BOOK REVIEW

ROUGHNESS CHARACTERISTICS OF NEW ZEALAND RIVERS by D.M. Hicks and P.B. Mason. Published in 1991 by Water Resources Survey, DSIR Marine & Freshwater, Wellington. 329pp, price $79.95.

Review by S M Thompson and I G Jowett

Details of 78 New Zealand rivers are presented with colour photos and data on the size and shape of the channels, bed material grain sizes and flows. The quality of the figures, photographs and binding are excellent. However we believe that it is marred by poor cross-section location and an analysis which follows slope-area gauging practice.

The data is directed to derivation of the Manning friction coefficient n:

$$n = \langle\text{wetted area}\rangle \text{ x } \langle\text{hydraulic radius}\rangle^{2/3} \text{ x } \langle\text{friction slope}\rangle^{1/2} / \langle\text{flow}\rangle$$

This coefficient is useful for:
— estimation of flow, given measurements of water levels and cross-sections;
— prediction of water levels, given a flow and measurements of cross-sections.
Both uses depend on an appropriate value of the coefficient n being estimated from experience based on the visual appearance of the river and measurements of its bed material. The long title "a handbook for assigning hydraulic roughness coefficients to river reaches by the visual comparison approach" indicates the authors intention to assist readers to gain that experience. It is therefore surprising that the flows at the time the photographs were taken are not presented.

There is a large body of data and some theory about logarithmic velocity distributions which suggests that the coefficient n will be constant for a given channel geometry, and this constancy is implicit in the methods which use it. However this book reports large variations of the coefficient n at most sites, and large differences between sites which do not relate to the visual appearance. Data from half the rivers has a two-fold or larger range in the values of n. The following pairs of rivers appear similar in the photos but the values of n at mean flow differ by factors of 3.5, 4.3 and 7.3; compare pages 31 and 267, 67 and 291, and 127 and 323. The content of this book therefore calls into question the invariance which underlies the Manning coefficient method, although the text does not say so explicitly. Perhaps we can use this data constructively to learn where we should be wary of using the method.

A marked increase of n as the flow reduces is evident in over 50% of the 78 rivers in the book, and we suggest two possible explanations:
— a consequence of local acceleration of flow around boulders;
— as the flow increases, river features causing head loss, such as riffles, are drowned out and the flow becomes more uniform.

On the other hand and surprisingly, given the prominence of such cases in research literature, there are only 5 or 6 rivers where n increases as the flow increases. In these cases, see pages 36, 44, 76, 156, 184 and 232, there are vegetated berms and the increase can be explained as a consequence of lateral mixing of the main flow with slow moving water on the berm. This book will assist by drawing attention to the need to adjust n for these effects.

Calculations in the book are by a method in which the size of the reach between each pair of cross-sections is represented by the geometric mean of the end values of Z:

$$Z = \langle \text{wetted area} \rangle \times \langle \text{hydraulic radius} \rangle^{2/3}$$

This is an arbitrary choice which has affected the values of n reported. It follows the slope-area flow gauging practice of the U.S. Geology Survey. Conventional calculations in New Zealand assign each end value of this quantity to half the length of the reach, as recommended in F M Henderson's and V T Chow's text books and implemented in the New Zealand computer programs Rivers, Ricoda and Rhyhabsim. The head losses calculated differ as follows:

$$h_f = n_g^2\, Q^2\, L_{1.2}/(Z_1\, Z_2) = (Z_1/Z_2)\, n_g^2\, Q^2\, L_{1.2}/Z_1^2$$
$$h_f = n_c^2\, Q^2\, L_{1.2}\, (0.5/Z_1^2 + 0.5/Z_2^2) = (0.5 + 0.5\, Z_1^2/Z_2^2)\, n_c^2\, Q^2\, L_{1.2}/Z_1^2$$

