A NEW CONVEYANCE ESTIMATION SYSTEM

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SUMMARY

The 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 Environment Agency commissioned a scoping study on 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 provides the outline for a targeted programme of research to make a step forward in the management of river capacity. This Targeted Programme is now underway involving a partnership between academic researchers, experts and users. 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. The output from the programme will be a new Conveyance Estimation System (CES) as open code and enabled for use within modelling packages. The CES includes a roughness advisor to provide access to the wide body of knowledge on the estimation of river resistance.

1 INTRODUCTION

The user need

Since the widespread flooding in the winter of 2000-01, the public interest and concern on flooding issues has increased. Nationally, most flood defences are managed by the Environment Agency and the expenditure on river flood defence activities for the maintenance of exiting defences, their improvement and provision of new defences is a significant element in the Agency's annual budget. All these activities require knowledge of the capacity of the river channel and its associated flood plains. The fluid mechanics of these natural systems is complex and has been the topic of substantial academic research in the past 30 years but so far the advances in knowledge and understanding from this research has made little impact in practice upon the management of river capacity in the UK.

The potential economic benefits of the use of improved methods for conveyance estimation will come from altering design, operation and maintenance practice as the degree of uncertainty is reduced. 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 are linked inexorably with understanding and controlling uncertainty.

The EPSRC Network

In 2000 the Engineering and Physical Sciences Research Council (EPSRC) established a research network on river and flood plain conveyance in the UK as a means of disseminating the research advances already achieved in this area and advancing the science as necessary. The EPSRC network comprises about 60 academic researchers and river engineers, in roughly equal proportions. The network meets approximately every six months to formulate research, discuss and disseminate project progress and plan contributions to related activities.

The scoping study

The Scoping Study on Reducing Uncertainty in River and Flood Plain Conveyance, which the Environment Agency commissioned at HR Wallingford in 2001, drew extensively upon the expertise and international contacts of the network. The Environment 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 (1994)). The outputs from this earlier work had not achieved widespread implementation despite showing significant improvements for the calculation of the capacity of nearly straight compound channels. The principal reason for this was the lack of accompanying software to support the methods. Software implementation was recognised as a critical means of disseminating the results of any future R&D in this area and 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 Scoping Study Report and other related papers and documents may be accessed freely from the network web site.

The main project: Reducing Uncertainty in River Flood Conveyance - Phase 2

The Environment Agency subsequently has commissioned a team led by HR Wallingford to develop the new Conveyance Estimation System (CES) as a part of the Agency's joint research programme on flood defence with DEFRA. The CES brings together the best knowledge from research on river flood capacity and address the needs of the different flood defence functions in the Agency including:

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

These functions use models or conveyance calculation in various ways as indicated in the Conceptual Framework of Figure 1.

The vision for the project is that the CES will 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 UK consultancies

