

Small steps and giant leaps?

(Thoughts for the future based on a decade of progress in understanding and modelling hydrologic and erosion processes)

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Sheffield Centre for



...with a little help from:

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- Andy Baird
- Nikki Dodd
- Sarah Dunn
- • •





The problem

Photron	FASTCAM-APX RS m	
3000 fps	1/0 sec	1024 x 1024
Center	frame : 314	+00:00:00.10433





Overall framework



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Lajeunesse *et al.* (2010) WRR



A small step backwards ...

• Why model?



Epstein's Sixteen Reasons Other Than Prediction to Build Models (JASSS vol. 11, no. 4 12):

- Explain (very distinct from predict)
- Guide data collection
- Illuminate core dynamics
- 4. Suggest dynamical analogies
- Discover new questions
- 6. Promote a scientific habit of mind
- 7. Bound (bracket) outcomes to plausible ranges
- 8. Illuminate core uncertainties.
- 9. Offer crisis options in nearreal time

- 10. Demonstrate tradeoffs / suggest efficiencies
- Challenge the robustness of prevailing theory through perturbations
- 12. Expose prevailing wisdom as incompatible with available data
- 13. Train practitioners
- 14. Discipline the policy dialogue
- 15. Educate the general public
- 16. Reveal the apparently simple (complex) to be complex (simple)





A simple exercise in data collection? (A historical step backwards)

R

A journey of a thousand miles begins with a single step Lao-Tzu





What do we measure when we measure "erosion"?



Conventional (implicit) assumption

Assuming limited transport distances



Assuming exponential transport distances (and uniform slope conditions)





Sohn Wainwright: john.wainwright@durham.ac.uk on sediment flux x + Lx + L(x) $\varphi(x + L) = \int E(\xi) \cdot d\xi \quad \dots \gg \quad \varphi(x + L) = \int K_1 e^{-2u^{4/9}}$ du



Theoretical curves for interrill erosion based on travel distance (Parsons et al., 2004)





Flume



21 m² & 2 m²

O John Wainweight, joon wain wight@2urham.ac.uk

57 m² & 2 m²

302 m² & 2 m²



Analytical scaling based on sediment flux x + Lx + L(x) $\varphi(x + L) = \int E(\xi) \cdot d\xi \quad \dots \gg \quad \varphi(x + L) = \int K_1 e^{-2u^{4/9}}$ du



Theoretical curves for interrill erosion based on travel distance (Parsons et al., 2004)

















MAHLERAN - Marker in Cell













Magnetite study 16 years later...





MAHLERAN - Marker in Cell





Dynamics of Runoff And Erosion Modelling (DRÆM)



New techniques



www.shef.ac.uk/draem





Dynamics of Runoff And Erosion Modelling (DRÆM)



Interaction of single water droplet with a flat surface – Particle Tracking



3000 fps, 1024 x 512 pixels (64.6 mm x 32.4 mm), 0.063 mm/pixel resolution Water diameter = 2 mm, Sand Dia. < 212 μ m, Height 0.5 m, Impact velocity = 2.8 m s⁻¹

Long et al. (forthcoming)



The University Of Sheffield.



-2.1

-2.2

-2.3

2.4

-2.5

-2.6

-2.7

-2.8

-2.9

-3.0

-3.1

-3.2

-3.3

-3.4

-3.5

-3.6

-3.7

-3.8

-3.9

z-displacement [mm]



Long et al. (forthcoming)





RFID tagging of particles









Moving up in Scale





© John Wainwright: john.wainwright@durham.ac.uk Connectivity: joined-up thinking?

Changes in measured water and sediment flux as flux as vegetation structure changes from grass to shrub

Turnbull *et al.* (2010) *Hydol Proc* (2010) *Ecosystems*









Chaos is merely order waiting to be deciphered José Saramago

Complexity and evolution

Top-down (Newtonian*)

- Grid- or element-based (usually fixed)
- Imposed model structure across entire domain
- Assumes system "knows" about all other parts
- Represents dynamics but in a static way

Bottom-up (Darwinian*)

- Cell-, particle- or individual-based (and may change through time)
- Model based on local interactions or rules
- Only interacting elements "know" about each other
- Can represent evolutionary dynamics







Longer time scales



change over 742 ka based on EPICA DOME C core of Augustin et al. (2004)



Small changes in catchment structure

Produce complex patterns in catchment runoff and sediment flux as a result of changing climate

... which are even more complex when rainfall and temperature change are asynchronous

Wainwright (2006) Catena





Comparison against sedimentary data





Briant et al. (forthcoming)







vegetation cove





kg m⁻²

7500

5000

2500

 Incorporates dynamic behaviour of animals and vegetation and effects of human decision-making Wainwright (2008); Wainwright and Millington (2010)



Closing Thoughts

- Models have various uses, so too must data
- What are the inbuilt assumptions of existing models (and thus data)?
- Parameterization based on physical principles rather than empirical convenience ...



