

## ***Interactive comment on “Darwinian hydrology: can the methodology Charles Darwin pioneered help hydrologic science?” by C. Harman and P. A. Troch***

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We would like to thank Dr Baker for taking the time to respond to our paper with this level of insight and intellectual depth. Our interest in philosophy is a practical one – a means to an end – resulting from our aim to find better ways to pursue hydrologic understanding. The opportunity to engage with someone whose interest and philosophical understanding runs so much deeper will certainly help us improve the manuscript, and our thinking.

Dr Baker has provided an excellent summary of our intent: to clarify the meaning of the

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term “Darwinian” and how it relates to the frequently-articulated need to go beyond the emphasis on fluid physics in hydrology, and engage with the complexity of landscapes. We appreciate his support for the overall message of the paper.

At the risk of over-simplifying or misrepresenting, we here summarize (in italics) the main concerns in his review and comment on each:

1) ***“Newtonian and Darwinian” science.*** *The designations of “Newtonian” and “Darwinian” are applied to ‘multiple, diverse concepts’, and more clarity is needed to define just which of these concepts we are interested in.*

This concern was echoed in other reviews and highlights an area where our communication certainly needs to be improved. We have not made a clear enough distinction between what we see as the most fundamental aspects of the Darwinian approach, and the additional concepts that aid that approach but are not fundamental to it. In our view, the most fundamental aspect is the kind of knowledge sought – the tools most suited to obtain that knowledge are derived from it, and therefore do not define it. The search of the Darwinian type of knowledge is nicely summarized by Dr Baker as: “...a scientific goal for hydrology that would place much more emphasis on the formulation of bold hypotheses to explain causally the patterns that are discerned in the course of hydrological investigations of populations of individual watersheds as they vary across time and space”

The hypothetico-deductive method Gheslin ascribes to Darwin is an attempt to abstract Darwin’s intellectual process as he so successfully reached for this kind of knowledge. We will be sure in a revised paper to clarify the distinction between these abstractions by Gheslin and others and the central Darwinian concept.

2) ***The “Newtonian” worldview and hydrology.*** *The ‘Newtonian’ moniker mischaracterizes the nature of Newton’s own work, which was not aimed at prediction in an engineering sense, but rather at understanding physical laws.*

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It is certainly also our understanding that Newton was not an engineer, and so was not in the business of accurate predictions. Rather his interest was in discovering the 'natural laws' that governed the universe. He could learn by making predictions and comparing them to data, but accurate prediction per se was not the point. This historical point is worth making (and we will do so in the revision), but it is also the case that the term 'Newtonian' has come to be associated with the kind of applied physics frequently invoked when constructing 'physically based' models for hydrologic prediction.

3) **The Darwinian worldview and hydrology.**

a. *Luna Leopold's 1994 paper makes some similar arguments to our paper, and some different ones, though it was focused on rivers.*

Thank you for drawing this to our attention. We will mention this work in the text and discuss the connections and contrasts with our ideas.

b. *The deductive step in the method described does not derive consequent hypotheses.*

We will replace 'hypotheses' here with 'conditions'.

c. *Darwin was not the pioneer of the methods of doing historical science, but rather they exemplify methods of geologic reasoning that pre-date him.*

We will amend the manuscript to point out that Darwin was not the first to use these methods, though he was clearly an early and successful exemplar of them. While his methods may be reflected modern methods of geological reasoning, this is surely partly the result of their demonstrated usefulness.

Furthermore, we should point out again that the use of methods like "extrapolating mechanisms, space for time substitution, and looking for patterns in history" is not what defines the fundamental nature of the "Darwinian" approach (see point 1).

4) **Darwin's methods.** *Darwin was not an advocate of methodologies like 'falsification-*

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*ism', and 'hypothetico-deductivism'. These are philosophical concepts that arose after Darwin and have been since challenged within philosophy.*

Dr Baker's comments here are illuminating. We have attempted to use the references provided to improve the manuscript. We do not wish to ascribe ideas to Darwin that he did not believe, and so we will aim to provide a clearer distinction between his actions and the methodologies that others have ascribed to him, including Ghiselin (1969).