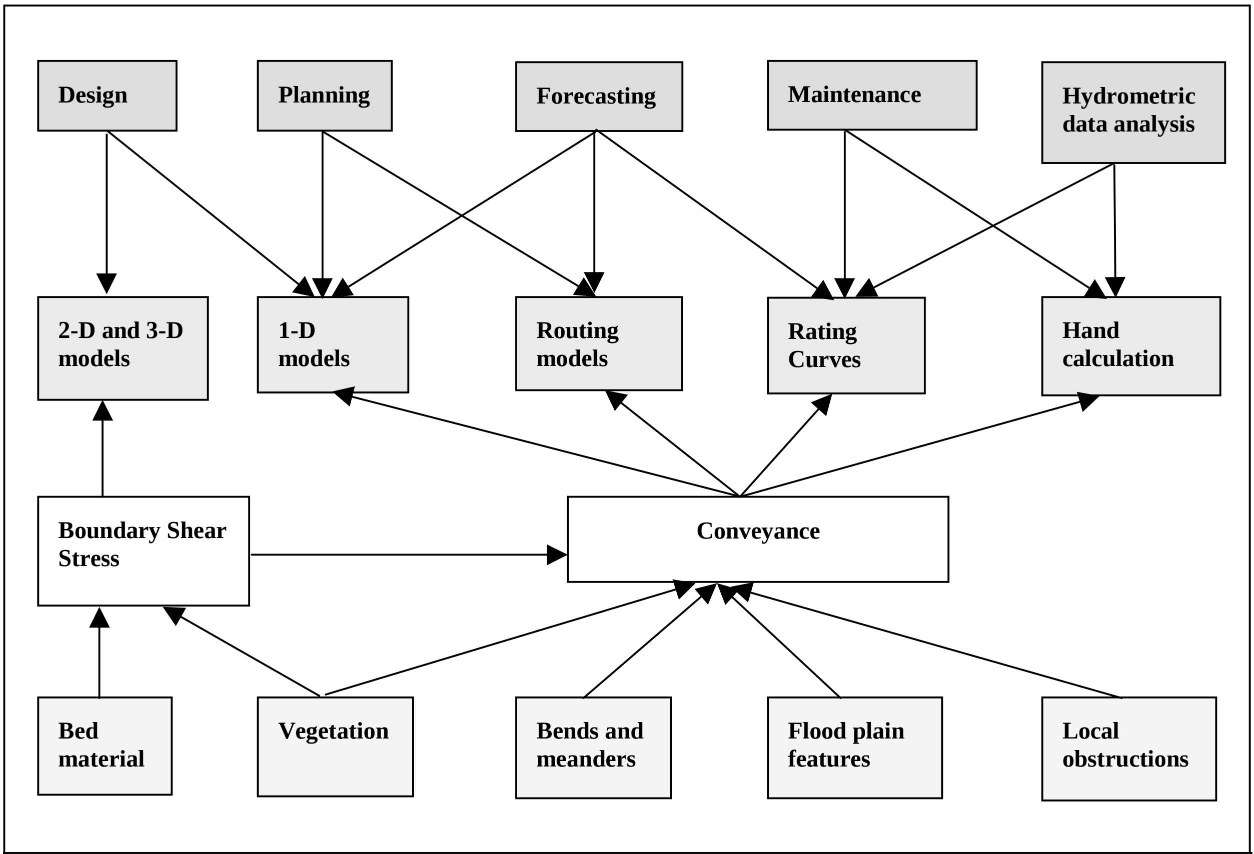

Figure 1 The Conceptual Framework

The CES will undergo a period of pilot testing within the Agency and its NEECA consultants before being launched for industry wide application. There will be a supporting programme of professional development. The CES will be delivered at the end of 2003 as a stand-alone PC application and implemented within the ISIS software used by the Agency and its consultants. In addition the open code from the project will be made available to other model suppliers to enable the other models used within the Agency to be enhanced as a result of the development.

2 APPROACH

Access to knowledge and expertise

The development of the project recognised that the success of the venture required access to the knowledge and understanding of recent research into the conveyance of straight, meandering and compound channels. The UK has been at the forefront of this research for at least two decades, supported by the EPSRC (and its predecessor the SERC) and the large scale flood channel facility (FCF) constructed at HR Wallingford for a managed programme of academic research between 1986 and 1995. The involvement of several members of the EPSRC network within the project ensures that the academic understanding from the national and international research programmes is pulled into the project. The academic advisory panel involves the Universities of Birmingham and Glasgow and Heriot Watt University. The project team includes not only HR Wallingford staff, but also external specialists on river vegetation (from CEH Dorset and the University of Birmingham) and on commercial model application in an engineering consultancy.

Involving users in the project

One of the measures of the success of the project is the acceptance by users of its output and the take-up in the profession of the science now available. Thus the project has been designed with close collaboration with users at several levels of detail. As with all major Agency R&D projects a Project Board has been established to monitor and direct the work so that it meets the overall specification and client needs. The project team has identified the need for a user consultative group comprising staff from various organisations and functions who may have a direct need to use the CES in their day to day work. These individuals represent the functions in the Agency listed above and also the Internal Drainage Boards. The rôle of the user consultative group is to discuss with the project team their needs from the system, assess the functionality of prototypes of the CES and be involved in pilot testing of the pre-release version of the software. Finally, although the Environment Agency has sponsored the development of the CES, it is envisaged that it will become the standard UK approach to flood conveyance issues. Hence the relevant authorities in Scotland and Northern Ireland have been approached to support the project and contribute their needs into the design.

