delivering benefits through science

Recommendations for maintaining the scientific relevance of the Conveyance and Afflux Estimation System

Report: SC070032/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

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This report is the result of research commissioned by the

Environment Agency's Evidence Directorate and funded by the joint Environment Agency/Defra Flood and Coastal

Erosion Risk Management Research and Development

Programme

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84911-145-4

Email:fcerm.science@environment-agency.gov.uk

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Dissemination Status:
Released to all regions
Publicly available

Keywords:
Conveyance, afflux, roughness, science, software, enhancements

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Project Number:
SC070032

Product Code:
SCHO1109BRHY-E-P

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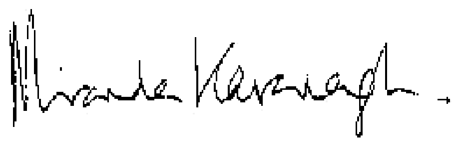

Miranda Kavanagh

Director of Evidence

Executive summary

This report is the primary output for the Science Project SC070032, entitled "Maintaining the Scientific Relevance of the Conveyance and Afflux Estimation System (CES-AES)". HR Wallingford (supported by Wallingford Software and JBA Consulting) has been commissioned by the Environment Agency under the joint Department for Environment, Food and Rural Affairs (Defra)/Environment Agency Flood and Coastal Erosion Risk Management Programme to provide prioritised recommendations for potential enhancements to the CES-AES. The CES-AES is a software tool for the improved estimation of flood and drainage water levels in rivers, watercourses and drainage channels. The recommendations include improvements to the science (and hence software functionality) as well as the software features to aid usability. The report has been prepared in close collaboration with the parallel CES-AES Support and Maintenance project, commissioned by Environment Agency Asset Systems Management as lead users, led by Wallingford Software, and includes feedback from this and a number of other sources, for example:

- A series of conveyance and afflux focal point activities (which include significant desk study tasks undertaken as part of the project by experts to assess the available published literature and other accessible knowledge for relevant new scientific information and technical developments in practice);
- Stakeholder consultations;
- User feedback from training courses, dissemination events and the website e-mail mechanism;
- Detailed software testing undertaken in-house by Wallingford Software; and
- The use of the software on parallel projects.

This report includes upwards of 70 recommendations prioritised following consultation with users in relation to benefits and value for money. The highest priority items have been grouped into five main areas of work which are described in more detail, emphasising the potential benefits and the implementation effort (where possible). These areas of work are categorised as:

- "Quick wins" - The science, knowledge and method are already sufficiently detailed and the approach can be included into the software 'as is';
- "Some science required" - There will be moderate effort in collating, developing and making use of existing knowledge to develop a final method; and
- "Major science required" - There will be substantial effort in developing new methods prior to preparation of a software functional specification and inclusion in the software.

The five main areas of further work (AFW) are:

1. ***Update to the RA*** (some science required). Aside from hydrology (outside CES-AES), roughness is the greatest source of uncertainty and aquatic vegetation has the greatest natural variability and is of major concern to channel managers in the UK. This AFW will allow for improved roughness information and calculations and hence wider user confidence and uptake through: developing seasonal vegetation

uncertainty curves; an update to the River Habitat Survey (RHS) data with additional fields; an update to the advice and roughness values for pools and riffles; an update to the Roughness Advisor (RA) photographic database and an update of the Roughness Review.

Costs & timeframe: Band B (£50-100K); 6 months.

2. ***Channel maintenance module*** (some science required). The use of the existing CES-AES tool in support of exploring different channel management options is onerous, is not always intuitive and different approaches may result in different outcomes. There is no embedded support (e.g. standard vegetation cuts, batch run, plotting tools) to aid the set-up and comparison of different management scenarios. This AFW will involve developing channel maintenance support within the CES-AES software tool. It will aid users in exploring "what-if" scenarios for different channel management regimes (e.g. cutting, dredging) through additional software functionality and outputs (e.g. ease of implementing standard cuts, new graphs, batching runs).

   Costs & timeframe: Band B (£50-100K); 10 months.

3. ***Culvert coefficients and multiple barrels*** (major science required). The existing CES-AES tool does not allow for modelling of complex culvert shapes and multiple barrel configurations. The need for this was originally identified in consultations leading to the development of the current CES-AES. What was achievable in the first Phase was limited, and user feedback (e.g. consultations, point contacts) has now confirmed the need to address these. This AFW includes: improving the current culvert energy loss coefficients which deal with idealised shapes (original US methods as adopted in the CIRIA guidance) to those which occur in UK practice and providing appropriate advice where this is not feasible; and improving the afflux calculation such that is can deal with multiple culvert barrels with different invert or soffit levels and, where this is not feasible, providing appropriate advice on how to best represent this with the current software set-up.

   Costs & timeframe: (i) Scoping & Method Development - Band A (< £50K); 6 months

   (ii) Implementation & Testing - Band C (> £100K); 12 months

4. ***Trash screen and blockage module*** (some science required). The existing CES-AES tool does not allow for modelling of trash screens and blockage. The need for this was originally identified in consultations leading to the development of the current CES-AES. What was achievable in the development phase was limited, and user feedback (e.g. consultations, point contacts) has now confirmed the need to address these. This work area would involve developing an energy loss unit for dealing with trash screens (including percentage blocked) and general channel blockage (e.g. debris) and a means to determine the impact on upstream water levels. This will consider the methods described in the Trash and Security Screen Manual (Environment Agency, 2007) where they offer utility and will be designed to link with the planned work under Flood Risk Management Research Consortium Phase 2 (FRMRC2), Work Package 4.1 "Predicting and Managing Flood Risk Associated with Debris at Structures".

   Costs & timeframe: (i) Scoping & Method Development - Band A (< £50K); 6 months

(ii) Implementation & Testing - Band C (> £100K); 12 months

5. ***Software usability and harmonisation - Phase 1*** (quick wins). The original CES development project intended, as a minimum, to deliver a simple spreadsheet approach for improved calculation of conveyance. In fact, during the project the team went a lot further and the final CES calculations were developed as a stand-alone module with a supporting simple Graphical User Interface (GUI). Since then, there has been substantial feedback on the GUI (as may be expected) and this work area is intended to address this where appropriate. It involves a series of software improvements such as ability to calculate water level given flow; ability to plot multiple vegetation curves with different colours; more user friendly error message system; etc. The value of this should not be underestimated, as the user's ability to navigate and interact with the tools is fundamental to gaining confidence in the results - leading to continued and widespread use.

   Costs & timeframe: Band B (£50-100K); 6 months

   Software usability and harmonisation - Phase 2 (major science required). This work area is intended to harmonise and merge the original CES and AES findings and calculations from the two development projects to provide a consistent and improved product. It involves software improvements which will require new knowledge and method development. It will include: improving the approach for calculating transition lengths, incorporating the conveyance calculation at structures and automatic calculation of longitudinal bed slope.

   Costs & timeframe: (i) Scoping & Method Development - Band A (< £50K); 6 months

   (ii) Implementation & Testing - Band C (> £100K); 12 months

Of these, AFW 5 is considered the highest priority in terms of gaining wider user acceptance and uptake for the CES-AES.

Four additional AFW were identified as the next highest priority. These are listed here as they may be considered high priority for other functions (e.g. flood forecasting) and/or funding organisations (e.g. EPSRC, National Environment Research Council [NERC]). These include:

- **Data acquisition programme:** This involves data gathering for vegetation (e.g. to build up a long-term record), flow properties and evidence of debris following storms (initiated in FRMRC2, WP4.1);
- Development of a **habitat module** to support habitat design;
- Development of methods and tools to support **extension of rating curves**; and
- Development of a sediment transport module.

**Please note that cost bands for AFW 3, 4 and 5 (Phase 2) are conservative and will become clear (and may move to Band B) following method scoping, as they are method dependent.*

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1 Introduction

1.1 Background and project scope

The Conveyance and Afflux Estimation System (CES-AES, Figure 1.1) is a software tool for the improved estimation of flood and drainage water levels in rivers, watercourses and drainage channels. The software development followed recommendations by practitioners and academics in the EPSRC-funded UK Network on Conveyance in River Flood Plain Systems, following the Autumn 2000 floods, that operating authorities should make better use of recent improved knowledge on conveyance and related flood or drainage level estimation. This led to a targeted programme of research aimed at improving conveyance estimation (Project W5A-057, Reducing uncertainty in river flood conveyance, 2001-04, www.river-conveyance.net/ces) and integration with other research on afflux at bridges and structures at high flows (Project W5A-061, Hydraulic performance of bridges and culverts at high flows, 2002-06, see: www.river-conveyance.net/aes). The resulting CES-AES software tool aims to improve and assist with the estimation of:

- Hydraulic roughness;
- Water levels and corresponding channel and structure conveyance;
- Flow (given the slope of the watercourse of energy gradient);
- Section-average and spatial velocities;
- Backwater profiles upstream of a known flow-head control e.g. weir (steady flow);
- Afflux upstream of bridges and culverts; and
- A measure of uncertainty linked to roughness information

The CES-AES Roll-Out Project (2006-07, Purchase Ref: 30137789) followed the development projects. The aim was to make the CES-AES stand-alone software available via the Environment Agency Corporate Information Service (CIS) systems as well as to the general public via the CES-AES launch website www.river-conveyance.net (Figure 1.2). The launch website was developed to include project background, links to the CES and AES development projects and documentation, the free software download, frequently asked questions (FAQs) and information on training. The CES-AES Roll-Out Project also involved training *circa* 50 Environment Agency staff in the use of the CES-AES. Subsequent training courses have taken this number to *circa* 170 trained users in the Environment Agency. Training and roll-out events have included representatives from Scotland and Northern Ireland and training has been carried out in Edinburgh, Scotland.

The aims of this project, "Maintaining the Scientific Relevance of the Conveyance and Afflux Estimation System (CES-AES)", are to ensure the scientific relevance of the CES-AES is maintained through:

- Identifying, tracking and assessing relevant new scientific information and technical developments in practice that have the potential to enhance the capability of the CES-AES;

- Scoping how advances can be incorporated into the tools in future developments and software releases e.g. calculation updates, new modules. This is undertaken in close collaboration with the user community to ensure the priority reflects the industry and user needs; and
- Identifying software usability updates with indicative costs and timescales (where practical).

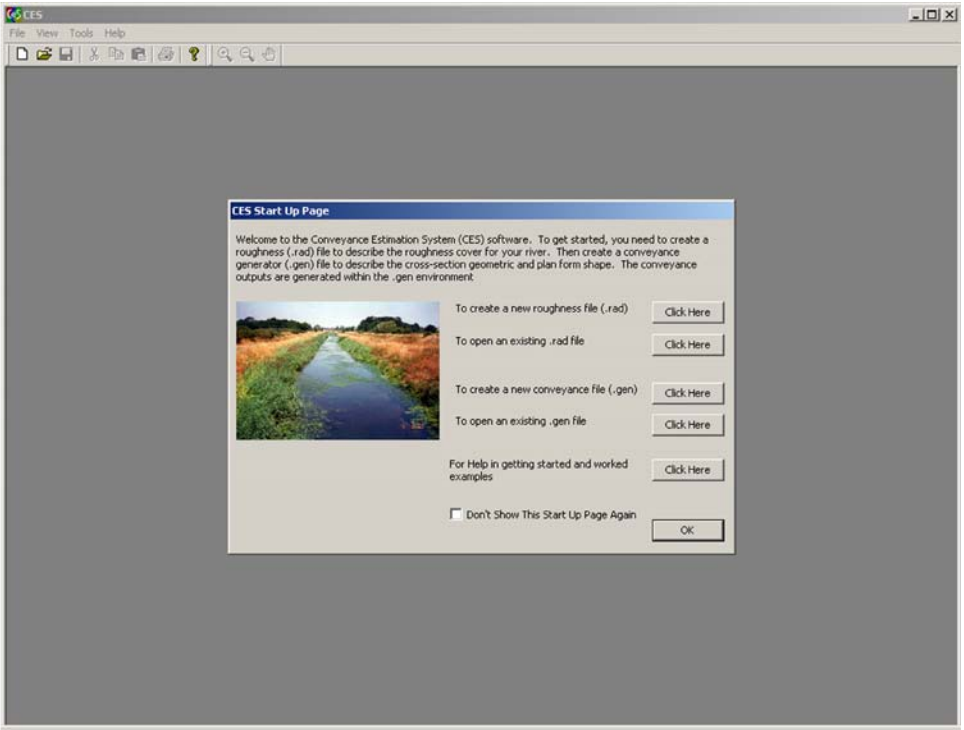

Figure 1.1 CES-AES stand-alone software - welcome screen.

Figure 1.2 The CES-AES launch website linking to the CES and AES development projects.

Use of the CES-AES has developed amongst the UK operational authorities and their consultants in support of Flood Risk and Land Drainage planning, design and management. These users played a fundamental role in the original development of the CES-AES and continue to provide feedback on usability, applicability, potential enhancements and business needs. The use of the CES-AES is likely to further increase with the emergence of supporting guidance.

This report is the main project output and it includes the findings provided as a series of prioritised recommendations. It has been prepared in close collaboration with the parallel CES-AES Support and Maintenance project, led by Wallingford Software, and includes feedback from this and a number of other sources including (detail in Chapter 3):

- A series of conveyance and afflux focal point activities (which include significant desk study tasks undertaken as part of the project by experts to assess the available published literature and other accessible knowledge for relevant new scientific information and technical developments in practice);
- Stakeholder consultations;
- User feedback from training courses, dissemination events and the website e-mail mechanism;
- Detailed software testing undertaken in-house by Wallingford Software; and
- The use of the software on parallel projects.

The need for a conveyance and an afflux focal point was identified early in the implementation process. The aim of these experts is to gather and disseminate knowledge through a variety of activities:

- Collation and review of relevant newly published science and practice to identify potential scientific information that can be incorporated into the CES-AES databases and technical advances which may be implemented in an updated CES-AES;
- Consideration of relevant 'lessons learned' (gathered via web feedback tool; face-to-face feedback at training, conferences; technical and software support queries etc.) as regards desirable improvements to the CES-AES;
- Knowledge of ongoing research programmes and projects and where there is potential to link with the CES-AES ongoing development; and
- Technical meetings where specific opportunities are identified and where possible, work is steered to meet CES-AES longer term objectives.

An important theme throughout the activities is to ensure consistency with the original CES-AES science and development and the quality of any potential updates. It is important to clarify three distinct areas for improvement and where they are being addressed within the two projects:

- Enhancements to the science and hence software functionality - covered by SC070032;
- Enhancements to the software features to aid usability and harmonisation - covered by SC070032; and
- Software bugs - covered by the parallel Support and Maintenance Project

Figure 1.3 provides an overview of how the activities and recommendations from this project link to potential updates to the CES-AES software. The CES-AES software releases ("yellow" or "third from left" box) are influenced by two projects: (i) this project ("green" or "first from left" box) which makes recommendations for new projects/developments ("blue" or "second from left" box), and (ii) the parallel Support and Maintenance Project ("orange" or "fourth from left" box), which involves maintenance releases to address software bugs. A key contribution stems from Process and Policy Guidance, which is represented along the bottom. This project differs from science projects, where a new product or report is produced and delivered to the user to implement, in that feedback from the current user and policy context has a strong bearing on the recommendations for improving and enhancing the CES-AES. A more detailed version of Figure 1.3, as developed amongst the project and client team, is available in Appendix 1.

The report readership is aimed at the Environment Agency client team and other potential user funders. It provides recommendations and the supporting evidence base for maintaining the scientific relevance of the CES-AES software.

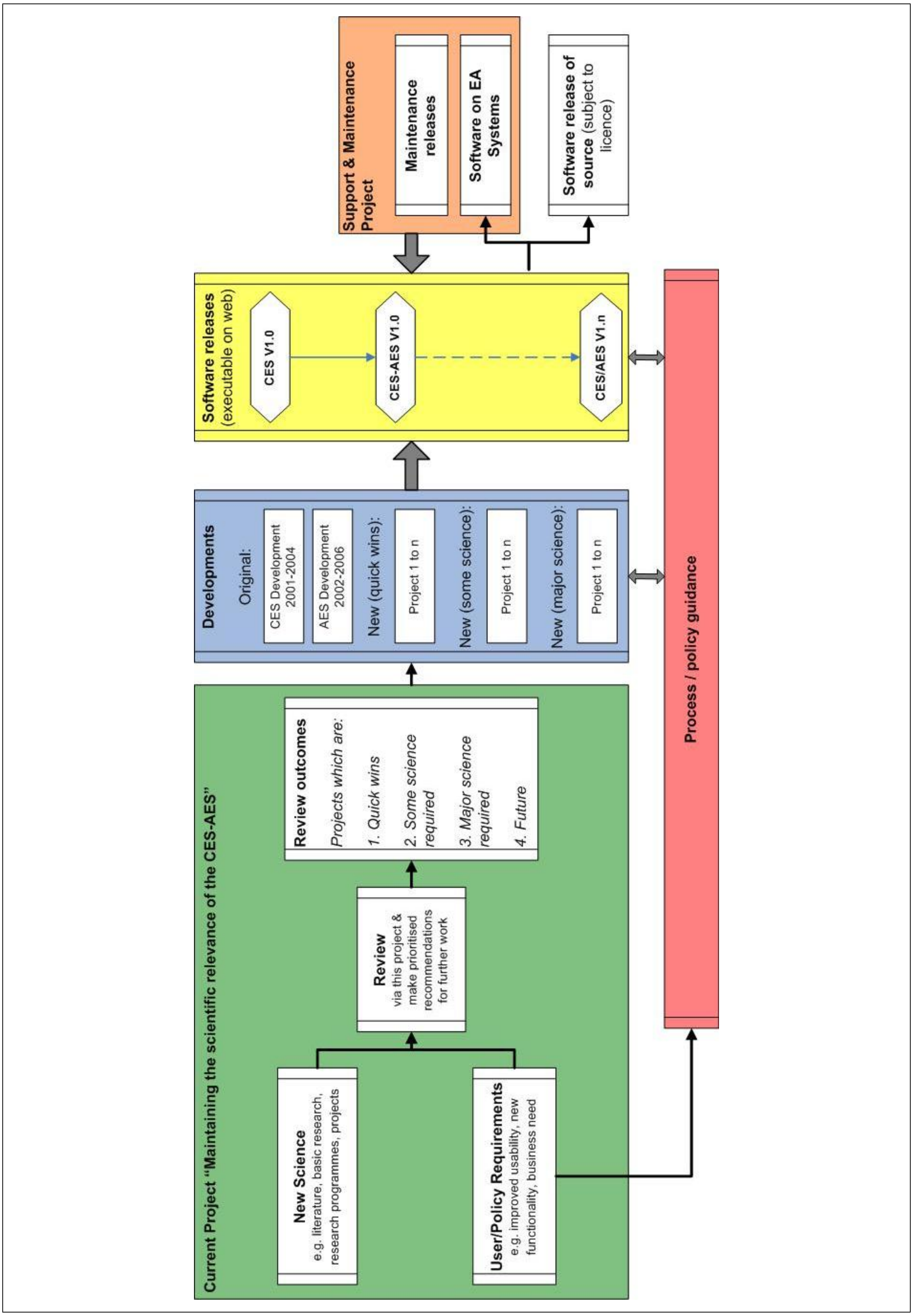

Figure 1.3 High-level overview of how this project and the parallel support and maintenance project feed into CES-AES software updates (detailed version in Appendix 1).

1.2 Wider context

The CES-AES software tool provides utility to support a wide range of objectives in existing legislation, policy and guidance.

EC Directives:

- Floods Directive (2007/60/EEC) - This relates to the assessment and management of flood risks. Each Member State of the EU must, within their boundaries, undertake a preliminary flood risk assessment, prepare flood risk maps and develop flood risk management plans for each river basin. Clearly an understanding of the way floods propagate within a river basin is important in carrying out these responsibilities;

- Water Framework Directive (2000/60/EEC) - This provides specific guidance on river ecosystem and hydromorphological management, and the implementation will require remediation of channels, focussing on restoring them to their natural state; and

- Habitats Directive (92/43/EEC) - This aims to promote the maintenance of biodiversity by requiring Member States to take measures to maintain or restore natural habitats and wild species at a favourable conservation status, introducing robust protection for those habitats and species of European importance. These requirements are now transposed to national laws in the UK (e.g. Conservation Regulations 1994, Conservation Regulations (NI) 1995).

UK Policy, Guidance and Programmes:

- Defra's Making Space for Water - Initiatives such as this advocate flood risk management solutions that satisfy a wider range of objectives such as hydro-morphological, ecological and even social needs;

- The UK Biodiversity Action Plans (1994) - These are the UK Government's response to becoming a signatory of the Convention on Biological Diversity. It contains 59 objectives for conserving and enhancing species and habitats as well as promoting public awareness and contributing to international conservation efforts. See: http://www.ukbap.org.uk/;

- Defra's Outcome Measures - The UK Government has established a framework of flood risk management outcome measures to allocate resources and to guide the activities of flood operating authorities so they reflect MSfW and Government policy in general. These include five outcome measures which relate to different measures of flood risk (including UK Biodiversity Action Plans);

- The Environment Agency's Asset System Management Section recognises the importance of informed channel management in achieving required performance of asset systems. It has supported the roll out and implementation of the CES-AES as a tool to support operational management. It is currently developing formal operational instructions for the consistent use of conveyance tools in support of channel management across the Environment Agency; and

- Although no formal programme of integration exists, the use of the CES-AES by Internal Drainage Boards (IDBs) and practitioners in Scotland and Northern Ireland is increasing.

A key driver in the development of the original CES-AES was the 2002 report to Government by the ICE Presidential Commission "Learning to live with rivers". This highlighted the relatively poor uptake by flood management practitioners of improved tools and techniques for estimation of flood water level. Subsequently, Sir Michael Pitt's Review (Pitt 2008) has noted that the Environment Agency is using the CES in assessing channel management options:

> *"7.66 The Environment Agency has been working to try to optimise its maintenance regime to gain the best value for money. To progress its understanding of how seasonal variation in vegetation affects the way in which watercourses behave, the Environment Agency has recently developed a tool called the Conveyance Estimation System (CES), which will help to deliver an improved maintenance programme. The costs and benefits of dredging are now also better understood and although widening and deepening a channel may seem like the obvious solution there are a number of constraints which need to be considered such as sustainability, waste material, environmental damage and cost." Chapter 3*

Similarly, the recently developed Drainage Channel Biodiversity Manual (Buisson *et al*., 2008) identifies the CES as a potential tool for exploring channel management options:

> *"In choosing the best technique to apply it is essential to examine the effect on flood conveyance in the specific location and circumstances that the technique would be used. This will require judgment informed by experience and one of the available flood risk modelling tools. In many circumstances, the Conveyance Estimation System (www.river-conveyance.net) may provide the information needed. Modelling allows prediction of the effects of management techniques on conveyance and storage and can identify the additional capacity needed to offset any reduction in conveyance caused by additional wildlife habitat created, such as a wider uncut marginal strip of vegetation in the channel."*

An opportunity exists for the Environment Agency to promote CES-AES training within the foundation degree on River and Coastal Engineering at the University of the West of England. This is being made known to the course's supervisor.

1.3 Report layout

The remainder of the report is set out as follows:

Chapter 2 Provides an overview of the existing CES-AES software including the main functions it supports, the software architecture and calculation flow charts, the current software usage and training courses to date.

Chapter 3 Provides an overview of the conveyance and afflux focal point activities including meetings, stakeholder consultations, literature review, parallel projects and research programmes and dissemination.

Chapter 4 Provides prioritised recommendations for maintaining the scientific relevance of the CES-AES through improvements to science.

Chapter 5 Provides prioritised recommendations for improvements to the CES-AES software usability to promote wider user acceptance and uptake.

Chapter 6 Conclusions and recommendations

2 Overview of existing CES-AES

2.1 Primary functions CES-AES supports

The CES-AES software supports practitioners concerned with a range of flood risk management as well as other wider activities through, for example:

- Calculating water levels, flows and velocities for rivers, watercourses and drainage channels;
- Providing upper and lower uncertainty scenarios;
- Enabling on-line roughness advice and selection from an extensive database (>700 references, Defra/Environment Agency, 2003) including advice based on UK grid reference;
- Assessing flood or extreme water levels, and the sensitivity of these to channel adaptation or management options (particularly dredging and plant management);
- Assessing the impact of timing and nature of vegetation cutting;
- Assessing the impact of blockage of channels due to vegetation or debris;
- Understanding the influence of in-stream structures on water levels;
- Calculating the localised effects of bridges and culverts on water levels;
- Finding holistic solutions which address both environmental (e.g. Water Framework Directive) and flood risk management or land drainage objectives; and
- Implementing guidance and procedures e.g. supporting work instructions for channel maintenance and performance specification (in the UK).

Important definitions are:

- ***Roughness*** - The effect of impeding the normal water flow of a channel by the presence of a natural or artificial body or bodies that interfere with the flow. In the case of the CES, roughness accounts for bed material, vegetation and irregularities (e.g. hedges, urban trash). Other components of resistance such as channel shape and form are explicitly handled in the CES conveyance calculation;
- ***Conveyance*** - A measure of the volume of water per unit time conveyed by a river, with similar units to flow i.e. m^3s^{-1}. Conveyance, K, can be related to flow, Q, by $Q = KS^{1/2}$ where the slope S is approximated from the longitudinal energy gradient. In practice (e.g. Manning Equation, Chezy Equation, CES Reynolds-Averaged Navier-Stokes approach), this is typically estimated assuming normal depth of flow and hence the energy gradient is taken as parallel to the water surface and channel bed slope;

- ***Backwater*** - Backwater effects occur when sub-critical flow is controlled by the downstream conditions resulting in a localised disturbance to normal depth of flow e.g. presence of an outfall, blockage, dam. The backwater length is the distance upstream before normal depth is re-established. This distance may be approximated as 0.7xDepth/Slope (Samuels, 1989); and

- ***Afflux*** - The maximum water level difference between normal depth of flow and raised water levels due to the presence of a structure e.g. bridge, culvert. The afflux typically occurs a small distance upstream of the upstream structure face.

The main CES-AES software elements include:

- ***RA*** which is a database of roughness information including descriptions, photographs and unit roughness values from over 700 references including the RHS (Raven *et al*. 1998). Information on seasonal vegetation, cutting and regrowth patterns is provided;

- ***Conveyance Generator*** which estimates water level (and associated uncertainty), flow, conveyance, velocity, area, perimeter, and Froude and Reynolds Number for each flow depth, and provides lateral distributions of velocity, boundary shear stress and shear velocity;

- ***Backwater Module*** which includes an energy-driven backwater calculation to determine the flow profile upstream of a control point i.e. known depth and flow; and

- ***Afflux Estimator*** which calculates the afflux upstream of bridges and culverts as well as the energy losses through these structures. It includes arch and beam bridges with up to 20 openings, and pipe, box and arch culverts with up to 10 identical barrels.

It is important to understand the limitations of the methods being used. For the use of the CES-AES, the most important limitations are (Defra/Environment Agency, 2004; Knight *et al*., 2009):

- Steady flow (i.e. negligible attenuation);

- Fixed bed (i.e. no scour or deposition);

- Fixed roughness (i.e. uninfluenced by velocity);

- Small to medium sized channels and rivers (say 0.5 to 500 m width, 0.2 to 10 m depth, gradients 10-2 to 10-4 approximately), low to moderate sinuosity;

- Sub-critical (or tranquil) flow - although a large limitation, super-critical flow is uncommon in practice; and

- Unobstructed bridges and culverts (i.e. not partially blocked by debris or sediments).

2.2 Software architecture

A brief overview of the software architecture is provided here to enable the recommendations in Chapter 4 and 5 to be related to the existing architecture and calculation engines where appropriate.

Figure 2.1 provides an overview of the software structure from a user's perspective. The software incorporates three main elements, the RA, the Conveyance Generator and the Backwater Calculation. The afflux is calculated as part of a backwater as this provides the necessary downstream water level for the afflux method.

Data specific to the site of interest are stored in two data files:

- The .RAD file contains the user specific data relating to vegetation, substrate and irregularity for each of the roughness zones of interest. This file is saved by the user and stores the output of the roughness calculations carried out within the RA; and
- The .GEN file contains the geometrical data for the channel and any bridge and culvert structures, as well as information on which roughness zones are used for calculating the section conveyance.

Together the .GEN and .RAD files contain all of the data relevant to a particular site.

The raw data for the RA is provided from a number of databases that capture the outputs of the roughness review (Defra/Environment Agency, 2003) carried out for the original conveyance estimation project. These databases are in a simple .CSV format and this was selected to allow users the flexibility to edit and update the files if they have access to improved or alternative roughness data, though for most purposes the data should be considered as fixed.

The roughness, conveyance, backwater and afflux calculation engines are provided in Appendix 2, Figures A2-1 to A2-4. These illustrate the calculation process and logic from user and default inputs through to the final outputs.

Figure 2.2 provides the underlying structure of the CES-AES software. The main software procedures are all handled by the Convey.DLL module, including file access, data structure and manipulation, roughness calculation, backwater calculation and interfacing to the conveyance and afflux calculation modules. This structure effectively allows a programmer with access to the source code to replace the standard user interface with a simple interface of his or her own, and run all of the underlying calculation code.

In practice, the overall structure shown is more complicated at the level of the source code itself, with the code sub-divided into classes in line with good software development procedures. A further complication is that the code has been written in three different languages. The core conveyance calculation engine (ConveyCalcs) is currently written in C for maximum portability, whilst the afflux interface and engine are written in Visual Basic. All other parts of the software are written in C++. The AES was developed separately and in parallel to the CES, and whilst the CES Visual Basic prototype code was translated to a formal C version within the original CES project, the opportunity for a similar translation was not realised within the original AES project. It is recommended that this takes place as part of AFW 5, Software usability and harmonisation, Phase 2 (Chapter 5). It is probable that future updates to the software may result in changes to this structure though these will not remove the capability of running the calculation modules from outside the user interface.

