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

Afflux at bridges and culverts

Review of current knowledge and practice

R&D Technical Report W5A-061/TR1

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AFFLUX AT BRIDGES AND CULVERTS

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Statement of Use
This Technical Report contains the results of the first phase of a study to improve the estimation of afflux at river structures in high flows. The information in this document will be used in developing improved software and guidance for flood defence and land drainage practitioners, and is made available for reference and use.

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

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EXECUTIVE SUMMARY

This report sets out the results of a Scoping Study into the hydraulic performance of bridges and other structures, including effects of blockages, at high flows. It reviews current knowledge and practice. A separate document was produced which identifies the options for further research and development to improve current practice. This includes the need to

- develop robust algorithms for afflux and blockage risk,
- collect good quality field data,
- provide specific tools for users (including a robust afflux estimation system),
- consider any further gains and benefits from research.

This review of current knowledge and practice contains useful information as it stands and is published to make this available for practitioners pending the production of improved tools (due in late 2005).

The approach taken to the Scoping Study has been a mixture of consultation with key practitioners and academics, review of available literature and condensing of existing knowledge within and outside of the project team. Also specialist review papers have been commissioned from leading industry practitioners, and are published in a separate Technical Report.

Key findings

- There is confusion as to the definition of afflux and how it differs from headloss. For any flow, afflux is defined as *the maximum difference in water level, at a location upstream of the structure, if the structure were removed.*

- There is a general lack of confidence of users when estimating afflux. Users are unsure as to which is the 'best formula' to use in particular situations and many have no 'feel' for how much afflux to expect at high flows.

- Existing guidance is poor, either because it involves using several information sources, or because it is overly complex or too design-orientated.

- The most typical structures analysed are existing arched bridges and arched culverts.

- The most critical locations are considered to be in urban areas or reaches with formal flood defences, particularly where the structures may be subject to blockage. The flow conditions of most interest are bank-full or when structures are overtopped.

- The most typical tools available for estimating afflux are hand calculation or a 1-D river model such as MIKE-11, ISIS or HEC-RAS.

- Some of the most important users of afflux information are development control officers within the Environment Agency, Internal Drainage Boards and Local Authorities. Few of these users have access to river models and are unlikely to be able to make use of them even of they were available. Developers (and their consultants) are also important users of afflux data and estimation tools.

- The implementation of existing afflux formulae in river modelling software is poor. It is generally not possible to readily compare different formula and it is not made clear to the user the relative importance of the various input variables as regards their affect on afflux. The significance of the opening ratio, angle of approach and tailwater depth in particular are not highlighted. The significance of cross-section spacing on the afflux calculations is not readily apparent to the user.

- The available datasets on afflux are largely from laboratory studies and are poorly documented. There is little awareness or agreement of how afflux should be measured in the field – probably because it is rarely done. The currently available data is predominantly for bridges and is extremely variable in quality. Field data is required for bridges and culverts where overtopping occurs and for structures blocked with floating debris in order to confirm the adequacy of existing estimation methods. To obtain better field data will require a specifically targeted effort. All datasets could be improved by being clearly linked to blockage ratio and tailwater depth.

- Blockage is considered an important issue, particularly with regard to trash screens and culverts, and this adds to the uncertainty of afflux calculation. There is currently no consistency on when or where blockage should be a consideration in an analysis. There is no guidance on how blockage should be best addressed in flood risk mapping.

- There is a reasonable degree of confidence among users and experts in the SW Region 'Blockage Risk' model, which was examined under this study.

- Professionals estimating afflux or blockage in the UK typically have a minimal background in hydraulics and are unlikely to have used hand methods for afflux estimation. This contrasts sharply with US and other European practice, where professionals are more likely to have specific background experience.

- There are limitations to using physical/laboratory models to estimate afflux. These limitations are more pronounced for blockage. Physical models will still require prototype (field) data for validation.

Afflux estimation and decision making in a risk-based framework

Defra, the Environment Agency (EA) and other operating authorities manage the risk of flooding. They have recognised the value of considering the performance of systems of defences, within risk-based methods of planning, design and management. Key concepts are performance (achieving a desired outcome) and risk (the chances and consequences of failing to do so).

Afflux and blockage at structures are important components of flood risk, and thereby influence the performance of structures, and hence of defence systems. Conveyance, which is also a topic of Defra/Environment Agency research, plays a related role in determining reach performance. In both cases, uncertainty is an implicit and, increasingly, explicit part of management and decision making.

Future practice regarding the hydraulic performance of structures and reaches should therefore seek to adopt a consistent language and framework for addressing risk, performance and uncertainty. This will be guided, wherever appropriate, by the risk-based framework to which Defra and operating authorities are moving. This follows the general approach set out in a recent R&D report on 'Risk, Performance and Uncertainty in Flood and Coastal Defence' (Defra/EA R&D Technical Report FD2302/TR1), which has provided a review of concepts and methods. It is agreed that a consistent approach should be adopted to dealing with risk and uncertainty across the different flood management guidance tools and techniques now being developed or used.