Openness and flexibility

A core requirement from the Agency for the project was that of openness. Since several commercial river models are in use within the Agency and its Consultants, the methods of the CES must not be available solely through a single software source. Thus the project specification requires HR Wallingford to produce the methodology as "open code" which is in the public domain and available to all model suppliers, but the implementation of the CES methods will be the responsibility of the individual software suppliers. The Company's commercial software house, Wallingford Software, has undertaken to produce an implementation of the CES within ISIS by the end of the contract in December 2003. This will ensure that the methods are enabled within a generic river modelling package at project completion, so overcoming a key blockage in the take up of new methods into modelling practice. In common with other research commissioned under the joint DEFRA-Environment Agency research programme, the project has a web site providing information on the background and progress of the work: www.river-conveyance.net.

Through the involvement of the academic community in the research programme it is intended that the CES and underlying software will be available for research purposes to encourage further enhancement of the methods as new research understanding becomes available. In addition, the design of the software will take account of the potential need to modify methods whilst maintaining the same overall structure. There is a clear need to maintain and support an "official" release of the CES alongside the variants produced by third parties.

Technology implementation

The issue of implementation of the new methodology into everyday practice was identified in the Scoping Study and the main project includes a component on the preparation of professional development material. This will be tested with the organisations and individuals involved in the pilot testing programme in the second half of 2003 and will be revised as necessary for the roll-out of the new method across the profession. It is envisaged that there will be several regionally based training events for Agency staff, the NEECA consultants and any other organisation or individual who wishes to use the new software.

Scale of assessment

A critical issue in the development of the CES is the "scale" of the assessments it will support. River flow processes can be viewed at a variety of spatial scales and the treatment of the physics will depend upon the questions to be addressed. For example the Modelling and Decision Support Framework (MDSF) developed under the DEFRA-Environment Agency programme couples models and other processes together at a catchment scale to support the development of Catchment Management Plans. The modelling in the CFMPs will not deal with local variations in conditions, say around a structure but treats the river in coherent reaches of many kilometres. In contrast the determination of local head losses at a structure or the ecological assessment of habitat may require fine resolution of flow variations at the scale of 1 metre or less. The scale of the CES fits between these two extremes, See Figure 2. The CES will enable the calculation of river channel and flood plain capacity over reaches with reasonably consistent properties. For design of new works, development control and for river maintenance these may extend over a few kilometres. For review of rating curves, a single site may be studied and in flood forecasting several sites may be assessed to produce a reach average flood wave speed, for example using the methods of Tang et al (2001).

