Defra/Environment Agency
Flood and Coastal Defence R&D Programme

Scoping Study into Hydraulic Performance of Bridges and Other Structures, Including Effects of Blockages, at High Flows

Proposed Research Programme

R&D Project Record W5A-061/PR7

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SCOPING STUDY INTO HYDRAULIC PERFORMANCE OF BRIDGES AND OTHER STRUCTURES, INCLUDING EFFECTS OF BLOCKAGES, AT HIGH FLOWS

Proposed Research Programme

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Statement of Use
This Project Record contains the results of the first phase of a scoping study to improve the estimation of afflux at river structures. The information in this document was produced for discussion and selection of future research. It does not represent an actual programme of work.

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Afflux, backwater, blockage, bridges, culverts, channel structures.

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EXECUTIVE SUMMARY

This report documents the results of a Scoping Study into the hydraulic performance of bridges and other structures, including effects of blockages, at high flows. The study was commissioned as part of the Defra/Environment Agency Flood and Coastal Defence Research and Development Programme, Engineering Theme. It has drawn upon reviews of current knowledge and practice, and identified further work required to develop improved practice.

The main results of the Scoping Study are detailed in the Final Report W5A-061/TR1 and annexes PR1 to 6. This accompanying report, W5A-061/PR7, outlines a possible future research programme for afflux and blockage, drawing upon the results of the Scoping Study.

There is a significant opportunity for Defra and the EA to establish best practice in the consideration of the effects of bridges and culverts at high flows relatively quickly and at low cost. A series of Targeted Research activities has been identified which would take around 18 months to implement. The research would be highly cost beneficial to flood defence operating authorities. A further programme of Strategic Research over a three to four year time scale is identified to address inadequacies in understanding and hydraulic theory. This research would be suitable for collaborative programmes with academia.

It is expected that the actual research to be carried out under Defra / Environment Agency funding in Phase 2 will be selected and developed from the research activities in this larger "Proposed Programme".

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OVERVIEW OF THE RESEARCH PROGRAMME

1.1 Primary Objective

The primary objective for this research is to allow target users to have confidence in the predicted water levels generated by current analysis methods for river channels that include bridges and large culverts. These structures may produce afflux by constraining the flow area and/or as a result of blockage.

The study has highlighted the following key issues:

1. Research should be targeted at the most common type of structures and the most important situations. These are:
   (a) Flows at or above bankfull
   (b) Bridges and culverts in urbanised (contained) channels
   (c) Bridges with embankments or roads that are overtopped
   (d) Blockage due to floating debris

2. There must be confidence in the afflux methods used.

3. Any new "tools" must be available at a range of different complexities -from a design chart/simple spreadsheet to 1D river models (such as ISIS, HEC-RAS and MIKE-11), and 2D and 3D models.

4. There is value in integrating blockage of structures into routine design and analysis. In some cases the blockage allowed for may be zero but the discipline of always considering it is best practice.

The issues of identifying and disseminating best practice can be dealt with in the Targeted Programme, and the issues of inadequate knowledge or data take more time and can be dealt with in the Strategic Programme.

The combination of the Primary Objective, the results of consultations, and the review of current theory and practice leads us to a Targeted Programme whose funding will be led by the Environment Agency. Essentially, the product of this Targeted Programme will be Afflux and Blockage methods for:

- users who require afflux determination for rapid use without a river modelling package (the Manager/Asset Maintainer and the Flood Defence Professional defined in sections 4.10 and 4.11)

- users who require the best available estimate of afflux determination for design incorporation into a river model (the Designer and the River Modeller defined in sections 4.12 and 4.13)

The Agency will benefit through the improved design of structures over and within watercourses, and improved flood risk management.

It is also proposed that a Strategic Programme of research be implemented in close accord with that proposed by the Scoping Study on "River Flood Conveyance" (HR Wallingford, 2001). Inevitably, the first part of this Strategic Programme will be centred on further research required to enhance the results of the Targeted Programme. The second part is aligned with the HR Wallingford "River Flood Conveyance" proposal in pursuing developments in fluvial modelling. It is proposed that funding for such a programme be sought from the Research Councils (EPSRC, NERC, EC Framework programmes).

1.2 A New Title

We propose that the Targeted and Strategic Research continues under the rather shorter umbrella title of *'Hydraulic performance of bridges and culverts at high flows'*. The consideration of blockage will be an integral part of the performance assessment but the pure risk elements are being dealt with elsewhere. Also it is proposed to only deal with bridges and culverts. An extension of the terms of reference to include the afflux generated by trash screens is worth investigating.

The risk and uncertainty aspects of afflux estimation are best not dealt with in isolation and can be covered under the Risk and Evaluation and Understanding of Uncertainty Theme.

Much of the work will also apply to pipes, sluices, siphons and other structures, but as they will not be treated as separate areas of investigation we suggest that they are not included in the title. The effects of scour and blockage by ice are peripheral to the core requirements of this research and are best dealt with elsewhere.

