What Manning's *n*? A need for clear definitions in computational modeling

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Introduction

Manning's *n* is arguably the most important parameter in open-channel hydraulics for estimating flow resistance. Flow resistance can be caused by a multitude of factors, e.g., sediment grains, bedforms, vegetation, various types of obstructions (large woody material, engineering log jams, bridge piers, etc.), and channel alignment, all of which are typically lumped into a Manning's *n* value. Since the debut of Manning's equation in 1891 (Manning, 1891), hydraulic engineers have enjoyed the convenience of using one single parameter to capture the complexity of flow resistance. However, it also draws criticism due to the same reason. The major criticisms are the large uncertainty and the empiricism nature of how the equation was developed. Such criticisms are amplified in modern-day computational hydraulics modeling where Manning's *n* is often the only tuning parameter in various one-dimensional (1D) hydraulic models and the main tuning parameter in various two-dimensional (2D) hydraulic models, e.g., HEC-RAS, SRH-2D, and RiverFlow 2D. Therefore, it is not only a friction factor but also a surrogate for what terrain and hydraulic models cannot resolve, which creates many misconceptions about what Manning's *n* is under different modeling approaches. The lack of clear definitions of Manning's *n* in different modeling approaches is the root cause of this confusion. This short note strives to bring some clarity to this matter, especially in the context of 2D computational hydraulic modeling.

Manning's *n* definition in the real-world

In the physical world, Manning's *n* has the textbook definition of a flow resistance parameter, which can be termed the real-world total Manning's *n*. In the literature, there are three categories of methods for determining the real-world total Manning's *n*: 1) tabular methods (Aldridge and Garrett, 1973; Arcement and Schneider, 1989; Brunner, 2021), 2) photographic methods (Barnes, 1967; Aldridge and Garrett, 1973; Hicks and Mason, 1998; Yochum et al., 2014), and 3) quantitative methods (Arcement and Schneider, 1989, Yochum et al, 2012; Rickenmann and Recking, 2011; Aberle and Smart, 2003; Lee and Ferguson, 2002; Bathurst, 1985; Jarrett, 1984; Griffiths, 1981; Hey, 1979; Limerinos, 1970).

In several of the quantitative methods, the common approach is to add contributing Manning's *n* together to get the total (Shields et al. 2017). Although this approach provides a useful conceptual framework for calculating Manning's *n*, it is physically and mathematically flawed. Flow resistance is proportional to the square of Manning's n. Thus, the total Manning's n should satisfy the following relationship: $n^2 = n_1^2 + n_2^2 + n_3^2 + \cdots$, where n_1, n_2, etc. are component Manning's *n* from different contributing factors. For example, Arcement and Schneider (1989) include this type of formulation for including vegetation effects.

Manning's *n* definition in the numerical world

In the numerical modeling world, the total Manning's *n* is divided into two parts: resolved and unresolved Manning's n values. In a 2D model, part of the flow resistance can be resolved by its terrain data, mesh detail or resolution, mathematical formulation, and numerical scheme. The remaining part is what should be parameterized by the unresolved Manning's *n*. **As a result, the Manning's *n* specified in 2D models should only be the unresolved Manning's *n***. A feature is resolved if it is geometrically and hydraulically resolved. It means that the feature should be correctly represented by the terrain and mesh. Furthermore, the hydraulic effects of a feature should be correctly captured by the computer model, which is mainly controlled by model governing equation, the numerical scheme used, and sufficient mesh resolution. The unresolved part of Manning's *n* depends on many numerical aspects of a model. For example, numerical diffusion introduced by a specific numerical scheme particularly in a field with significant or reversing velocity gradients (e.g., recirculating flows) may affect the Manning's n value. Therefore, the Manning's n to be specified in 2D models is not only a physical parameter, but also a numerical one.

The clear definition of the Manning's *n* in 2D models has many implications in practice. For example, if the wall shear reported in 2D models was calculated with the specified (unresolved) Manning's *n*, it only represents part of the total wall shear (flow resistance). It cannot be directly used for other purposes, such as erosion and scour calculation.