Natural variability underlies most flood risk analysis, and contributes to the uncertainty about afflux and blockage, not least through randomness in the frequency and magnitude of flood flows.

Knowledge uncertainty about afflux includes uncertainty about process models, resulting in the existence of many different methods for estimation, and uncertainty about data, especially the lack of 'benchmark' information on measured afflux. This contrasts for instance with conveyance estimation where there is greater agreement on the use of a formula (Manning) and related data (such as VT Chow or the new Conveyance Estimation System).

Process uncertainty associated with the different afflux estimation methods is not necessarily as significant as it first appears. There are clearly differences in afflux estimates depending on the choice of a particular set of equations and the parameters within them – but these generally do not lead to variations of more than 10-150mm for in-bank flow. Where process uncertainty is most marked is when flow reaches bank-full, or water levels reach or exceed the bridge/culvert soffit. In these situations current practice is almost universally to use an orifice or weir representation. Whether this is a valid approach to assessing the effects of structures on water levels at high flows is a key issue, and one that requires further investigation.

This study has shown that much of the uncertainty about afflux associated with data can be attributed to the location of the cross-sections used in calculations, particularly where river models are used. This can be addressed by providing clearer guidance and training, improving software packages, and ensuring that existing guidance such as the EA's National Survey Specification and Flood Risk Mapping Guidelines are updated accordingly.

Recommendations for improving current practice

The uncertainties identified above are reflected largely in the confusion generated by having several different methods for afflux estimation and the lack of 'benchmark' information on measured afflux. The research programme developed within this scoping study has been designed to advance on this position. Key recommendations are:

- Setting out the available methods with a clear understanding of the limits of their validity and known 'pros' and 'cons'.
- Providing a tool that allows rapid comparison of the valid methods and provides a clear visualisation of the process.
- Providing reference examples of structures stating the afflux and the features of the structure that have most influence on the afflux.
- Future development of afflux estimation tools needs to be integrated with the development of (a) conveyance estimation, and (b) overall performance-based flood risk management systems.

Bridges and culverts come in a multitude of sizes, shapes and interact with the river flow in numerous ways. It will never be possible to derive universal approaches that will fit all these situations exactly. A reasonable aim should be to develop procedures that will adequately address the most common structures/scenarios but will also clearly identify the 'special' cases, which require the use of specialist approaches such as physical modelling or 2-D or 3-D computer modelling.

Blockage

Blockage is a material consideration when assessing the effects of a bridge or a culvert at high flow and adopting a risk-based approach to flood management. It should not be an 'add-on' and it will be helpful to introduce the discipline of always considering blockage. The key questions relating to blockage are:

1. What material or objects might be available to cause a blockage?
2. What is the risk of blockage and the uncertainty associated with this?

The answer to the first question is already well known historically (but could change in the future). In the UK, blockage is usually caused by floating debris from natural and anthropogenic sources that collects on the piers and abutments and at the soffit of bridges and culverts. Blockages from sediment accumulations, ice, and large obstructions (everything from caravans being washed downstream to whole trees) are much rarer.

The risk of blockage is much more difficult to quantify and research into the subject is severely hampered by the difficulty of obtaining useful data. The risk of a particular structure blocking (which is a key question for new structure design) is a subtly different issue to the additional flooding risk blockage may present along a whole watercourse. This latter point focuses the question to 'what is the additional flooding risk that blockage may present?' The question needs to be addressed within the analysis of the overall system, and should be included in flood management decision-making, flood risk maps and assessments. Issues relating to the management of fluvial defence systems are currently being assessed through an R&D Scoping Study on Performance Based Asset Management Systems (PAMS).

Future research on afflux at bridges and other structures

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 programme of Targeted Research has been identified which would take 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 proposed to address inadequacies in understanding and hydraulic theory. This research is also cost beneficial and would be suitable for collaborative programmes with academia.

Best interim guidance

Until the research is completed, Appendix 4 of this document provides details of best interim guidance for the estimation of afflux and blockage.

ABBREVIATIONS

ADA	Association of Drainage Authorities
EA	The Environment Agency
ASCE	American Society of Civil Engineers
BIS 'A'	Best Interim System, Class A
CEH	UK Centre for Ecology and Hydrology (formerly IH, Institute of Hydrology)
CFMP	Catchment Flood Management Plan
CFR	US Code of Federal Regulations
CIRIA	Construction Industry Research and Information Association
CIS	Commonwealth of Independent States
CIWEM	Chartered Institution of Water and Environmental Management
CoSLA	Confederation of Scottish Local Authorities
Defra	Department for Environment, Food & Rural Affairs (formerly MAFF)
DTLR	Department of Transport, Local Government and the Regions
IDB	Internal Drainage Board
FEMA	US Federal Emergency Management Administration
FHWA	US Federal Highways Administration
FRMA	Flood Risk Mapping Framework Agreement
GIS	Geographic Information System
HA	UK Highways Agency
HEC	Hydrologic Engineering Center, Davis, California
HEC-RAS	HEC River Analysis System
HRW	HR Wallingford
ICE	Institution of Civil Engineers
IFM	Indicative Flood Map
ISIS	HRW/Halcrow river modelling programme
JBA	JBA Consulting - Engineers & Scientists
LEAP	Local Environment Agency Plan
MIKE 11	DHI (Danish Hydraulic Institute) river modelling programme
MM	Mott MacDonald Consulting Engineers
NCPMS	National Capital Programme Management Service
NSF	National Science Foundation
NEECA	National Engineering & Environmental Consultancy Agreement
SEPA	Scottish Environment Protection Agency
SNIPS	Construction, Standards and Rules of the former USSR
TAG	Theme Advisory group
USACE	United States Army Corps of Engineers
USBPR	United States Bureau of Public Roads
USGS	United States Geological Survey
WSA	WS Atkins Consulting Engineers
WSPRO	FHWA Water Surface Profile modelling programme