Thus using the same data the values of n differ by the ratio:

$$n_{geometric}/\, n_{conventional} = [0.5\, (Z_1/Z_2 + Z_2/Z_1)]^{1/2}$$

For example if a reach is contracting or expanding with $Z_1/Z_2 < 0.3$ or < 3.3 respectively, and there are several such cases in the book, then the ratio of the alternative estimates of n is > 1.35. This problem is described by the U.S. Army Corps of Engineers in their documentation of the well-known computer program HEC2, and they point out that if the reach lengths are short, the alternative assumptions provide essentially the same result and they advise "adding more cross-sections . . . even though the additional cross-sections may only add computation steps and do not reflect changes in geometry". HEC2 has an option for insertion of extra cross-sections by automatic interpolation. Use of this technique could have made the reported values of n independent of any arbitrary assumption.

We believe that some reaches are markedly non-uniform and poorly represented by the selected cross-sections, with the maps and photos showing inappropriate locations. For instance see the Tongariro at Turangi (pages 194–197) where the reach extends from a pool on a bend to a bar on a straight. We suspect that errors due to poor representation of the longitudinal profile are much larger than the error estimates in the book which take no account of this source of error. In the case of the Oakden Canal, it is reported that n ranges from 0.027 to 0.037, when there is a wealth of data which indicates that n is constant in large uniform trapezoidal canals. Reasons for unusual results such as this are not discussed in the book and we can only speculate. Was the velocity unusually high out of the culvert which discharges into the upstream end of the measure reach so that there was an expansion loss not allowed for in the calculation? Details of the velocity measurements could answer such questions.

Reply by D M Hicks and P D Mason

We thank Thompson and Jowett for their efforts to make some constructive comment in their review of our book "Roughness characteristics of New Zealand Rivers".

Their first point suggests that it would have been useful to present information on flow rates at the times that the reach photographs were taken. Perhaps, but we wonder what would be gained, especially beyond the details contained in the hydraulic parameter tables. The main purpose of the photographs is to provide an overall impression of the channel size and form and to illustrate the boundary roughness elements. This purpose was best served by photographs taken, wherever possible, at low flow conditions when a maximum of the bed was exposed — the actual flow rates were not considered important to this purpose.

Thereafter, their comments concern factors that could account for the variation in Manning's n presented in the book — among sites and at-a-site as discharge changes. The factors they explore include: (i) some physical reasoning, (ii) the method used to calculate a representative Z parameter along a reach, (iii) non-uniformity of the reach, and iv) "unusual results" of speculative origin. We address each of these in order.

We agree with Thompson and Jowett that there exists a large body of data and some theory as to why Manning's n should remain constant for a given geometry. The bulk of this, however, stems from study of flumes and canals. There is an equally large body of data from natural channels indicating that Manning's n at-a-site can vary (for example, see the classic hydraulic geometry studies of Leopold and Maddock, 1953, and Wolman, 1955; see also Limerinos, 1970, and Jarrett, 1984). In natural channels, roughness can vary with flow magnitude for a multitude of reasons, including relative inundation of bed material and bars, bank vegetation, berms, bedload transport, and bedforms. It was not part of our work brief in preparing the book to interpret the factors causing n fluctuations in each of the 78 reaches in the study. We welcome Thompson and Jowett's attempts to do this for some of the reaches, and agree that probably much of the observed increase in n with decreasing discharge is associated with energy dissipation around emergent bed material elements and larger-scale channel bed irregularities. Possibly, though, some of the increase in n with decreasing depth in the shallow, steep, cobble-and-boulder bed streams may result from an under-measurement of the mean velocity in a vertical by the "single-" or "two-point" method. This assumes a logarithmic velocity profile, while such streams typically have "S"-shaped velocity profiles with much higher surface velocities and lower near-bed velocities (Jarrett, 1984). We suspect that the cases in the book where n increases as discharge increases are more generally associated with bank vegetation protruding into or overhanging the main channel flow rather than with slower moving berm flow (see, for example, the Ngongotaha River on page 155).

