Anonymous Referee 1

Peer Review: Technical Note: A Double-Manning approach to compute robust rating curves and hydraulic geometries

1. Summary of the Paper

The authors introduce the Double-Manning methodology for developing rating curves ($Q = k\ (z_s - z_b)^P$), which utilizes knowledge of the underlying physics of flow in open channels to minimize the need for ad-hoc parameters when regression models are used to fit observations.

The double-Manning approach is closely related to a suite of modern efforts aimed at developing more flexible, physically grounded rating curves. The authors aim to provide a middle ground between purely empirical fits and full hydrodynamic models.

The authors argue that, compared to other recent methods, their developments are innovative in coupling two Manning equations to reflect channel and floodplain contributions to flow – a concept simple in formulation yet powerful in practice. The concept of double manning emphasizes practical adaptability (via open-source implementation and easily interpretable parameters), whereas some other state-of-the-art methods emphasize comprehensive uncertainty quantification or hydrodynamic completeness. Each approach has its strengths: double-Manning excels in simplicity and physical interpretability, Bayesian methods in statistical rigor, and dynamic models in capturing transient behavior. The existence of these parallel developments underlines a converging theme in hydrology: the need for rating curve models that can handle non-standard conditions (evolving channels, limited data, unsteady flows) more robustly than the old static empiricism. In this context, Wickert et al.'s contribution stands out as a practically minded yet scientifically sound method that complements recent advances. It pushes the field toward rating curves that are mechanistically informed and update-ready, which is an important step for improving flood forecasting, stream monitoring, and water resources management under changing environmental conditions.

Thank you for the well-written and comprehensive note on one of the two major goals (the straightforward and physically based rating curve). We note that this review focuses exclusively on this goal. Our second major goal is to build an approach that integrates geomorphological research and observations, which can aid efforts to build effective rating curves. We appreciate the comments from this review, and further take this focus as a call to draw further attention to the inclusion of geomorphology in a revision.

2. Relevance and Coverage of Citations

The authors of this technical note demonstrate a strong awareness of both the foundational and the latest literature in stage–discharge rating curve development and open-channel hydraulic modeling. They explicitly cite classical, seminal works such as Manning's original formulation for flow resistance (Manning, 1891) and Leopold & Maddock's landmark study on hydraulic geometry (1953). The paper also covers recent advances (within ~10 years) in rating curve methodology and uncertainty quantification. For example, it cites Kiang et al. (2018), a comprehensive comparison of streamflow uncertainty estimation methods (which includes modern rating curve techniques), as well as Hrafnkelsson et al. (2022), who introduced a generalized power-law rating curve using hydrodynamic theory and Bayesian hierarchical modeling. They also reference Le Coz et al. (2014), an influential study that combined hydraulic knowledge with uncertain gaugings in a Bayesian framework (the "BaRatin" method). The authors even refer to Quintero et al. (2021), which describes "synthetic rating curves" generated via hydrologic/hydraulic models for stage-only gauges, illustrating that they have surveyed contemporary innovations in establishing rating curves when direct measurements are limited.

There do not appear to be obvious omissions of critical recent work.

We are glad to read that the citations seem complete. Thank you for the thorough review.

3. Originality and Publication History

This article is an original contribution. We find no evidence that the core ideas or results have been previously published in any journal or formal conference proceedings by these same authors. The methodology appears to be an original synthesis rather than a repackaging of the authors' earlier works.

True; thank you for checking.

4. Comparison to Recent Methods and Tools

The double-Manning approach enters a landscape of active research on improving rating curves, and it shares goals with several recent methods and tools.

The most closely related developments from the last decade include:

Bayesian/Physical Hybrid Rating Curves (e.g. BaRatin and RUHM): Compared to these, the double-Manning approach is less computationally intensive and forgoes an explicit Bayesian treatment of uncertainty in its current form. Its innovation lies in using two applications of Manning's equation (for channel and floodplain zones) as a constrained form of a piecewise rating curve, rather than relying on generic power-law segments or full hydrodynamic simulations. However, it currently does not inherently provide probabilistic uncertainty estimates as RUHM or BaRatin do. The trade-off is between ease-of-use and statistical rigor: double-Manning favors a straightforward, deterministic calibration with physically plausible parameters, while methods like RUHM prioritize a full accounting of uncertainties and leverage advanced computation (MCMC or other Bayesian algorithms) to fuse models and data.

We agree.