An example of limited parameterization data

- The threshold for flow detachment for mixtures of particle sizes can be demonstrated to vary significantly about the threshold for a uniform particle size ...
- ... so threshold parameters cannot be independent of each other (and must change dynamically) Wainwright *et al.* (2003)





Closing Thoughts

- Models have various uses, so too must data
- What are the inbuilt assumptions of existing models (and thus data)?
- Parameterization based on physical principles rather than empirical convenience ...
- ... and thus also be dynamic
- ... and reflect uniqueness of place
- What do models produce? And is it the same with data?
- So what are we actually doing when we compare models with data?



Closing Thoughts

- How "valid" are "validation" data?
- Most data have implicit scales which need to be recognized when parameterizing models
- Calibration is NEVER the last step of a study (nor is application of a calibrated model)
- Connectivity means seeing the environment as a whole
- ... which means also speaking to other environmental (including social) scientists (disciplinary connectivity)
- Complex response means we need to test the limits of existing reductionist approaches

Thank you for listening!

Questions?



References

- Parsons, AJ, J Wainwright and AD Abrahams 1993 'Tracing sediment movement on semi-arid grassland using magnetic susceptibility', *Earth Surface Processes and Landforms* **18**, 721–732.
- Wainwright, J, AJ Parsons, DM Powell and RE Brazier 2001 'A new conceptual framework for understanding and predicting erosion by water from hillslopes and catchments', in JC Ascough II and DC Flanagan (eds) Soil Erosion Research for the 21st Century. Proceedings of the International Symposium, 607–610, American Society of Agricultural Engineers, St Joseph, MI.
- Brazier, RE, DM Powell, AJ Parsons and J Wainwright 2003 'Monitoring and modelling runoff in semi-arid areas from the hillslope to the watershed scale', in KG Renard, SA McElroy, WJ Gburek, HE Canfield and RL Scott (eds) *First Interagency Conference on Research in the Watersheds (Benson, Az, October 27–30, 2003)*, 101–106, USDA-ARS, Washington DC.
- Powell, DM, RE Brazier, J Wainwright and AJ Parsons 2003 'Stream bed scour and fill in loworder ephemeral stream channels', in KG Renard, SA McElroy, WJ Gburek, HE Canfield and RL Scott (eds) *First Interagency Conference on Research in the Watersheds (Benson, Az, October 27–30, 2003)*, 180–185, USDA-ARS, Washington DC.
- Parsons, AJ, J Wainwright, DM Powell, J Kaduk and RE Brazier 2004 'A conceptual model for understanding and predicting erosion by water', *Earth Surface Processes and Landforms* **29** (10), 1293–1302.
- Powell, DM, RE Brazier, J Wainwright, AJ Parsons and J Kaduk 2005 'Stream-bed scour and fill in low-order dryland channels', *Water Resources Research* 41, W05019, doi:10.1029/2004WR003662.
- Parsons, AJ, J Wainwright, RE Brazier and DM Powell 2006 'Is sediment delivery a fallacy?', Earth Surface Processes and Landforms **31**, 1325–1328.
- Parsons, AJ, RE Brazier and J Wainwright 2006 'A conceptual model for sediment and nutrient fluxes from rural land', International Journal of Biodiversity Science and Management 2, 1–3.
- Parsons, AJ, RE Brazier, J Wainwright and DM Powell 2006 'Scale relationships in hillslope runoff and erosion', *Earth Surface Processes and Landforms* **31**, 1384–1393.
- Powell, DM, RE Brazier, J Wainwright, AJ Parsons and M Nichols 2006 'Spatial patterns of scour and fill in dryland sand bed streams', *Water Resources Research* **42**, W08412, doi:10.1029/2005WR004516.
- Powell, DM, RE Brazier, AJ Parsons, J Wainwright and M Nichols 2007 'Sediment transfer and storage in dryland headwater streams', *Geomorphology* **88**, 152–166.
- Brazier, RE, AJ Parsons, J Wainwright, DM Powell and WH Schlesinger 2007 'Upscaling understanding of nutrient dynamics associated with overland flow in a semi-arid environment', *Biogeochemistry* **82**, 265–278. Doi: 10.1007/s10533-007-9070-x
- Müller, EN, J Wainwright and AJ Parsons 2007 'The impact of connectivity on the modelling of water fluxes in semi-arid shrubland environments', *Water Resources Research* **43**, W09412, doi:10.1029/2006WR005006.