1.3 The Targeted Programme

This Interim Report has covered in some detail the basic theory and current practice for estimating afflux and blockage risk. The Targeted Programme will synthesise and integrate this existing knowledge, in addition to obtaining the most recent detail of modern research. A total of nine technical tasks are detailed in Chapter 12 (Table 12.1) towards this end, and the associated products may be summarised as follows:

- A database of "Afflux Measurements and Blockage risks"
- A database of " Bridge and Culvert types with dimensions"
- An "Afflux Adviser" for rapid use by field engineers
- An "Afflux Estimator" for detailed use by design engineers
- A manual on "Afflux determination with Blockage risk" for use by field and design engineers
- Professional development and training material

The activities required for these products are also detailed in Table 12.1, and a progress chart for their execution is given in Table 12.2.

The Targeted Programme is achievable within 18 months.

1.4 The Strategic Programme

This programme is intended to supplement the Targeted Programme with the necessary research into afflux and blockage. The research topics have been divided into two parts. The first is directly relevant to afflux, and the second is a common requirement detailed by the

Evans et al (2001) study towards fluvial design and modelling. Part 1 is detailed in Table 13.1, and has the following seven products:

- Field verification of afflux determination
- Risk analysis and uncertainty for structural blockage in the field
- Afflux determination in compound, vegetated channels
- Estimate of energy losses and their physical extent at flow expansions and contractions
- Improved estimates for the coefficients used in high bridge flows
- Investigation of the afflux of model culverts with the type of blockage
- Produce a single method for estimating afflux with its standard error

Part 2 is in accord with ongoing research into reducing uncertainty in river channel conveyance, and consists of eight research products, summarised as follows:

- Better efficiencies in design from the cost-effective use of 2 and 3D computer models.
- Revised law of the wall for use in 3D computer models.
- Adaptive grids in 2D and 3D computer models used for better simulation of river flows.
- Improved simulation of the 3D velocity field by computer models, which may result in better predictions of sediment transport
- Data accessibility by the World Wide Web
- More field data is required to support research activities
- "Flood Channel Facility" model data still needed to support research activities
- Evaluation of the use of remotely sensed data in computer model development

Ideally, the Strategic Programme should be conducted parallel with the Targeted Programme. However, this is dependent on interest and sponsorship.

1.5 Benefits of the Future Research

The benefits of the further research are as follows:

- Reduction in the time taken to estimate afflux and blockage

- Less dispute on the most appropriate methods for estimating afflux and blockage

- A clearer understanding of the significance or afflux and blockage for decision making

- Increased public confidence in flood risk management.

- Better targeting of maintenance (in particular for debris clearance)

- Improvements in UK-developed river modelling software

1.5.1 Who will benefit?

The Agency will benefit directly from this research both through greater reliability of its flood management measures (flood risk mapping, defence design) and also better targeting of maintenance. Other UK drainage authorities such as Scottish Local Authorities (who have a duty of maintenance under the Land Drainage & Flood Protection Scotland Act), Rivers Agency for Northern Ireland will also have use (and can provide a valuable input to) the research.

Asset owners and maintainers such as Highway Authorities, the Highway Agency, Railtrack, British Waterways and Northern Ireland Railways will also benefit from better design of new structures and better targeting of maintenance.

1.5.2 Financial benefits

The following financial benefits from further research have been identified:

- Improved understanding of afflux will assist the EA, developers, local authorities and insurers in assessing the longer-term financial consequences of particular management and design options.
- Improved decision making based on better estimates of afflux for flood alleviation schemes or in the design of other structures, with resulting improved value for money.
- Reduction in the cost of preparing afflux estimates through ease of access to information and methods and avoiding duplication of effort.
- Improved efficiency of Agency staff when processing applications involving bridges and culverts.
- Better operational efficiency in dealing with blockage potential.
- Improved efficiency and effectiveness of wider UK community in dealing with afflux.

It is not possible to quantify many of the benefits because:

- They are political in nature
- There are no relevant data on the longer term financial consequences of improved planning decisions.

The financial benefits are by their nature difficult to quantify and sensitivity analyses have been carried out assuming that only 50% of the estimated benefits are realised.

Financial estimates have been made of the following benefits:

Improved effectiveness of flood alleviation schemes

The effectiveness of flood alleviation schemes can depend on decisions based on estimates of the given probability of a level. This can be highly dependent on the estimate of afflux or how much blockage is considered. Estimates of afflux based on locally measured values are rarely available. It would be reasonable to suggest that at least 10% of these schemes may be influenced to some degree by afflux. This research could lead to cost increases or decreases, but in both cases, reducing uncertainty will lead to benefit either in terms of improving the level of defence (and reducing damages) or reducing the need for future scheme enhancement.

Current annual spending on flood alleviation schemes is around £100million and a saving of 0.5%-1% of this, i.e. £1 million per annum is not without reasonable basis.