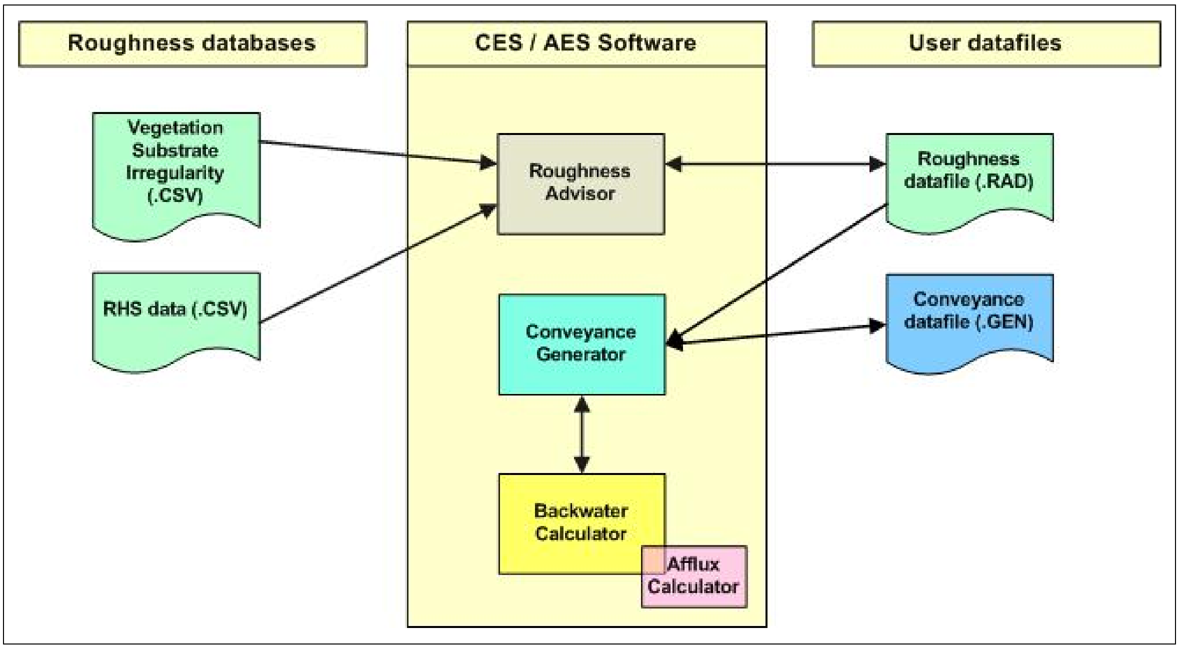

Figure 2.1 Overall structure of the CES-AES software (Knight *et al*, 2009).

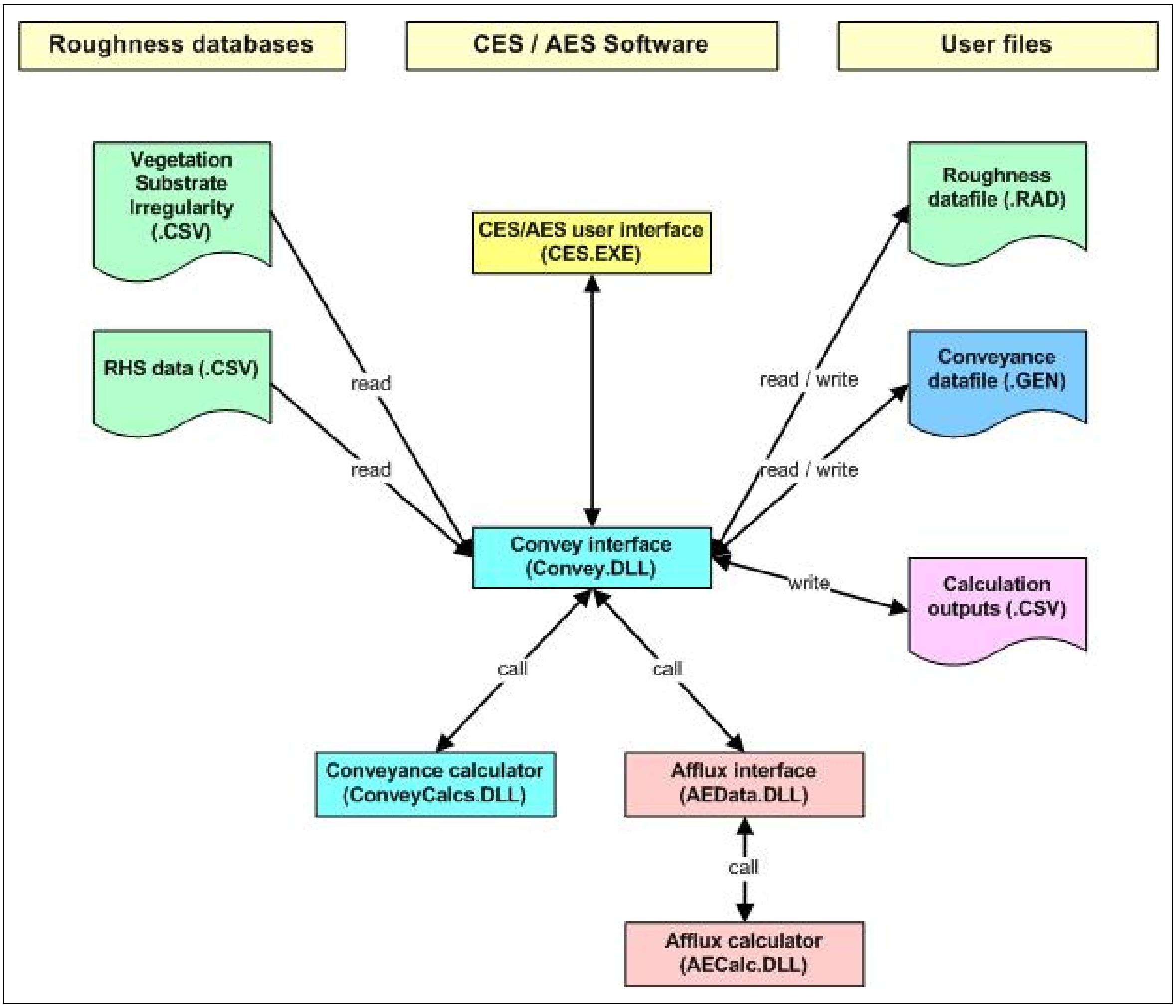

Figure 2.2 Underlying structure of the CES-AES software (Knight *et al*, 2009).

2.3 Current usage and training

The CES-AES stand-alone software and the CES calculation have been made available via four main mechanisms:

- Wallingford Software's 1D hydrodynamic modelling software **InfoWorks RS** (Version 6.5 & onwards) has enabled access to the CES within 1D model runs as an alternative to the Manning equation (July 2005 & onwards);
- Halcrow's 1D hydrodynamic modelling software **ISIS Flow** (Version 2.3 & onwards) has enabled access to the CES-AES as stand-alone and the CES within 1D model runs as an alternative to the Manning equation (August 2006 & onwards);
- the **Environment Agency CIS system** which includes the stand-alone CES-AES (February 2008);
- the **CES-AES roll-out website** which includes the free download of the stand-alone CES-AES, see: www.river-conveyance.net (June 2008).

The nature and timing of these releases is significant as it influences the degree of use and feedback to date. It is anticipated that feedback will increase substantially over the next 12 to 18 months as the software has been made more widely available in 2008 together with the emergence of user guidance for specific applications (e.g. Environment Agency Operational Instructions; Association of Drainage Authorities (ADA) & Natural England's Drainage Channel Biodiversity Manual - Buisson *et al.*, 2008; update of the Fluvial Design Guide).

It was recognised at the stakeholder meeting (25/11/2008, Section 3.3) that whilst the CES-AES was developed with specific user communities in mind (e.g. Asset Systems Management, development control, flood warning), those involved in managing these activities need to support effective implementation by developing appropriate work instructions for using the CES-AES tools for relevant end-use procedures (e.g. establishing compliance with performance specification for conveyance). It was considered vital at this stage to get operational staff using the software consistently for some mandatory tasks so that some, at least, of the science developments could be driven by efficiency improvements. This issue is being taken up by the Environment Agency in parallel with this study. Specific actions include (i) confirmation is being sought as to whether James Addicott is championing CES-AES; and (ii) the Environment Agency Head Office Asset Systems Management team have commissioned Royal Haskoning to develop some text for an operational instruction on conveyance under a separate contract.

Over 170 Environment Agency staff have been formally trained in the use of the CES-AES stand-alone software and further staff training is expected once there are formal operational instructions for specific use of the CES-AES. Training and roll-out events have included representatives from Scotland and Northern Ireland and training has also been carried out in Edinburgh, Scotland. The software and technical support queries have been relatively low over 2008, reflecting low usage, but these are anticipated to increase in 2009 with the development of formal guidance.

Consultancies have used the CES-AES stand-alone tool and the CES calculation within ISIS and InfoWorks RS for Flood Risk Management activities. The support queries for these are gradually increasing, reflecting use.

The CES-AES software use by Internal Drainage Boards is anticipated to increase with the recently published Drainage Channel Biodiversity Manual (Buisson *et al.*, 2008) making explicit reference to the CES-AES as a supporting tool. Formal training followed by regular use will be needed to promote the benefits of the tool and hence take-up.

There has been over 300 web downloads of the CES-AES stand-alone tool since June 2008. Data has been collated on:

- Name;
- Email;
- Organisation;
- Likely application area;
- Principal country of use; and
- Require further information regarding updates.

The predominant country of use is the UK and the main focus (where provided) has been on flood risk management and research activities and some use for drainage, habitat design and teaching.

The CES calculation has also been used in the delivery of various project specific methods and tools including:

- The development of the **Second Generation Flood Hazard Map for Scotland** (McGahey *et al*., 2005; Scottish Environment Protection Agency [SEPA], 2006) for the undefended floodplain, see: http://www.multimap.com/clients/places.cgi?client=sepa. The CES was used to establish all rating curves making use of the national DTM for survey and slope information and the Land Cover Map 2000 for roughness values;
- The development of the **National Strategic Flood Map for Northern Ireland** (NIRA, 2009), see: http://www.riversagencyni.gov.uk/index/stategic-flood-maps.htm. The CES was used to establish all rating curves making use of a national ground model for survey and slope information and the Land Cover Map for roughness values;
- The development of the **Rapid Response Catchment Map for England and Wales** which indicates catchments which are susceptible to flash floods and could pose a serious risk to life (Defra/Environment Agency 2005; Defra/Environment Agency, 2009). The CES was used to establish flows, depths and velocities to be used in the hazard rating;
- **Assessing the benefits of channel management** as part of the Environment Agency's System Asset Management Plans (SAMPS) study which involved using the CES to translate changes in channel management (do nothing, vegetation cutting, dredging) to changes in flood risk (Defra/Environment Agency, 2008);
- The **Sediments and Habitats Phase II** project made use of the CES calculation to predict flows and lateral velocity distributions at various sites following maintenance works e.g. dredging; and
- For river **rehabilitation modelling** for rivers in the east of England where the CES is was used to confirm the design requirements for different channel modifications e.g. dredging (Janes *et al*., 2005).

The CES-AES training courses held in 2008/09 include:

- CES-AES stand-alone courses
  - 2/10/2007 20 delegates (Howbery Park)
  - 26/3/2008 20 delegates (Howbery Park)
  - 27/3/2008 20 delegates (Howbery Park)
  - 10/4/2008 20 delegates (Leeds)
  - November 2007, (Edinburgh);
- CES-AES in InfoWorks RS
  - 21/11/2008 4 delegates;
- CES-AES in HR Wallingford's introductory course on river hydrology and hydraulics (6 monthly, 20 delegates); and
- Specific courses for Environment Agency Ops Delivery & Senior Management in Anglian Region on CES and its role in catchment modelling (May 08).
- Dedicated courses for specific Environment Agency area applications (e.g. scheme design and flood mapping course held on 13 October 2009 at HR Wallingford, 12 delegates)

3 Scientific relevance watching brief

3.1 Parallel projects, research programmes and literature review

The conveyance and afflux focal points have engaged in numerous activities to ensure the latest knowledge and information have fed into this recommendation report. Table 3.1 provides a summary of the projects, research programmes, literature and key individuals who have been consulted in this process. The outcomes from these have helped steer the recommendations in Chapter 4 and 5.

Table 3.1 Summary of main projects, research programmes and documents considered in this study.

No.	Project / Research Programme / Literature	Contact	Interaction
1	Performance-based Asset Management Systems (PAMS)	Common staff (HRW)	Ongoing
2	PAMS Measured Steps Forwards	Common staff (HRW)	Now complete
3	Sediments and Habitats Phase 1	Roger Bettess, HRW	Now complete
4	Sediments and Habitats Phase 2	Roger Bettess, HRW	Now complete
5	Sediments and Habitats Phase 2 - Additional Studies	Marta Roca-Collell, HRW	Ongoing
6	Modelling and Decision Support Framework II (MDSF2)	Common staff (HRW)	Ongoing
7	Development of Operational Instructions	Matt Harding, Royal Haskoning	Initiated
8	River Restoration work	Martin Janes, River Restoration Centre, Cranfield University Karen Fisher, Independent	Ongoing
9	Centre for Ecology and Hydrology (CEH) ongoing research on vegetation (measurements, drag force theory) and ecology	Mattie O'Hare – CEH Edinburgh Hugh Dawson, Pam Naden, Ponnambalam Rameshwaran – CEH Wallingford	Mtgs: 10/6/08; 30/7/08; 14/1/09
10	ENPC work on extension of rating curves (HYDRATE, FLOODsite)	Eric Gaume, Laboratoire Central des Ponts ete ChaussÃ©es (LCPC), France	Mtg: 29/9/08 Ongoing
11	Ongoing research into channel roughness in terms of friction factor f – as used in CES	Eric Pasche, Exeter University	Mtg: 03/04/08
12	Compound channel conveyance basic research including international Compound Channel Group	Numerous e.g. Didier Bousmar (Wallonie Hydrauic Research Laboratory, Belgium), Donald Knight (Birmingham University), Koji Shiono (Loughborough University), Chris James (University of Witwatersrand, South Africa) etc.	Ongoing
13	Flood Risk Management Research Consortium II (FRMRC2)	Scott Arthur, Heriot-Watt University Nick Wallerstein, Nottingham University	Ongoing (HRW, JBA)
14	US Department of Agriculture (USDA) research on grass-lined and vegetated channels	Greg Hanson, USDA	Ongoing
15	Assessing the benefits of channel management as part of the Environment Agency's SAMPS	Marta Roca-Collell, HRW	Ongoing

No.	Project / Research Programme / Literature	Contact	Interaction
16	US Army Corps work on roughness and conveyance	Numerous	Ongoing
17	Ongoing roughness and vegetation research and interests	Karen Fisher, Independent	Mtg: 30/07/08 Ongoing
18	ADAs and Natural England's Drainage Channel Biodiversity Manual	Martin Mitchell / David Sisson, IDBs	Ongoing
19	Trash and security screen guide (2008 version)	Royal Haskoning, HRW & JBA role as reviewer	Considered
20	CIRIA Culvert Design and Operation Guide (CDOG) – revision of document	Charlie Rickard, Independent	Ongoing
21	Environment Agency RHS Team for the 2003-09 survey	Lucy Taylor, Environment Agency RHS Team, Warrington	Ongoing
22	Upcoming under MAR Theme – Flood risk in low-lying areas using the Risk Assessment for Strategic Planning (RASP) methods e.g. risk associated with pumping station		To be initiated
23	Aquatic Weed Control Operation - Best Practice Guidelines (CAPM, 1997 and update)		Considered
24	Environmental options specifications for flood maintenance (Environmental Agency, 1997) and recent updates provided by Gary Tustin (05/11/08)		Considered
25	Environmental Guidelines for Vegetation Management in Channel and on Banks (Environmental Agency, 1998a)		Considered
26	Management of vegetation on raised embankments (Environmental Agency, 1998b)		Considered
27	Handbook for assessment of hydraulic performance of environmental channels (Fisher, 2001)		Considered
28	Update to the Fluvial Design Guide	Underway, Black & Veatch with input from Charlie Rickard & Haskoning	To be initiated

3.2 Dissemination

An important aspect in promoting the use of the CES-AES software and the strong science which underlying science is dissemination and awareness-raising. This was raised as the stakeholder workshop (25/11/09). Activities include:

- Keeping the **CES-AES launch website** up to date e.g. documents, training information, FAQs. This has recently (Jan 09) been improved to aid users in accessing the software more readily and to improve navigation around the main pages;
- Through **conferences and events**:
  - Environment Agency's Flood and Coastal Risk Management Conference (July 2008) - promotional material and slides for the Environment Agency's CES stand;
  - The Association of Drainage Boards Catchment 08 Conference - promotional material at stand (Sep 2008);
  - FLOODrisk 2008 - promotional material at conference stand (Sep-Oct 2008);

- Presentation at the 41st Robson Meeting for aquatic weed management on the use of CES-AES to balance ecology needs (habitat creation) with those of flood risk management (vegetation cutting, dredging) with practical examples;

- Preparation and input to **articles**:
  - on availability of the CES-AES software on the main HR Wallingford website from June-August 2009;
  - on “Appropriate modelling for river rehabilitation”, a recently published article by Karen Fisher which promotes the use of the CES-AES tool.

- Preparation and submission of **journal papers** on the application of the CES - undertaken in parallel with project activities:
  - Journal of Flood Risk Management, Estimating river flow capacity in practice (McGahey *et al*., 2008);
  - ICE Water Management, Computation of afflux ratings and water surface profiles (Mantz & Benn, 2009);
  - ICE Water Management, Advice, methods and tools for estimating channel roughness, (McGahey *et al*., 2009 - accepted for publication);
  - Journal of Hydrology, Variability in roughness measurements or vegetated rivers near base flow, in England & Scotland, (O’Hare *et al*., 2009c - submitted; and
  - Journal of Ecology, Eutrophication impacts of the standing crop of a keystone macrophyte species, (O’Hare *et al*., 2009b - submitted);

- Preparation of the **CES-AES book** to promote the rich underlying science incorporated into the software: D W Knight, C McGahey, R Lamb, P G Samuels & R Millington, Practical Channel Hydraulics - Roughness, Conveyance and Afflux, in preparation, to be published by Taylor & Francis; and

- **Adaptation of the course** “Introduction to River Hydrology and Hydraulics” run by HR Wallingford to introduce the new roughness and conveyance concepts and worked simple examples of these (courses held in February, May and November each year).

3.3 Stakeholder engagement

A stakeholder workshop was held on the 25th November 2008 at the Orange Studio in Birmingham. The aim of the workshop was to discuss the emerging science and usability priorities for this project with representatives from science, academia, flood risk management consultancies, Environment Agency regions, policy etc. It was unfortunate that on the day a disproportionally large number of people had withdrawn at the last minute for a variety of reasons. Thus, those present were not fully representative of the user and research communities involved with the CES-AES. Despite this, the workshop was successful and provided valuable input to this study (Workshop minutes included in Appendix 3). The main issues that were noted include the need for:

- An overall interaction diagram indicating the context of the current CES-AES project and where it fits with other wider processes (first draft Section 1.1);

- A list of what the CES-AES is good at (addressed Section 2.1);
- Operational Instructions to key user groups (separate project now underway); and
- Enhancement / clarification on vegetation roughness, blockage, multiple barrels / arches (addressed in Chapter 4 recommendations).

In addition to the formal workshop, feedback and suggestions for improvement have been invited through the various consultations (Table 3.1), training and dissemination events. In general the feedback has been positive, including:

- "Tool fantastic", "lots of potential";
- The vegetation curves, cutting & regrowth advice is very useful;
- The photographs are helpful;
- Users prefer the ease and simplicity of selecting CES unit roughness values in the RA compared to estimating the Manning n resistance from Chow (1959) & other sources;
- It is useful to see the velocities;
- It is useful for simple reaches (no need for complex1D models) ;
- It is useful to aid understanding of structures;
- It is useful for dealing with different bridge geometries; and
- The software is intuitive and logical to navigate through;

Less positive feedback relates to software bugs (largely addressed in the version ready for next release) and limitations in usability (addressed in Chapter 5).

Two examples of recent feedback following the Robson Meeting aquatic weed management meeting include:

> *"From the perspective of a Biodiversity Officer, I could do with a modelling tool that's simple to use, and can demonstrate the effects of various river rehabilitation techniques. That might include different types of flow deflectors, introducing meanders, attaching ledges to the insides of culverts for otters to use, installing fish passes on weirs, weir removal, introduction of riffles and side bars, introduction of woody debris to name a few. All the sort of stuff engineers model and say needs removing due to impacts on conveyance really.*
>
> *You said you would be interested in feedback on bits that practitioners might like to see developed. If there is any scope for the model to be developed, to help us demonstrate the effects of such techniques, it would be great."* Biodiversity Officer, Environment Agency

> *"I am very pleased to see this tool has been developed as there is a definite need for it. Please send me the example applications from your slides so I can pass these on to others."* Former ADA Chief Executive.

4 CES-AES science recommendations

4.1 Screening of potential science enhancements

The science recommendations arising from the focal point activities (Chapter 3) have been grouped into 45 topic areas (Table 4.1, S1-S45) and categorised as relevant to roughness, conveyance, backwater, afflux or other (e.g. new features, data, guidance). These categories relate to the software modules in Figure 2.1 (Chapter 2). Each topic area covers a potential improvement area for the CES-AES. For example, S7 "Use of aerial photography to inform roughness" is a means to improve available roughness information within the RA based on the use of aerial photographic imagery and linking this to the current CES roughness advice. Some topic areas cover more than one aspect with a common theme e.g. improved vegetation values from different sources.

The initial screening process involved collation of information for each topic area covering (Appendix 4, Table A4-1):

- A description of the proposed method enhancement;
- The CES-AES tool enhancement;
- The perceived benefit;
- The implementation effort indicating needs for basic research, method development and/or software development; and
- Stakeholder support.

The 45 topic areas were then prioritised as high, medium and low based on this collated information, with emphasis on potential benefits and stakeholder support as this reflects the science and industry needs. From these, five AFW were identified to capture the highest priority topic areas. Each AFW is classified as:

- "Quick wins" - The science, knowledge and method are already sufficiently detailed and the approach can be included into the software 'as is'. This means the software functional specification can be developed with no further research and the software changes may then be implemented;
- "Some science required" - There will be moderate effort in collating, developing and making use of existing knowledge to develop a final method. Following this, a software functional specification may be developed and the software changes implemented; and
- "Major science required" - There will be substantial effort in developing new methods prior to preparation of a software functional specification and inclusion in the software. This effort will include a more detailed literature review and potentially some new research.

The medium and lower priority areas may be considered in future recommendations. Some of the topic areas are related to more basic academic research and could well be promoted for funding principally by EPSRC or NERC. For example, S2 "Ongoing annual vegetation measurements to further reduce uncertainty" could be funded by a NERC grant with support from other government agencies.

The five proposed AFW include:

1. **Update to the RA** (some science required, Appendix 4 reference: S1, S3, S10, S43): This includes: developing seasonal vegetation uncertainty curves; an update to the RHS data with additional fields; an update to the advice and roughness values for pools and riffles; an update to the RA photographic database and an update of the Roughness Review;
2. **Channel maintenance module** (some science required, Appendix 4 reference: S11, S16 (part), S42): This involves developing channel maintenance support within the CES-AES software tool. This will aid users in exploring "what-if" scenarios for different channel management regimes (e.g. cutting, dredging) through additional software functionality and outputs (e.g. ease of implementing standard cuts, new graphs, batching runs);
3. **Culvert coefficients and multiple barrels** (major science required, Appendix 4 reference: S34, S35): This includes: improving the current culvert energy loss coefficients which deal with idealised shapes (original US methods as adopted in the CIRIA guidance) to those which occur in UK practice and providing appropriate advice where this is not feasible; and improving the afflux calculation such that is can deal with multiple culvert barrels with different invert or soffit levels and, where this is not feasible, providing appropriate advice on how to best represent this with the current software set-up;
4. **Trash screen and blockage module** (some science required, Appendix 4 reference: S32, S33): This involves developing a energy loss unit for dealing with trash screens (including percentage blocked) and general channel blockage (e.g. debris) and a means to determine the impact on upstream water levels. This will consider the methods described in the Trash and Security Screen Manual (Environment Agency, 2009) where they offer utility and will be designed to link with the planned work under FRMRC2, Work Package 4.1 "Predicting and Managing Flood Risk Associated with Debris at Structures"; and
5. **Structure conveyance and transition lengths** (some science required, Appendix 4 reference: S30, S31, S37): This involves incorporating the CES conveyance calculation for reaches with structures and improving the approach for calculating transition lengths.

Note that AFW 5 above "Structure conveyance and transition lengths" is different to AFW 5 in the Executive Summary. Following discussion on 05/02/2009, this has been moved to form part of AFW 5 "Software usability and harmonisation (Phase 2)" and is described further in Chapter 5.

During the development of the CES, it was envisaged that the RA would be periodically updated. This may relate to small changes (e.g. improve a single roughness value, add a photograph) or more substantial changes (e.g. incorporate a new RHS database field, dynamically relate roughness to velocity). For the former, this is most easily linked to maintenance updates. For the latter, new science may warrant a dedicated AFW. AFW 1 above is a dedicated AFW originally intended to incorporate the outcomes of the Centre for Ecology and Hydrology (CEH) Aquatic Plant Management Group (APMG) research which was specifically steered by the CES project team to maximise common benefits. Here, it has been extended to include other small updates.

Table 4.1 Summary of prioritised list of enhancement topic areas (Priority: High, Med, Low).

Ref.	Recommendation
	Roughness & Vegetation
S1	Reduce vegetation uncertainty building on CEH work
S2	Ongoing annual vegetation measurements to further reduce uncertainty
S3	Update the RA database to include latest RHS information
S4	Explore potential dynamic link to RHS database (Environment Agency users)
S5	Link the RA database to Land Cover Map 2000
S6	Data feedback (wider issue for Environment Agency)
S7	Use of aerial photographs to inform roughness
S8	Impact of climate change on vegetation growth patterns
S9	Flow-vegetation-sedimentation interaction (long-term)
S10	Improved definition for pools and riffles
S11	Database of typical vegetation cuts, nature and timing
S12	Two-dimensional roughness for deriving unit *n* from measurements
S13	Use of Biologists & CES-AES classification of channels to inform likely features
S14	Incorporate variation of resistance with passage of storm
S15	Develop capability to handle multiple vegetation species in one location
S16	Incorporate a method to handle alluvial friction
S17	Incorporate an approach to update cross-sections to equilibrium conditions
S18	Incorporate a roughness method for modelling mountain rivers with boulders
S19	Incorporate a drag force term for emergent vegetation
S20	Investigate impact of the current boundary friction assumptions (e.g. 1 m depth)
	Conveyance
S21	Improvements to core CES engine models & coefficients
S22	Improvements to high flow predictions through extension of rating curves
S24	Incorporate methods to model non-prismatic channels
S26	Improve meandering channel approach through use of two-layer model (long-term)
S27	Further benchmarking & testing of methods
	Backwater
S29	Improve the backwater energy balance
	Afflux
S30	Update the structure conveyance calculation to be consistent with CES
S31	Improved afflux estimation at bridges through use of CES method
S32	Incorporate energy losses due to trash screens
S33	Improved handling of blockage
S34	Improved culvert coefficients from original US data to simulate inlets as they occur in reality
S35	Incorporate capability to model multiple barrels with different invert levels
S36	Improve afflux approach to include conservation of momentum methods for bridge piers
S37	Improve method for estimating transition lengths
	Other e.g. data, guidance, new features
S38	Data acquisition programme
S39	Improve boundary shear stress predictions at sharp changes in geometry.
S40	Development of a sediment transport module.
S41	Development of a habitat module
S42	Channel maintenance support/advisory module
S43	Advice on use of CES-AES for environmental features (ties in with S10 / S39)
S44	Analysis of cross-section survey data to improve understanding of the sensitivity
S45	Development of a module to support exploration of river rehabilitation techniques

Four additional AFW are noted here for future reference as they also received considerable support:

- **Data acquisition** (Appendix 4 reference: S2, S12, S38): This involves gathering data on vegetation (e.g. seasonal measurements of select plant types to build up a long-term record), flow properties and evidence of debris following storms (initiated in FRMRC2, WP4.1). This AFW would ideally be supported by multiple funders e.g. Environment Agency, NERC, EPSRC. Widely agreed feedback at the stakeholder workshop (25/11/09) was the philosophy "to measure more and model less." For example, the Japanese have an extensive measurement programme to measure velocities and boundary shear in rivers;

- **Development of a habitat module** (Appendix 4 reference: S41). This would be a post-process tool to support habitat design;

- **Extension of rating curves*:*** Development of methods and tools to support extension of rating curves. This would build on the existing approaches (e.g. Extension of Rating Curves at Gauging Stations - Best Practice Guidance - Ramsbottom & Whitlow, 2003) and tools (e.g. Sked, Whisky) which make use of regression analyses to extend gauge data. This project would ideally be supported by multiple funders e.g. EPSRC, Environment Agency; and

- **Development of a sediment transport module** (Appendix 4 reference: S40): This would be a post-process tool to support sediment transport modelling. This project should await the outcomes of the Sediments and Habitats Phase II - Additional Studies (underway under separate contract).

The review findings, initial screening process and recommended AFW were discussed at the project team teleconference meeting on 05/02/2009. It was agreed that the remaining effort should be channelled into improving the information on the five leading identified potential AFW. The information should be structured around presenting the business case for carrying out each AFW. This is done by addressing the key sections of the Environment Agency's Financial Scheme of Delegation Low Risk Project Short Form A (as provided 16/02/09). To this end, AFW 1 to 4 are described in more detail below.

