” as I tend to think that includes the hillslopes as well as the channel. It would be very helpful if the paper explained more clearly what processes occur in which parts of a basin. I assume that OverlandFlow could be coupled to a surface wash geomorphic transport law (GTL) on the hillslopes? This could be discussed in section 8.

This is an excellent point. We have now clarified early on that the OverlandFlow component can route a hydrograph at all points, on hillslopes and channels. We have also changed some references throughout the text and figure captions to specify channels, particularly when hydrographs are plotted. The future applications section also now mentions sheet-wash as a potential coupling opportunity.

3) There is no mention of infiltration until section 8 at the end of the paper. I think it would be very helpful to the reader if the assumptions are mentioned up front and if there was a clear explanation behind the rationale of effective rainfall and how this is calculated for the examples. I think there is an existing Green and Ampt infiltration component for Landlab, so I assume this can be easily coupled to OverlandFlow? Again, this would be worth discussing.

We have added several mentions to infiltration in the text now, particularly focusing on how the model (by default) assumes no infiltration explicitly. As a model description paper, we kept the assumptions simple to keep the results clear. The future work section notes coupling with infiltration as an opportunity for evaluation.

4) Hydrological theory needs beefing up in the background section as many of the model results discussed are common knowledge in hydrology. Please provide theoretical background on runoff generation, steady vs nonsteady runoff, spatial and temporal variations in discharge and the role of basin characteristics, and the impact of this runoff on erosion and incision.

All very good points. To address this, we have added a paragraph about the traditional hydrology methods, with focus on the steady-state (Q = PA) assumption. Additionally, we added discussion about how discharge scales with temporal rainfall patterns, per the study of Huang and Niemann (2014). Finally, there has been discussion added about the steady-state assumption's failure to capture differences in basin organization and shape, even though theoretical background in hydrology states that basin characteristics drive hydrograph shape. For example, watersheds with identical drainage areas but different basin shapes may have dramatically different outlet hydrographs not captured by steady-state assumption.

Specific comments:

1) Manuscript structure: My personal preference would be for the two 'Background' sections (6.1 and 7.1 on p. 9 and 11) to be incorporated into the Introduction of the paper. Much of the information in those sections is key to appreciating the new component developments (i.e. steady state vs non-steady state runoff) and the impacts on fluvial incision. The novelty of the new component (relative to typical approaches in LEMs) needs to be stated much more clearly upfront.

These sections have been moved to the introduction.

2) Abstract: The first couple of sentence do not link well to the rest of the abstract and they lack flow to the rest of the section. I'm not convinced that a couple of token general sentences about hydrological or rainfall-runoff models add anything or help direct the reader. I think what would work better would be to discuss the hydrological capabilities of LEMs and go from there. There is a plethora of very sophisticated hydrological

models for event to decadal timescales, which is probably not relevant in the context of Landlab – so I'm not convinced that those are the ideal starting point for the paper. Finally, I think that the abstract should more clearly state what the novelty of the new component is, what the assumptions in the paper are (i.e. no infiltration), and what the timescales of the application in this paper are (i.e. individual storm to 10 years of simulation). On [5] what do you mean by "longer term landscape evolution"?

We have reworded the first few sentences to explicitly outline how this model is different from traditional landscape evolution models. We have now clearly stated all assumptions, and reworded the abstract to include the timescales explored. Additionally, we clarified what is meant by traditional rainfall-runoff application of OverlandFlow (event scale) and what we mean by landscape evolution applications.

3) Introduction (p.2): The opening paragraph [2-6] is in my opinion, a slightly odd (atypical) selection of applications for overland flow models. Maybe it's just me, but I wouldn't put urban flooding and post-wildfire runoff as the top two examples of overland flow models! Again, I'm not so sure that this section is even needed. I would focus the discussion on the hydrology within LEMs which are still relatively unsophisticated in terms of hydrological processes compared to hydrological models. Because even in your improved representation, there is a lack of hydrological processes (subsurface or infiltration components), and is predominantly therefore, a flow routing algorithm (using uniform effective rainfall as a proxy for runoff generation). In other words, if you were developing a watershed hydrological model for use over short timescales (event to decades) then this would not really be considered that novel.

We have reworded this section and added several more recent citations. We want to appeal to both hydrology and geomorphology communities, so we left all of the hydrology commentary in. This is because all hydrologic processes could eventually be possible within the Landlab framework, even if they are not fully complete now. We have also added discussion about traditional landscape evolution/steady-state assumptions, and explained how this new model and method differs from existing models.

4) p2 [12-13] merge these two sentences as they repeat the same thing.

Completed.

5) p2 [18] What is a “hydrological timestep” and a “geomorphic timestep”? Do you mean timescale?

Changed to address timescales particularly, not timesteps.

6) P2 [22] I would say most (not “many”) hydrological models route storm hydrographs through basins and represent non-steady discharge. This is a pretty standard feature in watershed hydrological models.

Changed to “most”.

7) P2 [30 34] and P3 [1-9] It would be helpful if the introduction included some outline of hydrological theory regarding runoff generation, steady vs nonsteady runoff, spatial and temporal variations in discharge and the role of basin characteristics, and the impact of this runoff on erosion and incision. I just feel like we’re missing a step or two in fundamental theory which would provide a useful backdrop to the reasonableness or not of the various assumptions in LEMs.

This has been added, our response to an earlier comment (General Comment #4) addresses this specifically.

8) P3 [17] What is “short-term landscape evolution”? Please define “short-term” in this context.

Specified that short-term meant decadal scale runs.

