

Reducing Uncertainty in Conveyance Estimation

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ABSTRACT: Estimation of conveyance is a core component of flood management, water level prediction and flood defence design. All river modelling software includes one or more methods for conveyance estimation, usually based upon methods dating from research completed more than 50 years ago with little or no account taken of recent advances in knowledge and understanding. In 2001 the British Environment Agency commissioned, as a research project, a scoping study to define actions for reducing uncertainty in conveyance estimation. The paper describes some of the conclusions of that scoping study including the needs of different users, the diversity of current knowledge and the outline of the targeted programme of research that is now underway to produce an improved conveyance estimation system. Particular issues of concern are the effects of riverine vegetation, the influence of natural shaped (and re-naturalised) channels and the interaction between river channels and flood plain flows.

1 INTRODUCTION

Over the past 20 years much research has been undertaken on the capacity of river and flood plain systems, including a concentrated experimental programme on the conveyance of compound channels in the Flood Channel Facility (FCF) at HR Wallingford, see for example Knight & Sellin (1987) and Sellin *et al* (1993). This has produced greater physical insight into the fluid mechanics of these flows but this improved knowledge of the processes of flood propagation has not been taken into general practice. The former British National Rivers Authority (1994) commissioned the derivation of hand calculation methods for assessing the conveyance of straight and compound channels based upon the research undertaken in the first two phases of the experimental programme of the FCF. Although these methods performed well in tests against experimental measurements and those from real rivers, the methods remained largely unused.

In 2000 the Engineering and Physical Sciences Research Council (EPSRC) established a research network on river and flood plain conveyance in the UK with participation of about 60 academics and river engineers. An early action resulting from the EPSRC network was the commissioning by the Environment Agency of a Scoping Study on reducing uncertainty in river flood conveyance. The Envi-

ronment Agency was concerned that the Scoping Study should address the whole, multi-user nature, of flood management as the end objective, not the design function (as had been the case in the earlier work of the National Rivers Authority). Furthermore, the Scoping Study had to reconcile the needs for both research openness and the supply of commercial software systems for river simulation.

The objective of the scoping study was to identify a programme of work to synthesise current knowledge and filling in the gaps, in order to take a measured step forward in river management practice. A team drawn principally from the membership of the EPSRC network and led by HR Wallingford undertook the Scoping Study. The project involved directly and through consultation:

- recognised academic experts and researchers
- operational staff and
- consulting engineering practices

The Scoping Study included a questionnaire targeted at specific individuals and distributed by mail, by the IAHR e-mail contact group on “Rivers-list” and by posting it on the EPSRC network internet site (<http://ncrfs.gla.ac.uk/>). The industry and academic communities were involved through two workshops, one on the user needs and the other as a validation of the first draft of the research recommendations. The study also included the preparation of a series of expert review papers on flow measurements (field and experimental), effects of vegetation, conveyance calculation methods in 1-D models, implications for

2-D and 3-D models and the use on remote sensing. These expert papers were prepared by members of the EPSRC network and the texts are contained in an annex to the final report (Environment Agency, 2001) and provided the documentation of the state-of-the-art which underpinned the scoping study research recommendations.

The vision set for the end-product of the subsequent targeted research and development programme was that it should lead to:

- Significant improvement in UK practice by updating knowledge and tools employed
- National economic benefits in terms of improved performance and risk reduction
- International recognition of the UK research and enhanced opportunities for consultancies

2 THE USERS AND THEIR NEEDS

The Scoping Study report (Environment Agency, 2001) identifies the different practitioner groups in flood management with a need to establish river capacity as being:

- Planning and development control
- Flood Forecasting
- River maintenance
- Design of new works
- Hydrometric data analysis

However, the individual technical needs and backgrounds of these users are diverse.

A key requirement established in the Scoping Study was that the “users” should have confidence in and ready access to the latest knowledge and understanding of flood hydraulics. The needs and practices of users were explored in the scoping study through the structured questionnaire and the specialist user workshop held in March 2001.

The questionnaire covered the methods used for river modelling, the use of hand calculation, the determination of flow resistance and the use of recent methods of conveyance calculation. In addition the respondents were invited to contribute any other comments they wished. A satisfactory response (26 in total) was achieved, with 85% of the individually addressed questionnaires being returned; there was inevitably a bias to responses from the UK. The principal messages from the questionnaire were that:

- most river modelling is based on commercial software rather than in-house models
- hand calculation is still used, mainly as a check on modelling results
- several methods are in use for estimating resistance, the most common being individual experience and the use of comparative photographs
- although most modellers rated their confidence in roughness estimation as “medium-high”, 30% have low confidence in their estimates

- few respondents used recent methods published for conveyance estimation
- approximately one-third of the respondents used separate estimation of the effects of vegetation from the general channel resistance.

