6^{th} International Conference on Hydroinformatics - Liong, Phoon & Babovic (eds)
 ISBN 981-238-787-0

IMPROVED CONVEYANCE ESTIMATION

DAVID FORTUNE
Wallingford Software Ltd., HR Wallingford Group, Howbery Park
Oxfordshire, OX10 8BA, UK

CAROLINE MCGAHEY
HR Wallingford Ltd., HR Wallingford Group, Howbery Park
Oxfordshire, OX10 8BA, UK

ANDREW NEX
Wallingford Software Ltd., HR Wallingford Group, Howbery Park
Oxfordshire, OX10 8BA, UK

The estimation of conveyance is fundamental to river maintenance and to one-dimensional (1-D) river modelling. Current software packages are generally based on methods derived from research completed more than 50 years ago. Subsequent advances in knowledge and understanding have had little impact on industry practice. In 2002, the Environment Agency in England & Wales commissioned a targeted programme of research to produce an improved conveyance estimation system, building on recent advances and industry best practice. The programme focuses particularly on the effects and management of riverine vegetation, the interaction between river channel and floodplain flows, and the behaviour of natural shaped channels. The paper describes the advances in roughness and conveyance estimation. The application of the new techniques is described as a simple application for river maintenance engineers and as an improvement to complex, 1-D river modelling.

BACKGROUND

Water level prediction is essential for flood management tasks such as flood forecasting and flood-risk mapping. High-quality water level predictions enable more informed decisions regarding infrastructure design and operation and emergency evacuation planning. Flood levels are further necessary for strategic planning i.e. evaluating and comparing options against criteria, for hydrometric users, and for channel maintenance e.g. timing, scheduling and prioritisation of dredging and vegetation cutting. Figure 1 identifies the different flood defence functions and the use of models and conveyance calculations to meet these flood management requirements. Conveyance here is a quantitative measure of the discharge capacity of a watercourse, based on the channel's ability to resist flow through surface friction and channel morphology.

The estimation of conveyance in existing one-dimensional hydrodynamic modelling software such as iSIS Flow, MIKE11 and HECRAS is principally based on some form of the Manning Equation. This empirically derived equation, first published in 1891 [1], is not based on rigorous physics and provides meaningless results for sudden changes in area or wetted perimeter with depth. When applied as a Divided Channel Method, it ignores the lateral shearing and momentum transfers between the vertical divisions. Essentially, all the energy losses are wrapped up in the widely used Manning n, which lumps all the physical flow processes into one ‘catch-all’ parameter, providing little understanding and interpretation of the independent energy loss mechanisms.

Research over the past twenty years, including a managed programme of research on the EPSRC Flood Channel Facility at HR Wallingford, reflects a vast improvement in the calculation approach to channel conveyance. This ranges from the understanding and interpretation of the complex flow mechanisms in a channel section, to the advent of computing tools that enable more sophisticated solution techniques. An extensive and ever-increasing database of both physical model and real river measurements has provided a sound basis for testing these research advances. Significant contributions include those of Chang [2], Ervine & Ellis [3], Ervine *et al* [4] and Shiono & Knight [5]. For further details see [6] and [7]. A significant contribution to this new research is the increased knowledge on river resistance from a diverse set of sources, covering different types of vegetation and surface material (bed, bank and floodplain) for the fluvial system.