Thomson and Jowett raise a valuable point regarding the variation in Manning's n among sites that appear similar visually. Clearly, less visible factors must also be important. Prominent amongst these factors appears to be slope, which is often hard to judge simply from a photograph. Indeed, Jarrett (1984) found slope to be the most significant variable in a regression of factors causing variation in n for streams with slopes steeper than 0.002. A factor-of-ten difference in slope accompanies the difference in Manning's n values at mean flow shown by the Hutt River ($s \approx 0.004$) on page 127 and the Huka Huka River ($s \approx 0.04$) on page 323.

A lot of the so-called variation in Manning's n among sites is actually an artifact of using the n value at mean flow as a "reach-representative" value.

As explained on page 11, we used these "representative" n values simply to order the reaches in the book, and we used the mean flow for this purpose only because we had n measured at mean flow for almost all sites. In consequence, where n varies with discharge the representative n values are influenced by flow regime. Thus while a number of visually similar reaches may have very different "representative" n values due to their different flow regimes, for given discharges or relative depths their n values are much the same. This explains the "differences" noted by Thompson and Jowett between the Monowai River, a hydro-power regulated lake-outflow river (Mean Flow = 16.8 m^3/s, Mean Annual Flood = 39 m^3/s, page 67) and Butchers Creek, which has a natural regime with a much lower mean flow value (MF = 0.35 m^3/s, MAF = 25.3 m^3/s, page 291); similarly for the regulated Wanganui at Warehu Canal (MF = 16.6 m^3/s, MAF = 35 m^3/s, page 31) compared to the natural regime Northbrook (MF = 0.12 m^3/s, MAF = 1.0 m^3/s, page 267).

Considering the above points, we suggest that when selecting a reference from our book, readers consider not only reach physical appearance but also the slope and flow regime (as indexed, perhaps, by the ratio of the mean annual flood to the mean flow — the values of which are provided in the book for every site).

We disagree with some of Thompson and Jowett's comments on our use of the geometric mean approach for determining the representative Z parameter for adjacent cross-sections in a reach. For reference in the discussion that follows we repeat their equation for the ratio of n-values:

$$n_{geometric}/n_{conventional} = [0.5\,(Z_1/Z_2 + Z_2/Z_1)]^{1/2} \qquad (1)$$

Our use of the geometric approach is neither arbitrary nor unconventional. We used this approach in order to (i) maintain consistency with the two widely-used existing texts that match roughness coefficients with reach descriptions and photographs (i.e., Chow, 1959, and Barnes, 1967), and (iii) because it is, in fact, *the* conventional approach for slope-area flow assessments (e.g. Chow, 1959, p.147; Benson and Darlrymple, 1963; Herschey, 1985). It is far from the preserve of the U.S. Geological Survey, as we are sure many New Zealand engineers and hydrologists already know! The approach that Thompson and Jowett refer to as "conventional" is keyed to the "standard-step" approach for determining water surface profiles — while it may rightly be termed the "convention" for this latter application, it is wrong to imply that it is necessarily the convention to follow for all utilisations of Manning's n, including slope-area assessments.

Equation (1) applies only to cases where a reach is represented by two end cross-sections, whereas most of the reaches in our book were represented by three to five sections. As Thompson and Jowett themselves indicate by reference to the HEC2 documentation, the addition of intermediate cross-sections serves to reduce any discrepency between $n_{geometric}$ and $n_{std-step}$. For example, if a reach has three cross-sections and the ratio Z_1/Z_3 is x (and, for simplicity, we assume that Z changes geometrically along the reach so that Z_1/Z_2 equals Z_2/Z_3 equals $x^{1/2}$ and also that the sections are uniformly spaced), then

$$n_{geometric}/n_{std-step} = [(1+x)/2x^{1/2}]^{1/2} \qquad (2)$$

With four cross-sections and Z_1/Z_4 is x (with Z_1/Z_2, etc. equal to $x^{1/3}$), then

$$n_{geometric}/n_{std\text{-}step} = [(0.5x^{-2/3} + 1 + x^{2/3} + 0.5x^{4/3})/(x^{-1/3} + x^{1/3} + x)]^{1/2} \quad (3)$$