The workshop provided an appreciation of the current knowledge and practices. The participants at the workshop were asked to identify issues in several categories to inform the later stages of the scoping study. The participants were also invited to consider potential difficulties in implementing the outputs from any Targeted Programme of research in this area. The topics, which achieved the most significant rating in each category, are as follows:

1 Issues in uncertainty

- The number of modelling methods and the variation in their results
- The confidence of choice of Manning’s n
- Seasonal variability affecting vegetation
- Lack of adequate calibration data / errors in data
- Variation of parameters along a river reach

2 Gaps in Knowledge

- Effect of vegetation / hedges / banks / bushes on flow levels and extent of flooding
- Interaction between the main channel and flood plain
- Comparative benefit of different conveyance methods – validity of methods

3 Barriers to uptake of knowledge

- Lack of understanding and consensus on the best approach arising from lack of confidence in knowledge
- Tradition, risk from using the unfamiliar and inertia
- The time to do project work coupled to the cost of the project (i.e. budget constraints)

This led to the identification of some priorities for the development and implementation of an improved method of conveyance calculation. Firstly, there is a need to systematise information on river roughness for use by modellers including guidance on roughness estimation. Secondly, guidance is needed on the selection of method(s) on conveyance for incorporation in 1-D models. The failure of the earlier National Rivers Authority design method based upon the FCF experiments to make an impact indicates the need for a software implementation of any new method developed, preferably using open code, which is accessible to third party developers. Finally, there will be a need for a professional development programme to update the knowledge and skills of practising river engineers and managers, coupled with the appropriate resources to use an unfamiliar methodology on projects.

3 SOURCES OF UNCERTAINTY

There are differences between accuracy, error and uncertainty. Accuracy deals with the precision to which measurement or calculation is carried out; potentially, accuracy can be improved by better technology. Errors are mistaken calculations or measurements with quantifiable differences. Finally, uncertainty arises principally from lack of knowledge or of ability to measure or to calculate which gives rise to potential differences between assessment of some factor and its “true” value.

There are several contributions to uncertainty in the estimation of conveyance, the principal ones being:

- 1 process uncertainty which arises from the selection and approximation of physical processes and from parameterisation made to define conveyance
- 2 representation uncertainty from the density of the discrete survey points and interpolation rules, i.e. the difference between the shape of the river and the physical features on the flood plain as represented in the calculations and in “real” life
- 3 data uncertainty from the limitations of the survey methods used
- 4 uncertainties arising from parameter estimation – particularly the experience and expertise of the modellers who set up and calibrate computational models of river flows
- 5 uncertainties from the model calculation methods, approximations and rules; these are the domain of traditional numerical analysis, and
- 6 uncertainty from seasonal variations in vegetation, temperature etc.

The estimation of uncertainty is an active area of research in the flood defence sector, particularly so in flood forecasting and estimation, see for example, Aronica *et al* (1998) and Romanowicz & Beven (1998). Specifically for flood level estimation, there have been investigations of some of these sources of uncertainty individually and in combination, e.g. by Burnham & Davis (1990), Defalque *et al* (1993), Samuels (1990, 1995) and Yang & Kung (1994).

However, a full framework for the combination of all these sources of uncertainty and other important uncertainties such as flood discharge estimation still needs to be established. A desirable outcome of the uncertainty estimation would be to give an expected range of uncertainty (e.g. as measured by the standard deviation of the process) together with an estimate of the upper bound.

4 IMPACT OF UNCERTAINTY

A separate issue on uncertainty is the tolerability of uncertainty in the end use of the conveyance estimations. It is possible that for some uses a greater de-

gree of uncertainty is permissible enabling simpler methods to be used, less field data to be gathered or less intensive calibration of the parameters. The effects of uncertainty in the estimation of conveyance differ with the various business sectors of flood management. The potential consequences of uncertainty and typical current methods of mitigation for the uncertainty are listed in Table 1.