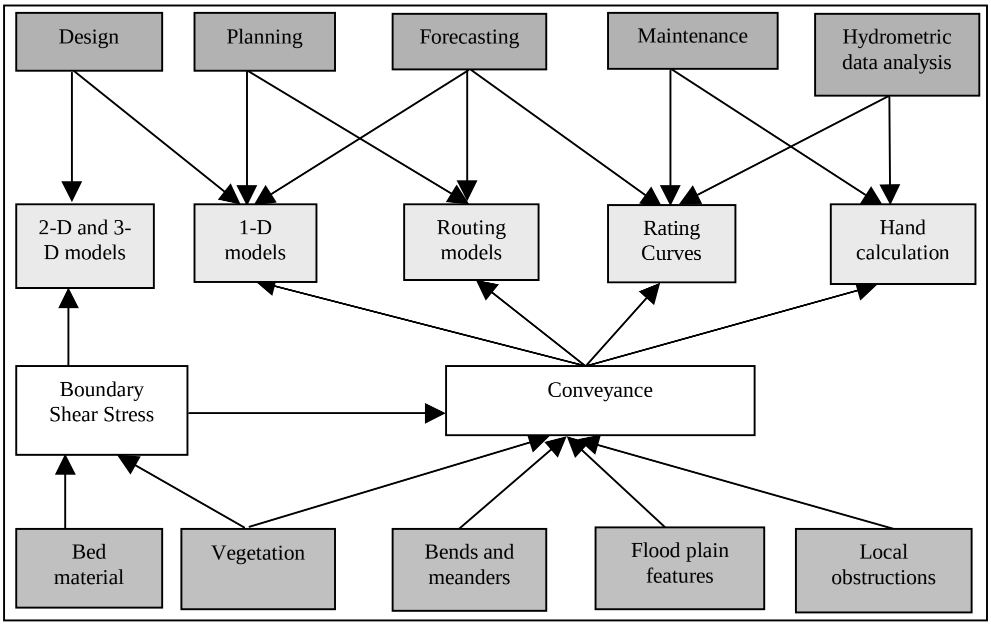

Figure 1. The Conceptual Framework

The Environment Agency of England and Wales identified the need to reduce the uncertainty associated with flood level prediction through incorporating these recent research advances into a Conveyance Estimation System (CES), and thus making these more advanced techniques available for general use in river modelling. Uncertainty and risk are closely related in that the greater the uncertainty in the predicted water level, the greater the probability of the project or flood management scheme not achieving its objective. As a result, a key component of the CES is to quantify the uncertainty in water level for a given flow rate, and present it in a manner which can be readily interpreted by the user and enable better, more informed decisions. The CES is therefore designed to capture the advances in all three components i.e. the diverse roughness knowledge, the improved methods of conveyance estimation and the quantification of uncertainty.

SCOPE OF PROJECT

In 2000, the Environment Agency commissioned a Scoping Study into reducing the uncertainty related to flood level predictions. The key outcome was a 2-year Targeted Programme of research to be undertaken by a multidisciplinary team of experts and led by HR Wallingford, which would deliver the CES. The CES will encompass, categorise and provide access to current knowledge and understanding to facilitate the estimation of conveyance by the various types of user in the UK, thus attempting to bridge the gap between academic findings and practical problem solving techniques. The need for a Strategic Programme of research, with a timeframe of 3-5 years, was also identified. This would be developed in parallel with the Targeted Programme and incorporate any new knowledge into the CES.

The Targeted Programme of research is now approaching completion. A thorough literature review of channel roughness, including over 700 references, has been undertaken and is available as a complete report [8]. A comprehensive review of the conveyance estimation methods, including the more recent advances, has been undertaken. The algorithms for the new approach have been developed and tested against a variety of data sets, ranging from small-scale experimental flumes to purpose-made real river testing [6]. The approach for reducing the uncertainty has been developed with particular emphasis on practical application and use. These reviews form the basis of the technical input to the CES software, which is in the final testing phase. In addition, the CES software has been incorporated into iSIS Flow Version 2.1 and is currently being tested for application to large scale (50-100 km) river models.

The project deliverables will be completed early in 2004 and will include documentation, conveyance and roughness manuals, training material and the CES software.

CONVEYANCE ESTIMATION SYSTEM

The CES comprises three core components, the Roughness Advisor (RA), the Conveyance Generator (CG) and the Uncertainty Estimator (UE). The RA provides advice on the cross-section unit roughness. This unit roughness is different to the widely used Manning n-value as in Barnes [9], Chow [10], Cowan [11] and Hicks & Mason [12], which is applied to whole portions of the cross-section. It is essentially a Manning *n* value that has been stripped of all other energy losses e.g. shape, form, sinuosity and is based entirely on local skin friction.

The total unit roughness at a point in the cross-section is composed of up to three component roughnesses: vegetation, surface material and / or irregularities. The RA provides a minimum, maximum and expected roughness value, as well as seasonal variations in vegetation growth and the facility to implement cutting regimes e.g. percentage cut and date. Selection of the unit roughness in the RA is based on the local roughness description and an extensive photographic database (e.g. Figure 2). In the absence of data, the user can enter the UK grid reference of the study reach and receive advice on the expected in-channel and bank-side aquatic vegetation. These vegetation morphotypes are based on data obtained through the national survey of river habitats [River Habitat Survey (RHS), Raven et al [13]]. This survey was based on a 10 by 10 km square grid and 25 items were assessed at each river cross-section, spaced at 50m intervals, in 500m long river segments.