At the Project Board meeting (10/03/2009) it was requested that broad cost bands and timescales be provided for each AFW (where possible). These costs bands are provided as a guide to the Environment Agency in developing future project specifications and broadly allocating their budgets and should not be considered formal quotations. It is likely that costs will change subject to formal detailed specifications (e.g. pending required documentation, further consultation, number of meetings, final methods, degree of testing etc.). The cost bands are as follows:

- Band A < £50K
- Band B £50-100K
- Band C > £100K
- Band D >> £100K

4.2 AFW 1: Update to the RA

Background

Roughness plays an essential role in water level estimation as it reduces the discharge capacity through energy expenditure on boundary generated turbulence as well as physical blockages due to vegetation. Apart from the hydrology analysis for determining the inflow to the river system, the largest source of uncertainty for estimating water levels in channels is roughness (Latapie, 2003; Mc Gahey, 2006). Of the different roughness types, vegetation roughness includes the greatest natural variability (e.g. Sellin & van Beesten, 2004; Defra/Environment Agency, 2003) and is of major concern to channel managers in the UK. This AFW is aimed at reducing the uncertainty associated with roughness information in the RA through a series of Tasks:

- Task 1: Improving the vegetation uncertainty information drawing on the outputs of two related CEH studies (O'Hare *et al*., 2008; O'Hare *et al*., 2009c) to develop (i) a pragmatic approach for an immediate update to the vegetation curves involving provision of vegetation uncertainty information through time based on latest data measurements and information; and (ii) a more scientific approach for the longer term;
- Task 2: An update to the RHS data embedded in the RA to potentially include new data fields (e.g. substrate, blockage) and new vegetation information based on the 2003-09 survey;
- Task 3: An update to the RA advice and information based on experience from the "Guidelines for River Rehabilitation for Eastern Rivers". In particular, this will address the improved handling of pools and riffles;
- Task 4: An update to the RA photographic database with new photographs sourced from the original RHS (Raven *et al*., 1998), the new RHS (River Habitat Survey Guidance Manual, 2003); the Poland RHS survey (courtesy Hugh Dawson) and the CEH studies (see Task 1); and
- Task 5: An update to the Roughness Review (Defra/Environment Agency, 2003) to ensure the scientific relevance of this document is maintained in parallel with the CES-AES. This is particularly important in relation to vegetation, an active research area.

Objectives

Implementation of Alternate Option 1 (below), the recommended option, will meet the following objectives:

1. Reduced uncertainty in predicting water levels in channels with aquatic vegetation - including seasonal variations;
2. Improved advice on likely vegetation, substrate and other RHS parameters based on geographical location i.e. where site information is limited;
3. Improve estimation of water levels where pools and riffles are present;
4. Improved photographic evidence for aquatic vegetation species (to support objective 1) and other roughness types e.g. substrate, irregularities; and
5. Up-to-date supporting Roughness Review document

Consultation

The elements within this AFW have received support from:

- The Roughness Review Steering Group Meeting (03/07/08);
- The CES-AES stakeholder workshop (25/11/08) which explicitly highlighted the need for vegetation curves to consider natural 3-year growth cycle, variations in start time due to spatial location in UK and seasonal uncertainty;
- The ADA representative at the above meeting noted the most important aspect from a drainage perspective is the impact of seasonal variations in vegetation, the associated uncertainty and climate change on vegetation curves;
- Ongoing feedback from users on the large uncertainties associate with the roughness information (e.g. How to interpret this information? Why are the bands so sided? Why do some elements have no/few photographs? etc.);
- Use on projects such as (i) assessing the benefits of channel management as part of the Environment Agency's SAMPS which required the need for substrate data nationally and (ii) river rehabilitation work which identified concerns re pools and riffle values; and
- Support from the RHS team and the Environment Agency Conservation and Ecology.

The issue of the sensitivity of channel capacity to vegetation growth and its maintenance was a key underlying issue in the discussion on channel maintenance in the Pitt Review.

Do Nothing

Option

- To do nothing i.e. no RA or Roughness Review updates and improvements

Costs & Timeframe

- No cost

Risks

- The RA information does not benefit from the improvements of recent knowledge, data and information.
- This may result in no wider user acceptance and hence uptake.
- Whilst the current information in the RA consolidates much research from the past 50 or so years (Defra/Environment Agency, 2003), the vegetation research is an active area and this should be reflected to maintain the scientific relevance.

Do minimum

Option

- This would be to include Task 1 (most important) and Task 4 (quick win, small effort). Task 1 will involve developing a pragmatic approach to representing seasonal uncertainty for different vegetation types. The CES-AES currently includes seasonal variations of unit roughness for different vegetation morphotypes with fixed upper and lower values regardless of the time of year. Here, the proposal is to develop seasonal uncertainty bands (e.g. Figure 4.1) which take the following into account:

  - The 3-year natural growth cycle;
  - Seasons starting at different times pending UK location;
  - Variations in local nutrient levels (e.g. phosphates); and
  - General uncertainties noted for any given measurement into account (e.g. Figure 4.2).

  An important aspect will be relating the measurements from the two measured species (Emergent reeds - *Sparganium Erectum*; submerged fine-leaved - *Ranunculus pencillatus*) to infer curves for the full range of species. Task 4 involves the review of photographs (via the Environment Agency's information) and placing these in the RA database.

Benefit

- Reduction in uncertainty associated with water levels where aquatic vegetation is present. Although it is difficult to provide an estimate of the reduced uncertainty for all cases (i.e. channel shapes, vegetation types, seasons), a recent example for a channel with water crowfoot and gravel cover showed that an improved unit roughness estimated range of 0.113-0.163 (O' Hare *et al.*, 2009c) from a previous range of 0.029-0.251 (current RA values), led to reduced water level uncertainty from ± 0.25 m to ± 0.05 m, for ~1 m depth of flow;
- Introduction of seasonal uncertainty for aquatic vegetation;
- Particular benefit to users dealing with the timing and nature of cutting in vegetated channels (a major concern to channel managers in the UK);
- Improved confidence in results;
- Wider user acceptance as uncertainty scenarios are narrower; and
- Improved photographic evidence to identify roughness types.

Costs & Timeframe

- Band A (< £50K), 4 month duration

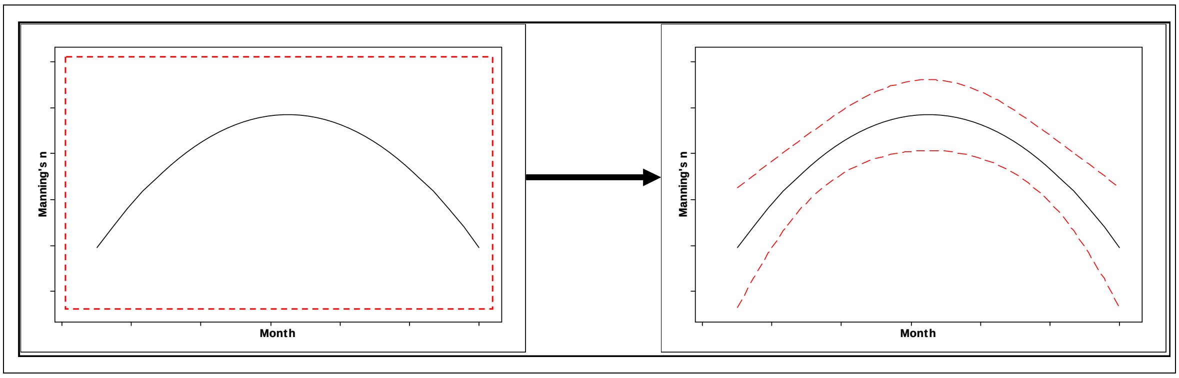

Figure 4.1 Example of pragmatic approach output for reducing vegetation uncertainty (O'Hare *et al*., 2008).

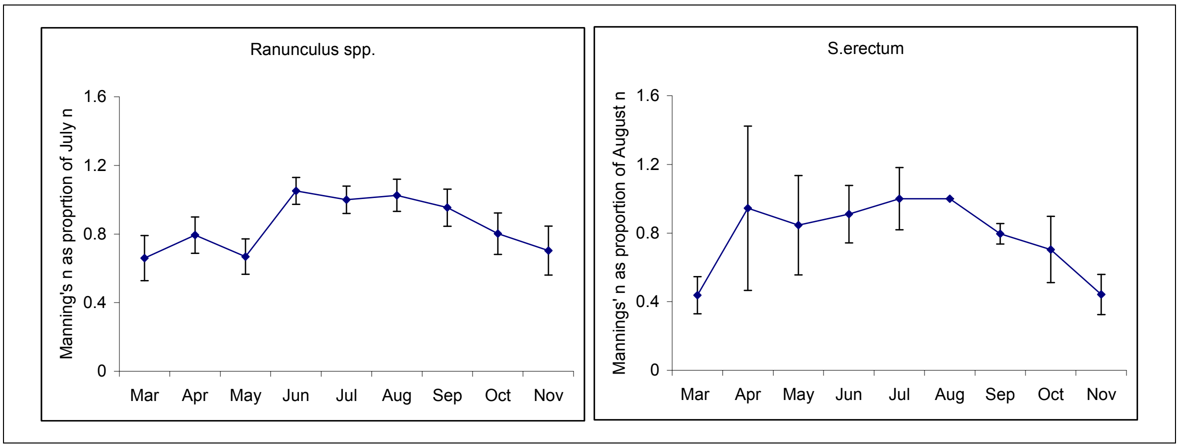

Figure 4.2 Example of measurements available to inform uncertainty (O'Hare *et al*., 2009a).

Risks

- Aquatic vegetation is an active research area. It is likely that in the foreseeable future more advanced methods may be possible as national snapshots of plant biomechanical data (biomass, percentage cross sectional area (CSA), phosphate levels via Mean Trophic Ranking System) become available. This will lead to further refinements of this information, but it is felt this future update is not inconsistent with the Task 1 planned refinement;
- A future update which dynamically relates roughness to vegetation and depths is possible, particularly for emergent species. This is unlikely in the short-term and hence this improvement to uncertainty is advocated;
- The risk of not incorporating the RHS geographical data means (Task 2) that (i) projects at larger catchment scales (e.g. SAMPS, exploring management options in National Flood Risk Assessment (NaFRA/MDSF2) will not easily make use of the tool; and (ii) users would not have access to data which may support improved technical and ecological understanding;
- The risk of not incorporating the advice on pools and riffles is less user uptake e.g. for river rehabilitation work;

- The risk of not updating the Roughness Review document (Task 5) is less user acceptance as the information is dated and the Roughness Review would not reflect the new information from Task 1; and
- The risk of not implementing Task 1 to 4 together is that software implementation costs may increase i.e. multiple updates/releases.

Alternate Option 1

Option

- To incorporate Tasks 1 to 5 and, for Task 2, the RHS data will be obtained from the new survey (2003-09). Task 1, 4 and 5 are as described above. Task 2 and 3 require further clarification. Task 2 would involve a Principal Component Analysis of the new RHS database to translate any fields used to the UK grid references. This was previously undertaken for the 95/96 survey data (Defra/Environment Agency, 2003); however as the sites have changed, this would be required if the new survey data is to be used. The data incorporated in the RA would include additional fields (see Appendix 5 for 2003 survey instruction), with recommended priority as follows:
  - Substrate fields for in-channel, left bank, right bank;
  - Land-use e.g. trees alongside channel;
  - Possible use of section dimensions e.g. top width, height;
  - Trash present;
  - Choked channels e.g. greater than 33% blockage;
  - Channel modifications which would be linked to irregularities;
  - Flow types which may be linked to engineering or environmental needs; and
  - "Habitat Quality" & "Impacted by Man" scores to inform users of likely management practice. This would be useful in terms of extrapolating the findings from the Sediments and Habitats studies.

  The RHS database is the principal means of tracking changes to the nature and state of UK riverine habitats. Some significant changes have taken place since the 1995/96 survey and it is not appropriate in the current 'climate' of implementation of the Water Framework Directive (WFD), and of partnership between flood/drainage practitioners and environmental managers, for the CES-AES to retain the historic reference data when more up-to-date data exist.
- Pools and riffles are important for simulating ecological processes in low to medium flow depths, whereas the original CES design placed more emphasis on high flows where these features are drowned out. The installation of pool-riffle sequences for river enhancements mainly for fisheries purposes have become more prevalent for low gradient engineered rivers. Riffles change the morphological and hydraulic diversity but there has been few studies investigating the impact of these features. Task 3 will involve:
  - Revision of the existing RA values. Sear and Newson (2004) investigate the impact of the pool-riffle sequences on the water levels and flow

resistance. The installation of the gravel bedforms increases the physical diversity of the reaches investigated with a greater range of depth, velocity and substrate conditions across the flow range. At bank full discharge the water surface elevation is not significantly increased. The range of resistance characteristics and values measured in the paper will be used to refine the values within the RA;

- Provision of guidance and examples based on recent work see “River Rehabilitation Guidance for Eastern England Rivers- River Restoration Centre, November 2005, for the Environment Agency.” This includes suggested cross-sections and spacing etc; and

- Validation of above approach at pools and riffles from measurements

Task 1 to 4 may be carried out in parallel. For efficiency, the final part which involves the implementation into the RA software should be carried out for Tasks 1 to 4 together. Task 5, the update to the Roughness Review, may be initiated in parallel but it will be finalised on completion of the other Tasks as it includes the update to the RA. For example:

Project 1 - Update to Roughness Advisor		M1	M2	M3	M4	M5	M6
Task 1-4 (science & software spec)	Vegetation update						
	Update to RHS						
	Pools & riffles						
	Photographs						
Task 1-4 (software implementation)							
Task 5 (science)	Update roughness review						

Benefit

As for Do Minimum as well as:

- The benefit of using the new survey data is that there are more sites available and the data is more up-to-date;
- The benefit of using the RHS data is improve geographical information which may be used for large catchment studies (e.g. SAMPS, NaFRA MDSF2 etc.), in the absence of sites visits (i.e. no data advice) and for improved ecological and technical understanding;
- The benefit of including the pools and riffles information is improved information and hence wider use, confidence and uptake (e.g. for river rehabilitation, fisheries); and
- The benefit of updating the RA is that the document is current in terms of science and representative of what is in the latest CES-AES software i.e. following any improvements here.

Costs & Timeframe

- Band B (£50-100K), 6 months.

Risks

As for Do Minimum first two bullets as well as:

- There is a question regarding how useful a new Principal Component Analysis of the 2003 data is compared with re-use of the exiting analysis with the 1995/96 data. Of the newly recommended fields, these are all available in both surveys. The new survey includes more sites, does this necessarily mean improved quality?

Alternate Option 2

Option

- To incorporate Tasks 1 to 5, with Task 2 making use of the 1995/96 RHS Principal Component Analysis.

Benefit

- As for Alternate Option 1 but without the benefit of more RHS sites and more up-to-date information.

Costs & Timeframe

- Band B (£50-100K), 5 months; and
- Note: the main change to Alternate Option 1 is less effort for not carrying out the new Principal Component Analysis of RHS data (*circa* 1 month impact on duration, *circa* £10K impact on cost).

Risks

As for Do Minimum first two bullets as well as:

- The RHS database would be based on historic reference data when more up-to-date data exists; and
- If the previous Principal Component Analysis is used, this may limit future RHS updates.

Example products

The recommended Alternate Option 1 would provide the following products:

- Updated vegetation curves with seasonal uncertainty distributions;
- Updated RHS information as well as new data with geographical location;
- Updated information and guidance on pools and riffles;
- Updated photographic database;
- Updated Roughness Review document; and
- Documentation covering all of the above.

4.3 AFW 2: Channel Maintenance Module

Background

There is a significant amount of literature and guidance available on channel maintenance (Centre for Aquatic Plant Management (CAPM), 1997; Environment Agency, 1997; Environment Agency, 1998a; Fisher 2001; Buisson *et al*., 2009). An important emerging theme amongst policy guidance (e.g. WFD, Habitats Directive, Making Space for Water, Defra's Outcome Measures) is the need to balance a range of objectives including flood risk management, ecology and social aspects. The CES-AES provides a vital tool for supporting the exploration of "what-if" scenarios to investigate different management options for channel design. Whilst the tool-set, user manual and embedded information provides a useful starting point, the process of investigating "what-if" scenarios is not straightforward. User experience is that navigation within the tool can be time consuming, that it is not always intuitive and that many of the outputs require further manipulation to provide them in a useful format to decision makers. This AFW is therefore aimed at:

- Task 1: Improving the navigation of options within the current CES-AES tool to aid exploration of different "what-if" scenarios for vegetation cutting (timing and nature) and dredging;
- Task 2: Improving the processing of outputs to provide user friendly graphs and tables which highlight the merits of the different scenarios;
- Task 3: Include a database of standard vegetation cuts (e.g. cut along one bank, cut along the central margin of the channel, cut 50% of the inbank vegetation etc.) with simple explanatory images (e.g. WB1, WB2); and
- Task 4: Provide supporting guidance and advice for these tools.

This AFW should be undertaken in close collaboration AFW 5: Software Usability and Harmonisation, Phase 1 (Chapter 5), which involves some simple improvements to the use of the vegetation curves. These linkages are described further in Chapter 5, Section 5.4.

Objectives

Implementation of Alternate Option 1 (below), the recommended option, will meet the following objectives:

1. Improved CES-AES functionality to support exploration of different channel maintenance options;
2. New post-processing tools to support channel maintenance options;
3. Support users through embedded database of standard vegetation cuts; and
4. Improved advice to support channel maintenance options.

Consultation

This AFW has received support from:

- The Roughness Review Steering Group Meeting (3/7/08) and through work in East Anglia for the IDBs;
- The CES-AES stakeholder workshop (25/11/08);
- Stakeholders at the Robson Aquatic Weed Management Meeting;
- Ongoing feedback from users on the difficulties of exploring specific cuts (e.g. why is percentage cut not related to channel width? How do I compare outputs of different options? Can I batch and plot results for different seasons? etc.);
- Use on projects such as (i) Assessing the benefits of channel management as part of the Environment Agency's SAMPS and (ii) Sediments and Habitats Phase 2. These raised the challenge of implementing specific spatial cuts for vegetation (a blanket value was adopted as a result); and (b) the implementation of dredging; and
- Numerous discussions with the Environment Agency.

Do Nothing

Option

- To do nothing i.e. no support for channel maintenance

Costs & Timeframe

- No cost

Risks

- No wider uptake of the CES-AES for channel maintenance activities due to difficulties in using the tool;
- Undermining the substantial benefits of the new science and information available within the RA through not making the results (and hence benefits) easily accessible.

Do minimum

Option

- Provide generic advice on use of CES-AES tool 'as is' for obtaining useful results for different maintenance options e.g. vegetation cutting, dredging.

Benefit

- Users have some support, albeit cumbersome, in navigating through the tool and manipulating results to explore "what-if" scenarios for channel management.

Costs & Timeframe

- Band A (< £50K); 3 months

Risks

- There is a fair amount of effort in manipulating data within the CES-AES to achieve desired outputs. Whilst provision of advice is a first step, the effort would be better spent in simple improvements to the current software set-up to support this.
- Once outputs data are obtained, there is a fair amount of effort in manipulating data to illustrate the results and benefits of different channel maintenance options. Whilst provision of advice is a first step, the effort would be better spent in improving the tool to illustrate/process outputs e.g. simple graphs.
- Different users may represent the standard cutting models or dredging differently with the tool-set – leading to inconsistent outputs. A standard database for vegetation cutting may reduce this likelihood.

Alternate Option 1

Option

- This would be to implement Tasks 1 to 4. These would involve consultation with Environment Agency, IDB and Local Authority representatives to ensure the channel maintenance information is structured in the useful format for application in practice. It would also consider current and emerging guidance (e.g. Buisson *et al*., 2009; Operational Instructions). Specific improvements would include:
    - Restructuring the vegetation information e.g. % cut relates to spatial cut across a cross-section;
    - Means to readily implement specific cuts for a set of cross-sections – informed from database of standard cuts (e.g. Figure 4.3);
    - Means to readily implement specific channel deepening for a section or set of cross-sections;
    - Means to batch process calculations including uncertainty (e.g. through time);
    - Means to batch process outputs (e.g. through time); and
    - Plotting of specific results and associated uncertainty. Figures 4.4 to 4.6 provide some examples of possible graphs.

A possible programme of tasks is provided below:

Project 2 - Channel maintenance module	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
Initial design of module functionality & layout	■			■						
Consultation e.g. EA, IDBs, LA to inform design		■								
Finalise design and functionality			■	■						
Develop functional specification					■	■				
Implementation into CES-AES							■	■	■	
Testing & bug fixing										■

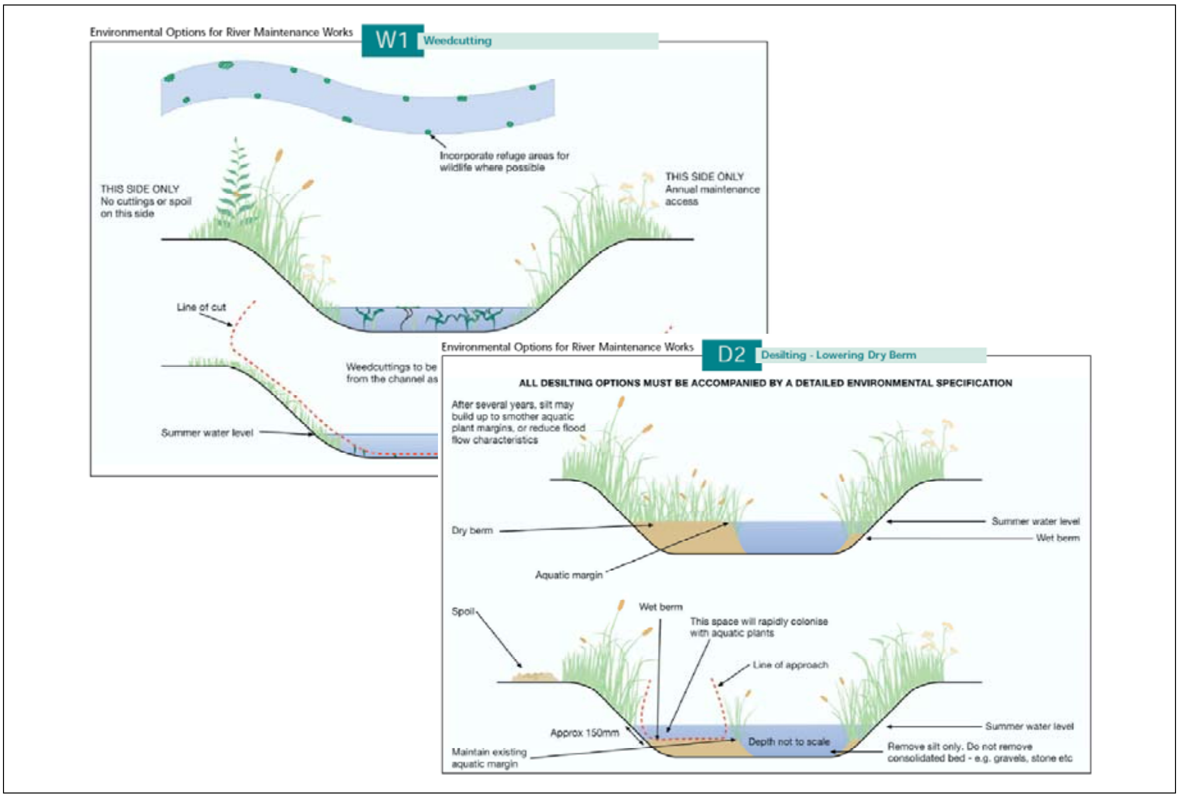

Figure 4.3 Example vegetation and channel deepening options which will inform standard database/advice on cuts (Environment Agency, 1997).

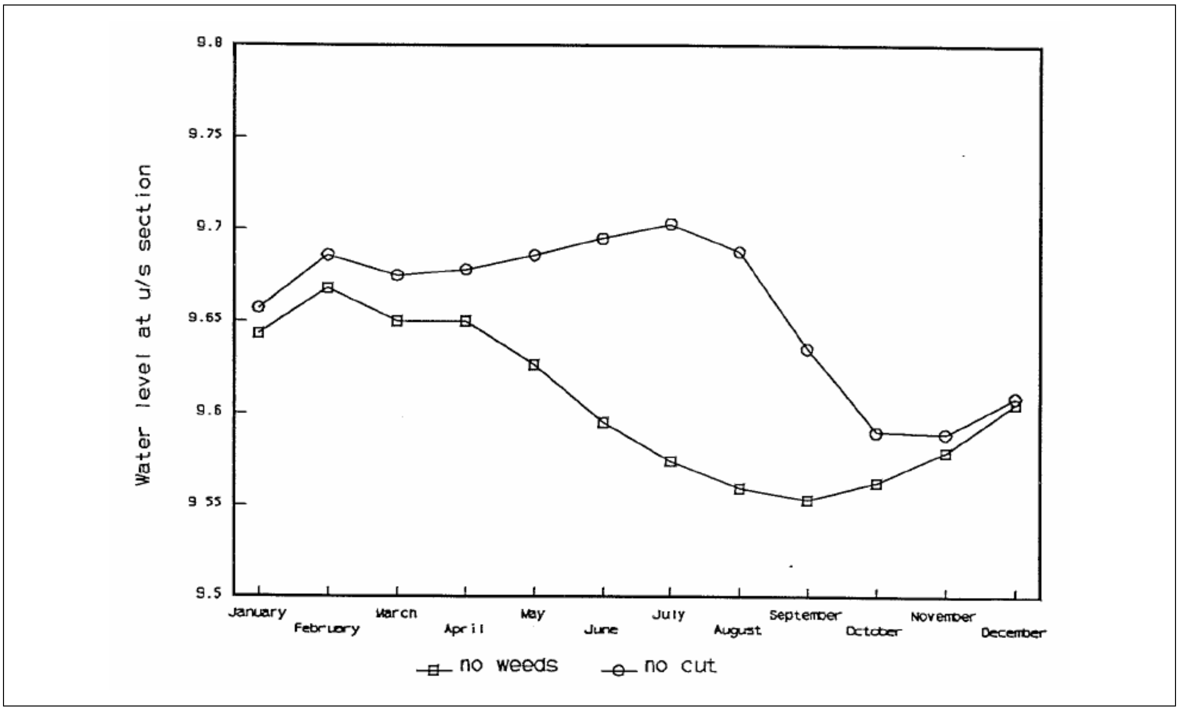

Figure 4.4 Impact on water level of vegetation growth in Candover Brook, Hampshire, with and without weed cutting (Fisher & Bettess, 1995).

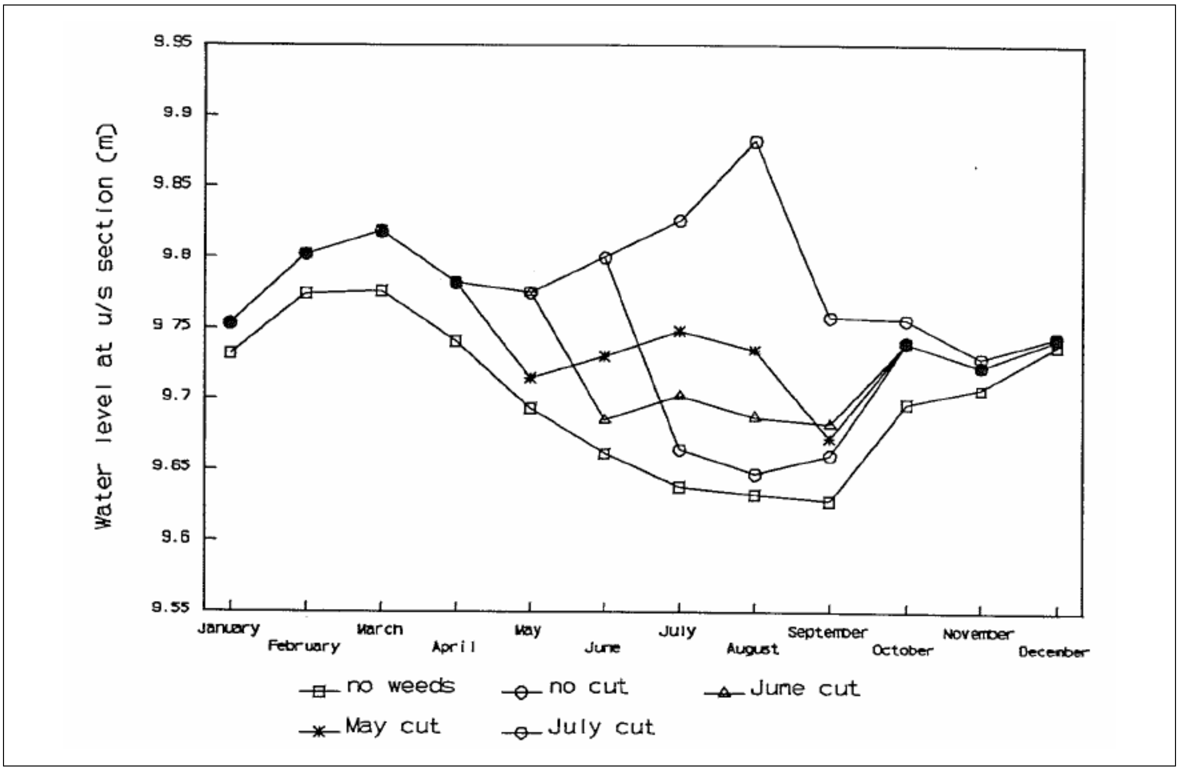

Figure 4.5 The hydraulic impact of vegetation growth and cutting at a given cross-section, assuming a specific growth pattern and maximum discharge (Fisher & Bettess, 1995).