The point about abduction is particularly interesting. This type of logical inference is apparently not well understood, even by practicing scientists, even though it is the sole source of novel causative hypotheses (if I understand Godfrey-Smith's arguments correctly)! The capacity to 'abduct' seems to be associated with the mysterious insight that a good scientist has, derived from some combination of broad experience and creativity.

5) *and the interpretive-historical sciences. While the 'historical sciences' are not geared towards making predictions, they have other advantages over the theoretical/experimental sciences. In particular 'the evidentiary process of the historical sciences is less concerned with prediction followed by confirmation/refutation than it is with the explanatory power associated with various hypotheses'.*

There are again many interesting points here, and we will keep them in mind as we revise the manuscript, but cannot do them justice without greatly expanding the scope (and length) of the paper! We hope that Dr Baker will expand on them in a future commentary of his own.

6) **Overemphasis on prediction.** *Prediction was not Darwin's aim, and aiming for better understanding in the service of better predictions will impoverish both. This echoes an earlier comment that 'combining the engineering goal of reduced uncertainty with the scientific goal of discovering something new about nature produces a hybrid that is neither good science nor good engineering, but is instead a combination that is but an impoverished cousin to each'.*

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This dichotomy is a serious issue that has (and will continue to be) debated within the hydrologic community. Tom Dunne articulated aspects of this challenge in his 1997 Wolman lecture to the National Research Council when he discussed whether there is a distinction between “applied hydrology” and “applicable hydrologic science”. Rather than argue that the goals of science and engineering are incompatible, he argued that a vital hydrologic science “confronts and even gains energy from its own uncertainties.” Scientists are rightly rewarded for focusing their attention on areas where our predictive uncertainties are greatest and the consequences of poor predictions most costly. Conversely, engineers frequently seek and find fundamental insights in the service of prediction – take for example the theory of information entropy developed by Claude Shannon as he worked at Bell Labs to improve electronic communication.

As we see ourselves as both engineers and scientists, we hope that it is possible to work in the service of both improved understanding and improved prediction. However, in order to avoid Dr Baker’s ‘impoverished hybrid’ it may be necessary to let one aim take priority over the other in specific cases as needed.

This is a stimulating topic, but not one that we can do more than touch on in the paper at hand. Again, we hope that Dr Baker will lay these ideas out in more detail in the future.

7) **The time factor, change, and the role of paleohydrology.** *‘I propose then that there is a “missing link” in what obviously needs to be added to define the “quintessential” problem of hydrological theory, and that this link is paleohydrology, which is the branch of hydrology that studies the past evidence of hydrological changes in much the same way that paleontology functions to study the past realities of evolution, a process of change that operates through time.’*

It is arguable that the gap between paleohydrology and the parts of hydrologic science focused on contemporary hydrologic processes is partly caused by the absence of a Darwinian hydrology that unites them. We have written this paper from the perspective

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of the latter group, and have precious little expertise in paleohydrology. We hope that our paper inspires some paleohydrologists to join with us in looking for ways to bridge that gap and bring to bear the technical advances that Dr Baker mentions.

8) **“Just-So” Stories.** *‘While this may seem to be a minor point, I am unclear as to why this terminology is being used (page 6408, line 17 and page 6420, line 16), unless perhaps because some Newtonian hydrologist might be inclined to apply it to a Darwinian explanation.’*

We will change this language to avoid clouding the central point here. We are referring to hypotheses that are plausible but are presented as conclusions in the absence of supporting evidence.

9) **Darwin’s Uniformitarianism.** *‘There are kinds of evolution in which rapid change occurs though extreme events that punctuate otherwise uniform rates. One should not exclude a-priori the possibility that hydrological science, pursued in the mode of the historical sciences that Darwin’s work exemplifies, might discover such modes of change in drainage basins.’*

We do not wish to exclude such possibilities, and will mention this in the revised text.

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