Another way of approaching this is to consider the damages caused by an inadequately designed bridge or culvert. Even excluding re-build costs, damages in an urban area caused by culvert blockage can easily amount to £250,000 to £1 million per incident. The authors alone are aware of at least 2-3 incidents a year on average resulting from inappropriate consideration of blockage in design.

Improved efficiency of consenting authorities

It has been estimated that there are a minimum of 2 enquiries per week in each of the EA's 26 area offices regarding consent for new structures and that each enquiry requires 0.5 man-day of staff time to deal with. Some enquiries will require days or weeks of effort to resolve.

This equates to:	1352 Man days/year
At a cost of:	£182/day
Giving a total cost of:	£246,000 pa

Following implementation of the project, it is reasonable to perhaps see a 50% reduction in the time needed to process these applications. Thus the benefit will be reduced to £123,000 per annum.

Reduction in the cost of preparing afflux estimates through ease of access to tools/data

It has been estimated that there will be at least 3,000 afflux estimates prepared in a year by developers, local authorities, consultants, and the EA. Access to a single, reliable, up-to-date guidance will greatly simplify aspects of the task. There may be a need for prolonged dialogue with the drainage authorities and repeated or abortive calculations will be made.

It is difficult to estimate the time saved for each estimate. If, however, it averages 2 hours, then the saving would be approximately 6000 hours per year at a typical cost of £25/hour totalling £150,000 pa.

Assuming in broad terms that the afflux estimates prepared in England & Wales represent three quarters of the UK total, the saving of unnecessary cost to the country as a whole is estimated at £200,000 per annum.

Operational savings

Better targeting of operational work – particularly the clearing of blockages and prevention of blockages could have savings on maintenance and reduction in flood damages. Given that a single blockage incident can cause many hundreds of thousands of pounds of damage the savings here are substantial. Better targeting of maintenance will make better use of scarce resources and allow them to be used more efficiently.

Summary of financial benefits

Although the above appraisal is only indicative, it shows that annual benefits of £1 million plus are possible through better methods of afflux and blockage estimation. The research proposed has a total expenditure of £800,000. The benefits of the targeted programme (cost estimate - £380,000) are clearly defined and achievable. This research is therefore clearly financially beneficial and the positive cost-benefit ratio would appear to remain robust even with allowance for the approximate nature of the calculations.

Other non-financial benefits of the research are:

1.5.3 Non-financial - technical

- Maximise the benefits from other research initiatives such as the river channel conveyance project
- Better training and awareness of UK professionals
- Provide easy access to the data required
- Provide reliable base data for further research

1.5.4 Non-financial - operational

- Single location for retrieval and dissemination of afflux and blockage data
- Access for all UK authorities to the information and data
- Reduction in response times to development control applications

1.5.5 Non-financial - other

- Consistency between Agency regions and other UK drainage authorities.
- An enhancement to the image and credibility of the drainage authorities.
- Better guidance will help to reduce the pressures on Agency staff, particularly as recruitment of engineering and other expert staff is proving difficult.
- The creation of an easily accessed and comprehensive afflux and blockage guide will help create a definitive single source of data leading to fewer disputes on data sources and adding clarity to the planning and design process.
- Use by Researchers, Universities and Schools – spreads knowledge.
- In the longer-term, a better understanding of flooding and risk should reduce public dissatisfaction with apparently flawed planning decisions or inadequate flood alleviation schemes.
- Improved competitiveness of UK consultants working overseas.

No attempt has been made to quantify the non-financial benefits but they clearly do have a financial benefit and a not inconsiderable one.

2 TARGETED PROGRAMME

The Targeted Programme is principally intended to take existing data and methods into practical application and benefit for river management. It also seeks to deliver best practice. Possible co-funders for the programme, in addition to the Environment Agency, are the Highways Agency, British Waterways, Railtrack, and other Drainage Authorities.

The Targeted Programme is independent of the Strategic Programme, in that it can be implemented without the completion of the Strategic Programme. Nevertheless, this twin-track strategy has been advocated by the Environment Agency as a key component to bringing the benefits of research into general use. The detailed activities and products offered in the Targeted Programme are listed in Table 12.1, and each item is summarised below.

In consultation with Engineering Theme Leader Dr. Mervyn Bramley and Theme External Advisor Dr. Andrew Pepper, the targeted programme is presented below in two phases; Phase I consists of core modules to develop and promote tools for afflux estimation (incorporating blockage frequency analysis), Phase II consists of modules to establish databases for afflux, blockage, and bridge and culvert types.

The management of the targeted programme will include liaison with the conveyance estimation R&D programme to ensure convergence of outputs where appropriate. In particular, software architectures, data, terminology and training requirements will be coordinated.