Table 1 Potential consequences of uncertainty

Management Function	Consequence of uncertainty	Current mitigation strategy
Flood defence design	Under capacity of defences leading to potential failure below the design standard or over capacity potentially leading to morphological problems or lower economic return than planned. Over estimation of capacity of defences leading to lack of implementation of schemes due to excessive cost.	Undertake sensitivity analyses and add a freeboard to allow for under capacity
Real time forecasting	Under- (over-) estimation of lead times, inexact inundation extent, and incorrect retention times of floods.	Implement real-time updating procedures
Hydrometry and rating curve extension	Incorrect discharges with potentially large errors, influences flood forecasting and statistical estimation of flood flows for design, impacts upon cost-benefit assessment and decisions to promote flood defence schemes.	Undertake sensitivity analyses
Maintenance	Inadequate or excessive maintenance activities, possibly unnecessary disruption to aquatic and riparian habitats or insufficient capacity of the watercourse leading to increased flood risk.	Maintenance according to a defined programme
Flood risk mapping	Indicative Flood Mapping (IFM) in error – inadequate tool for planning and information on possible flood risk, inadequate (or over necessary) development control, loss of professional and public confidence in the Agency’s technical abilities.	Give “health warnings” on use of IFM

The potential economic benefits of the use of improved methods will come from altering the mitiga-

tion strategies as the degree of uncertainty is reduced. The sensitivity of project decisions to uncertainty in conveyance estimation also needs to be established. Strategic decisions made early in the project life cycle can have far reaching consequences and it is at this early stage that uncertainties in information and data are greatest.

There is a close relationship between uncertainty and risk in that the greater the uncertainty the greater the probability of the project or maintenance activity of not achieving its objective. This is linked to the confidence on the performance of the scheme or process to meet its intended objectives. Thus, optimisation of performance and the confidence with which performance can be delivered is linked inexorably with understanding and controlling uncertainty.

5 BASIS OF CONVEYANCE CALCULATION

5.1 Definition of conveyance

Conveyance is a quantitative measure of the discharge capacity of a watercourse. It relates total discharge to a measure of the gradient or slope of the channel. Original definitions of conveyance assumed uniform flow (with no spatial or temporal variation) in regularly shaped channels with constant gradient. The definition is

$$Q = K s^{1/2} \quad (1)$$

where K (m^3/s) is the conveyance, Q (m^3/s) is the discharge and s (m/m) is the common uniform gradient. In this idealisation there is no ambiguity about the slope since the water surface slope, the bed slope and the so-called “energy” or “friction” slope all coincide.

5.2 Link to mean boundary shear stress

For a rigid-bed, straight, uniform channel, the rate of “loss” of specific energy is caused by the resistance of the flow boundaries. For this idealised case, dimensional analysis relates the mean boundary shear stress, τ , to the primary flow velocity, U , and density, ρ , by

$$\tau = \rho U^2 \Phi(\text{Re}, \text{shape}, \text{boundary-texture}) \quad (2)$$

In the general function Φ , Re is the Reynolds number of the flow and *shape* incorporates the dependence of the mean stress on the geometry of the section shape for a given flow area. The *boundary-texture* parameter(s) characterise the retarding nature of the boundaries, usually captured as a single parameter according to the precise formula being used (e.g. Manning’s n). The mean boundary shear stress is defined from integrating the actual stress distribu-

tion around the wetted perimeter. The resistive force F for length X of channel is given by

$$F = \tau P X \quad (3)$$

where P is the wetted perimeter. This may be put into a force-momentum balance for the channel to relate the channel gradient to provide the relation between boundary shear stress and slope.

$$\tau = \rho g R s \quad (4)$$

where $R = A / P$ is the hydraulic radius and A is the flow area. By eliminating τ from Equations (4) and (2) we obtain

$$U = (g R s)^{1/2} \Phi^{-1/2} \quad (5)$$

Which, since $Q = AU$ by definition provides the link to conveyance as defined in Equation (1) with

$$K = A (g R)^{1/2} \Phi^{-1/2} \quad (6)$$

Individual formulae for conveyance are based upon empirical relationships for the resistance function Φ for particular section geometries. For rough turbulent flow these are independent of the Reynolds’ number, but there is dependence on velocity through the Reynolds’ number for laminar, transitional and smooth-turbulent flow.

Boundary shear stress is a key physical parameter in 2-D and 3-D models. In these applications, it is evaluated in a similar fashion to the mean shear stress above, except that it is treated as a local property without the influence of the section average *shape* factor.

5.3 Factors influencing conveyance

For flows apart from steady discharge in a straight uniform rigid bed channel, other factors influence the conveyance. These include (in no relative order of importance):

- detailed cross-section geometry
- unsteadiness in time
- plan form induced rotations (secondary currents)
- effects of section variation in the downstream direction
- gross lateral variations in flow velocity in different section zones (lateral shear layers)
- resistance effects of vegetation
- large-scale features on the river bed (boulders, debris, dunes, riffles)
- force needed for sediment transport.