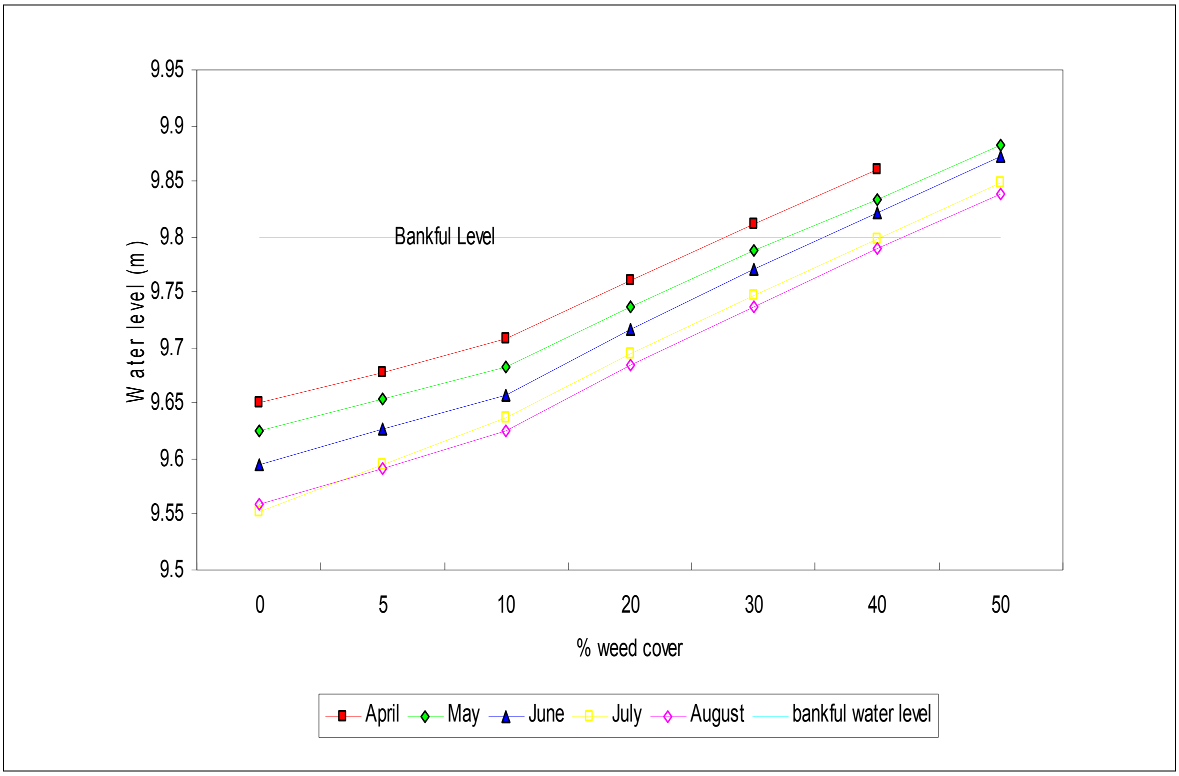

Figure 4.6 Water level for different % cover of weeds for the months April to August (Fisher & Bettess, 1995).

Benefit

- Improved CES-AES functionality to support channel maintenance activities including tool navigation, implementation of options and outputs;
- New capability to batch and process results through time and to plot specific views in support of identifying preferred management options; and
- Wider uptake and use for channel management activities.

Costs & Timeframe

- Band B (£50-100K), 10 months

Risks

- The channel maintenance module is too closely allied to specific guidance e.g. Operational Instructions. This will be mitigated through ensuring the additional functionality is generic to a range of guidance e.g. Local Authorities, Environment Agency, IDBs etc.

Example products

The recommended Alternate Option 1 would provide the following products:

- Vegetation post-process module including a database of typical vegetation cuts;

- Advice, including worked examples, of the use of the module; and
- Documentation covering all of the above including development and testing.

4.4 AFW 3: Culvert coefficients and multiple barrels

Background

The CES-AES stand alone tool allows users to estimate water levels and other flow variables in river channels containing bridge or culvert structures. There are a range of opening types available for bridges and culverts, with some flexibility to define the shapes of the openings; however more complex types such as multiple culvert openings with different shapes and invert levels or bridges with relief culverts cannot be represented directly. In addition, the road or parapet level of bridges is assumed to be horizontal and approach road embankments cannot be represented.

Whilst some of the issues are related to how the AES represents opening and cross section geometry, it is also becoming apparent that the coefficients used to compute energy losses for these configurations may require updating in light of laboratory and field research undertaken since the current generation of methods was established (see Appendix 6).

Accommodating more complex structures also raises questions about the lateral distribution of velocity in the flow. One approach would be to use an approximate two dimensional (2D) model such as the CES to determine the spatial velocity distribution of the undisturbed flow and hence to estimate the spatial velocity of the disturbed flow due to the presence of a structure using a simple adjustment. This aspect will be considered in AFW 5, Software Usability and Harmonisation, Phase 2 (Chapter 5).

Objectives

To improve the CES-AES capability such that it can model structures with more complex multiple openings and profiles.

This AFW will deliver strategic outcomes in terms of improved modelling capability, improving the quality of outputs from a current business-ready application, reducing uncertainty and improving functionality. The research will also include new or recently created knowledge from the scientific literature. Specific AFW tasks will include:

- Task 1: To review culvert and bridge structure configurations that would enhance the applicability of AES;
- Task 2: To understand the implications of more complex structures for conveyance and energy loss calculations; and
- Task 3: To develop and implement suitable algorithms to deliver improvements in the CES-AES software.

Consultation

This AFW has received support from:

- Consultations leading to the development of the current CES-AES. What was achievable in the first Phase was limited, and user feedback (e.g. consultations, point contacts) has now confirmed the need to address these;
- Supported through feedback from the current CIRIA CDOG project;
- The CES-AES stakeholder workshop (25/11/08); and
- Key individual stakeholders.

Do Nothing

Option

- Do nothing i.e. no further work on culvert coefficients and multiple barrels.

Costs & Timeframe

- No cost.

Risks

- No wider user acceptance and uptake of the tool.

Do minimum

Option

- Provide advice on how to use the current CES-AES ‘as is’ to model different culvert shapes and configurations. This will draw on available literature to advise on possible “fudges” e.g. altered coefficients.

Benefit

- Users have some support, albeit with large assumptions, in simulating more complex culvert shapes and configurations with the current tool.

Costs & Timeframe

- Band A (< £50K); 3 months.

Risks

- Does not use best science;
- The assumptions are likely to be substantial and the effort would be better spent in improving the tool to reflect the latest science and understanding; and

- The approach would need to cater to various culvert shapes and configurations and it would be difficult to quantify the accuracy of the approach for each i.e. the ‘fudge’ may work better for simple shapes.

Alternate Option 1

Option

- To deliver Tasks 1 to 3 outlined above. Task 1 will also include further user consultation. Supporting evidence which will feed into this study may be found in Appendix 6. In particular:
  - Appendix 6 summarises recent literature reporting experimental data to support Tasks 1 and 2 of the proposed AFW. There are several detailed experimental studies reporting calibrated values of coefficients that would be required in the development of the enhanced CES-AES algorithms. We can therefore be confident that AFW will deliver on all three tasks.
  - The CES conveyance method provides a lateral velocity distribution for channel flow and it may be possible to use this to enhance the way that the total conveyance and energy losses are computed for a culvert with complex openings. It is not yet understood how best to combine this information with the empirical data in the literature describing energy losses and hence changes in water level resulting from flows through culverts with multiple openings. However, should the work proposed in AFW 5, Phase 2 go ahead then we can be confident that the harmonised software for conveyance through structures will allow a suitable calibration to be made within the new CES-AES algorithm.

Restrictions lifted:

This module will lift the current restrictions of the types of culverts that can be modelled and allow, for example, users to model:

- Multiple barrel culverts with differing invert levels;
- Multiple barrel culverts with differing soffit levels;
- Multiple barrel culverts with differing spans;
- Multiple barrel culverts with differing barrel and opening shapes; and
- Bridges with relief culverts.

Restrictions remaining:

It will not extend the CES-AES to include more complex features of culverts such as changes in barrel cross section within the culvert, junctions, manholes or changes in slope. These are more appropriately handled by specialist culvert and drainage system models.

A proposed programme is as follows (note that this AFW should follow the first 15 months of AFW 5 - Phase 2 if the CES calculation is to be adopted at the structure - see Section 5.4):

Month: **Project 3 - Culvert capability & multiple barrels**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Scoping & method development - *review structure configurations, hydraulic approach, coefficients, algorithms*																		
Develop functional specification - *pseudo code, UI design, inputs, outputs, data flows*																		
Implementation into CES-AES - *software development*																		
Testing & bug fixing - *Alpha, Beta etc.*																		

Benefit

- Greater range of structure types modelled accurately in CES-AES;
- New capability and efficiency gain (previously analysis of these structure types would have required detailed hydraulic modelling or use of more complex bespoke software);
- Widespread application - many culverts, especially older structures, have complex opening and barrel geometries that cannot currently be represented adequately in CES-AES; and
- This will benefit a wide range of users and encourage wider user confidence and uptake.

Costs & Timeframe

- Scoping & Method Development - Band A (< £50K); 6 months; and
- Implementation & Testing - Band C (> £100K); 12 months.

Risks

- Many users are still in the early stages of using the AES component of the software. It may be that future feedback will be useful in further shaping the components of this AFW. To mitigate, user consultation has been incorporated in Task 1.

Example products

The AFW (based on Alternate Option 1) will deliver a review of research done to define energy loss coefficients needed to support modelling of culverts with multiple openings and an implementation of multiple openings of varying dimensions within the CES-AES software.

- Documentation of:
  - Consultation/review of required structure configurations to assess which opening types are most needed;

- Outcomes of a review of (i) hydraulic research to identify where new formulae or coefficients can improve the accuracy of water level estimates, and particularly whether recent research helps support structure types not previously included in AES (or earlier methods) and (ii) requirements and opportunities for improved modelling of flow processes in CES-AES at complex structures, particularly flow distribution at multiple openings; and
- Details of specification, algorithm and testing;

- Software product including i.e. implementation in CES-AES application code. The new capability will greatly increase the flexibility and generality of the CES-AES by allowing users to specify culverts with multiple openings of varying dimensions and shapes.

4.5 AFW 4: Trash screen and blockage module

Background

One of the primary factors that can create or worsen flood risk at a structure is the effect of blockage from floating and bed-borne debris. This is particularly an issue for culverts. With a culvert, blockage may occur within the structure or at a trash screen placed over the entrance. In either case, the result can be a significant increase in afflux and upstream water levels.

Blockage was an important part of the detailed scoping study that led to the development of the AES (Defra/Environment Agency, 2004 - Annex 4 & 5). However, blockage was not a part of the subsequent AES research and development project owing to lack of resources at the time. This was acknowledged to be a significant omission from the AES programme that should be addressed in future research and development (R&D).

Whilst the quantification of blockage risk is being considered in research underway in FRMRC2, there is currently no specific functionality in CES-AES to allow users to represent the hydraulic impact of blockage. This is therefore regarded as a priority for future development.

Objectives

The research and development will be aligned where relevant and possible with research in FRMRC2 WP 4 and current operational guidance (the updated CIRIA Culvert Design and Operation Guide and the Environment Agency's Trash and Security Screen Guide).

To develop an additional software module for the CES-AES to evaluate the affect of blockage at bridge and culvert structures. The module will also allow the utility of different mitigation measures to be tested.

The AFW will deliver strategic outcomes in terms of improved modelling capability, a business-ready application and best practice. The specific AFW tasks are:

- Task 1: To develop a conceptual model and hydraulic analysis for blockage scenarios relating to (i) sedimentation and (ii) debris accumulation (e.g. floating material and bed load);

- The Task 1 research will identify the most relevant trash screen and blockage scenarios with reference to the trash screen guidance, FRMRC2 WP4.1 and experience gained from management of blockage risk in specific case studies. The trash screens manual sets out recommended screen designs, which will be adopted in the development of the AES blockage module. FRMRC2 WP4.1 has identified key modes of blockage:

    a. Progressive build up of sediment in the culvert barrel from the invert of the culvert upwards;

    b. Progressive blockage by floating vegetation from the water surface downwards; and

    c. Abrupt blockage by large urban debris, e.g. table, shopping trolley.

  Blockage by sediment typically occurs both in the culvert entrance and along the barrel of the culvert, whereas the other blockage modes typically block the entrance only;

- Task 2: To investigate appropriate energy loss mechanisms and coefficients;

- Task 3: To implement the model within the improved CES-AES software.

Consultation

This AFW has received support from:

- Consultations leading to the development of the current CES-AES. What was achievable in the first Phase was limited, and user feedback (e.g. consultations, point contacts) has now confirmed the need to address these;

- Feedback from the current CIRIA CDOG project;

- Feedback from the users of, and the team updating, the Environment Agency's Trash and Security Screen Guide;

- The CES-AES stakeholder workshop (25/11/08); and

- Key individual stakeholders.

Do Nothing

Option

- Do nothing i.e. no further work on blockage.

Costs & Timeframe

- No cost.

Risks

- No wider user acceptance and uptake of the tool;

- Poor understanding by users of impact of blockage; and
- Inadequate flood risk management plans.

Alternate Option 1

Option

- As detailed in Task 1 to 3 above.

Restrictions lifted:

The AFW will allow users to investigate quickly the sensitivity of a culvert to blockage, accounting for the presence of a trash screen where relevant.

Restrictions remaining:

The enhanced CES-AES software will not include a blockage probability calculator - this is a separate process that should be informed by FRMRC2 WP4 research.

A proposed programme is as follows (note that this AFW should follow the first 15 months of Project 5, Phase 2 if the CES calculation is to be adopted at the structure - see Section 5.4):

Month: **Project 4 - Trash screen & blockage module**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Scoping & method development - *review literature, specify conceptual model, algorithm & blockage coefficients*	■	■	■	■	■	■												
Develop functional specification - *pseudo code, UI design, inputs, outputs, data flows*							■	■	■									
Implementation into CES-AES - *software development*										■	■	■	■	■	■			
Testing & bug fixing - *Alpha, Beta etc.*																■	■	■

Benefit

- Improved and consistent method and application to help optimise channel and structure maintenance where blockage is a risk;
- Consultation questionnaire survey as part of development of the CIRIA CDOG shows variable use of screens by different operating organisations, with some having very high use (e.g. Rivers Agency Northern Ireland, almost all urban and most rural culverts reported) to few (British Waterways);
- Benefit users dealing with blockage. Blockage from siltation quantified by four respondents in 5%, 10%, 22% and 50% of culverts (others have no data); and
- Efficiency gains for those that identify blockage problems – no need for specialist hydraulic modelling software.

Costs & Timeframe

- Scoping & Method Development - Band A (< £50K); 6 months; and
- Implementation & Testing - Band C (> £100K); 12 months.

Risks

- Requires scientific investigation where the outcomes are not known. [Note that blockage impacts can be considered within the current AES methodology in terms of impacts on conveyance through a structure and opening geometry. There may be some uncertainty about the impact of trash screens and blockage scenarios on calibration coefficients, which will be based on best available current knowledge in the literature.]

Example products

The AFW (based on Alternate Option 1) will deliver a trash screen and blockage calculation module within the CES-AES software, supported by accompanying technical documentation and guidance. It will allow users to select between a number of trash screen configurations and blockage scenarios, as defined above.

- Documentation of:
  - Conceptual model specification for blockage and trash screen hydraulic analysis within CES-AES, including data requirements, conceptual interface with blockage risk methods and data outputs.
  - Proof of concept basic numerical testing of conceptual model.
  - Detailed data structure, algorithm and user interface design.
  - User guidance, help, training material
- Software product implemented within CES-AES software.

5 CES-AES usability recommendations

5.1 Screening of potential software usability enhancements

The software usability recommendations are derived from a number of sources including user feedback, software bug reporting and detailed software testing undertaken in-house by Wallingford Software. Appendix 7 includes 32 potential enhancements (F1-F32) in Table A7-1. These have been prioritised into High, Medium and Low based on the emphasis users have placed on these, the views of the project team and the number of times these have been raised. An indication of the implementation effort is given where possible. As many of these fall into the “quick wins” AFW category, it is recommended that there is a Software Usability and Harmonisation AFW, with two phases, where Phase 1 deals with the “quick wins” and Phase 2 deals with the “major science required”. These are as follows:

AFW 5: Software usability and harmonisation

i. **Phase 1** (quick wins): This involves a series of software improvements which have been prioritised and given a clear indication of the implementation effort. Examples include: ability to calculate water level given flow; ability to plot multiple vegetation curves with different colours; more user friendly error message system; etc.

ii. **Phase 2** (major science required): This involves software improvements which will require new knowledge and method development. It will include: improving the approach for calculating transition lengths, incorporating the conveyance calculation at structures and automatic calculation of longitudinal bed slope.

Table A6-1 may then be used as a ‘shopping list’ in terms of identifying which aspects are addressed in Phase 1. Phase 1 and Phase 2 are described in detail below.

A proposed programme of work is given below:

Month: **Project 5 - Software usability & harmonisation**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Phase 1 (quick wins)																		
Prepare functional specification	■	■																
Implementation into CES-AES			■	■	■													
Testing & bug fixing						■												
Phase 2 (major science required)																		
Scoping & method development	■	■	■	■	■	■												
Develop functional specification							■	■	■									
Implementation into CES-AES										■	■	■	■	■	■			
Testing & bug fixing																■	■	■

5.2 AFW 5 (Phase 1): Software usability and harmonisation

Background

The original CES development project (Project W5A-057, Reducing uncertainty in river flood conveyance, 2001-04, www.river-conveyance.net/ces) intended as a minimum to deliver a simple spreadsheet approach (e.g. Microsoft Excel) for improved calculation of conveyance. In fact, during the project the team went a lot further and the final CES calculations were developed as a stand-alone, independent (of proprietary software) module with a supporting simple GUI. The main focus of the study was to improve the science and calculation methods and the GUI was provided as a 'nice to have' addition. Since the CES release, there has been substantial feedback on the GUI (as may be expected from the basic design) and a number of simple recommendations have been made to improve the usability. This AFW involves implementing the medium-to-high priority items which require no further science i.e. "quick wins".

Objectives

Implementation of Alternate Option 2 (below), the recommended option, will result in improved usability of the CES-AES through, for example:

- Improvements to use and options with vegetation curves;
- Improvements to the plotting functionality;
- Improvements to error messages; and
- Improvements to navigation and interaction.

Consultation

This AFW has received support from:

- Numerous training sessions;
- Feedback via the email support mechanism;
- Wallingford Software in-house testing;
- The Roughness Review Steering Group Meeting (03/07/08) and follow-up exchange; and
- The CES-AES stakeholder workshop (25/11/08)

Do Nothing

Option

- Do nothing i.e. no usability improvements.

Costs & Timeframe

- No Cost.

Risks

- No wider user acceptance and uptake of the CES-AES tool.

Do minimum

Option

- Incorporate select high priority aspects only i.e. the improvements to the vegetation curves F5, F12, F21 which have received the most substantial user support. The AFW would include additional functionality, where possible, for:
  - Memory e.g. remove/add cutting dates (ties in with F5, F12);
  - Different colours e.g. keep original curve but add one with cut for comparison;
  - Show % cut on screen in the colour of the new curve;
  - Shift date without having to reselect percentage change i.e. one button click;
  - Step-change in vegetation as valued entered on 15th of each month. Suggest smooth with linear interpolation e.g. fine leaved plants;
  - Enabling plotting of n-values for multiple vegetation types on one graph;
  - Make embedded velocity data for plants available to users;
  - Make biomass information available to user, e.g. additional plot;
  - Add a note to tell user the growth model is using biomass or give them the option of using cover or biomass; and
  - Suggest standardised axes for n values so it is quick to see the change between curves e.g. a range of 0.01-0.50.

Benefit

- Improved software usability for the most pertinent requests.

Costs & Timeframe

- Cost Band A (< £50K); 1 month. Table A7-1, Appendix 7 provides a measure of indicative software development effort and project management cost. Based on this, and on the effort in developing a functional specification, it is likely to be < £10K.

Risks

- User acceptance is not as wide as if all high priority changes are implemented.

- It may reduce costs if more improvements are undertaken in one AFW.

Alternate Option 1

Option

- Incorporate all high priority aspects in Table A7-1, Appendix 7.

Benefit

- Improved usability and hence wider user acceptance and uptake of the CES-AES tool.

Costs & Timeframe

- Cost Band A (< £50K); 4 months. Table A7-1, Appendix 7 provides a measure of indicative software development effort and project management cost. Based on this, and on the additional effort in developing a functional specification, it is likely to be < £35K.

Risks

- User acceptance is not as wide as if all low, medium and high priority changes are implemented (Alternate Option 2).
- It may reduce costs if more improvements are undertaken in one AFW

Alternate Option 2

Option

- Incorporate all low, medium and high priority aspects (except F3 which is covered in AFW 5 - Phase 2; and F23 & F26 which are covered in AFW 2). Note: the contribution from the low priority items is only 4 days effort and has therefore been included as part of this option.

Benefit

- Substantially improved usability and hence wider user acceptance and uptake of the CES-AES tool.

Costs & Timeframe

- Cost Band B (£50-100 K); 6 months. Table A7-1, Appendix 7 provides a measure of indicative software development effort and PM cost. Based on this, and on the additional effort in developing a functional specification, it is likely to be < £75K. Note that F25 “Audit trail” and F32 “Improved backwater case management” involve relatively large effort (and hence cost).

Risks

- None.

Example products

The recommended Alternate Option 2 would provide:

- A range of additional usability functions e.g. improved vegetation curves, improved navigation, improved error reporting.

5.3 AFW 5 (Phase 2): Software usability and harmonisation

Background

This AFW involves CES-AES stand-alone software improvements which require new knowledge and method development. It includes an improved approach for calculating transition lengths; updating the conveyance calculation at structures and automatic calculation of slope.

Transition lengths for length of flow expansion/contraction at structure:

The calculation of a water surface profile requires the integration of an open channel backwater model (part of the original CES package) and the AES model for a bridge or culvert. This integration requires the definition of internal boundaries between the CES backwater module and the AES upstream and downstream of the structure. The internal boundaries represent the extent of transition reaches - flow contraction into the structure and flow expansion on exit. Part of the scientific research in the AES development project (W5A-061) showed that these transition reaches are variable, dependent on flow conditions. Hence the AES includes a 'transition calculator' to determine appropriate reach lengths and loss coefficients.

Handling the transition reaches allows the AES to function over a range of physical scales, but means that the position of the internal boundaries between the CES and AES backwater modules can vary. The CES-AES includes a simple mechanism to deal with this, which means that in some situations the estimates of water level may be less accurate than they could be. This AFW will provide improved estimates of these transition lengths.

Conveyance calculation at structures:

The AES model for bridges and culverts incorporates a backwater calculation based on an energy balance through the structure to account for energy extracted from the main flow. This makes use of conveyance rating curves calculated both for the river channel as it would be in the absence of the structure (the 'undisturbed channel') and for the structure at its upstream and downstream faces.

The AES computes the required physical parameters such as cross sectional flow area and wetted perimeter as functions of flow depth for a range of opening geometries. In particular, it works for closed shapes such as arches and pipes, which is essential when modelling the conveyance for a bridge or structure. This calculation is based on a Divided Channel Method using Manning n resistance parameters for three panels. This is consistent with the original experimental research in the early 1950s. The

Divided Channel Method and CES calculation typically provide different solutions at the transition section and the use of two distinct approaches has raised questions from users regarding the need for both.

This AFW will involve adapting and incorporating the CES calculation for the reaches incorporating structures. An important change will be modifying the current CES algorithm for boundary treatment to deal with closed shapes such as circular culverts and arches and appropriate adaptation of the structure coefficients. It is recommended that there is an initial conceptual study to confirm the methods, the approach is then incorporated into the AES assuming reasonable confidence in the science and a parallel PhD study (independent of the project/AFW) is undertaken to further develop and validate the methods. This is a consistent format with the original CES development. Options for the PhD process include (i) set-up and sponsorship through research councils e.g. EPSRC, NERC; (ii) co-funded by the contractor organisation and the AFW funders; (iii) Collaborative Awards in Science and Engineering (CASE) Scheme. The findings of the PhD would confirm the sound science and provide recommendations for further enhancements and open publication in peer reviewed literature.

Slope:

The CES provides estimates of conveyance, but to evaluate flow, the longitudinal slope is required. This AFW would involve development of an automated approach(s) to calculate this based on embedded information e.g. cross-section survey, length between sections, water depths, etc. In defining the method, consideration will be given to scale. This slope is likely to be on a smaller scale than catchment slope or that of morphological processes and on a larger scale than that considered for ecological process (very localised). It is essentially a reach scale and should ideally be derived from the slope of the energy line. In practice, it may relate to a fall in water level of say > 0.1m and < 1.0m. An opportunity exists to use Geographic Information System (GIS)-based methods and/or to link the approach to the information downloaded from the EA global positioning tool (GPS) data-capture tools.

Objectives

The main objectives are:

- To improve the handling of the internal boundaries between the CES and AES backwater modules so as to improve the accuracy of water surface predictions;
- To provide a consistent and transparent CES-AES conveyance calculation approach through incorporating the CES calculation appropriately modified to handle structure shapes - thus making use of the latest science; and
- To incorporate method(s) of calculating longitudinal slope within a backwater reach.

The AFW will deliver strategic outcomes in terms of improved modelling capability, improving the quality of outputs from a current a business-ready application and reducing uncertainty.

Specific AFW Tasks:

- Task 1: Revision of the algorithms used to manage the transition reaches upstream and downstream of a structure to improve the accuracy and reduce uncertainty in water level estimates within CES-AES when a bridge or culvert is modelled;

- Task 2: Conceptual development of the CES method for flow at a structure;
- Task 3: Revision of AES conveyance algorithms and code to incorporate modified CES calculation at bridge and culverts; and
- Task 5: Development of algorithms for calculating longitudinal slope within the CES-AES.

Consultation

This AFW has received support from:

- The original development teams for the CES and AES;
- The current project team and board to promote wider user acceptance of the tool;
- User feedback (see F2, Table A7-1, Appendix 7);
- The CES-AES stakeholder workshop (25/11/08);
- The Roughness Review Steering Group Meeting (3/7/08) e.g. the CES-AES 'as is' confuses the issue of whether to use a unit roughness or Manning n.

Do Nothing

Option

- Do nothing i.e. leave the current use of the Divided Channel Method, the current approach for transition lengths and user entered slope.

Costs & Timeframe

- No costs.

Risks

- User confusion over (i) why the CES approach is not used in the afflux reach and (ii) when to use the new unit roughness value and when to use Manning n;
- No wider user acceptance due to inconsistency in CES and AES design;
- Differences in water level results at the US and DS boundary between the CES backwater calculation and the afflux reach, as the Divided Channel Method and CES approach will give different results for the same cross-section. There may be large differences for these for certain cross-section shapes e.g. narrow urban channels; and
- Does not use 'sound science'.

Alternate Option 1

Option

- To implement Task 1 to 6 above. This will include:
    - Specify conceptual model for transition between CES and AES backwater reaches, setting out possible combinations of cross section spacing and flow conditions, and identifying the conditions currently represented only approximately (or not at all) within the CES-AES code;
    - Conceptual analysis of the CES methods for flows at a structure with example calculations to demonstrate proof of concept;
    - Develop methods for calculation of slope based on available data in the system;
    - Implementation of transition lengths, CES calculation at structures and slope method in the CES-AES;
    - Checking and updating dependent features of the software such as long section plots and output files; and
    - Numerical testing to confirm correct implementation.

Benefit

- Reduction in uncertainty and improved accuracy in water level estimates over all scales and flow conditions;
- Improved usability for CES-AES software and greater confidence over scientific basis for conveyance calculations for reaches containing a structure;
- Benefit is ubiquitous to all users of CES-AES and in particular to any bridge or culvert analysis. Will deliver far more robust results with greater credibility over a range of flow conditions;
- Underpins advances in proposed AFW 3 by significantly improving the quality and consistency of information produced on partitioning of conveyance for complex structure openings; and
- Underpins proposed AFW 4 by improving quality and consistency of velocity information available to help users examine siltation issues.

Costs & Timeframe

- Scoping and Method Development - Band A (< £50K); 6 months; and
- Implementation & Testing - Band C (> £100K); 12 months.

Risks

- The CES calculation is found to be inappropriate for the structure conveyance. This is mitigated through development of an initial conceptual method for proof of concept and through revision of structure coefficients (i.e. re-analysis of the original experimental data based on this improved understanding).

Note that the two original science projects (CES and AES) delivered a thorough understanding of the hydraulic principles needed to improve the integration within the CES-AES software. The issues have been identified since the initial joint software development, where time and resource pressures demanded a pragmatic approach to obtain a first version of the working software product. There is no reason in principle or in practice why the deeper integration of the methods at an algorithm level cannot be completed and delivered in an update the CES-AES software product.

Example products

The main product of the research is improvement to the algorithms used in the CES-AES software to take full advantage of harmonising the work done in each original research project.

- Improved estimation of afflux as transition lengths improved;
- Afflux tool with structure conveyance calculation and input roughness; and consistent with CES approach
- Automatic estimation of slope.

An important second outcome of the AFW will be underpinning improvements in methodology and software to support related developments, such as handling more complex structures with multiple openings (AFW 3) and blockage risk (AFW 4).

5.4 High-level timeframe and linkages between AFW 1 to 5

Having described the five main Areas of Further Work including the timeframe of each, it is worth highlighting where there are linkages between these and hence potential benefits from the sequencing of the work. A suggested programme of work is shown in Figure 5.1, which takes the following into account:

- For AFW 1 and 5 (Phase 2), there are no inputs anticipated from other work. As these AFW provide input to others, these should start as soon as possible within the overall programme;
- AFW 5 (Phase 1) would benefit from AFW 1 having commenced. The reason for this is that AFW 5 involves updates to the usability features for the vegetation curves, and AFW 1 provides improvements and updates to the vegetation curves (e.g. seasonal uncertainty values for vegetation) which may influence this;
- AFW 2 would benefit from AFW 1 and 5 (Phase 1) having commenced. The reason for this is that the Channel Maintenance Module will build on the new software features in AFW 5 (Phase 1) (e.g. plotting of multiple curves in different colours, batching outputs etc.) and make use of the additional roughness and vegetation information provided in AFW 1;
- AFW 3 and 4 both require the concepts and methods associated with incorporating the CES calculation at structures in AFW 5 (Phase 2) to be finalised. A 3-month overlap has been allowed to enable the literature review and scoping to have commenced, however, the method scoping cannot be finalised without thorough knowledge of the AFW 5 approach.