PRINCIPAL NOTATION

A numerical subscript attached to a symbol usually indicates the location of the cross-section, or part of a cross-section, or the reach of a river according to context.

a	Cross-sectional area of flow in a (part full) bridge waterway opening (m^2).
a_W	Total cross-sectional area of a waterway opening when flowing full (m^2).
A	Total cross-sectional area of flow in a river channel (m^2).
A_N	Cross-sectional area of flow between the channel bed and normal depth line (m^2).
A_P	Cross-sectional area of the submerged part of the piers (m^2).
B	Net width (i.e. excluding pier width) of bridge opening at bed level at 90^o to flow (m).
b_S	Width between abutments of a skewed bridge, measured along the highway centreline (m).
B	Width of river channel (m).
B_R	Regime (Lacey) width of an alluvial channel measured at 90^o to the banks (m).
B_T	Top width of water surface between the river banks (m).
C, C_d, C_D	Coefficient of discharge (dimensionless).
D_b	USBPR method differential ratio to calculate the fall in water level across embankments.
d	Flow depth from bed (invert) (m).
e	Eccentricity (numerical ratio of abutment lengths, or conveyances or discharges).
f	Darcy-Weisbach friction factor
F	Froude number, or drag force in Chapter 6.
F_M, F_A	Mean/average Froude number calculated from mean/average depth on floodplain.
F_N	Froude number with normal depth flow (= F_4, dimensionless).
g	The acceleration due to gravity (9.81 m/s^2).
h	Height of water surface above the centre of curvature of an arch (m).
h_F	Head loss due to friction (m).
H	Elevation of water surface above datum level (m).
H^*_b	USBPR method bridge afflux (m) without adjustment for piers, skew, or eccentricity.
H^*_D	USBPR method afflux at a dual bridge (m).
H_1	Elevation above datum of water surface (with bridge) at section 1.
H_{1A}	Elevation above datum of water surface (no bridge) at section 1 with abnormal stage (m).
H^*_1	Afflux at cross-section 1 with normal depth, $H^*_1 = Y_1 - Y_N$ (m).
H^*_{1A}	Afflux at cross-section 1 with non-uniform flow conditions (m).
H^*_3	Distance of the water surface below the normal depth line at section 3 (m).
J	Proportion of bridge waterway blocked by piers or piles, or blockage ratio (HR method).
k	USGS method adjustment factors (various subscripts) to base coefficient of discharge.
k^*	USBPR method total backwater coefficient (dimensionless).
k^*_C	USBPR method total critical depth backwater coefficient (dimensionless).
K	Total conveyance of river channel (m^3/s), or friction factor in chapter 6.
K_b	Conveyance of the part of the approach channel equivalent to the bridge opening (m^3/s).
K, K_A, K_N	Yarnell, d'Aubuisson and Nagler coefficients for flow past piers.
K_R, K_Y	Friction factor coefficients in Rehbock (1921) and Yarnell (1934) equations.

PRINCIPAL NOTATION

continued/...

A numerical subscript attached to a symbol usually indicates the location of the cross-section, or part of a cross-section, or the reach of a river according to context.