5.4 Methods for estimating conveyance

Current methods for estimating conveyance are built primarily around a steady flow friction law such as Manning’s Equation developed in the 1880’s, applied on a section by section basis, coupled to ad-

justment factors for the complexities of real life. Thus we have

$$K = A R^{2/3} / n \quad (7)$$

from which the function Φ in Equation (6) can be deduced by comparison of the two formulae. The Manning's n roughness coefficient has been the subject of extensive research and publication in the engineering literature, relating its value to the nature of the river channel and the factors listed above which influence conveyance. Other equations are in use such as the semi-theoretical Colebrook-White equation developed originally for pipe flow and Chezy's equation, which predated Manning's equation by about 100 years. Much technical analysis of channel resistance and conveyance has been written in terms of the Darcy friction factor (denoted by the symbol, f or by λ).

6 COMPOUND CHANNELS

One difficulty in using Single Channel Method (SCM), Equation (7), for compound channels (e.g. a river and flood plain cross-section) is that the hydraulic radius, R , is a poor choice as the representative shape factor for the cross-section as the flow inundates the flood plain. This leads to the SCM underestimating conveyance by 50% or more for shallow flood plain flows. Thus, the conveyance calculation method in most 1-D river modelling packages is based on a version of the Divided Channel Method (DCM). The channel can be sub-divided by vertical, inclined or horizontal division lines. These implementations assume quasi-straight reaches and do not include any lateral momentum transfer effects. For example, ISIS uses a variant of the original Lotter (1933) method. Conveyance as in most models is tabulated and derived during simulation from look-up tables. Both aspects can give rise to approximation errors and need care in application. The DCM, however, can overestimate conveyance for shallow flood plain flows by 30%.

The more recent analysis of straight compound channels has concentrated on two approaches, either methods of adjusting the flows calculated for the channel and flood plain units in the DCM or calculating the conveyance as a cross-section integral of a two-dimensional momentum equation. A good example of the first approach is the coherence method (COHM) of Ackers (National Rivers Authority, 1994), which provides estimates within a few percent of measurement for most flow cases. The COHM is well established for compound channels with deviations of up to 10 degrees between main channel and flood plain alignment. This is however a considerable limitation for natural rivers as against man-made channels. The COHM requires an idealisation of the section geometry as a compound trapezoidal shape.

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The second category of methods include the Lateral Distribution Method (LDM) of Wark *et al* (1990), which provides a local 2-D approximation to the flow distribution at a channel and flood plain cross-section. It ignores the secondary flow terms and puts all the diffusion processes into a single 'catch all' parameter, the depth-averaged lateral eddy viscosity. The Shiono & Knight (1991) Method (SKM) extends the physical basis of the LDM. The channel may be divided into sub-areas and important processes modelled analytically in each sub-area, using three calibration coefficients concerned with bed friction, lateral shear and secondary flow. Like the COHM, these methods perform much better than the traditional methods (SCM and DCM) and have the advantage of providing a cross-sectional variation of velocity.

In meandering compound channels, streamwise curvature and the flood plain flow shearing over the flow in the lower meandering main channel provide further complications. Various methods have been proposed but most have been developed for in-bank flow and these are largely inapplicable to meandering channels with overbank flood plain flow. Examples of the potential approaches for flood flows are:

- the methods reported by Ervine & Ellis (1987) and Willetts & Hardwick (1993),
- the hand calculation design procedure of James & Wark (1992) and
- the methods developed for more natural geometries by Rameshwaran & Willetts (1999) and Lambert & Sellin (2000).

Further discussion on these and other methods is given in the expert paper prepared by Professor Knight in the annex to the Scoping Study report. Here, Knight recommended that further work may be grouped as

- comparison of the theoretical basis and advantages of methods,
- testing of algorithms against benchmarks,
- development of stage-discharge relationships for different channel shapes and heterogeneous roughness effects,
- further field and laboratory validation studies,
- assessing the impacts of hydraulic structures and vegetation, and
- assessing the effect of averaging algorithms in practical computations.

7 RESISTANCE OF VEGETATION

The Scoping Study paper on vegetation by Fisher & Dawson (see the Annex of Environment Agency, 2001) covers vegetation in-channel, along channel

edges, along the berm and on the flood plain including hedges and trees.

Methods traditionally used to estimate the roughness include photographic and tabular methods as found in the user survey (see Section 2 above), but a range of more quantitative assessments is also available.