2.1 Phase I – 'Afflux Estimation System'

The Phase I project will largely involve the development of two afflux tools (the 'Afflux Adviser' – designed for rapid overview analysis, and the 'Afflux Estimator' – designed for detailed analysis), production of a methodology best practice manual and, in a subsequent stage, training and promotion of the tools within the user community. This later stage is best carried out in parallel and part of the testing and training and dissemination of the Conveyance Estimation System. The Phase I project has been named the '<u>Afflux Estimation System</u>', underlining its ultimate integration with parallel work on conveyance estimation, and vice versa. An R&D management task will also be a continuous part of both phases of the project.

The Afflux Estimation System Phase I research project is outlined below, and broken down into discrete tasks.

Task T-0: Management (Phase I & II)

Background	The Afflux Estimation R&D project begins with the requirement for experienced leadership and vision.
Objective	To ensure successful outcome of R&D, appropriate linkage with related initiatives and proper uptake of the R&D outputs.
Scientific context	This task will benefit from an overview of current science in hydraulics, hydrology and risk and uncertainty, allied to experience of applications of methods in practice.
Outline specification	It is anticipated that a project manager will be in position throughout the 18 month project duration, and the necessary continuity required for knowledge acquisition, analyses and dissemination will be maintained. In general, all phases of the project will be managed by a single person. All activities and progress during the project will be recorded on a project website. The Project Manager will attend the monthly meetings of the Project Management Team of the Conveyance Project.
Linkages	It is important that the project manager has and maintains close links with the other Defra/EA research initiatives and also practitioners.
Indicative costs	£52,000 (for all phases of the Targeted Programme)

Task T-3: Testing Existing Afflux methods

Objective	To test and identify most appropriate methods for UK structures.
Scientific context	Afflux determination methods can be generally divided into single coefficient methods for use by hand calculation, and triple coefficient, iterative methods as used in 1D computer models (Appendix 1). The single coefficient methods can be simply calculated by use of spreadsheet programming, whereas triple coefficient methods are more demanding.
Outline specification	It is therefore intended to check all single coefficient methods by spreadsheet, for bridges and culverts, using new and existing afflux data. The triple coefficient methods must be run for each of the EA's BIS 'A' list models (HEC-RAS, ISIS, MIKE 11) in order to solve for the afflux. Again, new and existing data will be examined using the computer codes, and the most appropriate method for UK structures will be sought.
Linkages	This task establishes the methods to be taken forward to develop tools and best practice. It depends on availability of existing data and/or collation of new test data.
Indicative costs	£20,000

Task T-5: "Afflux Adviser"

Objective	To develop an "Afflux Adviser" tool for rapid afflux estimation.
Context	The Afflux Questionnaire (Appendix 2) has established the main users for Afflux data. These may be summarised as the Field and the Design Engineer. The Field Engineer requires a rapid method of estimating afflux for say, maintenance purposes.
Outline specification	It is therefore intended to optimise the single coefficient methods towards the most appropriate for UK design, and present it as a fast spreadsheet solution. This "Afflux Adviser" will contain a blockage application that may be used at will. As this task proceeds, feedback will be sought from user representatives about the product suitability.
Linkages	This task will provide spreadsheet software that will be documented in the "Afflux Manual". It will be essential to coordinate with the Conveyance Estimation System to ensure compatible methodology, data handling and software approaches, where appropriate.
Indicative costs	£27,000

Task T-6: "Afflux Estimator"

Objective	To develop an "Afflux Estimator" tool for detailed afflux estimation.
Context	The Design Engineer requires the best available tools, and therefore the triple coefficient method is more detailed and appropriate.
Outline specification	Following the testing of Afflux in 1D models (T-3), the most suitable model design will be selected and programmed for use with a single structure. Modern object oriented code such as Visual Basic will be used to code a visually interactive, bridge design programme. This "Afflux Estimator" will contain a blockage application that may be used at will. As this part of the project proceeds, feedback will be sought from user representatives about the product suitability.
Linkages	Will make use of conclusions about most appropriate calculation methods, based on the Scoping Study and Task T-3.
Indicative costs	£55,000

Task T-7: "Afflux and Blockage Risk Manual"

Objective	To document the R&D outputs in user manual form, leading to identification of best practice.
Outline specification	The most important part of any desk project is the descriptive manual. With this in mind, the philosophy and use of the Afflux Adviser and Estimator will be detailed with frequent user feedback. The manual would cover the results of Items T-3 to T-7. The manual should also consider a review of legal actions relating to blockage (which appear to be increasing as a result of new planning guidance such as NPPG7 and PPG25) to establish 'best practice' as the courts perceive it.
Linkages	Depends on the research and development outcomes of the preceding Tasks.
Indicative costs	£27,000

2.2 Phase I (additional) – Testing & Dissemination of 'Afflux Estimation System'

Task T-8: Initial testing and validation

Objective	To test and validate the R&D outputs.
Context	This Task is part of the process of ensuring effective uptake of the R&D outputs.
Outline specification	Following the results of the Questionnaire (Appendix 2), we have a list of key practitioners. A list of afflux users outside the EA is also given in Chapter 4.7. These persons will be contacted for discussion and testing of all products produced within this contract. All relevant feedback will be incorporated into the final design. The testing should include both design practitioners and also development control staff.
Indicative costs	£10,000 This task should be co-ordinated with and run parallel to the testing of the Conveyance Estimation System.