L	Length of bridge waterway in the direction of flow (m), or reach length with subscripts.
M	Bridge opening ratio = q/Q or a/A or b/B or K_b/K (dimensionless).
M_L	Limiting opening ration (dimensionless) at which the flow is at critical depth.
n	Manning's roughness coefficient (s/m$^{1/3}$).
P	Wetted perimeter of a channel (m).
q	Quantity of flow that can pass through the bridge opening unimpeded (m^3/s).
q	Discharge per metre width in Chapter 7 (m^3/s per m or m^2/s).
Q	Total discharge (m^3/s).
r	Radius of curvature of an arch, or radius of entrance rounding to waterway (m).
R	Hydraulic radius of channel (= A/P m).
R_S	Regime scoured depth of flow (m) corresponding to channel width B_R.
S_F	Longitudinal slope of total energy line (dimensionless).
S, S_O	Longitudinal slope of river bed (dimensionless).
S_C*	USBPR method afflux scour correction factor (dimensionless).
t	Thickness or width of a bridge pier.
V	Mean flow velocity (m/s).
V_C	Critical velocity (m/s), velocity when F = 1.0
V_N	Mean velocity when flow in a river channel is at normal depth (m).
V_u	Mean upstream approach velocity at either section 1 or 2 (m/s).
V_{2A}	Average velocity at section 2, in the opening, at the abnormal stage that would exist without the bridge (m/s).
X	Length approach embankment/abutments (m) for calculation of eccentricity.
Y	Depth of flow measured from the bed (m).
Y_C	Critical depth (m), corresponding to critical flow (F = 1.0) at minimum specific energy.
Y_d	Downstream depth measured above mean bed level on the channel centreline (m).
Y_M, Y_A	Mean depth, average depth (m). Numerical subscript indicates location of cross-section.
Y_N	Normal depth (m), e.g. as with uniform flow and predicted by the Manning equation.
Y_u	Upstream mean depth, the larger of the depths at sections 1 and 2 (m).
y_1, Y_1	Depth at section 1 (including the afflux) upstream of the bridge (m).
Y_{1A}	Depth at section 1 without the bridge when abnormal stage exists (m).
Z	Vertical height of bridge opening (to the top of an arch) from mean bed level (m).
ΔE	Energy loss (W)
Δh	Difference in elevation of water surface between sections 1 and 3 (m).
ΔH	Differential head (m) across the bridge
Δy	Representation for afflux used in chapter 6 (m).
Φ	Angle of skew, angle of bridge embankments or piers to the approach flow.
α	Kinetic energy correction coefficient, or contraction ratio in Yarnell (1934) equation.
β	Momentum correction coefficient

PRINCIPAL NOTATION

continued/...

A numerical subscript attached to a symbol usually indicates the location of the cross-section, or part of a cross-section, or the reach of a river according to context.

δ	Pier shape coefficient in Yarnell (1934) equation.
θ, η	Energy loss coefficients in Nagler (1917) equation.
λ	Dimensionless afflux ratio.

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SUPPORTING PROJECT RECORDS (PR)

Copies of technical papers commissioned as part of this study:

1 BACKGROUND

1.1 Defra/Environment Agency Joint R&D Programme

This scoping study is part of the joint Defra/Environment Agency Flood and Coastal Defence Research and Development Programme. This R&D programme is unique to Defra and the EA in that it is jointly funded and managed by the two organisations as a single programme.

The approach of the R&D Programme follows the recommendations of the joint Defra/Agency Research Advisory Committee. The R&D Programme provides:

- A thematic structure of key subject areas for R&D – following the policy making/scheme development/asset management process in flood or coastal defence.

- Enhanced links between (a) R&D and (b) the groups in Defra and the EA (and related organisations such as consultants and local drainage authorities). This includes the need for Research Contractors to maintain awareness of other related R&D projects and Concerted Actions.

- Improved system for management and uptake of R&D so as to increase its effectiveness to Defra and the EA. This includes the maximisation of collaboration with other relevant research-commissioning and professional bodies, such as DTLR, Research Councils, the Institution of Civil Engineers (ICE) and the Chartered Institution of Water & Environmental Management (CIWEM).

In developing the new programme, Defra and the EA are determined to achieve an integrated and user-led R&D Programme. Key guiding principles are:

- Justifying research from a user viewpoint, particularly through researcher/practitioner panels, to identify and address research issues within the context of current practice,

- Thinking 'sustainability' – with technical, environmental, economic and social elements, and,

- Focussing on delivering benefits through enhanced performance or cost reductions, and ensuring good dissemination and implementation of research outputs.

- This project falls within the Engineering Theme of the joint programme, which is led by Dr Mervyn Bramley and advised by a Theme Advisory Group (TAG). The programme in each Theme is set out in the Theme Work Plan.

1.2 Other related research initiatives

As part of the joint Defra/Environment Agency joint R&D Programme there are several related scoping studies or R&D projects in progress that have relevance or linkages to this project. The main projects are summarised below.

1.2.1 Engineering Theme

- W5A-057 *Reducing uncertainty in river flood conveyance*. Research Contractor is HR Wallingford. There is an identified input into the 'Improved performance of existing one-dimensional modelling codes' as part of Phase 2.

- W5A-059 *Concerted action on operation and maintenance of flood and coastal defences*. Research Contractor is Posford Haskoning.

- W5A-014 *Design and operation of trash screens – Phase 3.* Research Contractor is Posford Haskoning. .

- W5A-027 *Fluvial Design Manual – Phase 2.* Research Contractor is Binnie Black & Veatch.

- W5B-023 *Weirs – Best practice guidance.* Research Contractor is Mott MacDonald.

- W5-105 *Benchmarking of river models.* This updates earlier work undertaken in 1996 by the National Rivers Authority. The research contractors for this project are the Universities of Bradford, Leeds and Nottingham.

1.2.2 Risk Evaluation and Understanding of Uncertainty Theme

- FD2302 *Risk and uncertainty review.* Research Contractor is HR Wallingford. Due for completion in July 2002. R&D Technical Report FD2302/TR1.