Many of the methods for determining the impact of vegetation on the roughness of the channel are based on data collected on a particular river over one season or a number of seasons. Much of this data is valuable in indicating the large variations in roughness which vegetation can cause, but does not provide general relationships.

Extensive tests undertaken on grass cover (Ree, 1949 and Ree & Palmer, 1949) resulted in a Handbook of channel design, US Soil Conservation Service, (1954). The result of the work has been to define a series of relationships between Manning's n and the product VR , where V is the mean flow velocity and R is the hydraulic radius. The relationship is expressed as a family of curves, each curve defining the other principal variable, the physical characteristics of the vegetation. The product VR may be viewed as a Reynolds' Number (see Section 5.2 above), which is defined by $Re = \rho VR/\mu$, since the fluid properties of density, ρ , and viscosity, μ can be assumed to be approximately constant.

Kouwen *et al* (1973,1981) have attempted to extend the USDA method for grass-lined channels by introducing a parameter to represent vegetation stiffness. Kouwen & Unny (1973) carried out flume experiments to study flow over flexible vegetation. Analysis of the experimental results revealed a good relationship between friction factor and relative roughness. Kouwen *et al* (1981) indicated that the empirical Manning's n to VR method used for design cannot be used to extrapolate experimental data to any arbitrary slope or be used when the vegetation is short and stiff. Kouwen, *et al* (1981) present a modified method which is also applicable to low slopes. Klassen & Van Der Zwaard (1974) carried out laboratory experiments to investigate the effect of orchards and hedges which were not submerged by the flow on the roughness coefficient of vegetated flood berms. Klassen & Van Urk (1985) extended this work by investigating the resistance of drowned hedges.

Since 1985 a number of empirical studies have been undertaken investigating the impact of vegetation on roughness values which confirm that there is a relationship between roughness, the amount of vegetation and the product of velocity and hydraulic radius (VR). While these empirical relationships or equations based on correlation between Manning's n and VR could be coded into existing models, they are not ideal in that velocity is calculated using a coefficient which itself depends on the velocity. The same values of VR may be obtained from different

values of V and R and the relationship is not independent of slope. It is not clear that the roughness should be the same for a rapid, shallow partly submerged flow and a slow, deep completely submerged flow, which have the same VR product.

Recent research and associated papers have taken a different approach from producing a Manning's n to VR relationship by determining the drag coefficient of the vegetation and converting that into a roughness value. However, this more analytical local view of resistance may not capture the reach-scale effects of substantial physical features such as hedges, which break up conveyance "routes" on the flood plain.

In conclusion, although much literature exists based on Manning's n to VR relationships, the application of this knowledge is not easy. It is not obvious from the review whether the existing, diffuse knowledge base and approach provide a practical and advantageous way forward in the short term towards improving conveyance estimation in relation to vegetation. An attractive, alternative approach is the production of a national version, from sites in the UK River Habitat Survey database, of the photographic and tabular guides produced in other countries (e.g. by Chow (1959) and Barnes (1967) for the US and by Hicks & Mason (1991) for New Zealand).

8 KEY ISSUES IDENTIFIED FOR THE FUTURE TARGETED PROGRAMME

The state of knowledge and practice identified in the Scoping Study through the expert papers, questionnaire and workshops enabled the key elements of a Targeted Programme of R&D to be identified. There were several common themes from the review papers, workshops and questionnaire responses. The most important ones, which affect immediate practice in the Environment Agency and its consultants and the research programme, are presented in the following paragraphs.

Standard river modelling software packages rely only on a few methods, which do not incorporate the latest research findings. This implies that the scientific basis of much of the work undertaken for or by the Environment Agency and other Operating Authorities in the UK does not use recent advances in knowledge or understanding since the methods used in practice were published three to five decades ago. This observation is the most telling case for the need for the Targeted Programme of development.

The distribution of data especially from real sites was found to be diffuse, which hinders its use in validation of research methods. This leads to a need for compilation of this existing data into a form which can be used to validate methods for conveyance estimation.

There is an urgent need for guidance on the use of the many conveyance calculation methods available; Professor Knight identified over 20 in his expert review paper. Reduction to at most three or four preferred methods would seem appropriate.

There is limited use of 2-D modelling in engineering practice in the UK compared with mainland Europe. Hence, initial improvement in practice can concentrate on 1-D modelling procedures, with guidance on when higher dimensional modelling should be considered.

The information on the estimation of river roughness and the resistance of flood plain features is diffuse and somewhat conflicting nature, especially for the selection of Manning's n . This leads to the need for an "advisor" on river roughness.