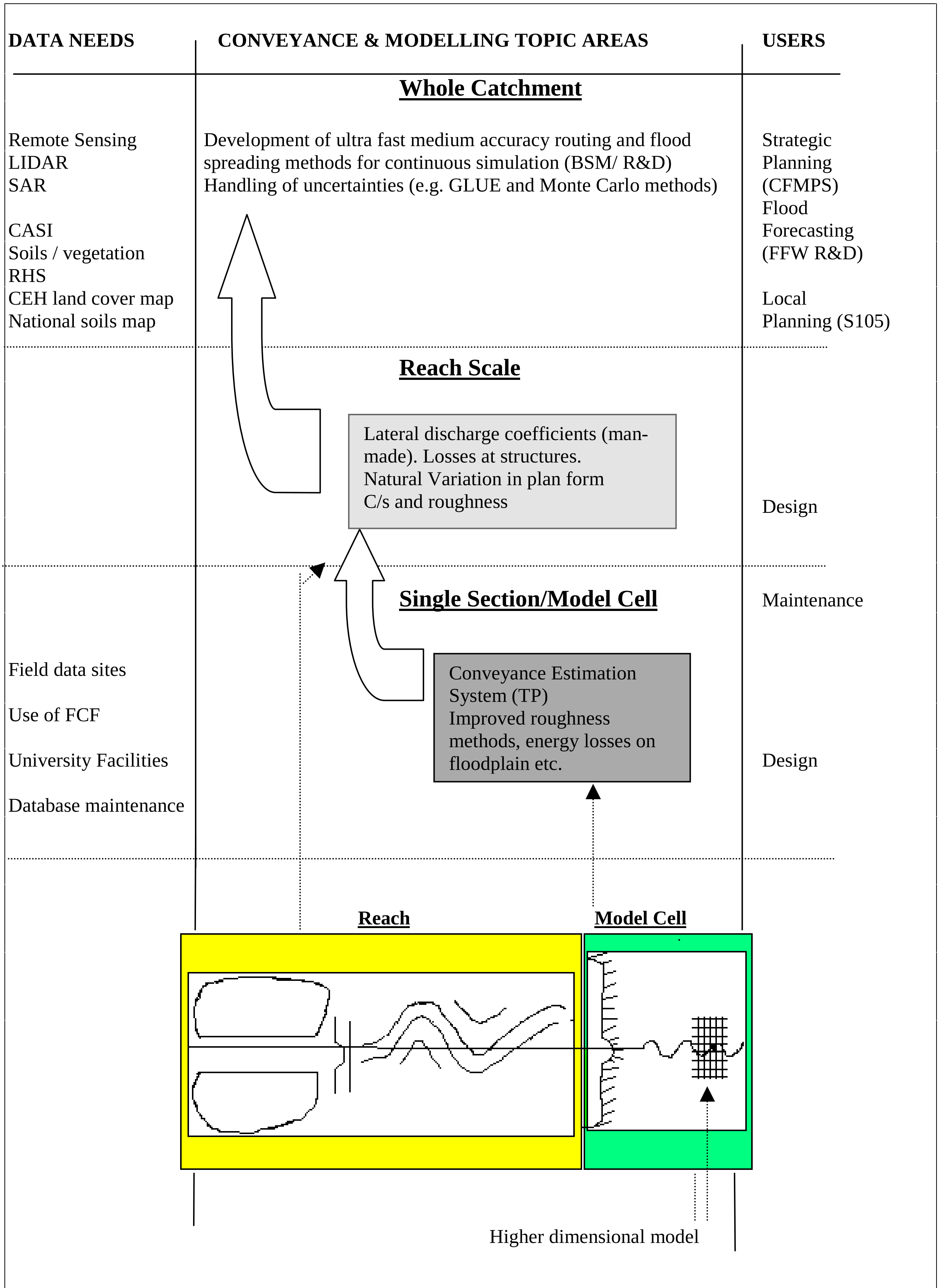

Figure 2 **Hierarchy of scales**

3 TECHNICAL BACKGROUND

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 (i.e. constant in time and space) in regularly shaped channels with constant gradient. The definition is

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

where K (m^3/s) is the conveyance, Q (m^3/s) is the discharge and s (m/m) is the common uniform gradient of the water surface, the total energy and channel bed. 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.

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

$$\tau = \rho U^2 \Phi(\mathrm{Re}, \textit{shape, boundary-texture}) \qquad (2)$$

In the general function Φ, Re is the Reynolds' number of the flow (which gives a measure of the importance of the effects of viscosity) 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 formula being used (e.g. Manning's n). The mean boundary shear stress is defined from integrating the actual stress distribution around the wetted perimeter. The resistive force F for length X of channel is given by

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

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.

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

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

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

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

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

Individual formulae for conveyance are based upon empirical relationships for the resistance function Φ for the particular section geometry. 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.

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)
- the force needed for sediment transport.

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

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

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.

Real River Geometry

An important challenge in producing the new conveyance estimation system is how to account for the complexities of real rivers within this framework taking account of their shape, sinuosity and differential roughness. Historically, this has been done by either

- various averaging techniques for producing a mean roughness in a section of simple shape and
- or splitting more complex section shapes up into a series of simple units or panels, calculating the discharge in each panel and summing the results, possibly taking account of interactions between panels.

These methods were driven by the need for procedures which were amenable to hand calculation before the widespread introduction of computational modelling. The current generation of 1-D hydraulic models, in general, still use these calculation procedures, even though the computational resources are available to increase the physical basis of the conveyance calculation. The methods being considered for the CES fall into two classes, one being variations of splitting the cross-section into several components with processes identified in each and the other being based upon a simplification of the 3-D fluid dynamics equations. There are advantages and disadvantages in each type of approach, which are currently under investigation.