With five cross-sections and Z_1/Z_5 is x (with Z_1/Z_2, etc. equal to $x^{1/4}$, then

$$n_{geometric}/n_{std\text{-}step} = [(0.5x^{-1/2} + 1 + x^{1/2} + 0.5x^{3/2})/(x^{-1/4} + x^{1/4} + x^{3/4} + x^{5/4})]^{1/2} \quad (4)$$

From equations (1) to (4), if x is 0.3, then for 2,3,4 and 5 sections respectively, the ratio $n_{geometric}/n_{std\text{-}step}$ equals 1.35, 1.09, 1.04, and 1.02. Clearly, even where a reach may be diverging or converging considerably, with more than two cross-sections the differences in Manning's n values determined by the geometric mean and standard step approaches become negligible, especially when compared to measurement error. For the record, only nine of the 78 reaches in our book had only two cross-sections, and, with the exception of Poutu at Ford, they are either canals or very uniform natural channels. Although we see little need for it, users of our book could, if they wish, use equations (1) to (4) to convert Manning's n values based on our book to values appropriate for water surface profile calculations.

To summarise this issue, it can be noted that (i) slope-area flow assessments and water-surface calculations tend to follow different conventions for deriving reach-representative Z-values, (ii) the differences between the approaches are only significant where the reaches converge or diverge strongly and are represented by only two end cross-sections, and (iii) where necessary, Manning's n values derived by the one approach may be corrected for use with the other approach using equations such as (1) to (4) above.

Thompson and Jowett rightly recognize that reach non-uniformity and siting of cross-sections can induce significant error in roughness determinations. Our discussion of errors on pages 8 and 9 warns readers of this and gives an indication of the level of uncertainty expected. In natural channels, this error source grows at lower discharges as irregularities in channel shape and water surface profile become more prominent. The error tends to decrease at higher discharges as the irregularities are drowned out. Where warranted, we explicitly pointed out reaches in our book that we considered significantly non-uniform. Thus the pool to riffle transition of the Tongariro at Turangi reach is clearly noted on page 194, and separate calculations of Manning's n are provided for the pool sub-reach. As it was our intention to provide readers with information sufficient for them to make their own assessment of the uniformity of a reach, we are gratified to know that Thompson and Jowett have been able to do this.

There is no speculation required to explain the range in Manning's n (0.027 to 0.037) measured on the Oakden Canal. Inspection of the data table (page 108) shows these variations lying within the range of measurement error, which is high due to the very low surface slopes (for example, ±28% error for the n=0.037 value, with a water surface slope of 0.00001).

In closing, we welcome most of Thompson and Jowett's comments. They point towards a number of areas requiring detailed field investigation, such as the effect on roughness coefficients of multi-scale bed topographical features and bank vegetation as water discharge and relative depth change; also the accurate measurement of velocity profiles in mountain streams. We are disappointed, however, that some of their comments are cursory, that they sometimes overlook information readily available in the book that either explains or discounts the issue.

We thank the editor for the opportunity to respond to this review.

REFERENCES

Barnes, H.H., Jr., 1967: Roughness characteristics of natural channels. U.S. Geological Survey Water Supply Paper 1849.

Benson, M.A.; Dalrymple, T., 1967: General field and office procedures for indirect discharge measurements. U.S. Geological Survey Techniques of Water Resources Investigations, Book 3, Chapter A-1.

Chow, V.T., 1959: Open-channel hydraulics. McGraw-Hill, New York.

Herschey, R.W., 1985: Streamflow measurement. Elsevier, London.

Jarrett, R.D., 1984: Hydraulics of high-gradient streams. Journal of Hydraulic Engineering, Vol 110, No. 11: 1519–1539.

Leopold, L.B.; Maddock, T., Jr., 1953: The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey Professional Paper 252.

Limerinos, J.T., 1970: Determination of the Manning Coefficient from measured bed roughness in natural channels. U.S. Geological Survey Water Supply Paper 1898-B.

Wolman, M.G., 1955: The natural channel of Brandywine Creek, Pennsylvania. U.S. Geological Survey Professional Paper 271.