There is a lack of appreciation or knowledge of magnitude and relative importance of the uncertainty inherent in conveyance estimation on the overall objectives for a project or operation. This leads to the need for the development of a practical framework for uncertainty estimation, which can provide a pathway for inclusion of knowledge and estimation techniques as they are developed.

The difference between normal and recognised best modelling practice should be addressed through the preparation of a guidance manual or document on modelling practice.

The lack of understanding by many model users, and those who rely on model outputs, of the basis of the calculation and assessment techniques for river conveyance implies a need for a programme of professional development to support the introduction of new methods into practice.

There is a need for information on flood plain resistance and the effects of obstructions at a scale finer than the typical computational grid, so that the river is modelled within the real-world context of the flood plain, which provides both additional conveyance as well as storage within retarded zones.

9 OUTLINE OF A PROPOSED CONVEYANCE ESTIMATION SYSTEM

The Scoping Study report recommends a Targeted Programme of research and development to provide as its output an integrated Conveyance Estimation System (CES), which will support the different user needs with respect to conveyance. The CES will be available as open code to maximise its dissemination and the CES will incorporate a conveyance manual and roughness advisor.

The Conveyance Manual will provide the key and entry point to the system. The users have quite distinct requirements of the system and these must be satisfied in a structured way in the manual.

The Conveyance Estimation System itself will have four sub-components:

- 1 The Roughness Advisor will be a dual paper and software system, consisting of sets of photographs of both vegetation and other substrate material, structured and accessed by morphotype. The latter will act as a key to the photographs, and will draw on and be related to the UK River Habitat Survey. Each photograph will be accompanied by Manning's n values, in the form of a median value plus upper and lower bounds. These will represent both uncertainty in the determination of n values, and natural variation in the roughness of the substrate including that due to seasonal growth and the cutting of vegetation. Whole-river photographs will also be provided, with global Manning's n values.
- 2 The Roughness Review will be a scientific document forming the underpinning of the Roughness Advisor and will be available to inform future research and assist users who need or wish to explore the topic area further.
- 3 The Conveyance Estimator may be based on an Excel spreadsheet. Users will input the channel cross section and its slope for which they wish to derive conveyance, either manually or from other data file. They will also assign Manning's n values derived from their use of the Roughness Advisor. The Conveyance Estimator will then compute a choice of outputs, such as global resistance values, either for single flows or for a range of flows; water levels for a given flow or complete stage-discharge curves. Behind the Conveyance Estimator will be a Conveyance Generator based on the preferred conveyance method(s). This should employ identical algorithms to the code which will be included in commercial 1-D models. It is essential that the preferred method uses readily predictable values for any turbulence-related parameters. These will be given as defaults in the Conveyance Generator, as most users do not have the knowledge to modify them.
- 4 The Uncertainty Estimator will provide users with estimates of the uncertainty in their conveyance estimates, using input such as estimates of the accuracy of survey data used and of the preferred method itself. A further option might be to generate stage-discharge curves corresponding to the upper and lower band roughness values from the Roughness Advisor.

As was shown at Scoping Study workshops, UK engineers depend heavily on river modelling packages to do their work. It is therefore essential to the overall success of the project that a replication of the Conveyance Generator is included in the commercial 1-D models widely used in UK. The questionnaire showed that the majority of model applications for flood defence purposes in UK are either HEC-RAS for steady flow, or ISIS for unsteady flows. The design of the CES as open code will enable

these software packages to be modified to include the new methods. It is expected that ISIS will be the example application for the new Conveyance System. Any agreement here must establish a satisfactory position for other commercial suppliers of river software packages to use the CES. Openness is likely to be a key to securing continuing innovation in the future.

10 EXPECTED USE OF THE CES IN THE ENVIRONMENT AGENCY

10.1 *Maintenance: planning of dredging and vegetation cutting*

At the simplest level operational staff will use the Conveyance Estimation System to estimate the effect of their proposed works on a single typical cross section of their river. By using the Uncertainty Estimator they would be able to identify better the level of risk and the sensitivity of water levels to maintenance operations, dredging and seasonal variation in vegetation.

At a second level, operators would be able to transfer the details of their proposed works to a simple backwater programme such as HEC-RAS containing the new methods, to verify their estimates taking backwater effects into account.