4 PROJECT COMPONENTS

Overview

The project is to produce a Conveyance Estimation System to encompass, categorise and provide access to current knowledge and understanding to facilitate the estimation of conveyance by the various users in the Agency. The project will synthesise and integrate existing knowledge and understanding into a practical framework and guidance rather than promote basic research to advance this area of engineering science. The project is best conceived as having three main phases:

- Data mining
- Development of the Conveyance Estimation System
- Implementation.

The main output form the project will be the CES and the other components provide background information for the CES and to support its uptake in practice. In all nine technical tasks have been identified together with project management and integration component. The principal outputs will be:

- The Conveyance Estimation System including:
  - A Roughness Advisor
  - A Conveyance Estimator
  - An Uncertainty Estimator
- A guidance manual
- Professional development and training material.

The Targeted Programme will support the estimation of conveyance at the section and sub-reach scales and the relationship between the elements of the CES is shown diagrammatically in Figure 3.

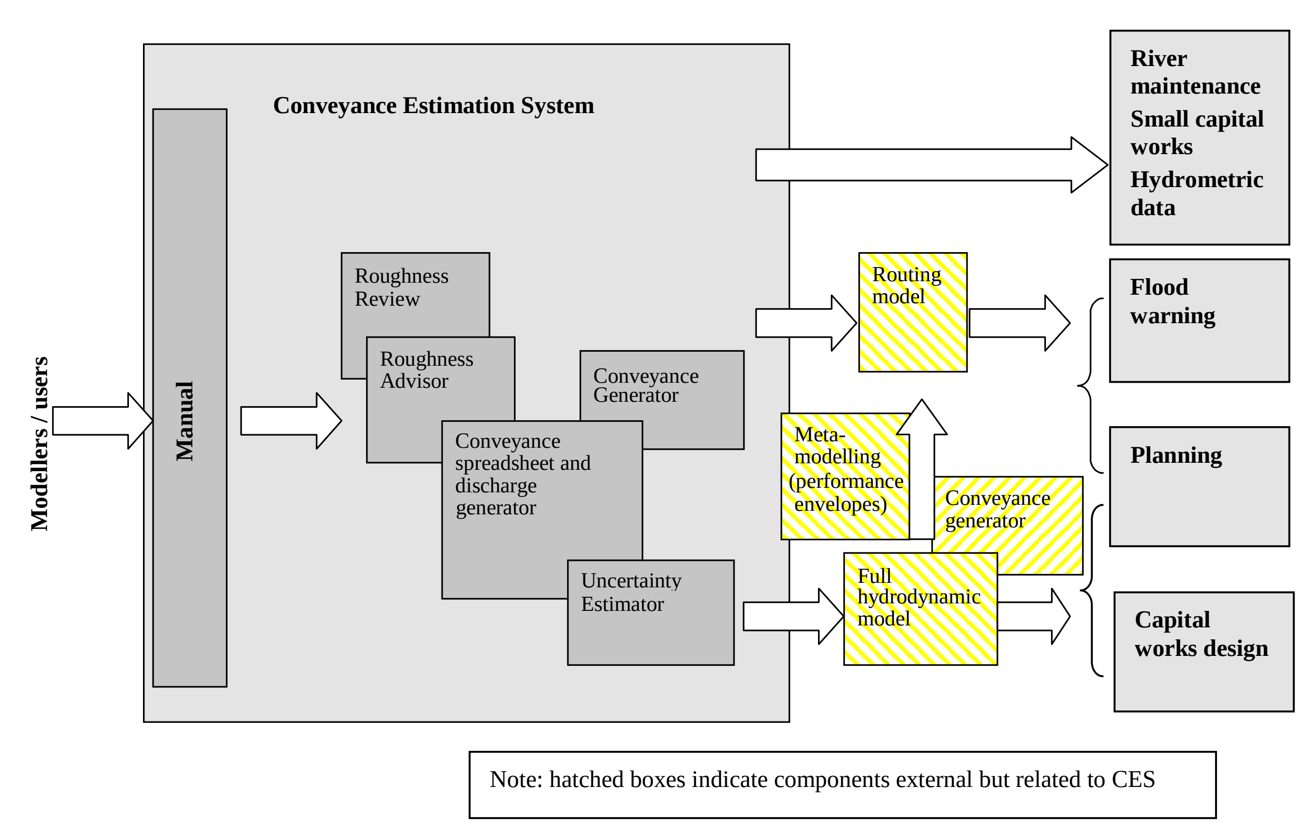

Figure 3 Components of the Conveyance Estimation System

Data Mining

The development of the CES will require high quality data sets to test the performance of the methods. Four types of data have been recognised as being available:

Type	Comments	Principal source
Small scale laboratory models	Detailed measurements of straight and meandering channels	Universities
Large scale laboratory models	Detailed measurements of straight and meandering channels	EPSRC FCF
High density river data	Rare, mostly from research studies	Environment Agency
Validated river models	Many models but variable coverage	Agency S105 models, Consultants

The project team has identified good quality data sets in each category and has aimed for using as much full-scale information as possible in the validation of the CES with some geometries (e.g. the River Blackwater) being represented by two data sets to provide a comparison across different scales. The research information from university laboratories and the EPSRC FCF will of course have been used to derive many of the methods under consideration for the CES.

The Roughness Advisor

The roughness advisor will facilitate access to expert knowledge and information on the roughness of UK rivers and flood plains for conveyance estimation. It will address the needs of users with a wide range of requirements. The availability of data will fall between two extremes – only limited or descriptive data to comprehensive data being available. In the first case if a grid reference is available then links with the Environment Agency River Habitat Survey (RHS) database will enable planform, substrate and morpho-types to be inferred. Comprehensive data would include:

- national grid reference
- width, depth and slope of the channel and whether the site is in the backwater influence of a structure etc