Task T-9: Training and Dissemination

Objective	To deliver training in the use of the afflux tools.
Context	This Task is part of the process of ensuring effective uptake of the R&D outputs.
Outline specification	The final product is a Professional Development Programme that is used to disseminate all data and software produced during the project. Provisionally, it is planned that this programme will be effected by means of "Single Day Awareness Courses" and "Dual Day User Courses". Each training course will be accompanied with relevant training material. Subsequent coordination with other R&D may alter this.
Linkages	It has been established that there are likely to be benefits from coordination of training in afflux analysis with the training and dissemination for conveyance R&D. This may involve some integration of the training courses and materials.

Indicative costs	£17,000 This task should be co-ordinated with and run parallel to the testing of the Conveyance Estimation System.

2.3 Phase II – Afflux Estimation System

Project management is continued by extension of Task T-0 from Phase I. Substantive tasks for Phase II are as follows:

Task T-1: "Afflux and Blockage" database

Background	A tentative list of existing Afflux and Blockage data is given in Appendix 3. These data have been abstracted from papers and reports in the literature, and are mainly from the US and UK sectors. An exhaustive study on all possible data sources has not been undertaken.
Objective	To produce a WWW-accessible database of blockage risks and afflux measurements suitable for UK situations.
Scientific context	Reliable field data on afflux is difficult to obtain. However there are measurements that have been identified by this scoping study, and possible sources of data are discussed in Sections 6.10 and 6.11.
Outline specification	It is probable that, as in the fields of US and UK hydrology, the US has a greater diversity of bridge structures and therefore afflux data that is not immediately relevant to the UK sector. It is therefore necessary to screen international data prior to using it as a possible design source for the UK. Note that despite this obvious comment, the USBPR afflux design method is used internationally. Particular use of the World Wide Web will be made towards attracting data by means of publishing existing data and soliciting contributions. There are, for example, numerous hydrology/hydraulics websites that may be solicited individually for information on bridge and culvert hydraulics.
Linkages	This task will link directly with the "Bridge and Culvert Types" database described below.
Indicative costs	£17,500

Task T-2: "Bridge and Culvert Types" database

Background	The comments for T-1 also apply to the Bridge and Culvert Types database, except that the focus is now on the UK.
Objective	To produce a WWW-accessible database of UK bridge and culvert types, including dimensions.
Scientific context	Structure dimensions and geometry are key controls on afflux and knowledge of the range of configurations existing in the UK will be valuable in guiding the use of best practice tools.

Outline specification	A list of bridge and culvert authorities has been given (Benn and Bonner, 2001), and they will be contacted for detailed information. Particular attention will be made towards the presence in database entries on the numerous bridge variables that can vary the afflux determination. These include the span and height, type of bridge piers, eccentricity, skew and design flood level. The data will be geo-referenced, so that it may be checked against data from other sources.
Linkages	This task will link directly with the "Afflux and Blockage" database described above.
Indicative costs	£15,000

Task T-4: Blockage Frequency analysis

Objective	To determine a frequency model for blockage.
Scientific context	A paper on Blockage Risk Assessment (Faulkner, 2001) has been presented as an expert paper in this report. This method for determining blockage is analytical, in that it attempts to estimate a blockage probability in terms of the flood magnitude, the nature of the blockage debris, and the geometry of the bridge or culvert. As an alternative, blockage risk may be ascertained in a similar way to conventional flood risk, using statistical extreme value analysis. If a time series of the number of blockage events for a catchment could be established, then the number of data could be ranked annually and analysed as for annual maximum flows. A blockage frequency or return period could then be associated with the number of catchment blockages, and the uncertainty may be estimated using Monte Carlo analysis (if an analytical probability distribution cannot be ascertained).
Outline specification	Data should already be available from Agency and other drainage authority databases or could easily be collected with minor modifications to existing reporting procedures. For example, the statistics may show that in a particular catchment, 1 bridge and 5 culverts are blocked, on average, at least once in every 100 years. It is probable that the number of blockage events are dependent upon the flood frequency, and thus a 100 year flood level could be modelled for the catchment by using the 100 year flood in conjunction with 1 blocked bridge and 5 blocked culverts. Obviously, the above "blockage frequency analysis" depends on collating the relevant existing data. In the absence of detailed records, attempts will be made to simulate a time series of blockage events from bridge and culvert maintenance records.
Linkages	This task will provide the method to be incorporated within the Afflux Adviser/Estimator tools and manual.
Indicative costs	£22,000

2.4 Activities and Outputs of the Targeted Programme

Table 12.1 below gives a breakdown of the key activities and outputs for each of the Tasks described above. The breakdown illustrates the structure of Phase I and II of the Afflux Estimation System project.