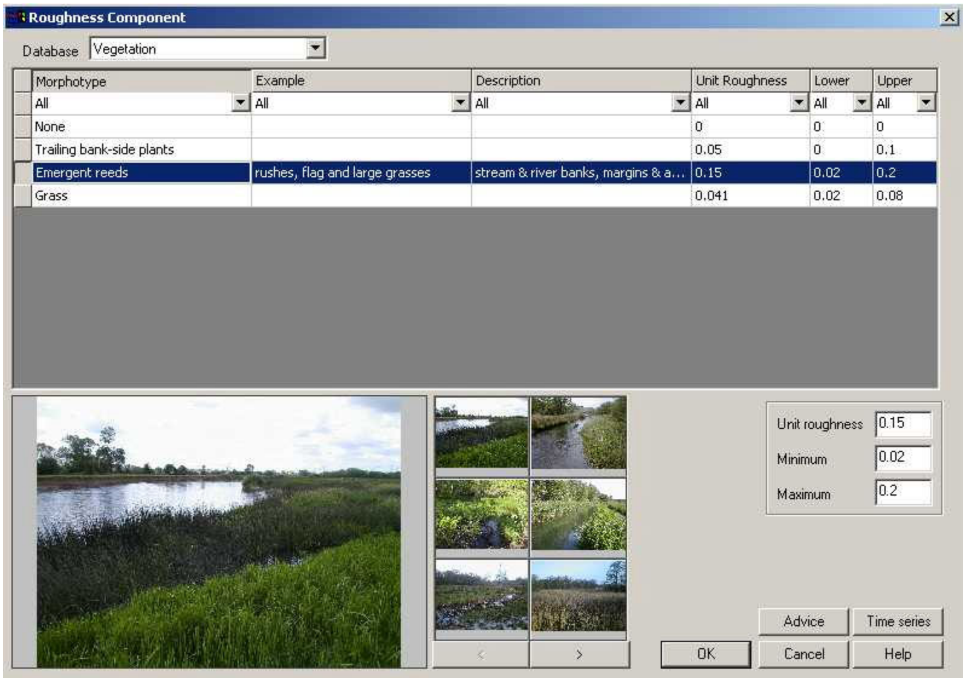

Figure 2. Screen shot of the Roughness Advisor with the emergent reeds option selected.

The total unit roughnesses or ‘ roughness zones’ are then passed into the CG for use in the conveyance calculation. The calculation is based on the depth integration of the Reynolds-Averaged Navier-Stokes (RANS) equations, further details in DEFRA/EA [6]. The total unit flow rate q (m^2/s) is solved for at each point within the cross-section and hence the total flow rate Q (m^3/s) is evaluated from integration of this lateral unit flow distribution across the channel section. The total cross-section conveyance K (m^3/s) is thus determined from,

$$K = \frac{Q}{S_f^{1/2}} \approx \frac{\int q\,dy}{S_o^{1/2}} \tag{1}$$

where the reach-averaged longitudinal friction slope S_f is approximated by the reach-averaged longitudinal bedslope S_o, and y is lateral across the section. This RANS equation has four calibration coefficients to account for the energy losses: the local friction factor f which is based on the unit roughness, the dimensionless eddy viscosity λ which accounts for lateral shear, and the secondary flow parameters Γ and C_{uv} which account for straight and meandering secondary flows respectively.

The CG user input requirements include cross-section geometry; top-of-bank markers to indicate the magnitude and orientation of the secondary flows; allocation of the total unit roughness extents or 'roughness zones' in the cross-section; approximate reach-averaged longitudinal bedslope; and planform sinuosity. The user can then generate a stage-conveyance curve and access additional options such as discharge, velocity, area, Reynolds number and Froude number with depth.

The UE provides some measure of the uncertainty associated with the calculation. Uncertainty arises principally from lack of knowledge or of ability to measure or to calculate and gives rise to potential differences between assessment of some factor and its "true" value. Understanding this uncertainty within our predictions and decisions is at the heart of understanding risk. The uncertainty is represented in the CES through upper and lower bands about the mean stage-conveyance curve. These bands should not be interpreted as minimum / maximum envelopes, but rather as 'soft' boundaries within which the 'true' values is likely to occur. A sensitivity analysis on the potential sources of uncertainty, e.g. quality of survey data and numerical grid resolution, identified the unit roughness as the principal contributor. These bands are thus based on the minimum and maximum roughness values, which may not be symmetrical about the mean.