9) P3 [23] “scientific problems” is too vague.

Clarified to address that Landlab can be used to address a range of hypotheses in Earth-surface dynamics.

10) P5 [21-22] “too-large timesteps” and “too-small timesteps” is awkward expression.

Please reword and also define “too small” and “too large” in this context.

Moved discussion about the Courant number requirement to earlier in the paragraph, to put the timestep into context. Also changed wording to clarify the “too-large” or “too-small” timesteps.

11) Section 3.1: Please explain how rainfall is treated. I am assuming there is no infiltration component (as there is no mention of infiltration) – so how do you derive this effective rainfall rate over the basin?

A paragraph was included at the end of this section about the default behavior of the model, regarding precipitation and infiltration assumptions that addresses this.

12) P6 [21] Does “flat” mean zero slope or less than some threshold?

Changed to state explicitly that we meant low-to-zero slope environments.

13) P6 [23] “Similar criterion were implemented” – reword as either ‘a similar criterion was implemented’ or ‘similar criteria were implemented’.

Reworded.

14) P7 [1] What is the meaning of “water discharges driven by overland flow”?

Reworded this to state that water discharges are calculated by the OverlandFlow component and used in model coupling.

15) P9, section 6.1 first 6 lines of Background feel too cursory.

This was moved into the introduction, per the earlier comment. It was also put into more context by adding more discussion and citations.

16) P10 [5-10] “Changing discharge values” unclear

Reworded this part to clarify.

17) P 10 [18] Are hydrologists the target audience here? Not geomorphologists? If so,

there needs to be some discussion of the assumptions (no infiltration, no subsurface flows etc.) that hydrologists would care about.

We have addressed the assumptions in the application descriptions.

18) P10 [23] Please provide a sentence or two as to why Spring Creek was chosen as a test case.

The Spring Creek watershed was selected because there is an abundance of field data for the site, collected by the U.S. Geological Survey. This DEM has already been used in previous Landlab work (the Hobley et al., 2017 cited within this manuscript). The DEM was pre-processed for use in Landlab, and we have added text to reflect this in section 6.1.

19) P10 [32-33] Please explain why 5 mm/h for 2 hours was chosen as the effective rainfall. Is this based on real data or chosen as a typical value for that place? Is this supposed to represent a large storm? 10 mm of uniform surface overland flow (effective rainfall) over a whole basin is pretty high.

We used an approximate depth from a NOAA dataset for central Colorado that is now cited in the text. This estimated a storm depth of 10 mm in 1 hour, with a 1 yr storm recurrence. We systematically increased and decreased duration to keep the depth the same for all storm runs. Text was added to reflect this.

20) P11 [1-2] Please explain the rationale for doing this. The peak Q at the outlet is unlikely to correspond to the peak shear stress on the hillslopes or other parts of the channel.

This was an excellent point. We have now updated Fig. 8 and text within section 6 and subsections to show the maximum shear stress value calculated each point.

21) P11 [5-15] These are not really results – it's as you would expect (basically, the model is behaving)

We have made it clear in the text that these are not results, but that the model is performing as it should.

22) P11 [22] What is the meaning of “the flow of hydrographs”?

This was an error. It has now been fixed.

23) P13 [1] “Discharge was recorded at all points throughout the watershed”. Does this mean on hillslopes and in channels? Please be specific.

In these runs, there are no “true hillslopes” in this model, as the landscape was evolved using a channel incision method. This has been clarified at all mentions in the text.

24) P13 [13-15] What is the rationale for looking at 10 year simulations?

Decadal scale runs were used as they are easy to reproduce on a personal machine, using the GitHub repository associated with this paper. These results can be used to make inferences about long-term landscape evolution runs.

25) P13 [22] “all points in the hydrograph are much less than the predicted steady-state”. Unclear sentence. Do you mean the non-steady discharge is always lower than the steady state discharge or that the total volume of water exiting the basin is lower?

We have updated the text to clarify this thought. Now it states that the actual discharge values represented in the hydrograph are less than predicted steady-state. The total volume of water is unchanged between steady-state and non-steady state, as all mass is conserved in the model.

26) P13 [25-30] As expected.

Changed in text.

27) P14 [3-5] What is the meaning of comparing erosion results from one single storm to geomorphic steady state?

We are comparing predicted steady-state erosion rate to the erosion drive by several

events (10 years). We have now clarified this in the text.

28) P14 [13-16] This is missing some context. It is the first mention of 10 years and number of storms (intensity, duration etc.).

We have outlined this in an earlier section, 7.1.

29) P15 Section 8. First mention of infiltration here. Needs to come further up. Beyond the examples of applications of this component, here I would really like to see more discussion of how the representation of hydrological processes may evolve within Landlab in the future and how the authors envision this rainfall-runoff component will be used to simulate long-term landscape evolution driven by surface wash (on hillslopes) and fluvial incision. It would be good to see some reflection on the representation of spatial variability too (e.g. in surface properties). I think you're missing a great opportunity to sell this model and its future potential by pitching to the landscape evolution / geomorphic community.

We have added considerable discussion to the future applications section. This includes addressing the longer-term landscape evolution question and possible applications distinguishing the difference between hillslope and channel processes.

30) Fig 6: Only channel hydrology

Changed text to state that the hydrographs are taken from within the channel.

31) Fig 7: Please redefine within caption h, S, n and all other symbols used in figure.

Updated figure caption per this suggestion.

I hope this helps. I look forward to seeing it published soon, and I will attempt to use it myself at some point! Best wishes, Katerina Michaelides

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