- W5B-02 *Risk Assessment of flood and coastal defence systems for Strategic Planning (RASP).* Research Contractor is HR Wallingford. Due for completion in March 2004.

- W5-070 *Performance based Asset Management Systems (PAMS).* Research consortium led by HR Wallingford. Due for completion in October 2003.

- W5B-06 *Performance and reliability of flood and coastal defence structures.* Research Contractor to be appointed.

1.2.3 Flood Forecasting and Warning Theme

- R&D Project WSC 01/5 *Real Time Modelling*. WS Atkins is the appointed research contractor for this project, due for completion in March 2002.

1.2.4 Broad Scale Modelling Theme

- W5F-01 *Demonstration system for broad scale modelling tools and decision support systems for flood defence planning*. Theme Leader for the research theme is Edward Evans. HR Wallingford is leading the software development of the modelling framework.

- Linked to this theme is Defra-funded work on developing the modelling and decision support frameworks in support of Shoreline and Catchment Flood Management Planning.

1.2.5 Policy Development Theme

- Monitoring, recording and analysing events (post event appraisal): Coordination, benefits and use study. Phase 1 (review, issues and recommendations for any further work/guidance). Research Contractor is Bullen Consultants/JBA Consulting. Scoping study due to be completed in August 2002.

The Agency also has the research on-going in R&D Project W6-061 ***E**xtension of rating curves at gauging stations using hydraulic models.* The research contractor for this project is HR Wallingford and a scoping report was published in late 2001.

Project W5A-057 *Reducing uncertainty in river flood conveyance* has particularly strong linkages with this project and has identified a parallel programme of future research with important linkages to afflux and blockage. The Inception Report for this project was completed in July 2002. Some aspects of the format of the Conveyance Scoping Report have been adopted here in order to ensure consistency, and the contribution it has made to this study is gratefully acknowledged.

2 STUDY OBJECTIVES

2.1 Terms of Reference

The Environment Agency's specification for this scoping study set out the following objectives:

(a) Identify and review current knowledge and research on afflux at bridges and large culverts.

(b) Identify and review current knowledge and research on the extent and effects of temporary blockages at bridges and large culverts.

(c) Review the EA's South West Region Project '*Risk Assessment of Structure Blockage during Flood Flows*'.

(d) Identify any further work required to deliver robust algorithms for simulating afflux at bridges and large culverts in hydraulic modelling packages (e.g. for flood warning and for hydraulic design). Assess whether existing data is sufficient to support algorithm evaluation and development, or whether further data would need to be gathered.

(e) To identify the general benefits, and to specify where agreed, the further phase(s) of R&D and/or information dissemination to be carried out to:
   (i) Improve the accuracy of modelling of bridges and/or large culverts (without blockages).
   (ii) Improve the modelling accuracy of partially blocked structures.
   (iii) Develop technique(s) for identifying the likelihood of blockage of structures.
   (iv) Develop techniques for the rapid assessment of extent of flood risk areas associated with blockages.
   (v) Assist in prioritising operational resources during a flood event to minimise flood damages during blockages.

(e) To review the need to extend the project to include structures other than bridges and culverts.

(f) To advise on the format and synergies of any future research. In particular whether further investigations should be as a single project, or split into two or more, e.g. one on bridge afflux, one on structure blockage, etc.

The requirement for a two-page summary of best interim practice as determined from the Scoping Study was added to the brief in May 2002.

2.2 Study approach

The project team has involved both consultants (JBA, Mott MacDonald and WS Atkins) and researchers (Paul Samuels, Professor Donald Knight). In addition other experienced practitioners (Vern Bonner, Chris Scott, John Riddell and Brian Faulkner) have made contributions.

Other contacts were also made with 'end-users' in the Environment Agency, Local Authorities, Consultants, Internal Drainage Boards and the US Federal Highways Administration and asset maintainers such as Railtrack and the Highways Agency.

The project was divided into several tasks as follows:

- Consultation with leading users and practitioners by means of a suite of targeted questionnaires and a workshop.
- Review of current theory and representation of afflux and blockage in commonly used software by specially commissioned papers from leading experts and by dialogue with model users and software developers.
- Review of current practice both within and outside of the UK in terms of published guidance and manuals.
- Identification of research needs for the targeted and longer-term research programmes.
- Development of a procurement strategy for the Targeted Programme, covering contract options, research organisations, programme management and user involvement in training/piloting.

In addition to this report, wider dissemination of this Scoping Study is sought by means of:

- A website for the project at www.project-information.com.
- Presentations to the Technical Groups of the EA's NEECA and Flood Risk Mapping Framework Alliances.
- Submission of a paper to the Chartered Institution of Water & Environmental Management – Rivers & Coastal Group meeting in May 2002.