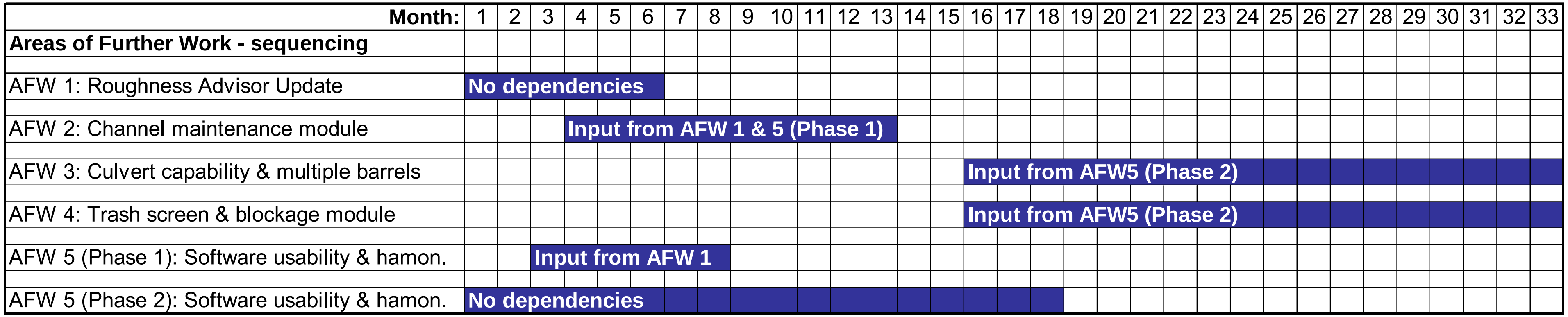

Figure 5.1: Overall programme of works illustrating dependencies and suggested sequencing.

6 Conclusions and recommendations

6.1 Meeting the project objectives

The project "Maintaining the Scientific Relevance of the Conveyance and Afflux Estimation System (CES-AES)" is intended to provide recommendations for potential enhancements to the CES-AES software. The specific objectives include:

- Identifying, tracking and assessing relevant new scientific information and technical developments in practice that have the potential to enhance the capability of the CES-AES;
- Scoping how advances can be incorporated into the tools in future developments and software releases e.g. calculation updates, new modules. This is undertaken in close collaboration with the user community to ensure the priority reflects the industry and user needs; and
- Identifying software usability updates with indicative costs and timescales (where practical).

The way in which this project has delivered these is described in this report. Chapter 1 provides an introduction to the CES-AES and its development. Chapter 2 provides an overview of the current CES-AES content, architecture and use. Chapter 3 details the project activities which broadly include:

- Watching brief to consider relevant projects, research and literature;
- Significant desk study tasks undertaken as part of the project by experts to assess the available published literature and other accessible knowledge for relevant new scientific information and technical developments in practice;
- Individual consultations;
- Dissemination;
- Collation of feedback from training, website, dissemination activities; and
- Stakeholder workshop.

Chapters 4 and 5 include prioritised recommendations for science and software usability respectively, with supporting evidence in the Appendices. Thus, this project has thoroughly met the original objectives and, in some instances, it has delivered more than hoped for given the resource. For example, there has been extensive consultation with stakeholders (workshop, face-to-face discussions, telephone calls, emails, training, conferences etc.) helping to shape and provide confidence in the early recommendations; indicative costs and timeframes have been provided for the Areas of Further Work; the information has been set-out in the Environment Agency's Financial Scheme of Delegation Low Risk Project Short Form A format; and the dissemination activities have been considerable (Section 3.2).

An important challenge for the next phase of this work will be how the Environment Agency can increase the involvement of other operating authorities to ensure their views and business needs continue to be reflected in the ongoing scientific development of the CES-AES. It is also essential that the use of CES-AES software is advocated through guidance and policy documents, for example, the Environment Agency's proposed Channel Maintenance Policy and associated maintenance performance measures. The recommendations herein, particularly AFW 5, will help to support this through improved software usability resulting in wider user uptake and acceptance of the CES-AES tool.

6.2 Project outcomes

A key conclusion is that the CES-AES is an increasingly valued tool for flood and drainage management practitioners, and that there are some potential enhancements that will enhance its utility. Some of the enhancements relating to software usability and harmonisation might be regarded as user developments rather than science.

The activities outlined in Chapter 3 fed into a thorough review which has identified 45 potential science topic areas (Appendix 4) and 32 potential software usability improvements (Appendix 7). A screening process which considered stakeholder support, expected benefits, the value of the new science and the implementation effort enabled the project team to identify key areas for further study. The recommendations are that five main AFW (plus the download of information from the Environment Agency GPS tools to the CES-AES software - already being addressed under separate contract see Project Board Minutes 10/03/09) are considered by the operational authorities for future funding:

1. **Update to the RA** (some science required): This includes: developing seasonal vegetation uncertainty curves; an update to the RHS data with additional fields; an update to the advice and roughness values for pools and riffles; an update to the RA photographic database and an update of the Roughness Review;

2. **Channel maintenance module** (some science required): This involves developing channel maintenance support within the CES-AES software tool. This will aid users in exploring "what-if" scenarios for different channel management regimes (e.g. cutting, dredging) through additional software functionality and outputs (e.g. ease of implementing standard cuts, new graphs, batching runs);

3. **Culvert coefficients and multiple barrels** (major science required): This includes: improving the current culvert coefficients which deal with idealised shapes (original US methods as adopted in the CIRIA guidance) to those which occur in nature and providing appropriate advice where this is not feasible; and improving the afflux calculation such that is can deal with multiple culvert barrels with different invert or soffit levels and, where this is not feasible, providing appropriate advice on how to best represent this with the current software set-up.

4. **Trash screen and blockage module** (some science required): This involves developing a hydraulic loss unit for dealing with trash screens (including percentage blocked) and general channel blockage (e.g. debris) and a means to determine the impact on upstream water levels. This will consider the methods described in the Trash Screen Manual (Environment Agency, 2009) where they offer utility and will be designed to link with the

planned work under FRMRC2, Work Package 4.1 “Predicting and Managing Flood Risk Associated with Debris at Structures”.

5. **Software usability and harmonisation**

    a. **Phase 1** (quick wins): This involves a series of software improvements which have been prioritised and given a clear indication of the implementation effort. Examples include: ability to calculate water level given flow; ability to plot multiple vegetation curves with different colours; more user friendly error message system; etc.

    b. **Phase 2** (major science required): This involves software improvements which will require new knowledge and method development. It will include: improving the approach for calculating transition lengths, incorporating the conveyance calculation at structures and automatic calculation of longitudinal bed slope.

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List of abbreviations

ADA	Association of Drainage Authorities
AES	Afflux Estimation System
AFW	Area(s) of Further Work
APMG	Aquatic Plant Management Group
CASE	Collaborative Awards in Science and Engineering
CEH	Centre for Ecology and Hydrology
CES	Conveyance Estimation System
CDOG	Culvert Design and Operation Guide
CIS	Corporate Information Services
CSA	Cross sectional area
Defra	Department for Environment, Food and Rural Affairs
EPSRC	Engineering and Physical Sciences Research Council
FRMRC2	Flood Risk Management Research Consortium Phase 2
GIS	Geographic Information System
GPS	Global Positioning System
ICE	Institute of Civil Engineers
IDB	Internal Drainage Board
MDSF2	Modelling and Decision Support Framework II
MSfW	Making Space for Water
NaFRA	National Flood Risk Assessment
NERC	Natural Environment Research Council
NI	Northern Ireland
OI	Operational Instructions
PAMS	Performance Based Asset Management System
RA	Roughness Advisor
RASP	Risk Assessment for Strategic Planning
RHS	River Habitat Survey
SEPA	Scottish Environment Protection Agency
WFD	Water Framework Directive
1D, 2D, 3D	One, Two, Three dimensional

Appendices

Appendix 1 Overview diagram

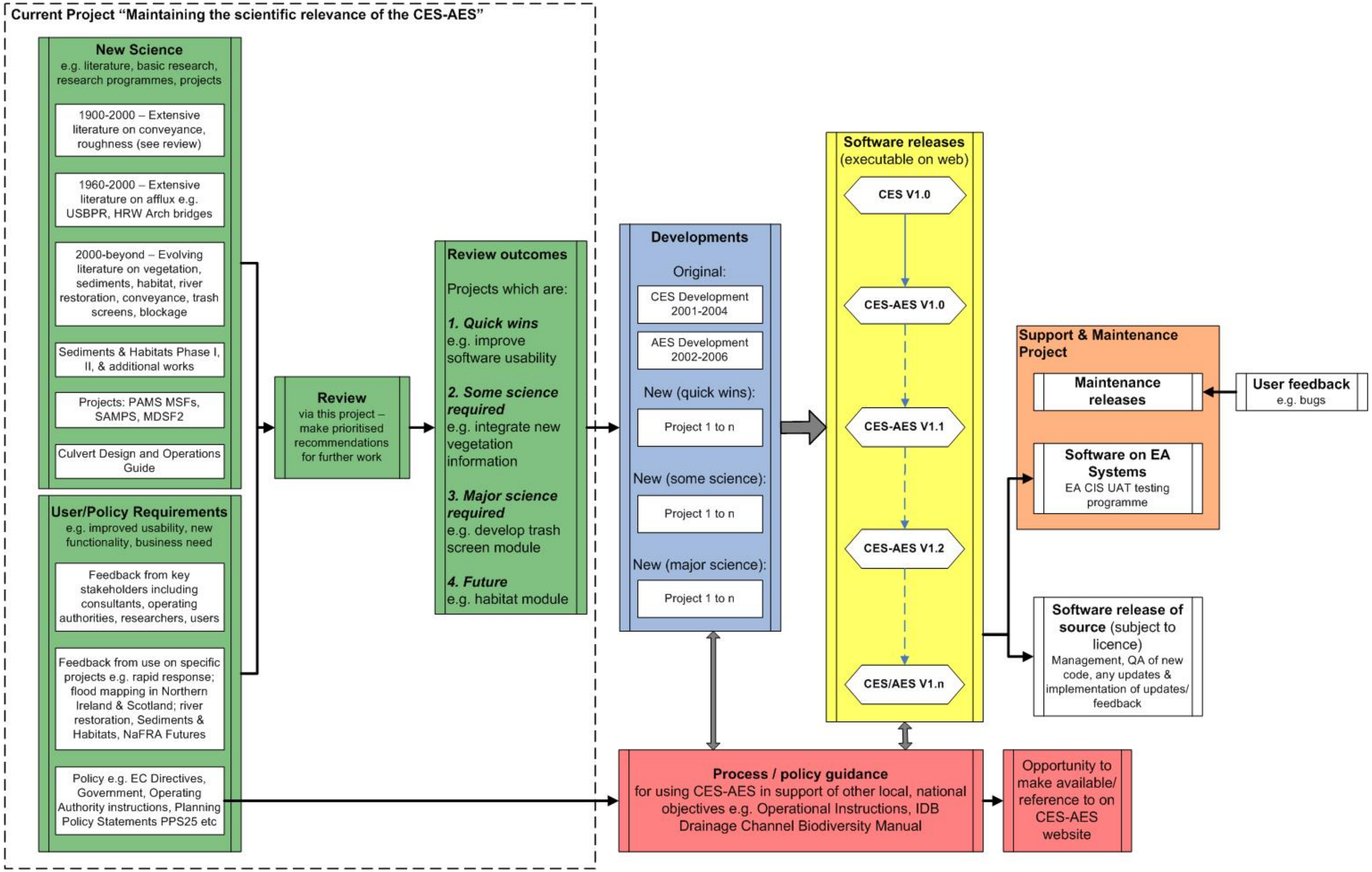


Figure A1-1 Mechanism for how this project and the parallel support and maintenance project feed into CES-AES software updates.

Appendix 2 Software calculation flowcharts

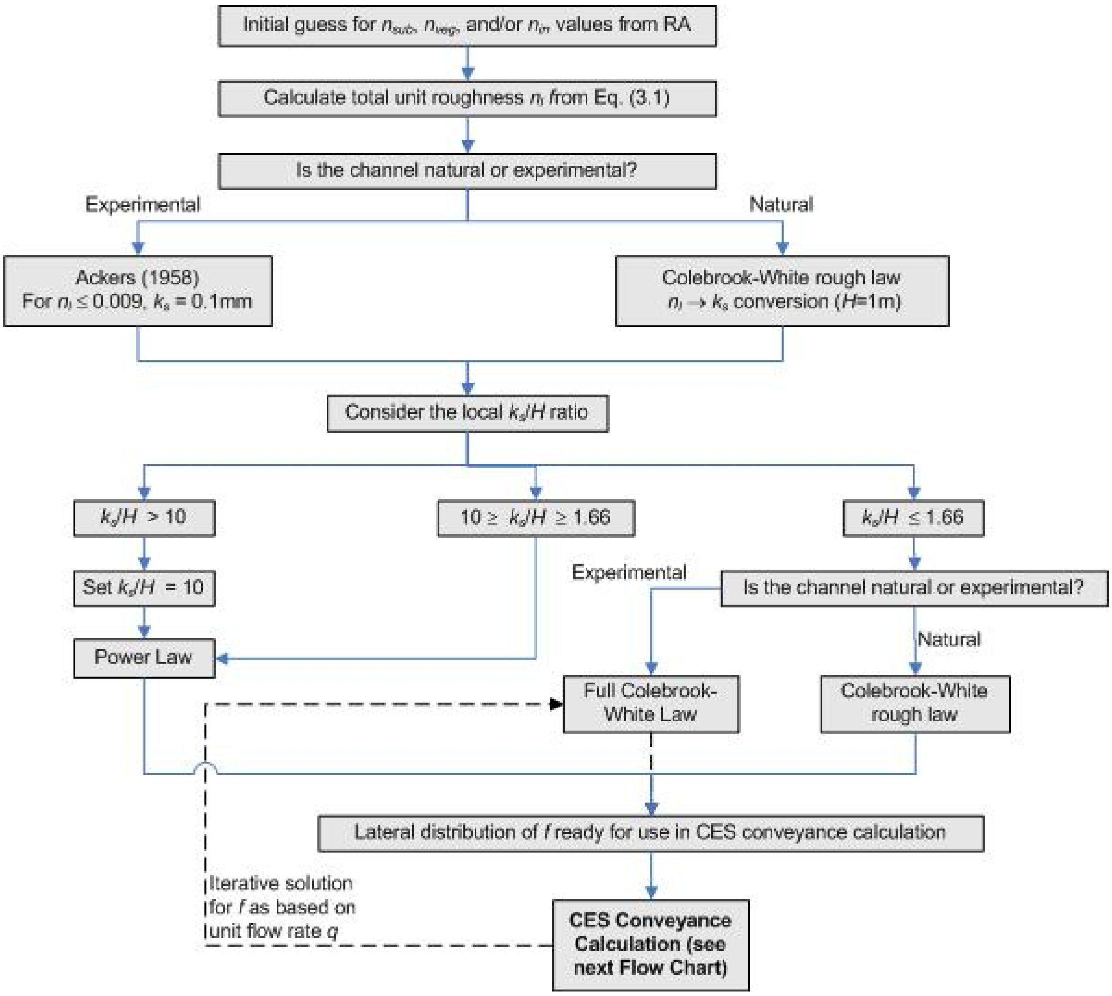


Figure A2-1: Roughness calculation engine (Knight *et al*, 2009).

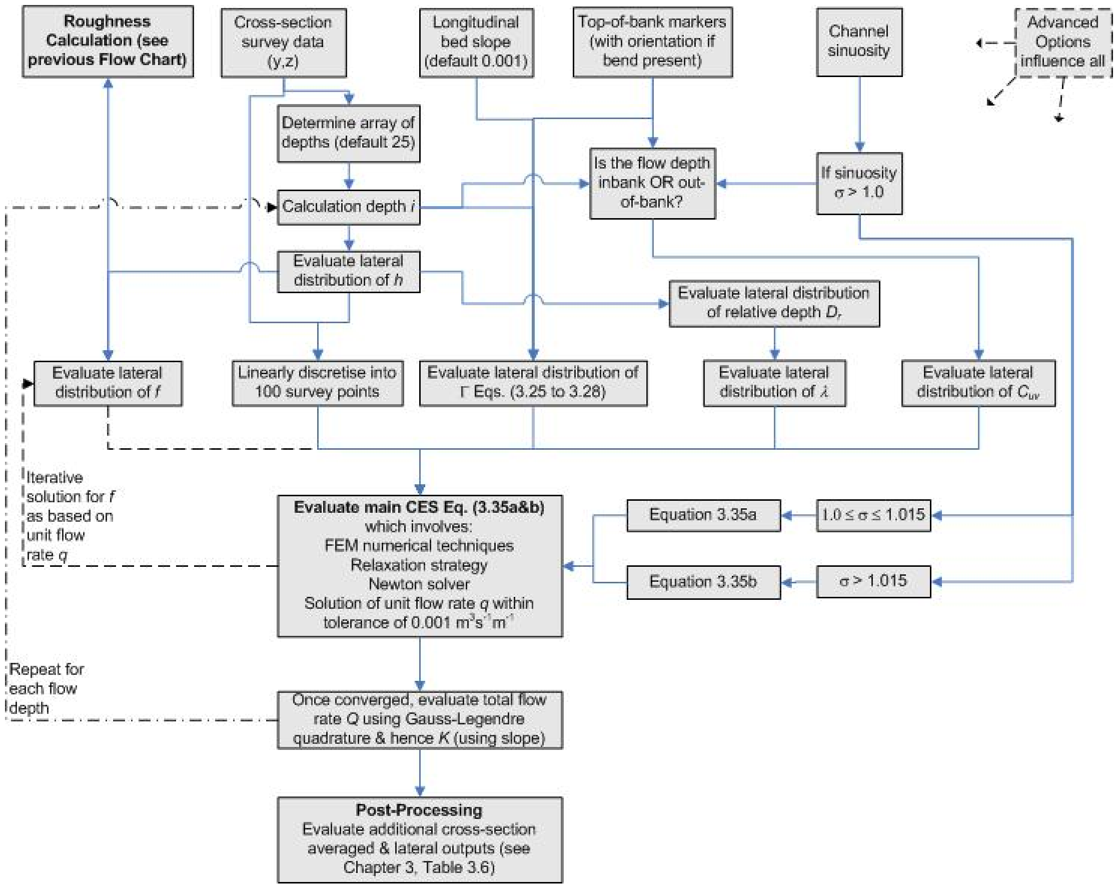


Figure A2-2: Conveyance calculation engine (Knight *et al*, 2009).

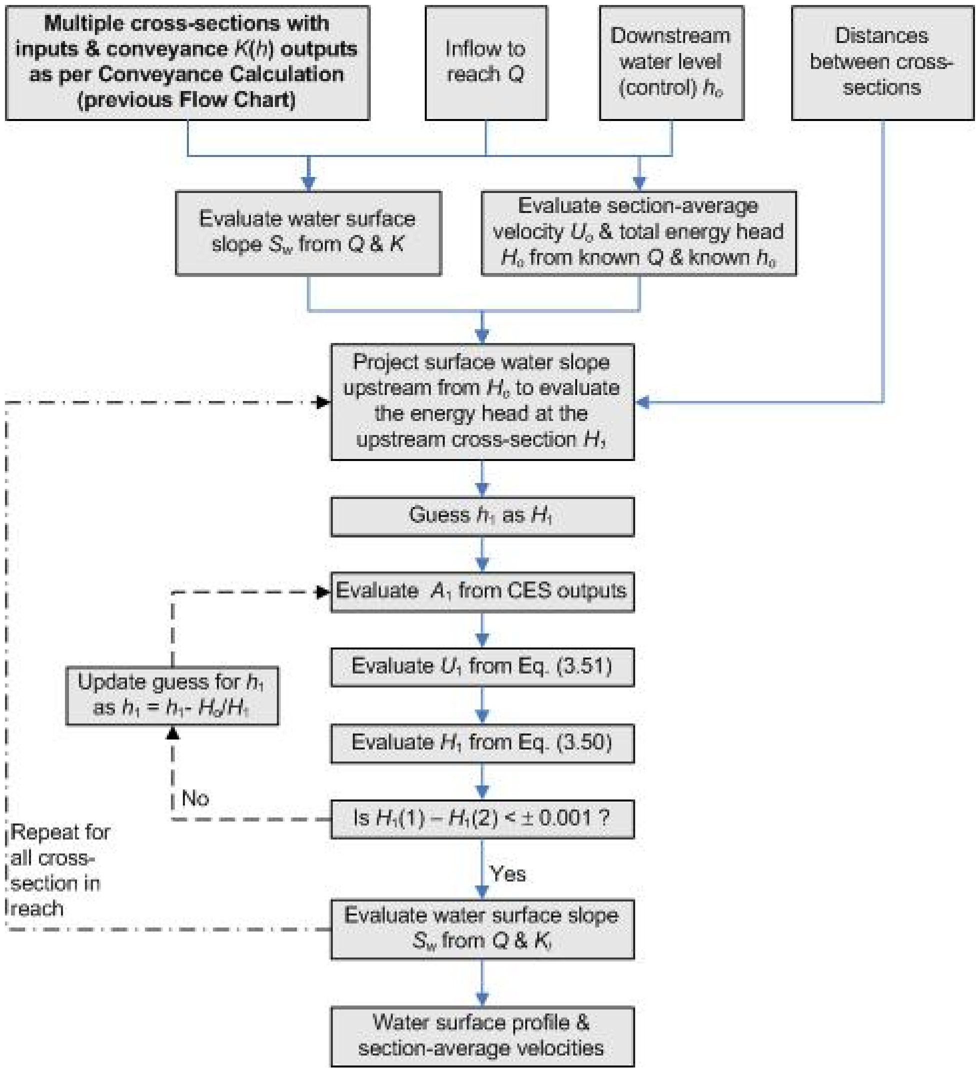


Figure A2-3: Backwater calculation engine (Knight *et al*, 2009).

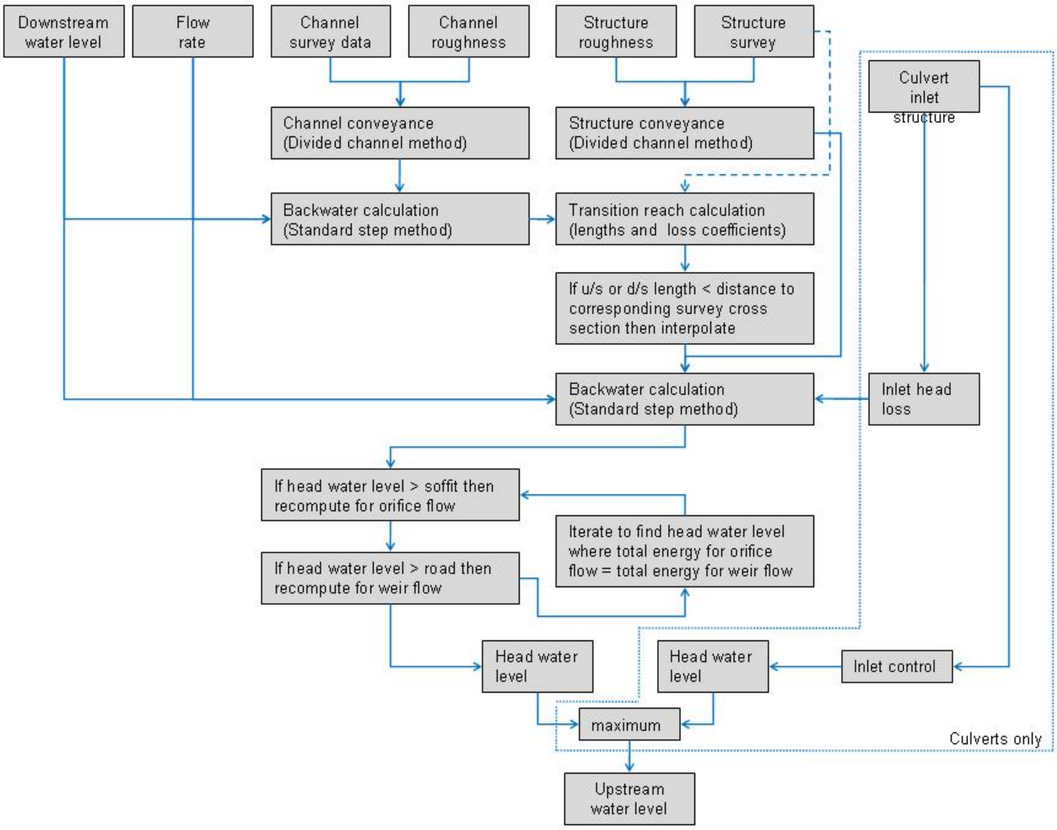


Figure A2-4: Afflux calculation engine (Knight *et al*, 2009).

Appendix 3 Stakeholder Workshop Notes

Maintaining the Scientific Relevance of the CES/AES CES/AES Workshop Notes

Venue: **Orange Studio, Birmingham**

Date: **25 November 2008**

Time: **10:00 – 15:00**

Attendees:

Name	*Role*	*Org*	*Abbrev*
Geoff Baxter	Project Executive; SAM Manager	Environment Agency	CM
Gary Tustin	Client Project Manager, EA Science	Environment Agency	GT
Peter Robinson	FRM ASM, Rep for EA Users	Environment Agency	PR
Mervyn Bramley	Rep. SAM Theme; also RFDC member	Independent	MB
Paul Samuels	Contractor Project Director	HR Wallingford	PGS
Caroline Mc Gahey	Contractor Project Manager	HR Wallingford	CMG
Marta Roca Collell	Contractor project team	HR Wallingford	MRT
Richard Body	Sub-contractor project team	Wallingford Software	RB
Neil Hunter	Sub-contractor project team	JBA	NH
Donald Knight	Academic, CES/AES development	University of Birmingham	DK
Martin Mitchell	Internal Drainage Boards o.b.o. D Sisson	Assn. of Drainage Authorities	MM
Scott Arthur	Lead researcher, FRMRC2 debris project	Heriot-Watt University	SA
Charlie Rickard	Culvert Design & Operation Guide reviewer	Independent; Rep for CIRIA	CR
Chris Tomlin	User; former User Acceptance tester	Environment Agency	CT
James Addicott	FRM ASM, Technical Advisor	Environment Agency	JA
Indu Kulasooriya	Users - Ops Delivery	Environment Agency	IK
Nevil Bussingham	Users - Ops Delivery	Environment Agency	NB

Apologies:

Rob Millington	Sub-contractor 1 PM	Wallingford Software	RM
Rob Lamb	Sub-contractor 2 PM	JBA	RL
Eleanor Heron	Flood risk science (and new Client PM)	Environment Agency	EH
Ian Nunn	Ops Delivery / Asset Management	Environment Agency	IN
Suresh Surendran	EA Science	Environment Agency	SS
Stephen Dawson	NI Rivers Agency Rep	NI Rivers Agency	SD
Nicholas Wallerstein	PDRA, FRMRC2 debris project	Nottingham University	NW
Mike Stringer	SFRM Consultant – user rep	Haskoning	MS
David Keiller	SFRM Consultant – user rep	Black & Veatch	DK
Fiona Mc Taggert	SNIFFER Rep	SNIFFER	FM
Karen Fisher	Roughness expert on former CES team	Independent consultant	KF

Supporting paper: These notes are to be read in conjunction with the CES/AES Workshop Briefing Note circulated by HR Wallingford to attendees prior to the meeting. This summarises the key outcomes from an earlier note including over 70 potential enhancements identified by the Project Team, ranging from basic research requirements to quick software fixes.

No *Item*

1 ***Purpose and style of meeting***

The project aims to ensure that relevant and important issues / objectives are identified and specified for updating the CES/AES software to reflect (a) newly available science and information, and / or (b) user requirements. The primary output of the project (ending in March 2009) will be a prioritised list of recommendations for CES/AES enhancements, plus specifications for the most beneficial of these.

The purpose of the meeting was to discuss the emerging priorities with a group of users and researchers so as to obtain feedback and views. It was unfortunate that a disproportionally large number of people had withdrawn at the last minute for a variety of reasons. Therefore those present were not fully representative of the user and researcher communities of involved with the CES/AES.

The workshop took place in both plenary session and in discussion groups. Some issues arose more than once in the course of the workshop. These notes seek to draw together the main issues – they do not reflect the sequence of the workshop.

2 ***Background***

Noted that there is now a significant user community of the CES/AES. This is within both the flood management Operating Authorities and the wider community of consultants, academics, researchers etc. In general, the feedback from users of the CES/AES has been positive. While the CES/AES was available of operational FRM staff within the EA, a key issue recognised by the Steering Group was the lack of formal requirement (e.g. Operational Instructions) for the use of the CES/AES for the various uses for which it had been developed.

It was clear too that, while the CES/AES was developed with specific user communities in mind (e.g. development control; flood warning; etc), those involved in managing these activities need to meet this halfway by developing appropriate guidance for using the CES/AES tools for some specific procedures (e.g. establishing compliance with performance specification for conveyance. It was considered vital at this stage to get operational staff using the software consistently for some mandatory tasks so that some, at least, of the science developments could be driven by efficiency improvements. This issue would be taken up by EA managers in parallel with the current project - **Action: Agency**.