- annual mean and median flood discharges
- information on the maintenance regime
- GIS data from a variety of sources

For users with limited data advice will be given on the collection of more data if the end uncertainty in the estimates is too great. Common information to both categories includes:

- Databases (e.g. the RHS, UK Vegetation Database, Roughness Characteristics of New Zealand Rivers)
- Qualitative appraisal of photographs of the site and similar
- Notes of visual inspections.

A separate review of river and flood plain roughness will guide the choice of methods in the roughness advisor, which will depend on the level of data input and may include calculation and descriptive rules. When more than one method is used, there will be no discontinuities between them. The advice on roughness will be based on Manning's n or on a variation on it and the rules will include an indication of the degree of uncertainty in the estimation procedure. The outputs from the roughness advisor may include:

- A base roughness parameter
- Upper and lower bounds for base roughness parameter, or similar
- Seasonal variation factor curve, or similar
- Long term variation factor (vegetation maturity, channel degradation, climate change etc.)
- Maintenance standard variation factor curve, or similar
- Flow and/or depth variation factor curve, or similar
- Velocity variation factor curve, or similar

In the development of the roughness advisor, certain issues need to be resolved, including:

- Some morpho-types have better data than others; this may be overcome by limited data collection to improve data sets
- The roughness advisor should provide links with other software packages, for example the RHS, but it must be capable of functioning as a stand-alone product.
- The uncertainty, accuracy and applicability of the methods
- The roughness advisor should not make unnecessary assumptions about the modelling process; e.g. it should not only work with section lines.
- Careful assessment will be necessary on the use that non-modellers will make of the roughness advisor and this will influence the calculation and delivery of results.

The Conveyance Generator

The Conveyance Generator takes the topographic representation of a river section or reach and the characterisation of the boundary roughness to produce the conveyance (flow carrying capacity) with information on the band of uncertainty about the "best" estimate. Design criteria are for the conveyance generator not to require significantly more data input than current 1-D modelling systems or for the users to estimate parameters which fall outside their general experience. Thus the data will comprise

- cross-section co-ordinates and the roughness description (aided by the roughness advisor)
- the river sinuosity and mean surface slope
- the range of levels or flows of interest
- possibly, a digital elevation model (DEM) of channel and flood plain
- possibly, the channel banks or centreline in GIS
- possibly, additional method specific parameters, which may be input by an expert or related by default to other data.