The primary outputs from the CES components are:

Roughness Advisor:	total unit roughness values or 'zones' [.RAD files]
Conveyance Generator:	stage-conveyance relationship [.GEN files]
Uncertainty Estimator:	upper and lower bands for the stage-conveyance relationship

IMPLEMENTATION IN ISIS

The CES-iSIS integration was designed such that the CES forms an additional module within the iSIS environment, providing the user with the option of calculating the conveyance with the new CES method or with the previous Manning approach. The conversion of 'river units' to equivalent 'CES units' is intuitively designed, with the facility to block large portions of the study reach and apply mass conversions of the river units to CES units. The RA can be accessed through the iSIS environment, allowing the user to alter roughness zones during the model calibration. The CES module within iSIS is currently undergoing testing, and early results indicate good stage-discharge predictions along the reach, and in particular, good representation of the observed variations in stage around bankfull depth. This representation provides confidence for the extrapolation of curves, thus potentially reducing the uncertainty associated with flood level predictions.

SUMMARY OF TEST RESULTS

The conveyance methodology has been tested against a range of data, covering small- and large scale experimental flume measurements, purpose-made real river measurements and Environment Agency Section 105 and MDSF (Management Decision Support Framework) models accompanied by real river observations. The data sets were carefully selected [14] to represent a range of channel types (rural / urban), channel morphologies (widths, gradients, aspect ratios), flow conditions and surface cover. The results were encouraging and showed an improvement on previous methods [6].

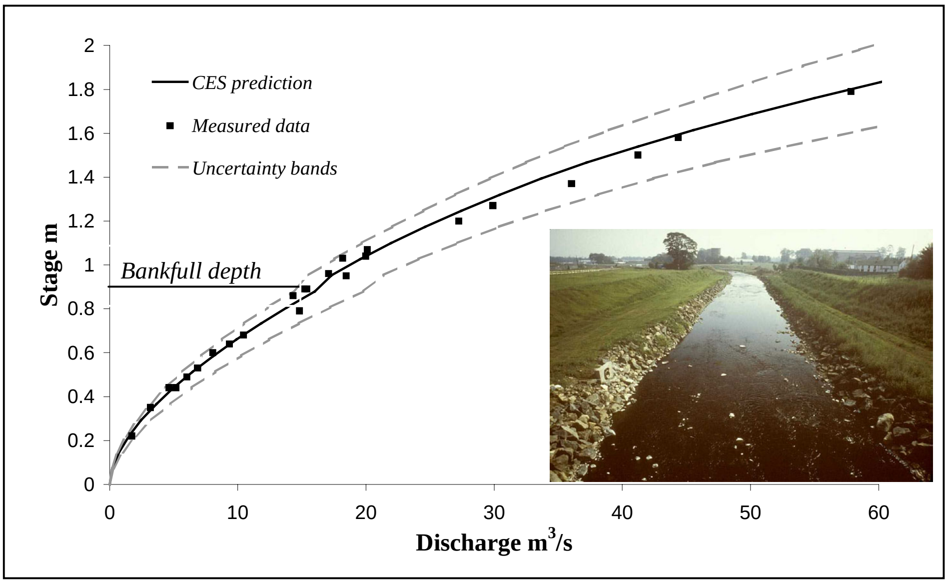

Figure 3. The River Main CES stage-discharge prediction

The CES was tested against measured data from an 800km reach of the River Main in County Antrim, Northern Ireland. Between 1982 and 1986 the channel was reconstructed and realigned to form a double trapezoidal channel from Lisnafillan Weir to the junction with the Braid River. The final dimensions include a top width of 14m, a total width inclusive of floodplains of 27.3-30.4m, and bankfull depth ~0.9-1.0m. The floodplains slope towards the main channel with a 1:25 gradient. The reach-averaged longitudinal bed slope is 1:520. The river bed consists of coarse gravel with a sediment size of 10-20mm. The main channel side slopes consist of quarry stone / rip-rap (0.5 tonne weight, 100-200mm size) and the berms are covered with heavy weed growth. The test section is taken in a straight section of the reach. Figure 3 illustrate the stage-discharge curve as predicted by the CES, with no calibration. The RA provides the gravel, rip-rap and channel unit roughness values. The upper and lower uncertainty bands are indicated, and the observed data falls well within these 'soft' boundaries.