It is important for the benefit of new users to highlight the original scope of the CES/AES, and the scientific and user input which drove the design. Some users or potential users are unaware of the extent of Government policy support for the application of the CES/AES. A key driver for the CES / AES was the 2002 report to Government by the ICE Presidential Commission - "*Learning to Live with Rivers*". This had highlighted the relatively poor uptake by flood management practitioners of improved tools and techniques for estimation of flood water level. Subsequently the Pitt Review had noted that EA was using the CES in assessing the requirement of cut vegetation in channels to maintain the required performance. **Action: Agency/Project Team - ongoing**

3 ***Context of the tool***

There was support for developing an overall diagram which clarifies the intended uses of the CES /AES, and how these interface with other guidance. This will then clarify what is reasonably in and what is out of the software (and the scientific enhancement project). There were three different contextual issues here: (a) coverage of different tools and manuals - e.g. Trash & Safety Screen Manual, Culvert Design & Operation Guide (CDOG), etc; (b) policy or procedural context for use of CES/AES (e.g. Performance Specification, WFD etc.) which should be covered by other guidance; and (c) interfaces between scientific enhancement (i.e. new functionality) and on-going upgrades to existing software, maintenance and bug-fixing (ongoing being funded outside Defra/EA Science). The diagram should address the boundaries and interactions between items in (a) and (b). **Action: Project Team** (1st draft will be in draft recommendation report)

4 ***Tool classification i.e. be clear on what it is for and can do***

Linked to the diagram, it was proposed that a list is prepared of what the CES/AES is good at (e.g. overbank flows) and what it is useful for. With the enhancement project, there is an observable tendency to focus on what the CES/AES can't do. The guidance list should note that the CES/AES is a 1D model that includes 3D processes - it is intended to be simple to obtain quick results. A key advantage of the CES is that more information is available despite not going to a higher level of modelling, which may be used to satisfy/support wider objectives e.g. FRM & WFD hydro-morphology objectives. **Action: Project Team** (will be in recommendation report)

There was a proposal to develop a spectrum of river/channel types and suggest which the CES/AES covers. *[Post workshop note – this channel classification has already been part developed under PAMS MSFs 3 & 4 and will be further developed under Sediments and Habitats Phase 2 additional studies.]* **Action: Project Team**

Science versus user requirements
It is important to differentiate between (a) user-driven needs within the intended areas of CES/AES use, and (b) curiosity-led or scientific issues that might be added to the CES/AES. Thus sediment and habitat issues related to ecosystem management were considered to be category (b) and a lower priority relative to estimation of afflux caused by trash screens or blockages. There is a wider issue of obtaining the balance between the complexity of the underlying science and the simplicity of end use. Ideally, the latter should not be compromised. However, we also need to ensure the limitations (e.g. no super-critical flow, multiple culvert openings, use in complex urban systems) do not make it too restrictive for practical cases. **Action: Project Team** will be reflected in recommendation report

5 ***Importance of roughness & vegetation***
It was agreed that roughness - specifically vegetation - is very important and that some improvement / expansion of the currently available information is desirable. With vegetation, there are several potential issues to address:

- seasons start at different times
- climate change
- natural growth cycle beyond the seasonal (typically 3 year)
- cutting for environmental considerations (hydraulic effects)
- vegetation response to velocity
- choked channels (e.g. when should vegetation growth not simply be represented as roughness alone but also as a reduction in cross-section area). This was agreed to be critical for smaller watercourses upstream of Main River and associated with picking up and / or reducing surface water flows.
- scope for investigation of different vegetation types (growth, decay, cutting)

All of the above should ideally be simulated in some manner in the CES/AES and should be address on a prioritised basis.

Most important aspects (from an ADA perspective) would be the vegetation growth curves, improving these and considering seasonal and climatic influence. It was noted that development and application of the relatively-simple CES/AES Standalone was largely promoted by IDB practitioners and has had strong support from the ADA Technical Committee. However, at present, maintenance often still tends to be based on expert local knowledge. The CES/AES Standalone is used for some cases - but there is necessarily a learning curve. Nevertheless, the need for IDBs to embrace appropriate developments in technology such as the CES/AES was one reason for the recommendations on 'optimal organisation' in the 2006 Internal Drainage Board Review (which had been commissioned by Defra and accepted by most IDBs).

Important to stress that the roughness is reach-averaged and to incorporate appropriate photographs (some are misleading). For example, a single shopping trolley is a point roughness and should only be included as an irregularity if it is representative of the reach i.e. many items of urban trash, multiple tree roots etc.

Vegetation in steeper watercourses
In steep watercourses, it is particularly important to consider the velocity interaction with vegetation. If smaller steeper channels are to be managed effectively, it is important to understand the extent to which relatively long vegetation (in relation to width or depth) lies down as flow / velocity increase. These channels typically occur higher up in the longitudinal profile. Proposed a short desktop study to confirm the impact of this - and then either improve the CES/AES tools or the guidance and understanding of how the CES/AES may be used to support conveyance assessment in smaller watercourses (most of which are outside the responsibility of the EA and are the responsibility of riparian owners, local authorities, highway authorities etc).

Batching capability
Would be useful to have a batching capability for seasonal vegetation outputs e.g. running the conveyance calculation for all times of year and providing multiple curves and water levels through time (daily, monthly, seasonal).

Action: Project Team to consider above & incorporate/reflect in recommendation report as appropriate

6 ***Improvements to culvert capability***

Main improvements suggested by users include assessing the effect of:

- multiple culvert openings/barrels
- different invert levels
- super-critical flow (important to note that super-critical flow is less than 2% of UK channels - usually engineered channels)

Use of CIRIA guidance for the inlet/outlet culvert coefficients was raised. These are based on dated US work and it can be difficult to apply the US shapes to the preferred or actual inlet/outlet geometry. In reality, culverts are very variable in terms of inlet/outlet shape (most are unique) and real world descriptions seldom match the descriptions in the literature or software. Outcomes:

- need to confirm the extent to which the CIRIA guidance is consistent with the CES/AES
- consider asking users who are familiar with culvert design to feedback knowledge on nature/performance of inlet/outlets
- laboratory study and / or data collection for culvert inlet/outlet head-loss parameters (see 8 below)

Action: Project Team

Safety aspects were higher profile following two recent deaths of general public trapped by culvert screens. Culvert inlets are associated with sharp changes in velocity and hence pressure differences which can cause suctions which hold people against the screens or pipe entry. Can the CES/AES provide an improved understanding of the flow conditions around culverts e.g. average velocities? **Action: Project Team** to consider & incorporate in recommendation report as appropriate

7 ***Improvements to bridge capability***

Main improvements from the users include:

- multiple bridge arches very important as most UK rivers have these
- multiple arch bridges with different arch dimensions (as per real world)

Action: Project Team to consider & incorporate in recommendation report as appropriate

8 ***Backwater calculation***

The backwater calculation in the CES / AES Standalone was deliberately made to be straightforward as befitted a simple standalone tool (no scientific advance on current methods and spreadsheet tools). The logic had been that advanced users would use more sophisticated software. Some users had queried whether there was potential to improve this. Check whether there are any strong reasons for changing this. **Action: Project Team**

For bridges and culverts, how far upstream does the flow revert to normal depth? Is this calculated within the afflux element or is this established with the CES backwater element? **Action: Project Team** to confirm**.** Note: there is a simple rule of thumb (Samuels, 1989[1]) approach for the approximate length upstream for a channel to return to normal depth a following downstream disturbance. This could potentially be incorporated in the user guidance. **Action: Project Team**

9 ***Modelling versus measuring***

It was suggested that the Agency should be encouraged to measure what should be measured for improving technical capability rather than what is easy to measure. Generally the philosophy should be "to measure more and model less". For example, the Japanese have an extensive measurement programme to measure velocities and boundary shear in rivers. This was strongly agreed to by all - there needs to be more funds in data collection (particularly post floods). **Action:**

[1] Samuels, P. G. 1989. Backwater lengths in rivers, Proc. Inst. of Civil Engineers, Part 2, Vol. 87, pp 571-582.

Project Team to reflect in recommendation report.

10 ***Alternative funding sources***

As the CES/AES tool covers a wide area, there needs to be consideration of alternative funding sources in particular EPSRC (which funded the original academic / practitioner network that gave rise to the CES). Need to be aware of underlying research outside of Defra/EA and other Operating Authorities that may potentially fill many gaps. For example, bridge measurements and modelling advances could potentially be 'responsive mode' proposals to EPSRC with some industrial contribution or they might be industrial supported PhDs (arch bridges); similarly there is much work underway for vegetation measurements (APMG, NERC). One option may be for Defra / EA or other operating authorities to work in partnership with universities to get them measurements through student training. **Action: Agency** with support from Project Team where appropriate

11 ***Blockage / Trash screens***

A richer description of channel blockage is needed to distinguish between roughness and blockage. This must be consistent with the channel condition concepts that have been added to the Condition Assessment Manual under PAMS Phase 2. JBA staff on AES to liaise with other projects on the Culvert Design & Operation Guide (CDOG) and Trash and Safety Screen Guide in developing / confirming appropriate approach to assessing the degree of blockage. There is also more work underway in FRMRC 2 Work Package 4.1 (Scott Arthur) - looking at a probabilistic approach to debris and blockage at structures.

Trash screens and blockages have the strongest impact on the afflux calculations. Important to remember that although culverts are more easily blocked (a common occurrence); for bridges it is less common but has a more catastrophic impact.

Important to understand the blockage mechanism e.g.:

- A fine vegetation filter screen may get blockages at the top. These are usually weed screens located at surface water intakes to pumping stations.
- Blockage of screens and culverts - understanding the sensitivity of afflux to degree and rate of blockage are important
- Blockage of bridges - associated with extreme floods

Action: Project Team to consider above & incorporate/reflect in recommendation report as appropriate

12 ***Current software usage***

Current software use was raised:

- 170 in Agency have been formally trained and further staff training can be expected once there are formal Operational Instructions for specific uses of the CES/AES
- FRM practitioners are using it in Stand-Alone version and also via ISIS / InfoWorksRS 1D models
- Over 200 web downloads of CES/AES Stand-Alone to date (FRM activities, research)

Of those present on the day:

- Limited use in ISIS
- Other tools used - HEC, design charts.
- Noted that CES/AES far better science but there may be a residual issue for some users that simple hand-calculations appear to be quicker (albeit that they're generally much less accurate).
- Expect small IDBs would only use occasionally (lack of familiarity, but see 5 above)

There is a need on CES/AES user side within the Agency to provide specific procedures for use (see 2 above). Thus, where appropriate, the tool status needs to move from "nice to do" to "need to do". **Action: Agency**

13 ***Parallel relevant projects / research programmes***

Upcoming project under the Defra/EA MAR theme looking into food risk in low-lying areas - making use of the RASP methods. Considers the risk associated with pumping stations.

Links to SAM Theme projects as in 9 above, plus PAMS Phase 2. **Action: Project Team**

Need to link with the update of the national River Habitat Survey to be published in 2009/10. This will supersede the RHS-sourced information in the current CES. **Action: Project Team**

14 ***User guidance***

Users raised the need for:

- a simple fact sheet to advise on use - sell benefits of CES/AES to the day job
- worked examples (with workshops that go through these)
- advice on data collation issues (incl. extension of data into floodplain)
- application-specific guidance
- advice on use of uncertainty information (It was noted that these are 'credible scenarios' capturing the variability in the measurements and these are not confidence intervals or envelopes)
- a different word to 'uncertainty', which does not instil confidence, e.g. 'variability' since this is related to the natural variability component of uncertainty
- guidance on the use of 'fudges' with the current CES/AES - e.g. use of culvert coefficients when modelling multiple barrel, different invert levels etc (see also 6 above). This should be clear together with the plans for how this may be improved in the future.

Action: Project Team to consider above & incorporate/reflect in recommendation report as appropriate

15 ***General user feedback***

Pre-workshop (from training):

- extremely positive e.g. tool fantastic, lots of potential
- vegetation curves, cutting & regrowth very useful
- photographs helpful
- prefer to estimating Manning n resistance from Chow & other sources
- useful to see the velocities
- useful for simple reaches (no need for complex1D models)
- useful to aid understanding of structures
- software bugs (note - these do not alter the calculation outputs)

At workshop:

- useful for bridge geometries
- intuitive software - logical to navigate through

16 ***Linking to other tools***

Should continue to be compatible with ISIS and InfoWorks RS. Be useful to link with other tools e.g. HR Breach. Clarify availability of CES/AES modules to other commercial software companies. **Action: Agency**

Should ideally be compatible with the Agency GPS data devices. Noted that in different EA Regions / Areas the GPS devices vary. These may be hand-held devices or survey devices. The hand-held devices have reasonable x, y but the 'z' may be up to a metre out. Need to be aware of the GPS accuracy and hence the uncertainty in the resulting cross-section survey (noted for the CES/AES parallel maintenance project which is investigating this). **Action: Agency** - imminent under CES Maintenance project.

17 ***Tidal flow***

Be good if you could use the CES/AES for tidal situations.

18 ***Awareness raising generally***
There needs to be continued awareness raising within the wider practitioner and academic communities e.g. at universities, grass roots level. This will be partly addressed via the technical book on the underlying CES/AES science which will be published in 2009. **Action: Project Team / Agency** - ongoing via dissemination activities

19 ***Conclusions and Next Steps***
In summary, the Workshop had been useful in airing and discussing a very wide range of issues and improvements that might be addressed in enhancements to the CES/.AES. The output from the Workshop would be reviewed at the next Steering Group meeting when the high priority enhancements would be assed against likely available budget for carrying them out in 2009/10.

Key issues noted at the Workshop had been the need for:
- diagram indicating uses and a list of what the CES / AES is good at
- Operational Instructions to key user groups (progressed in parallel with this project)
- enhancement / clarification on vegetation roughness, blockage, multiple barrels / arches

HR Wallingford; January 2009

Appendix 4 Science recommendation table

Table A4-1: Potential scientific enhancements to CES-AES (Priority: High, Med, Low).

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
	Roughness / Vegetation				
S1	***Reduce vegetation uncertainty building on CEH work*** New information and data from the recent APMG CES sub-project undertaken by CEH can be used to improve the vegetation roughness. This would involve: - Phase 1: Improve/extend uncertainty to cover seasonal variability based on CEH data - Phase 2: Improve annual growth curves to typical 3-year growth and regrowth cycles. If undertaken - would be emergent broad-leaved and water crowfoot only. May be difficult in practice as users must define at what stage in the cycle the growth is. Would also be informed by recent work on vegetation cutting (Batturo-Pedersen & Riis, 2004) covering the impact of cutting on species diversity and composition, providing information on how the vegetation grows after cutting. - Phase 3: Obtain a national picture of CSA, biomass and percentage plan form cover and develop plant indices for different catchments or reaches. This may be used to relate CEH standardised vegetation seasonal distribution curves for two main vegetation types to all locations. Aim to provide advice that does not require additional user input - most likely relate to %CSA only. These three (CSA, biomass and percentage plan form cover) should draw on work on multi-cross-sectional blockage factors (Green, 2005). - Phase 4: Introduce a new vegetation calculation for vegetation in steeper watercourses - relating resistance to velocity and hydraulic radius – iterative. Following recent discussion with Hugh Dawson (14/01/09) - agreed a pragmatic way forward for Phase 1 & 2. This will be to develop upper/lower uncertainty bounds making use of CEH work but taking into account all parameters: location (northing); phosphate level, annual variability (where applicable) and general uncertainties associated with the variability of measurements. Will need to link measurements to flow depths, channel dimensions (typically base flows). Other opportunities exist for future e.g. linking to phosphate levels across the country (Mean Trophic Ranking 'MTR' System dataset, RHS etc). See S3. About Phase 4 - In steeper watercourses it is important to consider the velocity interaction with vegetation. A review of the USDA work (papers from 1940s-2000s e.g. numerous Ree, numerous Temple, Palmer, 1949; Ree & Palmer, 1949; Green & Garton, 1983) together with the work of (Petryk & Bosmajian, 1975; Kouwen, 1980) reveal that these methods typically apply to emergent plants and grasses (with US focus); they relate to the product of the velocity and depth and may require biomechanical properties of the plants as input (e.g. biomass, stiffness per unit area, drag force) . The methods are therefore more difficult to apply in practice as they require dynamically linking the roughness to the velocity and depth calculation and detailed plant properties. These should be a longer-term consideration with a possible initial desk-top study to confirm the impact of this e.g. if vegetation bends, what is the channel capacity immediately before and after.	Improved aquatic vegetation values through time	Greatly reduces vegetation uncertainty through time - main source of uncertainty apart from hydrology E.g. moves from ± 0.6 m to ± 0.2 m in some instances	<u>*Research*</u> Limited for Phase 1, 2 & 3 <u>*Method*</u> Limited for Phase 1, 3 & 3 <u>*Software*</u> Database updates	IDBs, Environment Agency users, consultants Raised at workshop 25/11/08 Vegetation in steeper watercourses raised at workshop 25/11/08
S2	***Ongoing annual vegetation measurements to further reduce uncertainty*** Ongoing vegetation field measurements and analysis of results at select sites to ensure an ongoing record. This should be extended to two or three other species (initial set-up costs in selecting sites and thereafter fixed annual cost). Approach to be reviewed annually by roughness steering group to ensure direction is consistent with CES. Advice on best species: previous work covers two main vegetation types in the CES: "5 Emergent reeds" and "9 submerged fine-leaved". Potentially further work could be done on "8 submerged broad-leaved". There is also much literature on "5 Emergent reeds" which could be used to improve current models. No effort is recommended on "2 filmentous algae" as it gets washed out in high flows. This advice could be further substantiated by a survey for popular species. Previously undertaken for Environment Agency regions. Could do IDBs, Scotland and NIRA to aid buy-in.	Improved aquatic vegetation values	Potential to further reduce vegetation uncertainty – main source of uncertainty	<u>*Research*</u> Limited analysis of results <u>*Method*</u> - <u>*Software*</u> Database updates	Raised at workshop 25/11/08 "Measure more, model less"
S3	***Update the RA database to include latest RHS information*** This would involve a review of the RHS database and update of photographs and roughness values (photograph review now underway – also making use of Poland RHS photos). This may be extended to incorporate RHS nutrient data (GIS layer) which can be used to inform likely plant type and hence n. See S1. Following discussion / information gathering with Hugh / Lucy Taylor (RHS team) – some findings: - Question the effort related to reprocessing the updated RHS data. Mostly similar items are measured. There are more sites. It would involve a repeat of the Principal Component Analysis. - Alternative would be to make use of 95/96 RHS data until sure users are using it regularly. Then, in short-term, opportunities exist for more fields / information to be provided based on the previous Principal Component Analysis e.g. substrates (as used in SAMPs project) for in-channel, left & right banks; channel modifications - could link to irregularities?; flow types (environmental needs); land-use; choked channels (link to blockages); section dimensions; trash present etc. The RHS scores for "Habitat Quality" & "Impacted by man" may be recorded to inform users of likely practice. There is potential to extrapolate findings for the Sediments and Habitats work for five sites to the rest of the country - through use of these RHS score.	Improved geographic information for UK users e.g. vegetation, substrate, trash etc.	Confidence in selected vegetation, substrate in the absence of local data etc.	<u>*Research*</u> Limited <u>*Method*</u> No <u>*Software*</u> Database updates	

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S4	***Explore potential dynamic link to RHS database (Environment Agency users)*** This would involve a dynamic link for Environment Agency users to the RHS database rather than periodic updates to the database. This would need to be weighed against the need to periodically update the database for other users. See S3.	Improved access to series of RHS data fields for Environment Agency users	Up-to-date information for sites. Benefit can only be measured once more users are using CES-AES	*<u>Research</u>* No *<u>Method</u>* Yes – basic *<u>Software</u>* Yes	
S5	***Link the RA database to Land Cover Map 2000*** This would involve linking the Land Cover Map 2000 to appropriate unit roughness values and enabling users to select likely floodplain values based on UK grid reference. This approach was adopted in the Scotland and Northern Ireland national flood mapping and in the recent SAMPs project where different in-channel maintenance options (do nothing, maintenance as usual, improved maintenance, dredging where high sediment yield based on stream power) were explored. The Land Cover Map was used for floodplain roughness and RHS use for in-channel roughness. Opportunities to link this to the chance of debris blockage i.e. influences recruitment potential.	Improved floodplain roughness values (UK)	Provides default or first guess for flood flows i.e. where over floodplain. Relatively quick to implement. Benefits needs to be measured once CES-AES in more regular use.	*<u>Research</u>* No *<u>Method</u>* Yes – basic *<u>Software</u>* Database improvements	Support from project applications e.g. SAMPs, NI mapping, Scotland mapping
S6	***Data feedback (wider issue for Environment Agency)*** Provide a means for users to return local knowledge and data on channel roughness (e.g. vegetation types, degree of blockage etc.) to central RA or other database with UK grid references. [Note: a link with the National Flood and Coastal Defence database PAMS channel data is not proposed as the PAMS information is on blockage and roughness rather than vegetation type. There may be opportunities to link with AMIT in the future. This is also under consideration in PAMS, MDSF2, NaFRA programmes.]	New database feature	All UK users Improved local data & data management. Maximise use of existing knowledge – evolutionary process.	*<u>Research</u>* No *<u>Method</u>* No *<u>Software</u>* Database improvements	
S7	***Use of aerial photographs to inform roughness*** Link vegetation type and coverage to aerial photograph coverage i.e. develop a vegetation recognition system. This would allow for enhanced information on channel and floodplain vegetation type based on UK grid reference. Work currently underway by APEM who are conducting an aerial photographic survey of river reaches. Other options include linking to Google Imagery. [Note: original RHS opted for land survey due to high costs of obtaining imagery]	New database feature	All UK users in determining roughness for sites not visited. Not sufficient to warrant the high associated costs	*<u>Research</u>* Yes *<u>Method</u>* Yes *<u>Software</u>* Yes – database improvements	
S8	***Impact of climate change on vegetation growth patterns*** Explore impact of climate change on future growth patterns and ranges for different vegetation types. Hugh Dawson presented initial findings at the Robson Meeting. There are data (collected over 40-80 years) to support developing trends and looking to predict future growth curves. This work is currently at an embryonic stage and is unlike to provide sufficient information for a project in the short-term - but it will feed into future recommendations.	Vegetation growth curves – factored through time e.g. over 100 years	Support long-term planning e.g. NaFRA Futures, other strategic planning (MDSF2 inputs), etc. In keeping with Floods Directive (climate change mentioned at least seven times) and ADA biodiversity manual.	*<u>Research</u>* Yes PhD/MSc *<u>Method</u>* Yes *<u>Software</u>* RA database	Raised at workshop 25/11/08

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S9	***Flow-vegetation-sedimentation interaction (long-term)*** The interactions between flow, vegetation and sedimentation are generally not well understood. Jarvela *et al* (2006) discuss the key parameters and characteristics of vegetation with respect to providing reliable factors to use in sediment and hydraulic modelling. Research strategies to combine field, laboratory and numerical modelling approaches have been developed – which could be explored further. Schnieder *et al* (2006) carried out experimental research with different shrubs with different arrangements of branches and the influence of the vegetation density on the sedimentation rate was observed. A rating matrix is developed with the analysis of a hydraulic model which identifies the interaction of dense vegetation and sedimentation. This approach may be useful in extrapolating how the RA is used in combination with sediment models. More recently, the Sediments and Habitats Phase 1 & 2 work has looked into this. The findings are under review, but include for example: - Vegetation cutting in the channel centre increased sediment transport due to higher velocities. Cutting vegetation across the whole channel did not greatly increase sediment transport from the central cut. - Sediment size has a key role. Vegetation causes silting. Where vegetation is cut, there may be an infinite increase in sediment transport rates as channel goes from no transport to large amount of transport.	Potential functionality updates – long-term	Improved understanding of key processes. If incorporated, improved "what-if" tool to aid design to satisfy wider objectives e.g. WFD	*Research* Yes PhD/MSc *Method* - *Software* -	
S10	***Improved definition for pools and riffles*** The installation of pool-riffle sequences for river enhancements mainly for fisheries purposes have become more prevalent for low gradient engineered rivers. Riffles change the morphological and hydraulic diversity but there has been few studies investigating the impact of these features. Three proposed steps: - Step 1: Revise existing RA values. Sear & Newson (2004) investigate the impact of the pool-riffle sequences on the water levels and flow resistance. The installation of the gravel bedforms increases the physical diversity of the reaches investigated with a greater range of depth, velocity and substrate conditions across the flow range. At bankfull discharge the water surface elevation is not significantly increased. The range of resistance characteristics and values measured in the paper should be used to refine the values within the RA. - Step 2: Provision of guidance and examples based on recent work see "River Rehabilitation Guidance for Eastern England Rivers- River Restoration Centre, November 2005, for the Environment Agency." This includes suggested cross-sections and spacing etc. - Step 3: Validation of above approach at pools and riffles from measurements (O'Hare PhD).	Database updates Guidance?	Improved data *To quantify benefit from River Rehabilitation report.*	*Research* Validation PhD/MSc *Method* No *Software* RA database	Raised Karen Fisher on behalf of rehabilitation team
S11	***Database of typical vegetation cuts, nature and timing*** Develop a database of roughness zones for typical Environment Agency cuts (cross-section coverage, % cut in vertical, W5, W7 etc.) or more generically, cuts and timing based on plant types. This should be informed by the Environment Agency maintenance guides (which vary regionally), the aquatic plant management guidance (Centre of Aquatic Plant Management - CAPM – Jonathan Newman's work), the recently developed ADA drainage guidance and the Sediments and Habitats work. In the future, the aim should be to develop relationships between maintenance and plant behaviour based on the physiology of the plant.	Improves functionality in support of exploring vegetation maintenance options. Provides key output plots.	Aids users in assessing impact of typical cuts	*Research* Limited MSc/PhD *Method* Yes *Software* Yes	Raised at workshop 25/11/08 Raised in SAMPs & Sediments Habitats & PAMS Raised Karen Fisher
S12	***2D roughness for deriving unit n from measurements*** Explore the use of 2Dl roughness (based on local velocity) for determining unit roughness values from measurement. This would initially involve consideration of Robert Sellin's work (a case which has velocity measurements) on the Blackwater in Hampshire to develop an approach and hence identifying and reworking data in the literature to develop improved unit roughness values.	Improve database values derived from measurements	Improved roughness values – difficult to ascertain impact for water level estimation	*Research* Yes MSc/PhD *Method* No *Software* Updates to RA database	
S13	***Use of Biologists & CES-AES classification of channels to inform likely features*** Develop a classification of channels into small/medium/large in terms of depths, widths, slopes and upstream/downstream location. This would be used to link channel types to morphotype and whether plants are likely to be present at all e.g. >3 m depth, less likely. It would also advise on where vegetation roughness is likely to have minimal influence e.g. mosses. This is envisaged to be a simple matrix of slope, widths and depths with each plant type shaded in terms of its likelihood of occurrence. This should ideally be linked to location (UK grid reference) - building on the RHS and Mean Trophic Rank databases. The river classification could be supplemented with information on likely management e.g. small rivers may only be maintained every 3 years because of the 3-year regrowth cycle. This could link with the suggestion at CES-AES Workshop (25/11/08) to develop a spectrum of channel types and indicate which CES-AES is useful for. The Sediments and Habitats Phase II - Additional Studies is also considering this so it may be more beneficial to see how this work emerges.	Improve vegetation roughness values and no data advice		*Research* Yes - limited MSc/PhD *Method* Yes *Software* Improvements to RA database and/or guidance	Raised at roughness meeting 0/07/08 Raised at workshop 25/11/08

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S14	***Incorporate variation of resistance with passage of flood*** The CES-AES software is designed to deal with steady uniform flow. Modelling a time-varying flood hydrograph would require a move to 1D modelling e.g. ISIS, InfoWorks RS. This is not a limitation of the CES-AES – this was intended to keep it simple. However, it is known that both water surface slope and resistance (e.g. plants bending) varies as the flood passes through (e.g. Sellin & van Beesten, 2006) – and the resistance does not necessarily decrease as the flood passes through (e.g. plant bending may result in increased downstream biomass). It would therefore be possible to provide advice on unit roughness values for different stages of the flood hydrograph e.g. peak. Measuring the changing resistance during flood events is a challenge. Previous work (Angela Gurnel) includes some laboratory measurements. Planned ecological work (O'Hare & Nikora ongoing, Nikora et al, 2006) measuring real plants in a flume may further inform this. There are various papers from USDA on the impact of duration (up to 5 weeks) on vegetated flow resistance, failure and recovery on an experimental channel.	Improve database – unit roughness versus duration values	Improve water level predictions for the flood flows	*Research* Yes MSc/PhD *Method* No *Software* Updates to RA database & advice	
S15	***Develop capability to handle multiple vegetation species in one location*** The RA methodology assumes only one vegetation species is present or 'dominant'. In reality, there may be combinations of vegetation types. There is a need to investigate ways to combine contributions, possibly through measurements.	Database updates For now – user guidance?	Means of handling combined species	*Research* Yes MSc/PhD *Method* No *Software* Updates to RA database & advice	
S16	***Incorporate a method to handle alluvial friction*** *General Bedforms* In alluvial channels, the flow regime and bed forms (e.g. ripples, dunes) are closely related to the local velocity, the shear velocity and the boundary shear stress. The CES methodology could be extended to include an additional friction term f'', which accounts for bed form roughness. This would be based on local flow conditions to establish the flow regime and associated bed forms. Possible approaches for evaluating f'' include those of Brownlie (1983), Engelund (1966) and White *et al* (1980). *Sand bars* Need for guidance or an updated approach on handling sandbars which are sparse. Tendency for users to make use of cross-sectional analysis with sand bar present. Calculation is reach-based. The outcome is unnecessary and costly maintenance works. *Dredging* This relates to habitat as well. Large amount of money is spent on dredging - so important to manage (see Spring 2009 Environment Agency Floodnews). Dredging may be very bad for environment when undertaken in parts of the channel – as the water levels are lowered not necessarily providing new habitat (Sediments & Habitats). Opportunities to explore "what-ifs" in CES-AES and provide guidance.		Handles alluvial rivers with bed forms (not typical of UK)	*Research* Limited PhD/MSc *Method* Yes *Software* Yes (minor UI)	
S17	***Incorporate an approach to update cross-sections to equilibrium conditions*** Update cross-section shape(s) based on equilibrium equations (e.g. Blench 1966) or incipient motion criteria (e.g. Shields 1936; Liu 1958).	Core engine wrapped – updates section based on equilibrium conditions.	Handles non-rigid beds. Alluvial channels are less common in UK. Of international importance.	*Research* Yes PhD/MSc *Method* Yes – substantial effort *Software* Yes (and UI)	
S18	***Incorporate a roughness method for modelling mountain rivers with boulders*** Explore effectiveness of the boulder formulae (Ramette 1992; Abril & Knight 2004) and potential transitional rules between this at low flow depths and a Colebrook-White approach at greater flow depths. These boulder formulae have been shown to improve roughness predictions for various mountain streams and could be incorporated into the CES-AES methodology.	Additional calculation functionality to assess rivers with boulders	Improved estimation of water levels for channel with boulders (see Mc Gahey, 2006)	*Research* Limited PhD/MSc *Method* Yes *Software* Yes	Raised in literature