10.2 *Flood warning and planning studies*

Flood forecasting models frequently employ routing models because of their speed of running. However these only directly produce flows, which then have to be converted into flood water levels. Most routing methods utilise idealised or simplified river cross sections and do not take into account the effect of transverse structures such as weirs and longitudinal structures such as washland banks. They are thus sound in natural river reaches but weak where the rivers pass through heavily engineered reaches, namely in towns, which are precisely the areas of high risk and interest. A full hydrodynamic model may be used to generate more accurate stage discharge curves for use in routing models, thus drawing in the benefits of the CES.

Future Catchment Flood Management Plan (CFMP) studies in the UK will be based around the use of whole catchment simulation modelling to examine the long term implications of environmental and societal changes. These are based upon scenarios, including long term climatic forcing and land-use to account for changes in precipitation and runoff processes. The catchment scale modelling will be based mainly upon simplified routing models on account of their greater speed, with infilling of more detailed hydrodynamics where needed. The CFMP process is facilitated by a new Modelling and Deci-

sion Support Framework. The approach is similar to the piloted in the EUROTAS research project (Samuels, 2001). Thus the benefits of the CES will be brought in through the revision of routing speeds at the catchment scale and the assessment of river capacity in the hydrodynamic models. The Environment Agency also is a key player in the land-use planning process as a statutory consultee in national planning guidance. The Agency has produced indicative flood plain maps (IFMs) covering most watercourses in England and Wales. Many of these IFMs are produced from 1-D hydrodynamic modelling and hence the CES will bring benefits of reduced uncertainty in flood hazard mapping when the IFMs are reviewed.

10.3 *Improvement works and scheme design*

Designers of improvement works and new schemes normally use full hydrodynamic models to determine design water levels. It is envisaged that the modeller would use the Roughness Advisor to first divide the model up into reaches with similar geomorphological and biological morpho-types and then to obtain unit roughness values. At this point the modeller might choose to go to the Conveyance and Uncertainty estimators to obtain stage-discharge curves where they have some calibration data which could be directly compared with these, or simply explore the sensitivity of stage to variation in channel and vegetation parameters.

The modeller would then input the unit roughness values into the 1-D hydrodynamic model and run it for calibration flows. At this point it is usual for there to be discrepancy between predicted and observed water levels, and it is common practice to review both the inflows and the roughness values. The Roughness Advisor and Conveyance Estimator will be excellent tools to assist in this process by allowing the user to explore quickly and easily the effect of roughness changes before editing the roughness values in his 1-D model and re-running it.

Lastly the Uncertainty Estimator will allow the modeller to assess the sensitivity of the scheme to specific matters such as vegetation growth and siltation as well as system uncertainty.

11 CONCLUSIONS

The Environment Agency commissioned the scoping study on reducing uncertainty in conveyance estimation to identify means of delivering benefits from improved flood level estimation. The scoping study established the current state-of-the-art and practice on this topic, and identified that the methods in common use were those embedded within the software used by the Agency and its consultants. These methods mostly take little account of the advances in

knowledge and understanding generated by the research community in recent decades.

As a result of the scoping study, a targeted programme is now underway on drawing in best available knowledge into river management practice. This is concentrated on the production of a Conveyance Estimation System, which will link in an open way to many models, and will comprise:

- an expert advisor on roughness estimation
- a conveyance estimator for natural and engineered river and flood plain systems
- an uncertainty estimator to combine the influence of vegetation, shape and calculation methods.

The final outcome of the project should be the adoption by all practitioners in England and Wales of the Conveyance Estimation System and the new conveyance methods. This should lead to improved estimation of water levels and consequent reduced flood risk to the public at lower capital and maintenance cost.