Determination of the resolved vs. unresolved Manning's *n*

The determination of Manning's n values remains a difficult task simply because of the complexity in the real world and the fact that we lump everything in just one parameter. However, with the clarity brought in this paper and the knowledge we gained since 1891, we can better constrain the calculation of Manning's *n* to be used in 2D models. First, the real-world total Manning's n can be estimated using any of the three methods mentioned above. An unresolved Manning's *n* can then be determined with the following governing relationship between the total, resolved, and unresolved Manning's n values:

$$n^2 = n_{resolved}^2 + n_{unresolved}^2 \rightarrow \left(\frac{n_{resolved}}{n}\right)^2 + \left(\frac{n_{unresolved}}{n}\right)^2 = 1 \qquad (1)$$

Figure 1 is a graph of Equation 1, which is a quarter of a unit circle. Given a total n, once $n_{resolved}$ is determined, $n_{unresolved}$ can be calculated with Equation 1. Unfortunately, there is no easy way to accurately calculate $n_{resolved}$, which depends mainly on the resolution and accuracy of the terrain data and mesh. However, some general guidelines based on the unique properties of the unit circle shown in Figure 1 can be used. In general, there are three areas that can be used as a guide for a modeler to estimate the unresolved Manning's *n* (to be used in models):

- The first area is circled with the blue solid line where the resolved Manning's *n* is between 0 to 60% of the total. This happens when the terrain or mesh has low to moderate resolution. In this scenario, the unresolved Manning's *n* is in a relatively narrow range and the modeler may choose $n_{unresolved}$ = 0.8 to 0.9 of the total Manning's n as the starting point.

- The second area is circled with the blue dashed line where the resolved Manning's *n* is between 80% to 90% of the total. This happens when terrain AND mesh both have very high resolution. In this scenario, the unresolved Manning's *n* has a large variation within 0 to 50% of the total Manning's n. Fortunately, the majority of the flow resistance has been resolved by terrain and mesh. In this case, the unresolved Manning's *n* plays a secondary role. A modeler may choose $n_{unresolved}$ = 0.25 of the total Manning's n as a starting point.
- The third area is in the transition between the two areas described above. In this area, the portions of resolved and unresolved Manning's *n* are comparable. A modeler may choose $n_{unresolved}$ = 0.7 of the total Manning's n as a starting point. Note that the square of 0.7 is approximately 0.5, which means half of the flow resistance is resolved and the remaining half is unresolved.

The general guidelines above provide a starting point for the Manning's *n* to be used in 2D models. Proper model validation, calibration, and sensitivity analyses are still needed. Special attention should be paid to cases where the final Manning's *n* is much different from the starting point. It should also be noted that changing mesh resolution may require recalibration or adjustment of the Manning's *n* because more of the flow resistance due will be resolved by the model.

In the above guidelines, whether a terrain or mesh is of high or low resolution is relatively speaking to the characteristic size of roughness factors or features. For example, the characteristic size of bedforms would be their wavelength. In general, to fully resolve a feature, at least several grid points are necessary to cover one characteristic size in each spatial dimension.

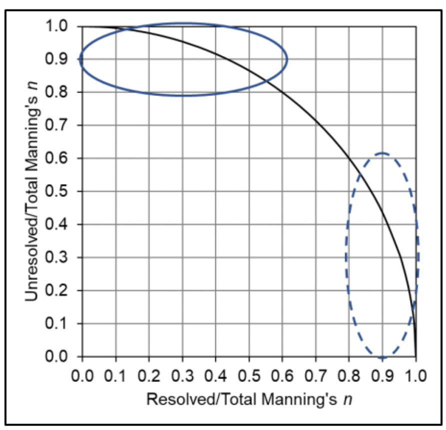

Figure 1. The quarter unit circle relating total, resolved, and unresolved Manning's *n* values.

The grain roughness, vegetation (i.e. short grasses and trees), and bedforms would likely always be included in the unresolved Manning's *n*. Grain roughness would not be resolved because individual bed material particles are typically not represented in the terrain or mesh geometry except when the obstructions of large boulders or large wood are resolved in terrain and mesh. Similarly, bedforms and vegetation would typically not be included in terrain or mesh geometry so the resistance of these features would be entirely within the unresolved Manning's *n*. **When channel irregularities and channel meandering are included in 2D models, the unresolved Manning's n should exclude the resistance from these features.**

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