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S19	***Incorporate a drag force term for emergent vegetation*** Substantial work has been undertaken at CEH into understanding flow around trees (or rods) in the floodplain. The quasi-2D CES equation has been extended to include a drag force term and this has been tested against measurements with promising results (Rameshwaran & Shiono, 2007). In addition, detailed 3D modelling (Pam Naden, personal communication; Naden, 2006) and measurement (Wilson *et al*, 2006) to explore the drag coefficients for different vegetation types has been undertaken.	Additional term in core analysis engine and supporting data (Cd coefficients)	Improves physics of handling of emergent vegetation.	*Research* Limited *Method* Yes *Software* Yes	Raised through one-on-one consultations
S20	***Investigate the impact of the current boundary friction assumptions (e.g. 1m depth)*** The conversion of unit roughness n_l to an equivalent length scale k_s at a 1m depth of flow is fundamental to the methodology. It is recommended that this underpinning hypothesis is investigated further. The 1m flow depth was selected as it is representative of a typical UK river depth, at which the vertical variations in roughness are virtually negligible. However, for deep rivers where bankfull flow depth is >10 m, this may be inappropriate.	No tool change	Improved confidence current in approach	*Research* Yes MSc/PhD *Method* No *Software* No	
	Conveyance improvements – core engine				
S21	***Improvements to core CES engine models & coefficients*** - *Eddy viscosity model*: Representation of the turbulence due to lateral shearing is based on Abril's (2001, 2004) dimensionless eddy viscosity model. This rule should be further investigated for compound channels. - *Secondary flow model - straight*: Abril & Knight's (2004) model is based on the average energy losses over main channel and floodplain. In reality, the secondary circulations change in orientation and magnitude across the section (Omran, 2005). A model should be developed to relate the actual transverse circulation pattern to a local, quantifiable geometric property in the cross-section (see the following Chlebek & Knight, 2006; Omran et al., 2008; Chlebek, 2009; Knight and Tang; 2009 all detailed in Knight *et al*, 2009) - *Secondary flow model – meandering*: Some limitations to the CES approach have been highlighted (Knight *et al*., 2009). - *Model coefficients*: The CES approach is dependent on 4 calibration parameters f, λ, Γ and C_{uv} and their lateral distribution across the section as the flow physics vary as well as the relative magnitude of each. These parameters should ideally be back-calculated from measured data, based on a wide range of experimental and river cases. This process is not straightforward, as all four parameters will vary for each site and it may be necessary to hold one or more as fixed quantities to gauge the value of the parameter of interest and to disaggregate the net affect. The approach to back-calculating these parameters also requires attention (Knight and Tang (2009). - *Model coefficients – cont*: The C_{uv} coefficient in the meandering secondary flow model is based on plan form sinuosity, with simple equations derived for inbank and overbank flow. These equations are based on the limited available data for meandering channels and should be improved with further measurement/validation. In particular, data should be used for cross-section locations spaced around the channel bend, as the current C_{uv} model was calibrated on cross-sections located at the bend apex.	Improved models & coefficients - core engine update	Improvements in prediction (see Mc Gahey, 2006)	*Research* Yes MSc/PhD *Method* Yes *Software* Yes	
S22	***Improvements to high flow predictions through extension of rating curves*** This would build on the HRW study for the Environment Agency (Environment Agency, 2003) extension of ratings curve work in the late 1990s and the more recent work of Eric Gaume (under Hydrate whilst at École des Ponts ParisTech which considers modifying roughness to account for changing processes and includes analysis of observed levels and velocities in storm events.			*Research* Yes MSc/PhD *Method* Yes *Software* Yes	Raised in one-on-one consultations Raised at Workshop 25/11/08
S24	***Incorporate methods to model non-prismatic channels*** The CES methodology does not incorporate an explicit model for non-prismatic channels. Bousmar and Zech (2004) proposed an Extension to an explicit Lateral Distribution Method (ELDM) for non-prismatic channels, which introduces a coefficient explicitly related to non-prismatic channel effects. This model could be extended for practical application within the CES methodology, which would require, for example, a plan form parameterisation of the channel geometry and a model to represent the transitions between the straight, skewed, converging, diverging and meandering channel flow models.	Additional model to handle form loss in consecutive cross-sections	Improves backwater calculation. Question over whether more useful to move to full 1D model.	*Research* Yes MSc/PhD *Method* Yes *Software* Yes	

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S26	***Incorporate meandering channel approach through use of a two-layer model (long-term)*** The CES methodology is based on a depth-averaged approach. Although this appears to work reasonably well in meandering channels, the model should strictly speaking be applied to straight channels only as the velocity vector changes direction from in-channel to out-of-channel flow. Two-layer models deal with this through modelling in-channel and out-of-channel flow separately (personal communication - Knight, Ramesh, Omran).	Revamp of CES calculation	Better predictions Improved science	*Research* Yes Series of MSc/PhD *Method* Yes *Software* Yes	
S27	***Further benchmarking & testing of methods*** - The CES methodology should be thoroughly benchmarked against previous methods available in the literature e.g. early divided channel methods to demonstrate the added value of the CES multi-parametric approach. - The CES should be 'blind tested' to assess the true predictive performance without calibration. This should be combined with a formal uncertainty analysis for both the CES and the methods in S27 to demonstrate the reduction, if any, in uncertainty when employing the more parametrically complex CES approach.	No change	Improved confidence in outputs & recommendations for improvements May alter embedded coefficients	*Research* Yes MSc/PhD *Method* No *Software* No	
	Backwater				
S29	***Improve the backwater energy balance*** The backwater calculation is currently based on a simple energy balance working upstream. It is for sub-critical steady uniform flow. More advanced approaches could be explored. It is currently envisaged that users requiring more advanced methods will move to full 1D hydrodynamic models e.g. InfoWorks RS, ISIS etc.	Update to backwater calculation to deal with trans-critical flow	90% channels sub-critical - question benefits.	*Research* Limited *Method* Yes *Software* Yes	Raised at Workshop 25/11/08
	Afflux related updates				
S30	***Update the structure conveyance calculation to be consistent with the CES*** The CES and AES use different models for conveyance. This is in part related to the advantages of retaining a Hydrologic Engineering Centers River Analysis System (HEC-RAS) style divided channel (with Manning's equation) for AES development that made heavy use of existing HEC analysis and validation against HEC-RAS. Also there is a question about the relevance of CES for the reach containing the structure and transition lengths. However, the present implementation in software leaves some loose ends that are awkward for users, even if not theoretically difficult.	Consistency & science of approach – user acceptance		*Research* No? *Method* Yes *Software* Yes	Raised numerous occasions including Workshop 25/11/08
S31	***Improved afflux estimation at bridges through use of CES method*** Traditionally, afflux methods have dealt with the ratios of cross-sectional areas which are blocked by bridge piers. The reason for this is that the ratios of the flow rates through the different bridge elements were unknown. With the new CES calculation, it is possible to determine the total flow rate and the distributed flow rates - taking boundary layers into account. Thus, a more radical change would be to update the afflux calculation to accommodate this knowledge. This is largely a reworking of experimental data to update the afflux versus blockage input curves and hence, in the software, using the CES to obtain local flow distributions.	Alter core AES tables / curves	Improve afflux estimation – physics behind approach. More theoretically sound	*Research* Yes Series of PhD/MSc *Method* No *Software* AES update of input curves	
S32	***Incorporate energy losses due to trash screens*** This should tie in with the Environment Agency's new trash screen guidance. It would be incorporated as a hydraulic loss unit.	Trash screen module – new feature		*Research* Limited *Method* Yes *Software* Yes	Raised numerous occasions including Workshop 25/11/08

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S33	***Improved handling of blockage*** Step 1: A simple fix by simply allowing a reduction in opening ratio. Step 2: Monitor FRMRC2 research on debris (Nottingham) to see whether this produces any conceptual advances that should be considered for future AES development. This is linked to inclusion of a hydraulic loss unit. Step 3: Monitoring FRMRC2 work regarding what can be said about the sources and amounts of blockage to inform blockage risk.	Blockage module / coefficient – new feature	Handles blockage	*Research* No / Yes PhD/MSc *Method* Yes *Software* Yes / Yes	Raised numerous occasions including Workshop 25/11/08
S34	***Improved culvert coefficients from original US data to simulate inlets as they occur in reality*** Coefficients used to compute energy losses for opening and cross section geometry configurations may require updating in the light of laboratory and field research done since the current generation of methods was established.			*Research* Yes *Software* Minor	Raised Workshop 25/11/08
S35	***Incorporate capability to model multiple barrels with different invert levels*** The CES-AES stand alone tool allows users to estimate water levels and other flow variables in river channels containing bridge or culvert structures. Currently there are a range of opening types available for bridges and culverts, with some flexibility to define the shapes of the openings; however more complex types such as multiple culvert openings with different shapes and invert levels or bridges with relief culverts cannot be represented directly. In addition, the road or parapet level of bridges has to be assumed to be horizontal and approach road embankments cannot be represented.			*Research* Yes *Method* Yes *Software* Yes	Raised Workshop 25/11/08
S36	***Improve afflux approach to include conservation of momentum methods for bridge piers*** These were explored in the AES research but not included in the AES software, mainly because of Peter Mantz's conclusion that the empirical coefficients to describe form drag were not sufficiently robust. The AES therefore uses the energy equation and models friction losses only, with piers being 'seen' by the model as continuous wall-like objects (in the longitudinal direction). This may be worth revisiting, even if only to confirm the original decision, but also in light of the FRMRC2 work and any related research in the USA.		Improved underlying science	*Research* Yes PhD/MSc *Method* Yes *Software* Yes	
S37	***Improve methods for estimating transition lengths*** Improve the methods of estimating transition lengths in the afflux calculation			*Software* Yes	
	Other e.g. data, guidance, new features				
S38	***Data acquisition programme*** There are limited channel measurements for afflux at bridges and culverts. A targeted programme of data acquisition would enable thorough testing of the AES methods and science. Question of telemetry/measurements raised with practitioners at RP901 Culvert Design & Operation Guide (CDOG) Consultation Workshop held on 10/9/08 in Birmingham. From open forum discussions it was clear that relatively few operators make use of telemetry. However, several individuals within the Environment Agency were identified as useful contacts. - David Walshe, Project Manager Culverts North West. Comment: “Telemetry used extensively and very helpful.” - Gary Watson, Operations Delivery Engineer. Comment: “The [Environment] Agency is currently trialling the use of “web cams” at sites in the Midlands. These have proved very useful for directing resources in ‘high water’ patrols.” - Mervyn Bramley, Agency Wessex REDC // Defra/Environment Agency Science advisor. Comment: “There is an [Environment] Agency project using CCTV in a number of tidal locations. If you have not picked up details of this, please talk to Peter Robinson.” - Mike Pomfrett, Team leader – Operations – Technical support. Comment: “Yes as much as we can, with a 24/7 standby pick up signal system. For urban fast responding catchments, telemetry is essential. Can also be improved by addition of CCTV. I understand Environment Agency has an R&D project ongoing on this?”	Possible - Database updates, model coefficient updates etc.	Improve confidence in results, improve database, improve coefficients, validate methods etc.	*Research* No? *Method* No *Software* No	Raised at Workshop 25/11/08 e.g. “measure more, model less”

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S39	***Improve boundary shear stress predictions at sharp changes in geometry*** The existing boundary shear stress calculation links the unit flow rate *q* to the shear velocity u_*, assuming uniform flow in a wide flat channel. The values at the channel banks or sharp changes in geometry are therefore over-estimated, creating an artificial 'spike' effect, reducing credibility of output. A method should be developed to improve the estimates, and as a minimum, a practical 'fix' should be incorporated to improve current outputs. A method would involve derivation of a direct relationship between friction *f* and *q*, to eliminate use of velocities. One approach is to consider measured values for both and identify any correlations.	Update to post-process of CES	Improves science and credibility of current methods	*Research* Limited PhD/MSc *Method* Yes *Software* Yes	
S40	***Development of a sediment transport module*** This would enable calculation of sediment flux (rates and concentration) in a channel section. It would make use of CES-AES outputs such as spatial depth-averaged velocity, boundary shear stress and shear velocity. Currently, users adopting approaches such as Ackers (1990) use section average velocities which ignore the important influence of channel boundaries and floodplain flow on main channel flow processes. This would involve selection and coding of a range of sediment transport formulae (e.g. Du Boys, 1879; Einstein, 1942; Bagnold, 1966; Engelund, 1966; Chang et al, 1967; White, 1972; Ackers & White 1973; White et al, 1980; Ackers 1990). [This enhancement should be undertaken with or as follow-on to S39.] The SAMPS and Sediments and Habitats work have demonstrated the usefulness of evaluating stream power along reaches (relatively simple update) and the use of CES outputs for sediment transport equations. Feedback was keen on a Sediment post-processing module to do this within the software.	Additional module – new feature	Sediment module to enable more detailed applications for sediment channels	*Research* Limited PhD/MSc *Method* Yes *Software* Yes (and UI)	Raised at Workshop 25/11/08 High priority for geomorphology stakeholders / researchers
S41	***Development of a habitat module*** The WFD highlights the need for exploring and designing for diverse habitat regimes which also meet flood risk management objectives. Existing software (e.g. PHABSIM - Physical Habitat Simulation for fish, RHABSIM - River Habitat Simulation) for environmental channel design are based on the Manning equation and hence use section average velocities. The CES outputs provide scope to improve these designs through use of the local depth-averaged velocities and resolution of local roughness conditions. Typically 2 approaches are used to evaluate habitat: (i) response curves e.g. velocity/depth versus species preference; and (ii) life scores e.g. invertebrates present versus flow/depth. [Note: PHABSIM uses Manning or imported depth grids and standard step method for backwaters, use tends to focus on affects downstream of dam discharges, it is very data hungry] PHABSIM includes hard-coded response curves, but many ecologists prefer to provide their own information on species. It is proposed that the CES potential is highlighted to ecologists (e.g. annual Robson Meeting - held 17/18 February in 2009) and knowledge gained on the preferred outputs/processing to support habitat decisions (and/or guidance). The scale of the approach is important e.g. reach versus catchment. Sediments & Habitats project explores a simple means to relate cross-sections vegetation, velocity and habitat requirements – using a spatial cross-section representation. Would be useful if module is developed.	Additional module – new feature	Habitat module to enables users to explore habitat "what-ifs" Enables more holistic FRM solutions in keeping with WFD, ADA biodiversity objectives; other	*Research* Limited *Method* Yes *Software* Yes (and UI)	Raised at Workshop 25/11/08 Discussed at Robson Meeting 17/18 Feb – value noted Raised through consultation e.g. Knight, Bettess
S42	***Channel maintenance support/advisory module*** There is a need for advice on how to go about exploring different maintenance regimes (vegetation, dredging etc.) within the CES-AES (building on PAMS work). This would provide a software module with associated guidance on how to identify channel reaches which the CES-AES is best used for and how to address these and when more complex models are required. This would most likely involve identifying different channel types e.g.: - channels where no maintenance is required - so less need for CES-AES other than to confirm the need for no maintenance - channels where extensive maintenance is required that it is unlikely there are many "what-if" scenarios which can be carried out i.e. CES-AES it likely to simply confirm the need for maintenance - channels where there are opportunities to relax or improve the maintenance regime and take other items into account e.g. local ecology needs etc. - where the CES-AES is very useful - channels which are dominated by structures e.g. culverts, bridges rather than channel vegetation or roughness. For these, the CES-AES would be useful but the water levels would be more dependent on the structure features rather than the maintenance regime. The supporting module will enable users to readily use the tool to explore what-if scenarios of dredging and vegetation maintenance as well batching results - and provide useful output graphs.	Channel maintenance module and supporting guidance to support users engaged in maintenance activities e.g. IDBs, Environment Agency, practitioners	Large – wider use, uptake etc.	*Research* Limited *Method* Yes *Software* Yes	Raised at Workshop 25/11/08 Raised at training, repeated user feedback Raised at Roughness Steering Meeting (03/07/08)

Ref.	Recommendation	Tool enhancement	Benefit	Effort	Stakeholder support
S43	***Advice on use of CES-AES for environmental features (ties in with S10 / S41)*** Provision of guidance and examples of the CES use with environmental features (e.g. pools and riffles, drying and wetting of berms, species preferences etc.) i.e. how to go about using the existing CES in this context and the measurements required.	Enables more holistic FRM solutions CES-AES specific guidance	Larger uptake and use of software – if applications / guidance is clear	*Research* Limited *Method* Yes *Software* No	Raised at Workshop 25/11/08 Raised from river restoration work and Sediments & Habitats
S44	***Analysis of cross-section survey data to improve understanding of sensitivity*** Sensitivity testing highlighted cross-section geometry as one of the most sensitive user input parameters. Channel survey data may come from a variety of sources such as on site survey, Digital Elevation Models, Ordnance Survey map contours or aerial photography. A detailed study could be undertaken to determine the typical size of the geometry discrepancies between cross-section measurements from different sources and the likely impact on the flow predictions. This would be undertaken for a range of channel types and scales.	Guidance on data requirements for CES-AES analysis	Support ease of use – all users	*Research* Yes MSc/PhD *Method* No *Software* No	
S45	***Development of a module to support exploration of river rehabilitation techniques*** A simple to use module that enables exploration of various river rehabilitation techniques. That might include different types of flow deflectors, introducing meanders, attaching ledges to the insides of culverts for otters to use, installing fish passes on weirs, weir removal, introduction of riffles and side bars, introduction of woody debris. These would include a mixture of advice and tools (e.g. loss units, weirs, fish pass representation at weirs).	Additional module – new feature	River Rehabilitation module to support choice of measures based on impact on conveyance	*Research* Some *Method* Yes *Software* Yes	Support from biodiversity officer (Environment Agency)

Appendix 5 New River Habitat Survey Data (2003-09)

RIVER HABITAT SURVEY 2003 VERSION: SITE HEALTH AND SAFETY ASSESSMENT			
Site Number[1]:	Site Ref:	River Name:	Date:
Grid References/Co-ordinates:	Spot 1[2]:	Mid-site:	End of site[2]:
Surveyor Name:		Accredited Surveyor Code:	
[1] Leave blank if new site.		[2] Optional	

Weather Conditions:	
Flow Conditions:	

Site details: (enter comments or circle if applicable and give details)	**Risk Level (Low/Mod/High)**
Access and Parking: (entry & exit)	
Conditions: comment on ground stability, footing, exposure/remoteness	
Obstacles/Hazards: fencing, stiles, dense vegetation, steep bank	
Occupied/Unoccupied: people, livestock, animals	
Activities/Land-use: agriculture, woodland, residential, industrial, construction, recreational	
Risk if lone-working	

IF THERE ARE ANY HIGH RISKS OR MORE THAN THREE MODERATE RISKS DO NOT CONTINUE WITH THE SURVEY.

Weil's Disease (*Leptospirosis*)

Instructions to card holders

1. As infection may enter through breaks in the skin, ensure that any cut, scratch or abrasion is thoroughly cleansed and covered with a waterproof plaster.
2. Avoid rubbing your eyes, nose and mouth during work.
3. Clean protective clothing, footwear and equipment etc. after use
4. After work, and particularly before taking food or drink, wash hands thoroughly.
5. Report all accidents and/or injuries, however slight.
6. Keep your card with you at all times.

Lyme Disease

1. Dress appropriately with skin covered up.
2. Regularly inspect for ticks when in the field.
3. Check for, and remove, any ticks as soon as possible after leaving the site.
4. Seek medical attention if bitten by a tick.

PHYSICAL ATTRIBUTES (SECTION E)

BANKS

Predominant bank material

NV = not visible

BE = bedrock
BO = boulder
CO = cobble
GS = gravel/sand
EA = earth (crumbly)
PE = peat
CL = sticky clay

CC = concrete
SP = sheet piling
WP = wood piling
GA = gabion
BR = brick/laid stone
RR = rip-rap
TD = tipped debris
FA = fabric
BI = bio-engineering materials

Bank modifications

NK = not known
NO = none

RS = resectioned (reprofiled)
RI = reinforced
PC = poached
PC(B) = poached (bare)
BM = artificial berm
EM = embanked

Marginal and bank features

NV = not visible (e.g. far bank)
NO = none

EC = eroding cliff (EC if sandy substrate)
SC = stable cliff (SC if sandy substrate)

PB = unvegetated point bar
VP = vegetated point bar

SB = unvegetated side bar
VS = vegetated side bar

NB = natural berm

CHANNEL

Predominant substrate

NV = not visible

BE = bedrock
BO = boulder
CO = cobble
GP = gravel/pebble (G or P if predominant)
SA = sand
SI = silt
CL = clay
PE = peat
EA = earth
AR = artificial

Predominant flow-type

NV = not visible
FF = free fall
CH = chute
BW = broken standing waves (white water)
UW = unbroken standing waves
CF = chaotic flow
RP = rippled
UP = upwelling
SM = smooth
NP = no perceptible flow
DR = no flow (dry)

Channel modifications

NK = not known
NO = none

CV = culverted
RS = resectioned
RI = reinforced
DA = dam/weir/sluice
FO = ford (man-made)

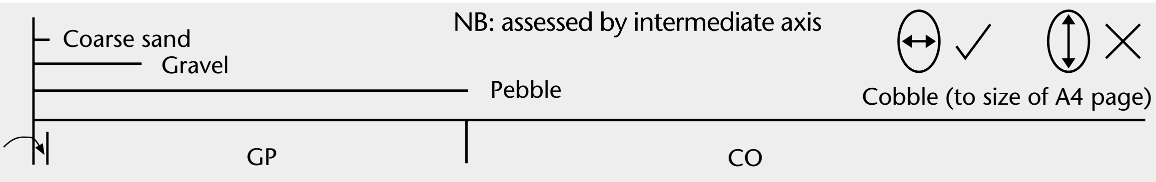
Channel features

NV = not visible
NO = none

EB = exposed bedrock
RO = exposed boulders
VR = vegetated rock
MB = unvegetated mid-channel bar
VB = vegetated mid-channel bar
MI = mature island
TR = Trash (urban debris)

FLOW-TYPES	DESCRIPTION
FF: Free fall	clearly separates from back-wall of vertical feature ~ associated with waterfalls
CH: Chute	low curving fall in contact with substrate ~ often associated with cascades
BW: Broken standing waves	white-water tumbling waves must be present ~ mostly associated with rapids
UW: Unbroken standing waves	upstream facing wavelets which are not broken ~ mostly associated with riffles
CF: Chaotic flow	a chaotic mixture of three or more of the four fast flow-types with no predominant one obvious
RP: Rippled	no waves, but general flow direction is downstream with disturbed rippled surface ~ mostly associated with runs
UP: Upwelling	heaving water as upwellings break the surface ~ associated with boils.
SM: Smooth	perceptible downstream movement is smooth (no eddies) ~ mostly associated with glides
NP: No perceptible flow	no net downstream flow ~ associated with pools, ponded reaches and marginal deadwater
DR: No flow (dry)	dry river bed

Scale



LEFT **Banks are determined by looking downstream** **RIGHT**

CHANNEL MODIFICATION INDICATORS

One or more of the following may be indicative of resectioning:

1. Uniform bank profile
2. Straightened planform
3. Bankfull width/bankfull height ratio <4:1
4. Uniform/low energy flow-types
5. No trees/uniformly-aged trees along bank
6. Intensive/urban land-use

LAND-USE WITHIN 5m OF BANKTOP (SECTION F) & 50m (SECTION H)

BL = Broadleaf/mixed woodland (semi-natural)
BP = Broadleaf/mixed plantation
CW = Coniferous woodland (semi-natural)
CP = Coniferous plantation
SH = Scrub & shrubs
OR = Orchard
WL = Wetland (e.g. bog, marsh, fen)
MH = Moorland/heath
AW = Artificial open water
OW = Natural open water
RP = Rough unimproved grassland/pasture
IG = Improved/semi-improved grassland
TH = Tall herb/rank vegetation
RD = Rock, scree or sand dunes
SU = Suburban/urban development
TL = Tilled land
IL = Irrigated land
PG = Parkland or gardens
NV = Not visible

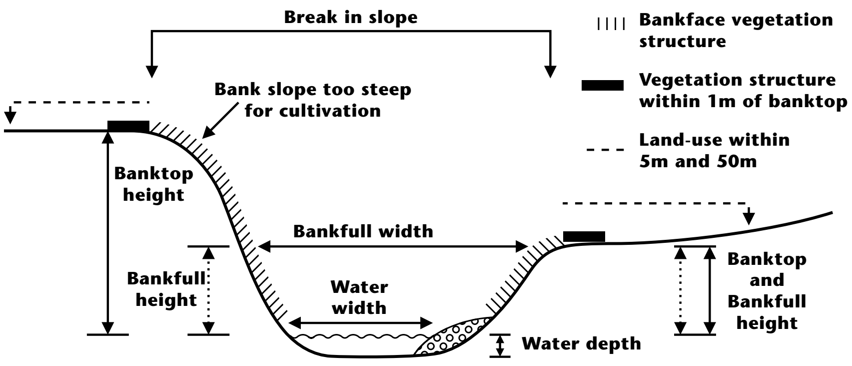
BANKTOP AND BANKFACE VEGETATION STRUCTURE To be assessed within a 10m wide transect (SECTION F)

			vegetation types
bare	B	bare earth/rock etc.	
uniform	U	predominantly one type (no scrub or trees)	bryophytes; short/creeping herbs or grasses
simple	S	two or three vegetation types	tall herbs/ grasses; scrub or shrubs
complex	C	four or more types	saplings and trees

Channel dimensions guidance (Section L)

- Select location on uniform section.
- If riffle is present, measure there. If not, measure at straightest and shallowest point.
- **Banktop** = first major break in slope above which cultivation or development is possible.
- **Bankfull** = point where river first spills on to floodplain.

Cross-section of channel showing definitions used to define where spot-check recording and channel dimensions measured



ENVIRONMENT AGENCY

EMERGENCY HOTLINE 0800 80 70 60

24 hour free emergency telephone line for reporting all environmental incidents relating to air, land and water.

A FIELD SURVEY DETAILS

Site Number: (leave blank if new site) ☐

Site Reference:

Spot-check 1 Grid Ref:

Spot-check 6 Grid Ref:

End of site Grid Ref:

Reach Reference:

River name:

Date / /20　　Time:

Surveyor name:

Accredited Surveyor code:

Is the site part of a river or an artificial channel? River ☐ Artificial ☐

Are adverse conditions affecting survey? No ☐ Yes ☐

If yes, state ....

Is bed of river visible? barely or not ☐ partially ☐ ±entirely ☐

Is health and safety assessment form attached? Yes ☐ No ☐

Number of photographs taken: ☐

Photo references:

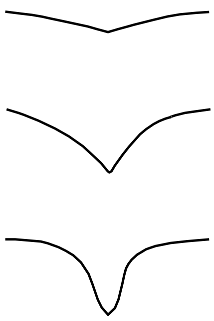
Site surveyed from: left bank ☐ right bank ☐ channel ☐

☐ **When options shown with 'shadow boxes', tick one box only**

LEFT　　banks determined by facing downstream　　RIGHT

B PREDOMINANT VALLEY FORM (within the horizon limit) (tick one box only)

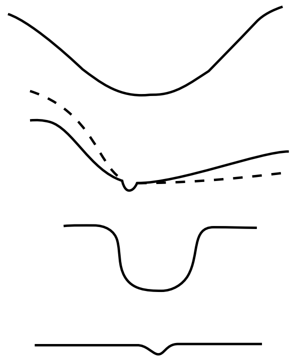
(tick one box only)



☐ shallow vee

☐ deep vee

☐ gorge



☐ concave/bowl

☐ asymmetrical valley

☐ U-shape valley

☐ no obvious valley sides

Distinct flat valley bottom? No ☐ Yes ☐

Natural terraces? No ☐ Yes ☐

C NUMBER OF RIFFLES, POOLS AND POINT BARS (enter total number in boxes)

Riffle(s) ☐

Pool(s) ☐

Unvegetated point bar(s) ☐

Vegetated point bar(s) ☐

D ARTIFICIAL FEATURES (indicate total number of occurrences of each category within the 500m site)

If none, tick box ☐

	Major	Intermediate	Minor		Major	Intermediate	Minor
Weirs/sluices				Outfalls/ intakes			
Culverts				Fords			
Bridges				Deflectors/ groynes/crovs			
Other - state							

Is channel obviously realigned? No ☐ Yes, <33% of site ☐ ⩾33% of site ☐

Is channel obviously over-deepened? No ☐ Yes, <33% of site ☐ ⩾33% of site ☐

Is water impounded by weir/dam? No ☐ Yes, <33% of site ☐ ⩾33% of site ☐

SITE REF.	**RIVER HABITAT SURVEY: TEN SPOT-CHECKS**	**Page 2 of 4**

Spot-check 1 is at: upstream end ❑ downstream end ❑ of site (tick one box)

E PHYSICAL ATTRIBUTES (to be assessed across channel within 1m wide transect)

When boxes 'bordered', only one entry allowed	**1 GPS**	2	3	4	5	**6 GPS**	7	8	9	10	**GPS**
LEFT BANK	Ring EC or SC if composed of sandy substrate										
Material NV, BE, BO, CO, GS, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI											
Bank modification(s) NK, NO, RS, RI, PC(B), BM, EM											
Marginal & bank feature(s) NV, NO, EC, SC, PB, VP, SB, VS, NB											
CHANNEL	GP- ring either G or P if predominant										
Channel substrate NV, BE, BO, CO, GP, SA, SI, CL, PE, EA, AR											
Flow-type NV, FF, CH, BW, UW, CF, RP, UP, SM, NP, DR											
Channel modification(s) NK, NO, CV, RS, RI, DA, FO											
Channel feature(s) NV, NO, EB, RO, VR, MB, VB, MI, TR											
For braided rivers only: number of sub-channels											
RIGHT BANK	Ring EC or SC if composed of sandy substrate										
Material NV, BE, BO, CO, GS, EA, PE, CL, CC, SP, WP, GA, BR, RR, TD, FA, BI											
Bank modification(s) NK, NO, RS, RI, PC(B), BM, EM											
Marginal & bank feature(s) NV, NO, EC, SC, PB, VP, SB, VS, NB											

← Enter channel substrate(s) not occurring as predominant in spot-checks but present in >1% of whole site.