Generalized Power-Law and Theoretical Extensions: A notable recent contribution is Hrafnkelsson et al. (2022), who generalized the traditional rating curve by deriving the power-law exponent and coefficient from hydrodynamic considerations and fitting a Bayesian hierarchical model. Their approach maintains the familiar power-law form but links parameters to physical quantities (like channel shape and flow regimes) and pools information across sites via a hierarchical Bayesian structure. The double-Manning approach shares a similar spirit of physically-informed modeling but implements it more directly: instead of modifying the power-law exponent abstractly, it literally employs Manning's equation in two flow domains. This makes double-Manning somewhat more prescriptive – it assumes a rectangular channel cross-section and, optionally, a rectangular floodplain – whereas Hrafnkelsson's framework is more flexible in form (adapting the power-law curve shape through theory). In terms of innovation, double-Manning's two-tier Manning equation is a fresh idea that effectively creates a compound rating curve without an arbitrary breakpoint; its method of using one Manning relation for in-bank flows and another (or a Manning-like power law) for overbank flows is an innovative yet intuitive extension of classical uniform flow theory.

Thank you for the compliment to our approach. I would like to add that I found the Hrafnkelsson et al. approach to be clever and well-reasoned. Our goal in developing the double-Manning approach is to overcome the common assumption of flow through a concave wetted perimeter (Hrafnkelsson et al., Fig. 2). Their example cases do follow such a geometry (Hrafnkelsson et al., Fig. 4). This is where a functional form that includes the possibility – though not requirement – of including a floodplain becomes an important piece of reality. This is what we provide in the double-Manning approach, and this is what a different f(h) could enable within the Hrafnkelsson et al. (2022) approach.

Dynamic and Non-Stationary Rating Methods: Another related thread is the development of rating curve methods that account for non-stationary conditions and flow dynamics (beyond the static stage–discharge assumption). For instance, researchers at the USGS have devised a “dynamic rating” approach to capture hysteresis effects during unsteady flows. Domanski et al. (2022) introduced DYNMOD and DYNPOUND, simplified hydrodynamic models derived from the Saint-Venant equations that can compute discharge from stage while accounting for changing energy slope and storage in the channel/floodplain (hysteresis). These methods effectively produce time-varying rating relationships that adjust during a flood wave, which a single static curve cannot do. The double-Manning method is complementary to such approaches: it addresses spatial complexity (channel vs floodplain flow regimes) and long-term morphological changes, rather than short-term unsteady flow dynamics. Double-Manning assumes quasi-steady uniform flow for given stages, so it will not capture hysteresis loops during events (as DYNMOD/DYNPOUND do).

This is a good note. The double-Manning approach includes the implicit assumption that body forces of the water and channel slope are balanced by frictional resistance along the channel margins, without pressure-force terms.

5. Strengths and Limitations

Strengths of the paper: The proposed methodology would reduce the need for the multiple measurements required in a purely empirical fit of a rating curve. However, this only seems to be the case when all the hypotheses of the double-manning methodology hold, and the authors do not present evidence that this situation is the most common in cross-sections with rating curves around the world.

Thank you for this note and opportunity to explain the rectangular-chan. Rating-curve approaches are often developed with a range of open-channel geometries, including triangular, rectangular, and parabolic channels, as well as "compound" geometries with channels inset within channels. Natural alluvial river channels have forms that are widely approximated to be rectangular – so much so that compilations of channel geometry simply include bankfull width and depth (Trampush et al., 2014). Conditions for bank stability and equilibrium hydraulic geometry generally lead to these rectangular channel forms (see, e.g., Parker, 1978; Dunne & Jerolmack, 2020) with wide aspect ratios (Trampush et al., 2014).

Based on this comment, we will clarify the basis for the rectangular channel assumption and its widespread applicability in nature. It is not perfect, but can suffice for a straightforward fit to data with minimal geometric constraints.

Weaknesses and limitations: The title suggests a level of generality of the application that is not supported by the results and analyses. The title could more explicitly reflect the methodological context and applicable site conditions—specifically, that it is intended for locations with available stage -discharge measurements and supporting field data.

All methods for developing rating curves require some amount of field data, be they stage–discharge data and/or geometries in the field. Therefore, our impression is that adding this information to the title would make it long and include information that readers would believe to be implicit.

Additionally, emphasizing that the approach is a hybrid hydraulic–empirical model for rating curve fitting would enhance clarity and precision.