Table 2.1: Summary of Targeted Programme activities and products

Item		Title	Key activities	Product
PHASE I / PHASE II	T-0	Project planning, management and integration	• Establish a database of potential users • Contact the potential users for feedback • Manage system design and documentation • Arrange initial training • Propose mechanisms for future support and development • Maintain a website detailing activities and progress • Develop and deliver a dissemination strategy	The successful adoption of an "Afflux Estimation and Blockage Risk" design system by field and design engineers
	T-3	Testing Afflux methods	• Use spreadsheet calculations to test single-coefficient methods in BIS codes • Use iterative programmable code to test triple-coefficient methods in BIS codes	Dissemination of "Afflux determination methods" to potential users for feedback
PHASE I	T-4	Frequency Analysis of Blockage data	• Preparation of an "Annual Maximum Number of Culvert Blockages" frequency chart for catchments with appropriate data • Analysis of the frequency uncertainty using Monte Carlo methods • Investigate the increased afflux for annual maximum extreme flows combined with blockage	Dissemination of "Blockage Frequency analysis" to potential users for feedback

Table 2.1: Summary of Targeted Programme activities and products

Item		Title	Key activities	Product
PHASE I	T-5	Afflux Adviser for rapid use	• Optimisation of single-coefficient methods for determining afflux (with or without blockage), with the aid of user feedback • Method to be presented with the aid of spreadsheet programming and animation • Estimate the standard error associated with the final design method • Disseminate results to potential users for feedback	An "Afflux Adviser" for determining Afflux values (with or without blockage), for rapid use.
PHASE I	T-6	Afflux Estimator for Design	• Optimisation of triple-coefficient methods for determining afflux (with or without blockage), with the aid of user feedback • Method to be presented with the aid of spreadsheet programming and animation • Estimate the standard error associated with the final design method • Disseminate results to potential users for feedback	An "Afflux Estimator" for determining Afflux values (with or without blockage), for detailed use by design engineers and fluvial mathematical modellers
PHASE I	T-7	Afflux and Blockage Risk Manual	• Prepare a manual describing the use of the Adviser and Estimator	A manual entitled "Afflux determination with Blockage Risk"
PHASE I (supplementary)	T-8	Initial testing and validation	• The Afflux Adviser to be tested and validated by all field engineers, and feedback requested • The afflux Estimator to be tested and validated by all design engineers and potential users, and feedback requested. • All feedback to be incorporated into the final system design	Final version of the "Afflux Adviser" and the "Afflux Estimator"
PHASE I (supplementary)	T-9	Professional development programme	• Preparation of additional training materials for the above • Establishing programme logistics	Establishing an "Afflux determination" training programme

Table 2.1: Summary of Targeted Programme activities and products

Item		Title	Key activities	Product
PHASE II	T-1	Afflux and Blockage data collection and assembly	• Screen existing international field and laboratory data for suitability towards UK rivers • Assemble modern field and laboratory data • Search for supporting data such as that used in existing river models • Compile a database of Afflux measurement and Blockage risk • Publish the database on the World Wide Web with the view to soliciting additional information	A database of UK oriented “Afflux Measurements and Blockage Risks”
	T-2	Bridge and Culvert database	• Contact all UK Bridge and Culvert Maintainers for a listing of the structure types with dimensions • Compile a database of UK Bridge and Culvert types with dimensions • Publish the database on the World Wide Web with the view to soliciting additional information	A database of UK “Bridge and Culvert types”. The database will include locations, dimensions, opening ratios, eccentricity, skew and other relevant variables.
PHASE II	T-4	Frequency Analysis of Blockage data	• Preparation of an “Annual Maximum Number of Culvert Blockages” frequency chart for catchments with appropriate data • Analysis of the frequency uncertainty using Monte Carlo methods • Investigate the increased afflux for annual maximum extreme flows combined with blockage	Dissemination of “Blockage Frequency analysis” to potential users for feedback
Final product: • A rapid method of Afflux determination • A design method for Afflux determination • Improved estimation of water levels, thereby reducing the costs of capital, maintenance and risk				

The total indicative cost for the Targeted Programme is £262,000. Of this Phase I requires £150,000, the testing and dissemination of the Afflux Estimator, £38,000 and Phase II £74,000.

3 STRATEGIC PROGRAMME

The Strategic Programme is needed to carry the work forward and produce a second generation of methods that will bring additional benefit to users. Funding for different parts of this programme will be met by different agencies. For example, Defra, the Scottish Executive and the Department of Agriculture and Rural Development in Northern Ireland may be interested in the data collection aspects whereas the Research Councils, EPSRC and NRC, will be interested in the pure research aspects. There may also be the possibility for additional collaborative funding from the EU in future "Framework" programmes.