Of the above, the last three items will not be mandatory, but we envisage that the coupling of the CES to a DEM and GIS may provide benefits in its application on large-scale modelling activities for natural rivers.

The Conveyance Generator will consider both categories of method outlined above for treating real river and flood plain sections. Thus the methods will be based either on the division of the section into physically identifiable units and flow mechanisms or on a simplification of the Reynolds Averaged Navier Stokes Equations. The methods being examined include those of Ervine *et al* (2000), Bousmar & Zech (1999), Shiono *et al* (1999) and Shiono & Knight (1991). These methods may include "secondary" parameters which account for other processes apart from the local bed resistance, such as the secondary circulation driven by meanders or interaction between flood plain and channel flows. These secondary parameters will be related as far as possible to physical measure of the river geometry so the users are not expected to guess values outside their experience. The output of the Conveyance Generator will include a table and graph of conveyance with stage and the uncertainty bands or distribution of the estimates.

Several issues remain to be settled in the development of the Conveyance Generator and these will be determined through dialogue with the user consultative group and considering the functions needed from the different application areas of the CES. These issues include:

- how to handle consistently reach average information such as sinuosity, small-scale section irregularity and mean surface or bed gradient,
- whether roughness and geometry are fixed or allowed to show a seasonal variation (growth and decay of vegetation), cycles of deposition and erosion, resistance depending upon the hydraulic conditions (especially velocity),
- whether to enable "expert" selection of any "secondary" method parameters
- whether the Conveyance Generator needs work in reverse to calibrate model parameters (roughness, secondary parameters) to match observed rating curves
- whether the Conveyance Generator should also include a function to show the implied cross-stream variation of unit flow or the derived depth average velocity.

The Uncertainty Estimator

The Scoping Study raised the need to identify the uncertainty in conveyance estimation, which arises principally from lack of knowledge or of ability to measure or to calculate. This gives rise to potential differences between assessment of conveyance and its "true" value. Uncertainty differs from accuracy and error and the contributions to uncertainty include:

- process uncertainty which arises from the selection and approximation of physical processes and from parameterisation made to define conveyance
- representation uncertainty from the use of survey points and interpolation rules, i.e. the difference between the shape of the river in the calculation and in "real" life
- data uncertainty from the limitations of the survey methods used
- uncertainties from parameter estimation – particularly the experience and expertise of the modellers who set up and calibrate computational models of river flows
- uncertainties from the model calculation methods, approximations and rules; these are the domain of traditional numerical analysis, and
- uncertainty from seasonal variations in vegetation, temperature etc.

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. 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 degree of uncertainty is permissible enabling simpler methods to be used, less field data to be gathered or less intensive calibration of the parameters. The potential consequences of uncertainty and typical current methods of mitigation for the uncertainty are described in the Scoping Study report.

The uncertainty in the conveyance estimates will be illustrated taking account of the uncertainty information passed from the roughness advisor, the degree of local calibration and the nature of the local topography and its influence on “secondary” method parameters. The user consultative group will be involved in determining how uncertainty will be expressed for the user of the CES for example as an upper and lower band or as a probability function.

5 CONCLUSION

The delivery of the Conveyance Estimation System at the end of 2003 should represent an important step forward in improving the scientific basis of flood management in the UK. The CES will be a stand-alone package but will also link in an open way to many river modelling packages. It will comprise an expert advisor on roughness estimation, a conveyance estimator for natural and engineered river and flood plain systems and an uncertainty estimator to combine the influence of vegetation, shape and calculation methods. The CES will be supported by a comprehensive manual and training material for a professional development programme. The final outcome of the project should be the adoption by all practitioners in England and Wales of the new conveyance methods leading to improved estimation of water levels and consequent reduced flood risk to the public at lower capital and maintenance costs.

6 ACKNOWLEDGEMENTS

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7 DISCLAIMER

This paper describes research and development in progress, and in general rather than in site-specific form. Further advice should be sought before this research information is applied in practice.

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