- Müller, EN, J Wainwright and AJ Parsons 2007 'The stability of vegetation boundaries and the propagation of desertification in the American Southwest: a modelling approach', *Ecological Modelling* **208**, 91–101.
- Parsons, AJ, J Wainwright, RE Brazier and DM Powell 2008 'Is sediment delivery a fallacy? Reply', *Earth Surface Processes and Landforms* **33**, 1360–1361. DOI: 10.1002/esp.1627.
- Parsons, AJ, J Wainwright, RE Brazier and DM Powell 2008 'Scale relationships in hillslope runoff and erosion. Reply', *Earth Surface Processes and Landforms* **33**, 1637–1638. DOI: 10.1002/esp.1628.
- Tatard, L, O Planchon, J Wainwright, G Nord, D Favis-Mortlock, N Silvera, O Ribolzi, M Esteves and C-H Huang 2008 'Measurement and modelling of high-resolution flow-velocity data under simulated rainfall on a low-slope sandy soil', *Journal of Hydrology* **348**, 1–12. doi: 10.1016/j.jhydrol.2007.07.016.
- Wainwright, J, AJ Parsons, EN Müller, RE Brazier, DM Powell and B Fenti 2008 'A transportdistance approach to scaling erosion rates: 1. background and model development', *Earth Surface Processes and Landforms* **33**, 813–826. DOI: 10.1002/esp.1624
- Wainwright, J, AJ Parsons, EN Müller, RE Brazier, DM Powell and B Fenti 2008 'A transportdistance approach to scaling erosion rates: 2. Sensitivity and evaluation of MAHLERAN', *Earth Surface Processes and Landforms* **33**, 962–984. DOI: 10.1002/esp.1623
- Wainwright, J, AJ Parsons, EN Müller, RE Brazier, DM Powell and B Fenti 2008 'A transportdistance approach to scaling erosion rates: 3. Evaluating scaling characteristics of MAHLERAN', *Earth Surface Processes and Landforms* **33**, 1113–1128, DOI: 10.1002/esp.1622
- Wainwright, J, AJ Parsons, EN Müller, RE Brazier and DM Powell 2009 'Response to Hairsine's and Sander's "Comment on 'A transport-distance based approach to scaling erosion rates:' Parts 1, 2 and 3 by Wainwright *et al.*", *Earth Surface Processes and Landforms* **34**, 886–890, DOI: 10.1002/esp.1781.
- Wainwright, J, AJ Parsons, EN Müller, RE Brazier and DM Powell 2009 'Response to Kinnell's "Comment on 'A transport-distance approach to scaling erosion rates: 3. Evaluating scaling characteristics of MAHLERAN'", *Earth Surface Processes and Landforms* **34**, 1320–1321.
- Brazier, RE, J Wainwright and AJ Parsons 2010 'Scaling soil-erosion models in space and time', in RPC Morgan and MA Nearing (eds) *Handbook of Erosion Modelling*, 98–116, Wiley-Blackwell, Chichester.
- Parsons, AJ, J Wainwright, T Furukawa and Y Onda 2010 'Using sediment travel distance to estimate medium-term erosion rates: a sixteen-year record'. *Earth Surface Processes and Landforms* 35, 1694–1700. DOI: 10.1002/esp.2011.
- Turnbull, L, J Wainwright and RE Brazier 2010 'Hydrology, erosion and nutrient transfers over a transition from semi-arid grassland to shrubland in the South-Western USA: a modelling assessment'. *Journal of Hydrology* **388**, 258–272, DOI:10.1016/j.jhydrol.2010.05.005.
- Wainwright, J, AJ Parsons, EN Müller, RE Brazier and DM Powell 2010 'Standing proud: a response to "Soil-erosion models: where do we really stand?" by Smith *et al.*', *Earth Surface Processes and Landforms* **35**, 1349–1356, DOI: 10.1002/esp.2047
- Turnbull, L, J Wainwright and RE Brazier 2011 'Nitrogen and phosphorus dynamics during runoff events over a transition from grassland to shrubland in the south-western United States'. *Hydrological Processes* **25**, 1–17. DOI: 10.1002/hyp.7806