As mentioned in Chapter 11, the Strategic Programme consists of 2 parts. Part 1 is detailed herein and listed in Table 13.1. It consists of 7 research items that are immediately sequential to the Targeted Programme. Part 2 consists of the Evans et al (2001) "River Flood Conveyance" research items that are common to both studies, and have been summarised briefly in Chapter 11. It is expected that the entire programme, if wholly funded, will take from 3 to 5 years for implementation.

3.1 Item ST-1: Field data collection

There is a need for continuous monitoring of field data from bridges and culverts, so that afflux can be measured for any specific flow condition. While it is recommended that sites with an existing and reliable means of flow measurement are selected, it is important that additional flow velocity instrumentation is installed specifically to collect data on afflux. It is unlikely that existing sites will provide the required level of detail for research purposes. The decision as to which bridges and culverts, and how many are monitored will depend on cost, suitability of sites, and being able to maintain the equipment. Furthermore, there is a need for velocity profile as well as water level data when verifying mathematical models of hydraulic structures. Additionally, it is necessary that the data be acquired real-time by telemetry, as no field sensor or data logger can be trusted to operate both reliably and continuously (Mantz, 2001).

As a start towards such a programme, it is suggested that at least 3 bridges or culverts be monitored continuously for water level at the 4 sections defined in Figure 6.4. Ideally, structures should be chosen which are subject to high afflux and frequent flooding. One structure should be likely to overtop or surcharge at relatively frequent flood intervals. The measurement of velocity profiles by acoustic means is an expensive effort, and therefore it is suggested that one profiler be used initially, and once proven should be replicated at other sites.

With the above programme, the verification of mathematical models can be made with more confidence. Furthermore, the use of modern technology towards real-time data collection can be used with bridge models to give real-time afflux determinations, and forecasting. Such information is of use towards the "Flood Warning" mandate of the Environment Agency, and may also be broadcast on the World Wide Web.

The Environment Agency has the best expertise for installing such instrumentation, and will be best able to suggest suitable sites. In summary, the requirements for field data collection are:

1. Use a structure opening ratio of 50% or less
2. Ensure the structure has an afflux of at least 200 mm (at the median flood flow)
3. Ensure the structural geometry follows one of the typical categories identified in Item T-2 and also meets the requirements of Item ST-3
4. Ensure the site has an established rating curve or method of recording flow

Note that research costs may be significantly reduced by selecting sites where electrical mains power, telemetry and data recorders are already installed.

3.2 Item ST-2: Blockage Frequency Analysis

It is inevitable that the Blockage data required for Blockage Frequency Analysis is limited, and that bridge and culvert blockage has been reported inadequately in the past. Ideally, Blockage Frequency Analysis is required for the all the catchments in the UK, in accord with the S105 Flood Risk Mapping programme. It is however doubtful that this can be achieved without the reorganisation of the reporting methods used by maintaining Authorities.

It is hoped that the Targeted Programme will reveal at least one catchment where the reported blockage data is sufficient to demonstrate the validity of a Blockage Frequency Analysis. However, a Strategic Programme should be geared at working with Authorities to develop data collection methods. It follows that when Blockage frequency can be determined from such data, the S105 Flood Risk Maps can be amended to allow for blockage.

3.3 Item ST-3: Compound channels/Overtopping flow

Natural streams are not straight, and their floodplains are usually much rougher than the unvegetated main channel (Figure 6.1). Unfortunately, existing afflux theory in 1-D models assumes straight streams with uniform roughness. There is a need to extend existing theory to the real world, by introducing natural variabilities (which may also include skewed bridges). In the past, this has been hampered by the complex calculation involved. However, computer technology that is correctly applied may overcome some of these difficulties.

A conventional method for expanding stream variability is that of physical modelling. The large Flood Channel Facility at HR, Wallingford is ideally suited to examine afflux determination for compound channels. It is therefore proposed that laboratory investigations should be conducted, and combined with the field results of Item ST-1 to improve afflux prediction.

3.4 Item ST-4: Two dimensional (2D) modelling

The approach and exit flow to a bridge or culvert is not 1D as modelled using the currently, most widely used, river modelling packages. It is therefore relevant that modelling improvements could be made by using 2D and even 3D computer codes. This has in fact been investigated by the US Army Corps of Engineers, who used field data from US bridges. It is therefore relevant that parallel studies be initiated for UK bridges.

Although the use of say, a 2D model requires the introduction of new coefficients for fluid turbulence, the correct interpretation of field data by the model adds confidence to the final result. A correct 2D model is able to determine the length of the entrance and exit reaches where energy is lost. The latter physical length is, at present, simply estimated by guesswork for a 1D model.