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REFERENCES

- Aronica G, Hankin B.G. & Beven, K.J. 1998, Uncertainty and equifinality in calibrating distributed roughness coefficients in a flood propagation model with limited data. *Advances in Water Resources*, 22(4), pp 349-365.
- Barnes H. H. Jr 1967, *Roughness Characteristics of Natural Channels*, US Geological Service Water Supply paper 1849
- Burnham M W & Davis D W (1990). Effects of data errors on computed steady-flow, *Jnl Hyd Eng, ASCE*, 116(7), pp 914-929.
- Chow V-T 1959, *Open Channel Hydraulics*, McGraw Hill
- Defalque A, Wark J B & Walmsley N (1993). *Data density in 1-D river models*. Report SR 353, HR Wallingford, March.
- Environment Agency 2001, *Scoping Study for Reducing Uncertainty in River Flood Conveyance*, Available at Internet site <http://ncrfs.gla.ac.uk/> and from Environment Agency R&D Dissemination Centre, WRc Frankland Road, Swindon Wilts SN5 8YF
- Ervine D. A., & Ellis J. 1987, Experimental and computational aspects of overbank flood plain flow, *Trans. Roy. Soc. Edinburgh*, Series A, 78, pp 315-325
- Hicks D. M. & Mason P. D. 1991, *Roughness characteristics of New Zealand rivers*. Water Resources Survey, DSIR Marine and Freshwater, ISBN 0 477 02608 7.
- James CS & Wark J.B. 1992, *Conveyance Estimation for Meandering Compound Channels*, Report SR 329, HR Wallingford
- Klassen G. J. & Van Der Zwaard 1974. Roughness coefficients of vegetated flood plains, *Journal of Hydraulics Research*, 12, pp 43-63.
- Klassen G. J. & Van Urk A. 1985, Resistance to flow of flood plains with grasses and hedges, *Proceedings 21st IAHR Congress*, Melbourne. Volume 3, pp 468-473.
- Knight D. W. & Sellin R. H. J. 1987, The SERC flood channel facility, *Jnl. Inst. Wat. and Env. Management*, 1 (2), pp 198-204
- Kouwen N. & Unny T. E. 1973, Flexible roughness in open channels, *Journal of the Hydraulics Division. ASCE*, 99, (HY5), pp 793-814.
- Kouwen N., Li R-M & Simons D. B. 1981, Flow resistance in vegetated waterways, *Trans ASAE*, 24 (3).
- Lambert M.J. & Sellin R. H. J. 2000, Estimating the discharge capacity of doubly sinuous compound channels, *Proc. Inst. Civ. Engrs. Wat. Marit & Energy*, 142 (2), pp 103-112
- Lotter G. K. 1933, Considerations on hydraulic design of channels with different roughness of walls, *Transactions, All-Union Scientific Research Institute of Hydraulic Engineering*, Leningrad, 9, pp 238-241 (in Russian).
- National Rivers Authority (1994), *Design of straight and meandering channels*, R&D Report 13, Environment Agency, Rio House, Bristol.
- Rameshwaran R. & Willetts B.B. 1999, Conveyance prediction for meandering two-stage channel flows, *Proc. Inst. Civ. Engrs. Wat. Marit & Energy*, 136 (3), pp 153-166
- Ree W O 1949, Hydraulic characteristics of vegetation for vegetated waterways, *Agricultural Engineering*, 30 pp 184-189.
- Ree W O & Palmer V J 1949, *Flow of water in channels protected by vegetative linings*. US Soil Conservation Service, Technical Bulletin 967, Feb 1949.
- Romanowicz R. & Beven K. J. 1998, Dynamic real-time prediction of flood inundation probabilities. *Hydrol. Sci. Jnl.*, 43(2), pp 181-196.
- Samuels P. G. 1990, Cross-section location in 1-D models. *Proc. 1st Int. Conf. on River Flood Hydraulics*, Ed White, J Wiley, pp 339-350
- Samuels P. G. 1995, Uncertainty in flood level prediction. *IAHR Congress HYDRA2000*, September 1995, Volume 1, Proceedings published by Thomas Telford, London.
- Samuels P. G. 2001, The European River Flood Occurrence and Total Risk Assessment System (EUTOTAS), *Paper presented at the Annual Conference of River and Coastal Engineers*, University of Keele, June 2001, papers published by DEFRA, London.
- Sellin R. H. J., Ervine D. A. & Willetts B. B. 1993, Behaviour of meandering two-stage channels, *Proc. Inst. Civ. Engrs. Wat. Marit & Energy*, 101(2), pp 99-111
- Shiono K & Knight D. W. 1991, Turbulent open channel flows with variable depth across the channel, *Journal of Fluid Mechanics*, 222 pp 617-646
- US Soil Conservation Service, 1954, *Handbook of channel design for soil and water conservation*. Publication number SCS-TP61.
- Wark J. B., Samuels P. G. & Ervine D. A. 1990, A Practical method for estimating velocity and discharge in compound channels, Paper E3, *Proc. Int. Conf. on River Flood Hydraulics*, Wallingford, Sept 1990, Ed White W. R., J Wiley.
- Willetts B.B. & Harding R.I. 1993, Stage dependency for overbank flows in meandering channels, *Proc. Inst. Civ. Engrs. Wat. Marit & Energy*, 101(2), pp 45-54
- Yang X. L. & Kung C. S. 1994, Parameter uncertainty in dam-break flood modelling. *Proc. 2nd Int Conf on River Flood Hydraulics*, Ed. White & Watts, J Wiley, pp 357-370.