F BANKTOP LAND-USE AND VEGETATION STRUCTURE (to be assessed over a 10m wide transect)

Land-use: choose one from BL, BP, CW, CP, SH, OR, WL, MH, AW, OW, RP, IG, TH, RD, SU, TL, IL, PG, NV

		1	2	3	4	5	6	7	8	9	10
LAND-USE WITHIN 5m OF LEFT BANKTOP											
LEFT BANKTOP (structure within 1m)	B/U/S/C/NV										
LEFT BANK-FACE (structure)	B/U/S/C/NV										
RIGHT BANK-FACE (structure)	B/U/S/C/NV										
RIGHT BANKTOP (structure within 1m)	B/U/S/C/NV										
LAND-USE WITHIN 5m OF RIGHT BANKTOP											

G CHANNEL VEGETATION TYPES (to be assessed over a 10m wide transect: use E (⩾ 33% area), ✓(present) or NV (not visible)

	1	2	3	4	5	6	7	8	9	10	
None (✓) or Not Visible (NV)											
Liverworts/mosses/lichens											
Emergent broad-leaved herbs											
Emergent reeds/sedges/rushes/grasses/horsetails											
Floating-leaved (rooted)											
Free-floating											
Amphibious											
Submerged broad-leaved											
Submerged linear-leaved											
Submerged fine-leaved											
Filamentous algae											

Use end column for overall assessment over 500m, including types not occurring in spot-checks (use ✓, E or NV)

SITE REF.	**RIVER HABITAT SURVEY : 500m SWEEP-UP**	**Page 3 of 4**

H LAND-USE WITHIN 50m OF BANKTOP Use ✓ (present) or E (≥ 33% banklength)

	L	R		L	R
Broadleaf/mixed woodland (semi-natural) (BL)			Natural open water (OW)		
Broadleaf/mixed plantation (BP)			Rough/unimproved grassland/pasture (RP)		
Coniferous woodland (semi-natural) (CW)			Improved/semi-improved grassland (IG)		
Coniferous plantation (CP)			Tall herb/rank vegetation (TH)		
Scrub & shrubs (SH)			Rock, scree or sand dunes (RD)		
Orchard (OR)			Suburban/urban development (SU)		
Wetland (e.g. bog, marsh, fen) (WL)			Tilled land (TL)		
Moorland/heath (MH)			Irrigated land (IL)		
Artificial open water (AW)			Parkland or gardens (PG)		
			Not visible (NV)		

I BANK PROFILES Use ✓ (present) or E (≥ 33% banklength)

Natural/unmodified	L	R	**Artificial/modified**	L	R
Vertical/undercut			Resectioned (reprofiled)		
Vertical with toe			Reinforced - whole		
Steep (>45°)			Reinforced - top only		
Gentle			Reinforced - toe only		
Composite			Artificial two-stage		
Natural berm			Poached bank		
			Embanked		
			Set-back embankment		

J EXTENT OF TREES AND ASSOCIATED FEATURES *record even if <1%

TREES (tick one box per bank)

	Left	Right
None	❑	❑
Isolated/scattered	❑	❑
Regularly spaced, single	❑	❑
Occasional clumps	❑	❑
Semi-continuous	❑	❑
Continuous	❑	❑

ASSOCIATED FEATURES (tick one box per feature)

	None	Present	E (≥33%)
Shading of channel	❑	❑	❑
*Overhanging boughs	❑	❑	❑
*Exposed bankside roots	❑	❑	❑
*Underwater tree roots	❑	❑	❑
Fallen trees	❑	❑	❑
Large woody debris	❑	❑	❑

K EXTENT OF CHANNEL AND BANK FEATURES (tick one box for each feature) *record even if <1%

	None	Present	E(≥33%)
*Free fall flow	❑	❑	❑
Chute flow	❑	❑	❑
Broken standing waves	❑	❑	❑
Unbroken standing waves	❑	❑	❑
Rippled flow	❑	❑	❑
*Upwelling	❑	❑	❑
Smooth flow	❑	❑	❑
No perceptible flow	❑	❑	❑
No flow (dry)	❑	❑	❑
Marginal deadwater	❑	❑	❑
Eroding cliff(s)	❑	❑	❑
Stable cliff(s)	❑	❑	❑

	None	Present	E (≥33%)
Exposed bedrock	❑	❑	❑
Exposed boulders	❑	❑	❑
Vegetated bedrock/boulders	❑	❑	❑
Unvegetated mid-channel bar(s)	❑	❑	❑
Vegetated mid-channel bar(s)	❑	❑	❑
Mature island(s)	❑	❑	❑
Unvegetated side bar(s)	❑	❑	❑
Vegetated side bar(s)	❑	❑	❑
Unvegetated point bar(s)	❑	❑	❑
Vegetated point bar(s)	❑	❑	❑
*Unvegetated silt deposit(s)	❑	❑	❑
*Discrete unvegetated sand deposit(s)	❑	❑	
*Discrete unvegetated gravel deposit(s)	❑	❑	

SITE REF.	RIVER HABITAT SURVEY : DIMENSIONS AND INFLUENCES	Page 4 of 4

L CHANNEL DIMENSIONS (to be measured at one location on a straight uniform section, preferably across a riffle)

LEFT BANK		CHANNEL		RIGHT BANK	
Banktop height (m)		Bankfull width (m)		Banktop height (m)	
Is banktop height also bankfull height? (Y or N)		Water width (m)		Is banktop height also bankfull height? (Y or N)	
Embanked height (m)		Water depth (m)		Embanked height (m)	

If trashline lower than banktop, indicate: height above water (m) = width from bank to bank (m) =

Bed material at site is: consolidated ❑ unconsolidated (loose) ❑ unknown ❑

Location of measurements is: riffle ❑ other ❑ (state)

M FEATURES OF SPECIAL INTEREST Use ✓ or E (⩾ 33% length) *record even if <1%

None	☐	Very large boulders (>1m)	☐	Backwater(s)	☐	Marsh(es)	☐
Braided channels	☐	*Debris dam(s)	☐	Floodplain boulder deposits	☐	Flush(es)	☐
Side channel(s)	☐	*Leafy debris	☐	Water meadow(s)	☐	Natural open water	☐
*Natural waterfall(s) > 5m high	☐	Fringing reed-bank(s)	☐	Fen(s)	☐	Others (state)	☐
*Natural waterfall(s) < 5m high	☐	Quaking bank(s)	☐	Bog(s)	☐		
Natural cascade(s)	☐	*Sink hole(s)	☐	Wet woodland(s)	☐		

N CHOKED CHANNEL (tick one box)

Is 33% or more of the channel choked with vegetation? No ❑ Yes ❑

O NOTABLE NUISANCE PLANT SPECIES Use ✓ or E (⩾ 33% length) *record even if <1%

		bankface	banktop to 50m		bankface	banktop to 50m
None ☐	*Giant hogweed	☐	☐	*Himalayan balsam	☐	☐
	*Japanese knotweed	☐	☐	*Other (state)..........................	☐	☐

P OVERALL CHARACTERISTICS (Circle appropriate words, add others as necessary)

Major impacts: landfill - tipping - litter - sewage - pollution - drought - abstraction - mill - dam - road - rail - industry - housing mining - quarrying - overdeepening - afforestation - fisheries management - silting - waterlogging - hydroelectric power

Evidence of recent management: dredging - bank mowing - weed cutting - enhancement - river rehabilitation - gravel extraction - other (please specify)

Animals: otter - mink - water vole - kingfisher - dipper - grey wagtail - sand martin - heron - dragonflies/damselflies

Other significant observations: if necessary use separate sheet to describe overall characteristics and relevant observations

Q ALDERS (tick one box in each of the two categories) *record even if <1%

*Alders? None ❑ Present ❑ Extensive ❑ | *Diseased Alders? None ❑ Present ❑ Extensive ❑

R FIELD SURVEY QUALITY CONTROL (✓ boxes to confirm checks)

Have you taken at least two photos that illustrate the general character of the site and additional photos of any weirs/ sluices and major/intermediate structures across the channel?	☐
Have you completed all ten spot-checks and made entries in all boxes in E & F on page 2?	☐
Have you completed column 11 of section G (and E if appropriate) on page 2?	☐
Have you recorded in section C the number of riffles, pools and point bars (even if 0) on page 1?	☐
Have you given an accurate (alphanumeric) grid reference for spot-checks 1, 6 and end of site (page 1)?	☐
Have you stated whether spot-check 1 is at the upstream or downstream end of the site (top of page 2)?	☐
Have you cross-checked your spot-check and sweep-up responses with the channel modification indicators given on page 2 of the spot-check key?	☐

Appendix 6 Supporting evidence for AFW 3 & 4

A6-1 Culvert Hydraulic Research

In the USA the design work on culverts follows the guidelines in the publication by the Federal Highway Administration referred to as HDS-5 (Norman et al, 2001). This report covers single culverts in most normal installation situations. Recent US research has concentrated on aspects of culvert design and installation that are not covered in this publication.

The recent (2005-2008) US and other publications can be sub-divided into several areas of research focused on particular aspects of culvert flow. They are:

- Multi-barrel culverts;
- Culverts for fish passage - partly buried culverts, baffles; and
- Single culverts with special features, e.g. inlet geometries, including screens, hydraulic jumps.

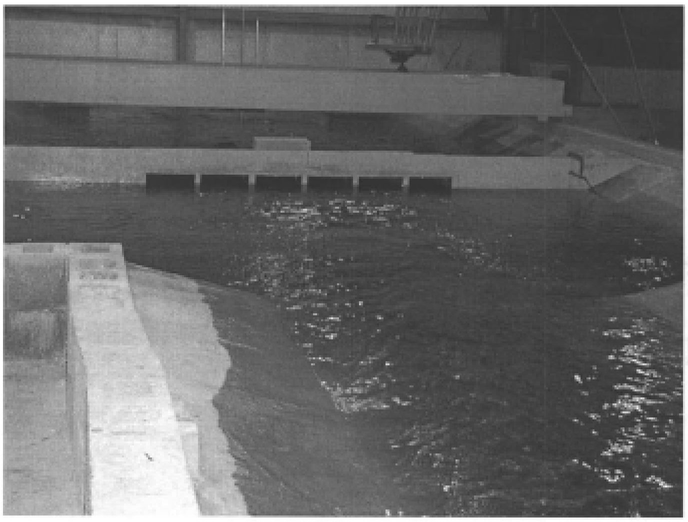
A6-1.1 Multi-barrel culverts

Multi-barrel culverts are normally installed to carry higher flow for the rise in upstream head. Multi-barrel culverts of box, circular or oval opening have been addressed in the papers by

- Wargo and Weisman, A comparison of single and multicell culverts for stream crossing, 2006;
- Haderlie and Tullis, Hydraulics of multibarrel culverts under inlet control, 2008; and
- Charbeneau, Henderson and Sherman, Hydraulic performance curves for highway culverts, 2006.

Wargo and Weisman (2006) studied the option to replace a single culvert to give better fish passage at lower flows, less scour at both inlet and outlet at high flows, sediment deposition upstream at low flows, and less afflux at high flows. They concluded that a multicell installation does have benefits over a single cell but they did not carry out an economic analysis to determine the cost difference between the two installations.

Charbeneau et al. (2006) used laboratory models to investigate the flow into a six multibarrel box culvert system to investigate the hydraulics of channel expansions located upstream of low-headwater box culvert systems. This can be seen in the photo below under high flow conditions.



Experiments were performed with various combinations of two, four, and six barrels open and for different flow rates. They identified that the flow in the six culverts is not the same, with higher flows in the central culverts. Using the measured heads and flow rates they plotted the data and identified the coefficients by least squares. They recommend using the coefficients in the HDS-5 inlet control equations of 1.0 and 0.67 for the design of multibarrel culverts. They also specify the total width of the culverts for low headwater culverts similar to those tested that gives a width lower than recommended in HDS-5.

Hardie and Tullis (2008) investigate the flow through multibarrel culverts and to assess how well the assumption that the average flow through one of the culverts is equal to the flow through a single culvert of the same diameter and with the same upstream conditions ('superposition' principle). They concluded that, in general, superposition can be used to predict the total flow through multibarrel culverts within 3% accuracy, likely to be good enough for most applications. However, the central barrel of a three barrel configuration will carry more flow than the two outside culverts. This may be relevant for fish passage and scour considerations.

A6-1.2 Fish passage and partial sediment blockage

There are several papers that focus on culvert modifications that assist fish passage. They are:

- Frei, Hotchkiss and Bergendahl, Design for Fish passage for Bridges and Culverts , 2005; and
- Tullis, Anderson and Robinson, Entrance loss coefficients and inlet control head-discharge relationships for buried-invert culverts, 2008.

Traditional single culverts set with their invert at stream bed level cause difficulties in most cases for the passage of fish, especially at low flows. This occurs because of the higher flow velocities and frequent scouring on the downstream side. The multi-culvert setup considered by Wargo and Weisman was in part designed to aid fish a passage and their paper is also relevant here.

Frei *et al,* (2005) describe the early stages of a major project to develop design guidelines for fish passage through culverts. The manual is to be entitled "Hydraulic Engineering Circular 26: Design of fish passage for bridges and culverts" and is to be produced by the Federal Highways Association and Washington State University. They refer to a web site (www.stream.fs.fed.us/fishxing) which is active and contains many case studies. It also holds a comprehensive listing of papers related to culverts and fish passage up to early 2005.

Tullis *et al,* (2008) consider the hydraulics of buried invert or embedded culverts. These are culverts where the invert is well below the stream bed and the culvert is filled with streambed material so that the bed is continuous through the culvert to aid fish passage, although a similar situation can arise due to partial blockage by sediment.

The research described was to test buried culverts in the laboratory to determine the loss coefficients at the entrance and the inlet control head-discharge relationships for largely circular buried culverts for various burial depths and entrance conditions. The results show that the parameters of the HDS-5 inlet equations should vary with the degree of burial of the culvert and vary with the entrance conditions. The coefficients they found are different to the normally installed single culverts and should be considered for incorporation in development of AES for this type of culvert.

A6-1.3 Single entrance culverts

The papers on single culverts largely focus on special features that are not covered adequately in HDS-5. For example, the impact on the hydraulic conditions of damaged entrances, trash screens over entrance, impact of hydraulic jump within the culvert, etc.

The papers covered in this section are:

- Kells, Performance of damaged-end corrugated steel pipe culverts, 2008;
- Tullis and Robinson, Quantifying Culvert Exit Losses, 2008;
- Hotchkiss, Flanagan and Donahoo, Hydraulic Jumps in Broken-back Culverts, 2003; and
- Hotchkiss, Thiele, Nelson, Thompson, Culvert Hydraulics: Comparison of current computer models and recommended improvements, 2008.

Kells's study is of damage to entrances or exits and it is the author's hypothesis that these damages significantly affect the hydraulics of culvert flow by either decreasing the capacity or increasing the losses at entrance or exit or both. He carries out laboratory experiments to determine the impact of these damages. He considers damage both to the inlet and the outlet and presents results graphs for both in terms of the head loss through the culvert - that is the difference between the total energy line at inlet and outlet. These graphs are similar in shape for inlet or outlet damage and they show little impact for damage of 0.125 of the diameter, a little more for 0.25 damage, a significant impact for 0.5 damage and a very large impact for 0.75 damage, e.g for a head loss to diameter ratio of 1.0 the term Q/AD0.5 is 1.2 for 0.75 damage and 3.0 for no damage. He also calculates the revised loss coefficients. These results show that damage has a major effect on the losses

The purpose of the Tullis *et al,* (2008) research was to quantify exit losses from culverts with projecting end outlets under outlet control under both submerged and unsubmerged conditions for a range of culvert pipe sizes. They compared their results to the Borda-Carnot equation as well as an equation given in HDS-5. The two equations are similar in form but have different loss coefficients. The loss is expressed using the HDS-5 equations and for the Borda-Carnot equation,

$$K_o = \left(1 - \frac{A_p}{A_c}\right)^2$$

where Ap is the cross section area of the flow in the pipe and Ac is the cross section area of the flow in the channel. The experiment was conducted in a large flume in a laboratory. The flume was 2.4 m wide, 1.8 m deep and 152 m long. The culvert pipes tested were 0.3 m, 0.61 m, 1.22 m and 1.52 m in diameter. They were all tested for unsubmerged flow but only the two smaller diameters from submerged flow in part due to buoyancy uplift problems. They found that the Borda-Carnot best described their experimentally determined loss coefficients.

Hotchkiss *et al*, (2003) investigated the effectiveness of software to predict the location and hydraulic properties of a hydraulic jump that will occur in a broken-back culvert. The software is called BCAP (Broken-back Culvert Analysis Program) developed in 2001 by the Nebraska Department of Roads. Broken-back culverts are ones with at least one change in slope and with a steep initial section followed by a flatter one. They are designed to save on excavation costs and to ensure that the hydraulic jump occurs before leaving the culvert to minimize scour damage. The paper compares the software program predictions with experimental results from model culverts. They showed reasonable agreement with experiment for head loss but less good for location of the hydraulic jump and suggested improvements to the software.

Hotchkiss *et al,* (2008) reports on investigations of a number of computer program that are available to aid culvert design. The program largely incorporate the hydraulics as described in HDS-5. The test was performed using manual calculations for four scenarios where the manual calculations follow the procedures recommended in HDS-5. Therefore, the test was to see how well the program reproduce HDS-5 procedures. As a result of these limited tests, where no comparison is made to observed data, they recommend HY-8 for most cases and HEC-RAS for culverts in series or affected by upstream structures. And for the ability for fish to pass they recommend the specialist programme FishXing. The AES culvert routines have been tested against HEC-RAS during development, which appears to be confirmed as a valid testing strategy.

A6-1.4 Papers reviewed

Charbeneau. R.J, Henderson. A.D. and Sherman L.C. 2006. “Hydraulic Performance Curves for Highway Culverts”. *J. Hydraul. Eng.*, Vol 132, No. 5, pp. 474-481.

Frei. C.M., Hotchkiss. R.H. and Bergendahl B., 2005."Design for Fish passage for Bridges and Culverts", Proc. World Water and Env. Res. Conf., ASCE, Anchorage, 1-10.

Haderlie. G.M. and Tullis. B.P., 2008. "Hydraulics of Multibarrel culverts under Inlet Control". *J. Irrigation and Drainage Eng*., Vol. 134, no. 4, pp. 507-514.

Hotchkiss R.H., Flanagan P.J., Donahoo K., 2003. "Hydraulic Jumps in Broken-back Culverts", Trans. Res. Rec. 1851, paper no. 03-4062, 35-44.

Hotchkiss R.H., Thiele, E.A., Nelson J., Thompson P.L., 2008. "Culvert Hydraulics: Comparison of current computer models and recommended improvements", Transportation Research Record: Journal of the Transportation Research Board, No. 2060, 141–149.

Kells, J.A., 2008. "Hydraulic performance of damaged-end corrugated steel pipe culverts", *Can. J. Civ. Eng.*, Vol. 35, pp. 918-924.

Norman, J. M., Houghtalen, R. J., and Johnston, W. J. _2001_. "Hydraulic design series number 5 (HDS-5), hydraulic design of highway culverts." Federal Highway Administration (FHwA), Washington, D.C.

Tullis B.P and Robinson S.C., 2008. "Quantifying Culvert Exit Losses", J*. Irrigation and Drainage Eng. ASCE*, Vol. 134, no. 2, pp. 263-266.

Tullis B.P., Anderson D.S., Robinson S.C., 2008. "Entrance loss coefficients and inlet control head-discharge relationships for buried-invert culverts", *J. Irrigation and Drainage Eng.*, Vol. 134, no. 6, pp. 831-839.

Wargo.R.S. and Weisman. R.N., 2006. A Comparison of Single and Multicell Culverts for Stream Crossing, *J. Am. Water Resour. Assoc*., Vol. 42, no. 2, pp. 989-995.

A6-2 Trash Screens Manual

This was reviewed in August 2008 and some references to the AES corrected. The draft seen by JBA provided useful information regarding recommended design and operation of screens which will be consulted in any work on development of an AES trash screen module. This information relates to the choice of standard shapes and the specification of relevant parameters to describe screens. The Manual as seen by JBA did not contain numerical hydraulic formulae or loss coefficients that would feed directly into the algorithms for the AES.

A6-3 Culvert Design an Operations Guide (CDOG)

This new CIRIA guide is being prepared by a consortium including JBA. The hydraulic analysis follows largely the original guidance from HDS-5 (FHWA), which also featured in the earlier CIRIA Report 168 Culvert Design Guide. The CDOG analysis has been aligned to be consistent with AES in terms of identified modes of flow and some of the definitions of terms. The CDOG does not include new hydraulic analysis that would contribute to AES algorithm development.

A6-4 FRMRC2 Work Package 4.2 (Blockage Risk)

JBA have reviewed the WP4.2 inception report and conducted a teleconference with Scott Arthur (Herriot Watt) and Nick Wallerstein (Notthingham) who are the principal investigators. The work is to do with quantifying blockage risk in terms of sources of risk in a catchment, not the hydraulic analysis of the impact of the blockage at a structure. Discussion at CES-AES meetings has explicitly set the scope for AES trash screen development to be on the hydraulic impacts, i.e. not to include a ‘blockage source risk’ calculator. However, it is clear that the benefits of the AES development will be maximised if the options available to a user for representation of blockage are in some way compatible with the type of information being produced by FRMRC2 on source of risk. Hence we expect close future liaison with the WP4.2. There is a modest level of industrial funding available to JBA from FRMRC2 for this work package, which will be used to assist in defining relevant user inputs for a future AES trash module to help ensure that the FRMRC2 outputs anticipated over the course of the programme will be compatible with an anticipatd future revision of the CES-AES software.

Appendix 7 Software usability recommendation table

Table A7-1: Potential software feature enhancements to CES-AES (Priority: High, Med, Low) (Bracketed number is Wallingford Software 'fogbugz' reference).

Small = 1 day development
Medium = 1 to 3 days development
Large = 3 to 5 days development
Large+ = > 5 days development
Also need to factor in management and testing, additional 20% on top of development time.

Ref.	Recommendation	Improves	Method required	Software change required	Estimated software effort	Software notes
F1	Changing Sinuosity on General Page should change it on the Section Data Page. This will give the user more confidence as to which value is being used. [1504]	Usability	No	Yes	Medium	Needs some thought about interaction between sinuosity values in different places. Should also make sinuosity fields non-editable where no bank marker is present.
F2	Enable user to change the value of a 'value zone'. These could have property sheets like the other zone types, but very simple ones with just name, description and value. For consistency with the other types, the value could then be removed from the Add Zone dialog. [1719]	Usability	No	Yes	Small	Implement properties for value zones including making high and low values editable.
F3	Automatic calculation of slope, through: - best fit straight line through the bed – or appropriate gradient method (in CES-AES standalone), or - initial conditions (in ISIS / InfoWorksRS) [1721]	Functionality	Yes	Yes	Medium	This requires some science to develop a method. The indicative effort is for a best-fit line. *This does not include work to bring in slopes from initial conditions in ISIS / InfoWorks.*
F4	Would be useful to have the variation in time for the total unit roughness - not only the vegetation. [1738]	Functionality	No	Yes	Medium	Non-editable display of time-series of unit roughness. On Roughness Zone – Components property sheet.
F5	Cutting record. Would be good to have a record of the cuts made (date, amount) and at least one degree of Undo? [1739]	Functionality	No	Yes	Large	Includes F12 & F21. Cutting dates need to persist. Improvements to display of cutting dates on graphs / property sheets.

Ref.	Recommendation	Improves	Method required	Software change required	Estimated software effort	Software notes
F6	Utility to convert VALUE zone to a proper zone. From the pilot testers, the only way to replace the value zones with proper zones is to delete the value zone and insert a new proper one. A utility (a right-click menu item?) to convert to a proper zone would be useful. [2056]	Usability	No	Yes	Small	Relatively simple but question the benefit in doing this.
F7	Roughness database editor. Allowing users to create their own additional RA values and save to the general database. [2058]	Functionality	No	Yes	Large	New user interface on the CSV databases.
F8	Insert sections above and below on section property grid. Currently insert at bottom and move upwards. [2121]	Usability	No	Yes	Small	
F9	Change chainage and elevation data columns on section data property sheet by selecting a number of rows and incrementing by a factor or set value. [2122]	Functionality	No	Yes	Medium	Data operations on grid fields.
F10	Comment field for each zone and section. This would include a tab on both the section and zone property sheet with an edit box that the user can put comments in, as in InfoWorks property sheets. [2137]	Usability	No	Yes	Medium	Implement a new Comments tab on Section and roughness zone property sheets.
F11	Enable the grid reference on the Advice dialog to be remembered as a property of the zone (i.e. saved to the RAD file?) [2148]	Usability	No	Yes	Small	
F12	Enable users to remove cutting date from vegetation time series. (ties in with F5) [11482]	Usability	No	Yes		See F5
F13	Set up radio buttons for the RA Grid Reference type. At present, two choices are given for grid reference type; only one should be enabled (i.e. you can enter a ref in both and then don't know which one it is using). [11483]	Usability	No	Yes	Small	
F14	Roughness Zone 'names' can overlap on cross section schematic view and hence not be read. Would require vertical shifting of overlapping names. [11484]	Usability	No	Yes	Small	

Ref.	Recommendation	Improves	Method required	Software change required	Estimated software effort	Software notes
F15	No Section Data message appears when adding outputs for all sections. E.g. go to the Outputs tab and click on 'Add Output'. The dialog 'No Section data: B1' appears. This message could be more helpful. [11486]	Usability	No	Yes	Small	
F16	'Requested Date out of range' when using interrogator on Outputs tab. Add a few outputs and then click on 'Interrogator. With 'Select date' 'default' checked specify a depth out of range. Message: 'Requested depth out of range'. Uncheck the default box and repeat test. The depth value changes to the nearest valid depth and Froude values are calculated. This is good functionality, but would be better if the two behaviours were combined i.e. if a depth out of range is specified then the warning message should be shown followed by the data entry being modified. [11487]	Usability	No	Yes	Small	
F17	Add a 'Remove User Defined Data' Button. The only way to remove user defined data is to add none and click ok. A clear data button would be useful here. [11497]	Usability	No	Yes	Small	
F18	Add 'Set Axis Limits' to all plots. The rather useful 'set axis limits' option when right clicking on a graph is only available for the outputs tab of a cross section. Can we have this on all our graphs please? [11504]	Usability	No	Yes	Large	Includes F19 & F20. Functionality is supported in the plotting tools but needs implementing.
F19	Changed Axis limits should be remembered [11505]	Usability	No	Yes		See F18
F20	If I set some axis limits for a graph, and then change, say, the date on which I'm viewing them for, then the axis limits get reset to the default value. Can these be retained? (ties in with F19).[11675]	Usability	No	Yes		See F18

Ref.	Recommendation	Improves	Method required	Software change required	Estimated software effort	Software notes
F21	Enhancements to Vegetation growth curves. These would cover: - Memory e.g. remove/add cutting dates (ties in with F5, F12); - Different colours e.g. keep original curve but add one with cut for comparison; - Show % cut on screen – in colour of new curve; - Shift date without having to reselect percentage change i.e. one button click; - Step-change in vegetation as valued entered on 15th of each month. Suggest smooth with linear interpolation. E.g. fine leaved plants; - Suggest plotting of n-values for multiple vegetation types on one graph; - Make embedded velocity data for plants available to users; - Make biomass information available to user e.g. additional plot; - Add a note to tell user the growth model is using biomass or give them the option of using cover or biomass; and - Suggest standardised axes for n values so it is quick to see the change between curves e.g. a range of 0.01-0.50.	Functionality	No	Yes		See F5
F22	Backwater output difficult to read. Suggest Upstream / Downstream labels as in some instances bed levels may rise - not intuitive. Also, need to close a run to look at other elements e.g. cross-section water levels. Be good to allow multiple windows to be open.	Usability	No	Yes	Small	

Ref.	Recommendation	Improves	Method required	Software change required	Estimated software effort	Software notes
F23	Improve usefulness of outputs in terms of maintenance. These could include, for example, water levels for a given flow rate at different times of year and different percentage cover (see HRW SR 346) i.e. make use of growth curves to help users interpret information (would require limited consultation). Could link the flow rates used to Environment Agency gauged flows near the reach.	Functionality aids interpretation of outputs	Yes	Yes	?	Now covered in Project 2
F24	Post-process tool to calculate depth given flow rate. The existing calculation is set-up to take in depth and provide flow and users are required to interpolate values for the reverse case.	Functionality	Yes	Yes	Large	This relates to stand-alone sections
F25	The software should save 'snapshots' of results rather than multiple files, for example, where one item is altered and the model rerun. This is could be handled in a similar manner to the IWRS audit trail. A further option could be similar to software "Minitab" which is a statistical software that keeps a log of actions in a little window (date, time, change etc.) as they are implemented. This could be written to a csv file as an action log.	Functionality	Yes?	Yes	Large+	This would be a significant block of work. Worth noting that the CES has been incorporated into InfoWorks RS which provides the audit trail capability.
F26	Batch processing. It would be useful to be able to batch process runs, through for example, a 3-year cycle using the time-varying roughness n. This could be extended to enable the input monthly discharges Q to be entered and hence output levels thought time (ties in with F24).	Functionality	No	Yes	Medium / Large+	Now covered in Project 2
F27	Improve error reporting and checks on user-entered data. For example, users should not be able to enter only vegetation or only irregularity. If this happens, a message should pop-up explaining a substrate is required. There are numerous other cases.	Usability	Basic	Yes	Large	Straightforward to implement but size of task depends on number of validation cases. A full list of validation is required. For now, assume five highest priority validation cases as 'Large' effort.

Ref.	Recommendation	Improves	Method required	Software change required	Estimated software effort	Software notes
F28	Improve plotting and labels – particularly for long-section plots where a structure is present. (ties in with F22)	Usability	Basic	Yes	Medium	Need to review current long section plot and come up with scheme for improvement.
F29	Improve and clarify the definition of the downstream distances between sections on the CES 'Backwater' tab when structures are included.	Usability	Basic	Yes	Small	More of a documentation issue, though could add a note / diagram on the interface.
F30	Add an additional field in cross section grid views (e.g. General and Backwater tabs) that says what type of section each one is (river, bridge, culvert).	Usability	No	Yes	Small	
F31	Provide advice in the software on super and sub-critical flow - near the backwater tab.	Advice	Yes	Yes		*Need clarification on what is required.*
F32	Backwater plot case management. Allow plotting of multiple lines for different boundary conditions, perhaps in different colours. At present, you have to close one plot and reset this to the new boundary conditions.	Functionality	Basic	Yes	Large+	Likely to be a substantial block of work.

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