2.3 Steering group and consultees

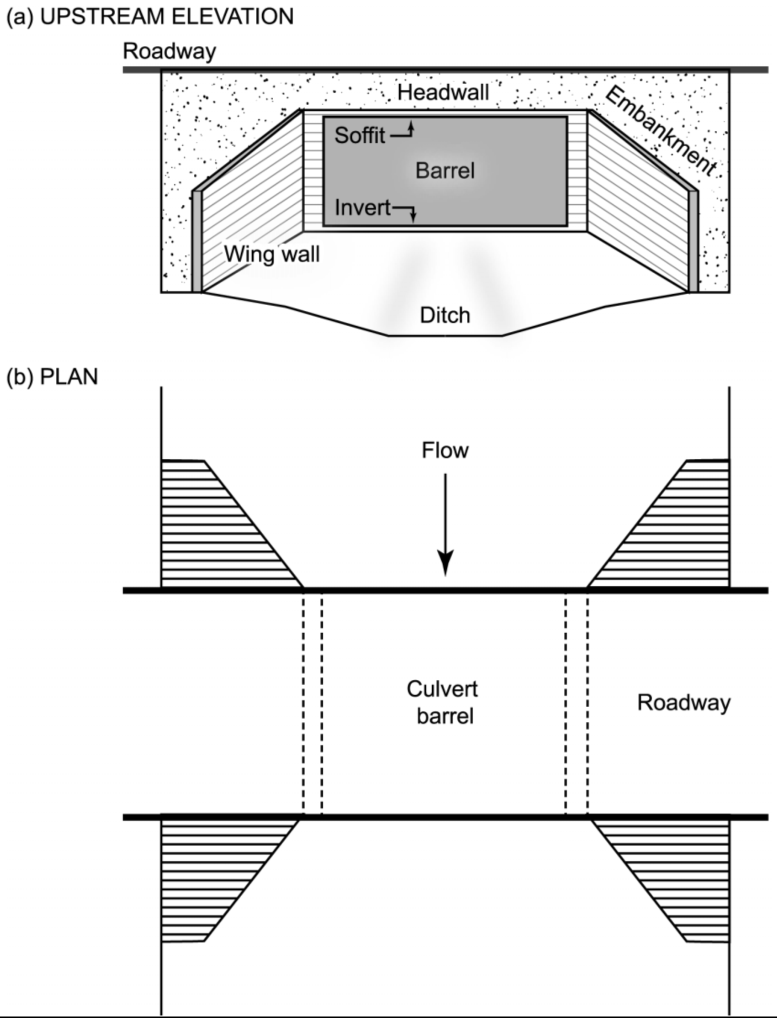
The study was project managed for the Defra/EA Joint R&D Programme by Andrew Pepper as external adviser on rivers and catchments to the Engineering Theme. Close links were maintained with Peter Spencer and Tilak Peiris (Flood Risk Modelling), Mervyn Bramley as Theme Leader and Project W5A-057 on river flood conveyance through Paul Samuels. These persons formed an informal steering group.

3 DEFINITIONS

3.1 Large bridges and culverts

The terms of reference specified that this study would be concerned with 'large' bridges and culverts because these are the most common structures studied in river systems. We have assumed that this includes structures with a notional diameter, width, or height greater than 1.5m. Openings with the prime dimension(s) less than 1.5m can usually be considered as pipes or simple orifices. However there is no definite limit, based on physical dimensions, between what constitutes a pipe or a culvert.

There are many definitions of what constitutes a 'bridge' and what constitutes a 'culvert'. Which one is most appropriate depends on the purpose of study (e.g. structural assessment, hydraulic assessment or asset management). The definition used here is that a culvert has integral walls, soffit and invert ('floor'). A culvert is also usually relatively 'long' (i.e. the length along the watercourse axis is several times larger than the span or width of the crossing itself). During flood conditions a culvert may often flow full or be surcharged at its entry or exit, but under normal flow conditions it will have a free water surface throughout its length.



Photographs of a box culvert – approach conditions (top) and the same culvert within a physical model at point of surcharge (bottom)

Figure 3.1: Physical features of a culvert

Bridges do not in general have an integral invert (although they may have one added as scour protection). They are usually relatively short – i.e. the distance from the upstream to downstream face is usually less than the span of the crossing. Under their usual flow conditions, bridges and culverts are rarely designed to form a hydraulic control to the flow. However, in extreme flood events, they may form a hydraulic control due to their constriction of the waterway cross section. Bridges are unlikely to develop pressure flow (i.e. 'flow full') although they may become surcharged at very high flows (i.e. water levels on the upstream are higher than the soffit). The design condition for bridges is usually for them to allow free surface flow beneath the structure.