This is a good point, especially because we thought that we had made this clear. The "hydraulic–empirical" language is good, and we will seek to use it in a revision.

The evidence that the methodology of double manning rating curves works is very minimal, and there isn't a formal comparison of errors with existing methodologies. The paper does not provide direct evidence of the methodology's accuracy, as it is applied to two sites with substantial stage–discharge measurements but without quantitative comparison to a reference or "true" rating curve—such as that provided by the USGS. In the third case, where only a few measurements are available, it is not possible to verify the accuracy of the resulting fit, particularly in the floodplain region where no observational data are available.

As a Technical Note, the purpose of this article is to present a "new development" of "methods and techniques". It should be "a few pages only" and already significantly exceeds this. We provided three examples of cases in which the double-Manning approach worked. We provide RMSE values as goodness-of-fit estimates. Comparisons to established rating curves, while helpful when considering implementation, would enter the scope of model intercomparison and go beyond presentation of a new technique. These seem to us to be sufficient to show that the method has promise, which is not a comprehensive test or intercomparison as the reviewer requests, but we believe this to be within scope of the goals of the article type.

We cannot find proof that there is an "economy" of data using this approach. We would have expected that the authors would show that a minimum set of observations is needed to obtain the same or less error than a traditional fit of the data.

Thank you for the chance to clarify. A traditional fit to data would not have yielded the break in the stage–discharge relationship between in-channel and on-floodplain flows, which we demonstrate in the example from La Dormida. This is because stage–discharge observations exist only for conditions in which the flow is confined by the channel banks. Therefore, the double-Manning approach can provide a physically grounded extrapolation.

Regarding the note on "economy" of data, this is not a claim that we make.

6. Figures

All the figures should be improved.

Figure 1:

Clarify flow regions. The distinction between Q_{ch} (channel discharge) and Q_{fp} (floodplain discharge) could be enhanced by using colored shading or distinct arrows for each flow component.

Adding directional flow arrows to illustrate how flow is distributed above the bankfull stage.

Figures 2, 3, and 5:

Add gridlines to improve readability.

Update discharge units from "$m3s^{-1}$" to "m^3/s".

Improve axis labels and enhance the visibility and style of dashed lines.

Increase the size of the observation points and consider using a different color than the model curve for clearer distinction.

For Figures 2 and 3, include a reference curve (USGS rating curve) for comparison.

Figure 4:

Add gridlines and a dashed horizontal line to indicate bankfull elevation, reinforcing the concept of overbank flow.

Improve labels clarity

We thank you for your recommendations and appreciate your attention to our figures. We will take those suggestions for Figure 1 into consideration, and specifically will seek to make it clearer that the demonstrated flow is above bankfull. On Figure 4, the labels are quite large; we do not know how they can be made clearer. On Figures 2, 3, and 5, the data points are a different color than the model curve. As noted below, we consider model intercomparison to be beyond the scope of this Technical Note. Other changes are stylistic and we will consider them.

6. Specific Recommendations

Line 11: While the abstract notes that the method “matches ground truth” and “enables predictions,” it does not summarize any specific performance metrics or case study outcomes. Include a brief reference to a specific result or performance.

We will update the abstract to be more specific about the data that are matched and include the relevant performance metric.

Line 97: The variability of the coefficients k_{fp} and P_{fp}, which are influenced by changes in floodplain width and roughness, is not fully addressed in the paper. In real-world settings, floodplains are often heterogeneous and exhibit substantial spatial variability along the river reach. However, the method appears to assume spatial homogeneity within the floodplain zone, which may oversimplify real-world conditions. In practice, floodplain heterogeneity introduces uncertainty that could affect the accuracy of the fitted rating curve, particularly in the overbank flow regime. How does the proposed method account for this heterogeneity, and how is the resulting uncertainty represented in the fitted rating curve? Given that these parameters directly influence the overbank component of the discharge, a discussion of how spatial variations and their associated uncertainties affect the reliability of Q_{fp} would strengthen the analysis.

Contrary to the observation of the referee, k_{fp} and P_{fp} allow us to simulate heterogeneous floodplains. Variability in floodplain topography affect its hydraulic radius in a way that become a function of flow depth. This approach using P_{fp} indeed emulates the generic power-law function for a rating curve. We note this in Lines 95–99. We will consider ways of expanding and clarifying this that do not significantly increase the length of this Technical Note.