CONCLUSIONS AND THE FUTURE

The CES and the improved iSIS software have been tested as prototypes by a variety of users. They have indicated that the new conveyance estimator is understandable and useable in both these systems. The test results summarized above show significant improvements in the calculation of water levels using the new techniques. So the aims of the project have largely been achieved.

Pilot testing will take place early in 2004, which will give information on the potential extent to which uncertainty can be reduced under real project situations. The intention then is to roll-out the new software to users throughout the UK, and elsewhere. It is expected that this will lead to a real improvements in working practice in both river modeling and river maintenance.

REFERENCES

[1] Manning, R., On the Flow of Water in Open Channels and Pipes, *Transactions of the Institute of Civil Engineers of Ireland*, Vol. 20, (1891), pp 161-207.

[2] Chang, H.H., Energy Expenditure in Curved Open Channels, *Journal of Hydraulic Engineering*, Vol. 109, No. 7, (1983), pp 1012-1022.

[3] Ervine, D.A. & Ellis, J., Experimental and Computa-tional Aspects of Overbank Floodplain Flow, *Trans. Royal Society of Edinburgh: Earth Sciences*, Vol. 78, (1987), pp 315–475.

[4] Ervine, D.A., Babaeyan-Koopaei, K. & Sellin, H.J., 2000. Two-dimensional Solution for Straight and Meandering Overbank Flows, *Journal of Hydraulic Engineering*, ASCE, Vol. 126, no. 9, September, (2000), pp 653-669.

[5] Shiono, K. & Knight, D.W., Two-Dimensional Analytical Solution for Compound Channel, *Proc. 3rd Intl. Symposium on Refined Flow Modelling and Turbulence Measurements*, Universal Academy Press, (1989), pp 591-599.

[6] DEFRA/EA, Reducing Uncertainty in River Flood Conveyance, Interim Report 2: Review of Methods for Estimating Conveyance, *R&D Technical Report to DEFRA /*

Environment Agency, Project W5A- 057, HR Wallingford Ltd., United Kingdom, (2003).

[7] Evans E.P., Pender G., Samuels, P.G. & Escarameia, M., Reducing Uncertainty in River Flood Conveyance: Scoping Study, *R&D Technical Report to DEFRA / Environment Agency*, Project W5A- 057, HR Wallingford Ltd., United Kingdom, (2001).

[8] DEFRA/EA, Reducing Uncertainty in River Flood Conveyance, Roughness Review, *R&D Technical Report to DEFRA / Environment Agency*, Project W5A- 057, HR Wallingford Ltd., United Kingdom, (2003).

[9] Barnes, H.H., Roughness Characteristics of Natural Channels, *US Geological Survey*, Water-Supply Paper No. 1849, pp214, Washington DC, (1967).

[10] Chow, V.T., *Open Channel Hydraulics*, McGraw-Hill Book Company, US, (1959) .

[11] Cowan, W.L., Estimating Hydraulic Roughness Coefficients, *Agricultural Engineering*, Vol. 37, (1956), pp 473-475.

[12] Hicks, D.M. & Mason, P.D., *Roughness Characteristics of New Zealand Rivers,* NIWA, Christchurch, (1998), 329pp.

[13] Raven, P. J., Holmes, H. T. H., Dawson, F.H., Fox, P. J. A., Everard, M., Fozzard, I. & Rouen K. J., River Habitat Quality The Physical Character of Rivers and Streams in the UK and the Isle of Man, *River Habitat Report No. 2, Environment Agency*, (1998), pp 90.

[14] DEFRA/EA, Reducing Uncertainty in River Flood Conveyance, Interim Report 1: Data Mining, *R&D Technical Report to DEFRA / Environment Agency,* Project W5A- 057, HR Wallingford Ltd., United Kingdom, (2003).

ACKNOWLEDGMENTS

This paper draws upon the Targeted Programme of research commissioned by the Environment Agency as project W5A-057 under the joint DEFRA / Agency Flood and Coastal Defence R&D Programme. We wish to thank Dr Mervyn Bramley, the Agency Project Manager for his encouragement and support. The contributions of all team members and academic expert advisory panel are also gratefully acknowledged. The views expressed in this paper are, however, personal and the publication does not imply endorsement by either the Environment Agency or the Department for Environment, Food and Rural Affairs (DEFRA).