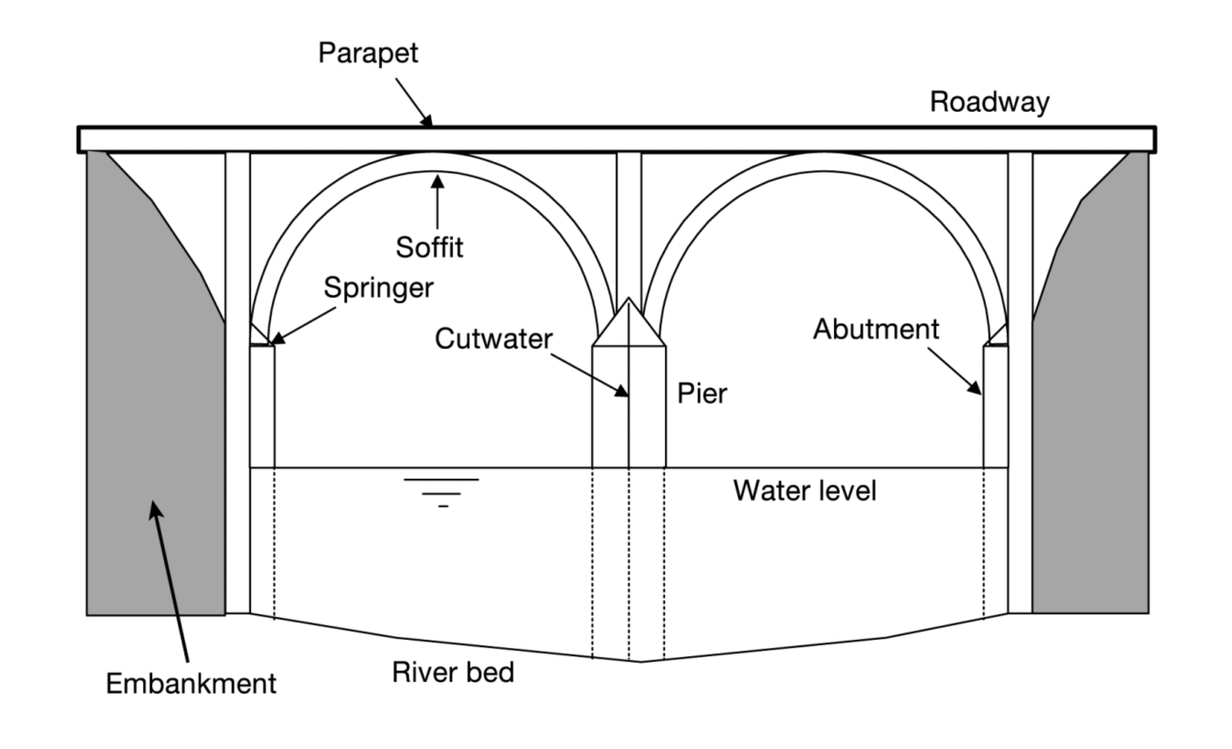


Figure 3.2: Physical features of a bridge

Figures 3.1 and 3.2 provide an overview of some of the terms used to define the geometry of a bridge and culvert. The CIRIA Culver Design Manual (CIRIA, 1997) provides a good overview of culvert types and the different hydraulic flow regimes.

3.2 Afflux

Prior to the placement of the bridge or a culvert across a watercourse, the water surface for a given flood discharge may assume a normal profile parallel to the bed (i.e. uniform flow) or a transitional profile due to other controls upstream or downstream (i.e. non-uniform flow). Due to the constriction in flow (and consequent energy loss) imposed by the presence of the structure, the water level at a location upstream of it (and unaffected by high local velocities caused by the constriction itself) will increase. The increase in water level provides the additional head needed to overcome the energy loss caused by the constriction; it is this process that creates afflux.

Afflux was defined in the project terms of reference as "the difference in water levels upstream and downstream of the structure – measured at a location unaffected by high local flow velocities caused by the constriction of flow". However in this report, afflux is more strictly defined as *the maximum difference in water level, at a location upstream of the structure, if the structure were removed*. The afflux is thus defined as the maximum difference in water surface elevation between the original (uniform or non-uniform) and the increased levels (see Figure 3.3).