Line 125: Section 3 (Data Constraints): The text mixing parameter estimation difficulty, data source types, and model sensitivity can be dense. Reformat Table 1 to include a column for “Parameter Sensitivity” (if known), and break Section 3 into clearer subsections for: Measurable parameters (e.g., b, S, h_β) - Estimated parameters (e.g., k_{fp}, P_{fp}) -Data-sparse strategies

Thank you for this suggestion. We will consider it when revising the paper.

Line 247: To better demonstrate the applicability of the methodology to data-limited sites, it would be helpful to conduct a set of controlled experiments at a single site using progressively reduced subsets of data. For example, the authors could evaluate model performance using only channel-stage measurements (excluding overbank flow), then with a few measurements spanning both channel and floodplain stages and compare the resulting rating curves to the full dataset fit. Each case could also be compared against a reference curve (e.g., the USGS rating curve) to assess the sensitivity and robustness of the approach under constrained data conditions (calculate some metrics). This would provide valuable insights into the model's behavior and reliability when applied to real-world scenarios with sparse (or none) observations.

This suggestion seems like a possibility for a follow-on study. The purpose of this Technical Note, which is necessarily limited in length and scope, is to present and demonstrate a new method to develop rating curves that takes advantage of common features of channel and floodplain morphology.

Line 369: Replace "n_{ch} = 0.38, which is virtually identical to the n_{ch} = 0.37" by "n_{ch} = 0.038, which is virtually identical to the n_{ch} = 0.0

Thank you for noting this typo. Indeed, the Manning's n was 0.038, which is virtually identical to the 0.037 value computed inferred from the bed-material grain-size distribution. This will be corrected.

Line 372: It could be valuable to include a fourth case study where the channel geometry deviates from the rectangular assumption—for example, a compound channel. This would allow the authors to explore the applicability and limitations of the double-Manning methodology under more complex geometric conditions, which are common in natural river systems. Such an example would also help assess the method's flexibility and the potential need for adjustments when applied to non-idealized cross sections. Including this type of case would further strengthen the practical relevance of the approach.

The authors contest that the "compound channel", which is a channel inset within a broader channel, while common in the rating-curve literature, is not a significant consideration in most natural river systems. Natural rivers tend to have a rectangular to trapezoidal channel geometry. A rectangular channel occurs predominantly in straight reaches (Parker et al., 1978), which are commonly associated with stream-gauging sites. Such reaches could be more closely approximated as trapezoidal, though the broad aspect ratio of most alluvial river channels (i.e., most river channels on Earth) means that the use of a trapezoidal approximation will not significantly change the result. A trapezoidal channel may also be used if one wishes to more appropriately characterize flows moving around a bend (e.g., Dietrich et al., 1979), in which case the point bar can be a long limb of the trapezoid. To answer possible questions of curiosity, there are dynamic reasons for the sparsity of natural "compound" channels, and these generally relate to the fact that shallow regions on the edges of rivers (a) require symmetrical *erosion and then deposition to form, which is unusual in curved channels (i.e., many in nature), and (b) that these shallow regions, if they do form, will receive a net flux of sediment from the channel center, causing them to fill. However, such are beyond the scope of this manuscript, and especially a short Technical Note.*

As a result of this, cases of "compound channels" in the literature often use the "compound channel" approach to simulate flow across a channel and a local floodplain (e.g., Carling et al., 2002). Indeed, some studies define the "compound channel" as a channel + floodplain (Myers & Brennan, 1990; Liu et al., 2025). This situation is something for which the double-Manning approach is well suited.

Therefore, it seems that the manuscript already includes compound channels, at least insofar as their main purpose exists, while allowing irregular floodplain geometries (topographic highs and lows) and different roughness on the floodplains than in the channel.

Line 442: The authors should consider expanding the conclusions section, which currently consists of a single paragraph. In addition to summarizing the strengths of the double-Manning approach, the conclusions should also acknowledge the method's limitations. For example, potential sources of uncertainty—such as assumptions of floodplain homogeneity, sensitivity to field-estimated parameters, and the challenges of validating results in data-sparse settings—deserve mention. Including both the advantages and constraints would provide a more balanced and complete perspective and help guide future applications and developments of the method.

Our goal was to maintain a short Conclusions section in this Technical Note. However, the reviewer makes some good points here and we will consider expanding it and clarifying some of the points here and above.

7. Recommendations
Reject

Thanks for the recommendation. We hope that the above comments and revised manuscript can change this.

REFERENCES

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