Author Responses

Re-discovering Robert E. Horton's Lake Evaporation Formulae: New Directions for Evaporation Physics

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Dear Dr. McMahon,

Thank you for your valuable review comments. Prof. Singh and I reviewed your comments, and we provide our point-by-point response below.

For convenience of reading, we have indented your comments, reduced font size, italicized, and changed color to blue.

Thanks and best wishes,

Solomon Vimal and Vijay P. Singh

Responses to Reviewer 1 Comments

> TM: I am privileged to review this excellent article. The authors have provided an eclectic assessment of Robert E Horton's lake evaporation formula. All of us until now have considered Horton's evaporation equation as another in a long list of empirical equations available to estimate lake evaporation. Solomon Vimal and Vijay Singh have provided us with a forensic analysis of Horton's research, much of which is buried as unpublished material.

SV and VS: We are privileged to have you as a reviewer, as your recent review paper on the subject of evaporation (McMahon et al, 2019) was a key reference for us. We thank the Handling Editor (Prof. Beven) for requesting your comments.

> TM: The authors have discussed thoroughly each aspect of the vapour removal from a water surface - diffusion, wind action and convection – in relation to each component of Horton's lake evaporation formula. In doing so they have provided at least to this reviewer a unique explanation of the various evaporative processes that occur at or near the lake surface.

The paper addresses a key question in hydrology, and it is most appropriate that it be published in HESS. Not only is it novel, but it addresses an important hydrologic issue, the calculation of lake evaporation. The title of the paper reflects clearly the content and sufficient details are provided in the Abstract for a curious reader to be excited to read it.

Although long in length, the paper is clearly and concisely written.

SV and VS: We are delighted to receive your positive feedback.

TM: I do have a number of edits, mainly minor, which I list below. Because Horton worked in the US system of measurement, the discussion around numerical values is mainly in those units. I strongly recommend the authors include the metric equivalent values wherever possible especially with respect to key parameters and equations, for example, Equation 3b.

SV and VS: Thank you for this comment. We will include metric equivalents in the Supplementary as part of a visual flowchart type schematic for practitioners, which also addresses a later comment of yours about outlining the steps to compute pan and lake evaporation in an easy to follow manner for practitioners. We will direct the reader to Supplementary in multiple places in the paper such that the reader will not miss it.

TM: L72: "etc" is unhelpful. Please insert other contributions or delete.

SV and VS: Thank you for pointing this out, we have deleted it.

L84: It would be helpful for future researchers to include in the supplementary material not only the year and title of Horton's work but also where the material can be accessed.

SV and VS: The paper links are not fully verified (some are broken), so it does not fit within our schedule to include the full reference with this paper, but we invite anyone interested to drop us an email for the current in-progress spreadsheet where citations and access details are available for many of Horton's papers.

Though we cannot at this time share an incomplete citation list, to aid the reader and to address the comment, we will include a section in Supplementary, titled, "**Tips to find Horton's papers and full bibliography:** 1) google this: "$title + $year + "Robert E. Horton" (side note: we found it easy to save the full citation using Zotero's plugin for browsers); 2) search in AGU's Virtual Hydrology bibliography list maintained here - https://connect.agu.org/hydrology/vhp-scope/roberthorton; 3) Check the online archive of Albion College (Horton's *Alma Mater*) ; 4) contact SV by email to check in his personal, unfinished, bibliography (access can be granted to an in-progress Google Sheet where notes on bibliography and the content and working website/download link are curated); 5) Go to National Archives in Maryland and dig into the 94 boxes (see list

of boxes in Beven, 2004a). One of these 5 approaches should help you access the full paper and citation.

L102: I think the word "kettle" will be unfamiliar to many. May I suggest this be briefly explained or another term used.

SV and VS: Thank you for pointing this out, we will include a brief explanation.

L102: Please indicate the location of the Hemlock lake system.

SV and VS: This is a good idea, we will do so.

L113: Comment in parenthesis is incorrect. The citation to Horton was from Rohwer (1931) as noted in Table 1 of McMahon et al. (2016).

SV and VS: Thank you for this comment. We cited Rohwer (1931), see in L59, but perhaps it is good to cite it again here.

L305: The term evaporative capacity is used several times in Section 3.1 and in Section 3.3. I am confused by its use. (i) Is this a term used by Horton? If so, then that should be made clear in the presentation. (ii) While I appreciate it is defined clearly in Equation1(a), it is, in fact, the pan evaporation. Why introduce a new term? (iii) In L315, the term Evaporation capacity is used. Is there a subtle difference between "evaporation capacity" and "evaporative capacity"? Is one a function of Vw and the other a function of Va? (iv) The definition in L320 appears similar to potential evaporation.