3.5 Item ST-5: Physical modelling of high flows

Physical model testing of an increased range of bridge and culvert structures would allow increased confidence in existing data and an extension to areas lacking in detail, i.e. multiple arch bridges, skewed approaches, non-uniform channel geometry, influence of channel grade and shape. Laboratory testing would also allow determination of sensitivity to eccentricity effects, differing pier widths and arch geometries.

Although the river modelling programs use similar theory for high flow situations (flows above the bridge or culvert soffit), the theory is still subject to high empiricism. For example, a weir flow equation is used when the structure is fully submerged, yet most weir flow coefficients have been derived for modular flow. The estimation of flow discharge using a drowned weir flow has been minimally researched. It is therefore relevant that the subject be researched with the view to understanding flow over fully submerged bridges.

The estimation of afflux for high flows is complex since the flow varies from a sluice gate type, to an orifice, to a pressurised orifice, then a combined weir and orifice, and finally a submerged weir flow. Systematic physical modelling is required to examine the entire rating curve for high flows over varied bridge types.

3.6 Item ST-6: Physical modelling of culvert blockage

It is inevitable that the frequency for culvert blockage will be higher than that for bridges. This is further aggravated by the presence of trash racks used for culverts, which reduce the opening size considerably. It is therefore relevant that any physical modelling for blockage be first addressed for culverts.

A particular example towards the variability of culvert afflux is whether the culvert is partially blocked from the top (say by wood) or from the bottom (say by sediment). Such an effect can be investigated in the laboratory with the aid of simple physical models. The modelling scale must however be very large.

3.7 Item ST-7: Uncertainty of Afflux analysis

This study has highlighted the issue of uncertainty, since a standard error of estimate is required for any design consideration. At present, the only error that can be associated with the many methods of Afflux determination is that of the variability of the results. If the afflux determination can be reduced to at least one or two methods, then the uncertainty can be reduced. This can only be achieved by the analysis of more field and laboratory data.

Table 3.1: Summary of Strategic Programme activities and products

Item	Title	Key activities	Product
ST-1	Validation of the Afflux Estimator	• Continuously monitor the water levels at say, 3 bridges in the field, for calibrating afflux determination. • Choose bridges for which the stage-discharge relation is well documented, and which are known to incur high flows above the soffit. • Also measure velocity profiles at bridge sections using an Acoustic profiler. This will enable the determination of afflux using momentum as well as energy methods.	Field verification of Afflux determination
ST-2	Improved Blockage Frequency estimates	• Establish a rapport with a Local Drainage Board who will record Blockage effects for every storm. Although it is expected that the storm frequency and blockage frequency are dependent, this must be verified. • Prepare charts for the extreme value analysis of the annual maximum number of blockages for a catchment, and compare with annual maximum river flows. • Repeat the investigation for several catchments, and compare the uncertainty of results using Monte Carlo estimates for the standard error.	Risk analysis and uncertainty for structural blockage in the field
ST-3	Investigate afflux in compound channels with vegetated floodplains	• Many UK river channels have vegetated floodplains which are infrequently flooded. The roughness for these surfaces increase considerably, and this influence on afflux should be investigated. • Laboratory investigations may be conducted using the existing flood Channel facility at HR, Wallingford • Field investigations may be incorporated into Item ST-1.	Afflux determination in compound, vegetated channels
ST-4	2D modelling of Afflux to quantify expansion and	• The US Hydrologic Engineering Centre (HEC, 1995) conducted 2D modelling experiments to quantify contraction and expansion energy losses. Empirical eddy viscosity coefficients are now required in the	Estimate of energy losses and their physical extent at flow expansions and contractions

Table 3.1: Summary of Strategic Programme activities and products

Item	Title	Key activities	Product
	contraction energy losses	model instead of the energy loss coefficients required in 1D flow. The method therefore provides an alternative for afflux estimation. • In addition to head loss, the length of the expanded or contracted flow may be estimated.	
ST-5	Physical modelling of high flows	• The high flow equations (sluice, orifice and weir) are the most important in a flood situation. Yet the coefficients used in their evaluation are still empirical. They therefore need to be uniquely tested and calibrated for bridge configurations. • Since it is unlikely that high flow levels and velocities will be measured accurately in the field, physical modelling is of importance.	Improved estimates for the coefficients used in high bridge flows
ST-6	Physical modelling of culvert blockage	• A culvert opening may be blocked from the top down (say by wood), or from the bottom up (say by sediment). It is possible that the afflux may change for either condition, thus adding a further variable towards its estimation. • The variability of blockage can be modelled in the laboratory, and its influence investigated. • In particular, the increase of afflux due to differing blockage conditions at different high flows may be modelled.	Investigation of the afflux of model culverts with the type of blockage
ST-7	Uncertainty analysis for the estimation of Afflux	• At present, uncertainty can only be estimated by comparing the standard deviation of results using different methods. With the advent of a continuous series of afflux data from ST-1, it is be hoped that a single method will be established for UK bridges, and the uncertainty will be considerably reduced.	Produce a single method for estimating afflux