SV and VS: Thank you for noticing this. In L307, we noted the same point as (ii) in your comment, that, "Pan evaporation (E_P), which is the same as evaporative capacity from lake (E_{Cw})". The reason behind using two terms to mean the same thing is that we wished to highlight that Horton used different terms to mean the same thing, so while reading his papers, the authors can bear this in mind to avoid any confusion. We will clarify this to avoid confusion in the three instances where we may expect readers to have the same confusion as you did (i.e. in L305, L315 and L320).

L314, "… in Sec 3": But this line is in Section 3.1. It seems to be referring to itself.

SV and VS: Thank you for noticing this. We will change it.

L314, "We provide revised values in Sec. 3 (Table 3)": This paragraph refers only to constant C. There is only one value of C in Table 3.

SV and VS: Thank you for noticing this. We will change it.

L315: "w.r.t": Suggest this be spelt out, and elsewhere in the manuscript.

SV and VS: Thank you for noticing this. We will change it.

> *L323, 324: To me, this sentence is particularly important and may not be appreciated by practitioners wishing to apply Horton's equation. To aid future applications, it would be very helpful if the authors were to add another section to the manuscript listing succinctly the steps in applying Horton's procedure to an evaporation pan and to small and large lakes.*

SV and VS: Thank you for this comment. We will include a simple visual schematic to show practitioners, and note this in the conclusion so interested readers/practitioners can have a quick guide rather than add more text. We think the right place for this might be the supplementary section as the text is already very long.

> *Ls432,433: Clumsy sentence, needs rephrasing.*

SV and VS: Thank you for noticing this. We will rephrase it as follows: "Similar important observations from experiments by various scientists (Dalton, Schübler, Soldner) have not been taken into consideration in modern mass-transfer formulations of evaporation.".

> *L438: Unclear what is meant by "... motivate the position ...".*

SV and VS: Thank you for this comment. To make it clear, we will reword this as follows: "the position of the term allows the equation to generalize for condensation".

> *Ls503,505: In Equation (4a), why introduce another variable Ecw when it equals Ep, and thus F = EL/Ep. By not introducing Ecw, the explanation would be less tortuous.*

SV and VS: Thank you for this comment. We believe this comment was also raised by the Editor. We pondered if we should simplify it, but we decided to retain it as is to have it be consistent with how Horton defined his variables. But to address your point, we can allude to this confusion directly in the paper in L503. 505, as well as the previous comment where you raised a similar point (L305, L315 and L320).

> *L514: "These relationships...". It's unclear which equations "These" refer to. Please clarify.*

SV and VS: Thank you for this comment. We clarified this in the text.

> *L593: Because Equation (8a) is the key equation in the paper, may I suggest the word 'lake' be inserted between "general" and "equation".*

SV and VS: Thank you for this comment. Yes, we will do so.

L594: Again, as Equation (8a) is the key equation, I recommend strongly that the suffixes be included. I had to go back through the text to ensure I understood which values of V and v were being referred to.

SV and VS: Thank you for this comment. We will include the suffixes.

L646: This sentence needs redrafting. What does "… various shapes…" mean?

SV and VS: Thank you for this comment. We can remove "various shapes" with no loss of meaning we wanted to convey in the sentence. By "shapes" we implied that the equation has same set of variables (except Konstantinov) by just a different position of coefficients.

L660, Tables 1 and 2: Although Horton's equation exhibits the smallest bias in all cases, nevertheless, the bias for say one day is ~+16%, which is large. Could the authors put this value in some context with the level of bias expected from procedures other than the empirical one discussed in the paper. I don't know how widely empirical procedures are currently used in practice compared with other non-empirical procedures.

SV and VS: Thank you for this comment. We can contextualize the expected errors based on literature reference. Non-empirical ones, e.g. Penman-Monteith (combination equation), may potentially produce a smaller bias, but would still have room for improvement because it partly relies on the aerodynamic equation which is empirical, and here shown to be less accurate than Horton's equation.

L683: Capitalize "h" in "How".

SV and VS: Thank you for this comment. We will capitalize it.

L693: "1,68,300" !!!

SV and VS: Thank you for catching this. We will correct this number. It seems to an earlier estimation in an older draft which we had later changed.

L699, Table3: (i) "H" should be "â" rather than "H" as the latter is used as Height in Equation 3. (ii) What is the time-step relevant to the H, K and C values. This comment applies to the other formulae, but it is less important to know that.

SV and VS: Thank you for this comment. We will make this correction.

L734: I'm unclear why P and Q are included in Figure 2. The paper is about Horton's contribution to E.

I suggest P and Q be deleted from the figure.

SV and VS: Thank you for the comment. This figure serves a particular purpose - the difference in E between the various climate normal periods may be readily explained by the anomalies in P which this figure provides. It can also help view the variation of P, E and Q together as a closed water balance system at the scale of aggregation, which is interesting to see, even though it is what we expect to see.

SV and VS: Again, we thank you and the editor for the careful review and editorial work that improved the quality of this manuscript.

With best wishes,

Solomon Vimal and Vijay P. Singh