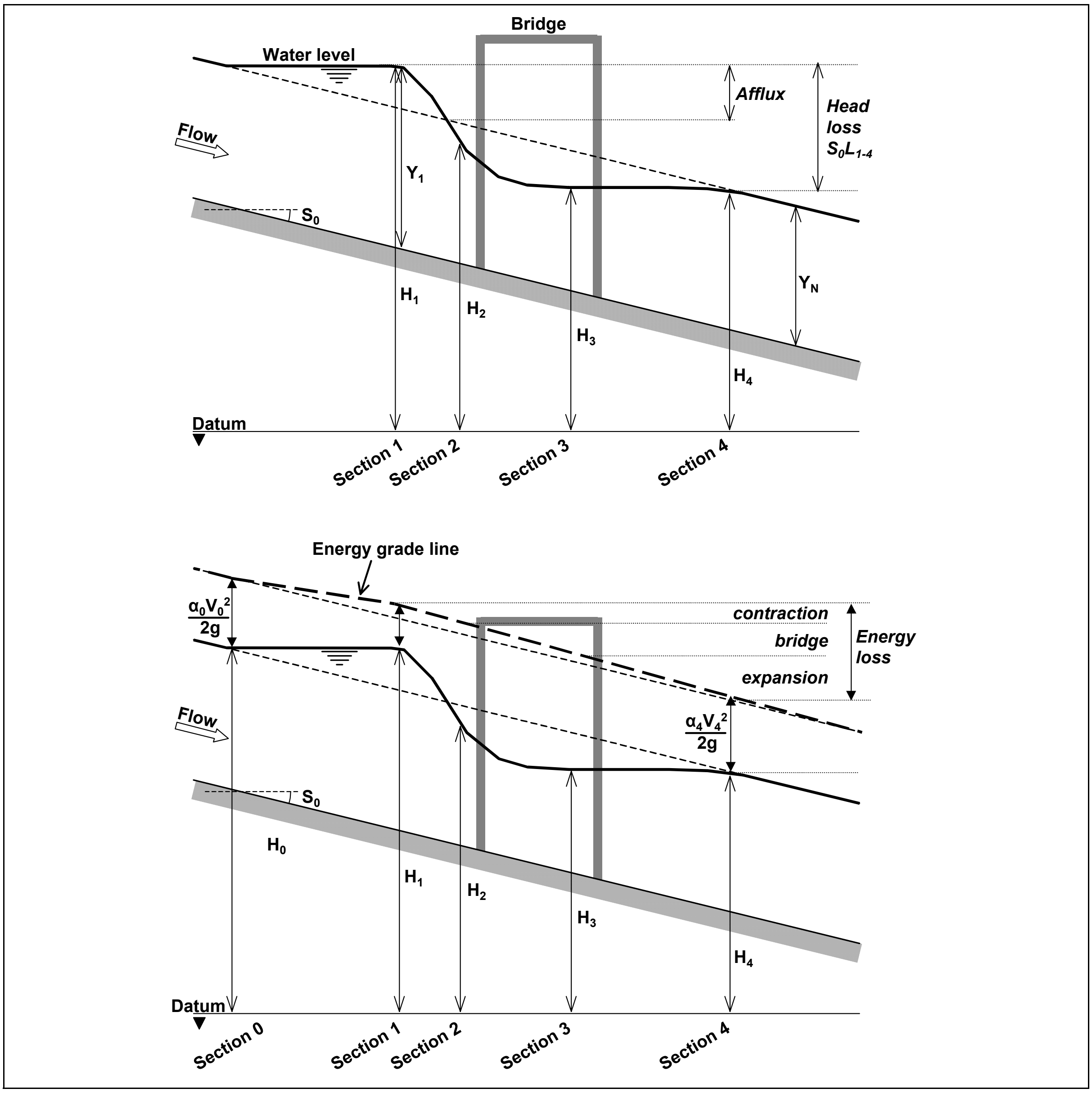


Figure 3.3: Definition of afflux, head loss and energy loss (after Hamill, 1999)

The numbered sections shown in Figure 3.3 correspond to typical locations of physical significance for flow through a bridge. Section 0 is a point upstream of the bridge where it has no effect on water level. Section 1 is the upstream point on the river centreline where the effect of the bridge on water levels is at a maximum (that is, the location of the afflux as defined above). Section 2 is a location at or near the upstream face of the bridge where the water surface passes through normal depth as it is drawn down through the opening. Contraction typically continues through the bridge, and section 3 indicates the point where the flow reaches a minimum width. Section 4 is a location downstream where flow conditions are no longer directly affected by the bridge.

The significance of locations 1 to 4 in Figure 3.3 is somewhat simplified in the description given above. The upper panel of Figure 3.3 is based on the assumption of a uniform flow condition as this provides a convenient starting point to illustrate the development of afflux. In this case, the afflux as defined above can be written

$$H^*_1 = \max(Y_1 - Y_N) \qquad (3.1)$$

where Y_1 is the depth of water and Y_N is the normal depth, measured at locations such that the difference between the two water profiles is at a maximum. Where there are bed instabilities or non-uniform flow conditions, then water levels, rather than depths, provide a more general definition. Definitions of afflux for non-uniform flow conditions will be discussed below and in Chapter 6. For a more detailed discussion of the terms illustrated in Figure 3.3, the reader is also referred to Hamill (1999, Chapter 2).

3.3 Head loss

The head loss is the difference in the water surface elevation between any two specified points. The head loss across the structure (for example between sections 1 and 4 in Figure 3.3) can be written in the case of uniform flow as:

$$\text{Head loss (sections 1 - 4)} = H_1 - H_4 = H^*_1 + S_0 L_{1\text{-}4} \qquad (3.2)$$

Equation 3.2 suggests that the head loss is related to the afflux, H^*_1.

The Environment Agency's current BIS-A 'Best Interim System' river modelling software programs (i.e. HEC-RAS, ISIS and MIKE-11) only calculate **head loss** across a structure. To estimate afflux using these packages it is necessary to undertake two simulations for identical boundary and flow/roughness coefficients. One simulation should include the structure and one should be without the structure. The **afflux** is the difference between the estimated water levels at a suitable location upstream.

A not infrequent error is to quote head loss rather than afflux as the principal hydraulic effect of a bridge or culvert.

3.4 Energy loss

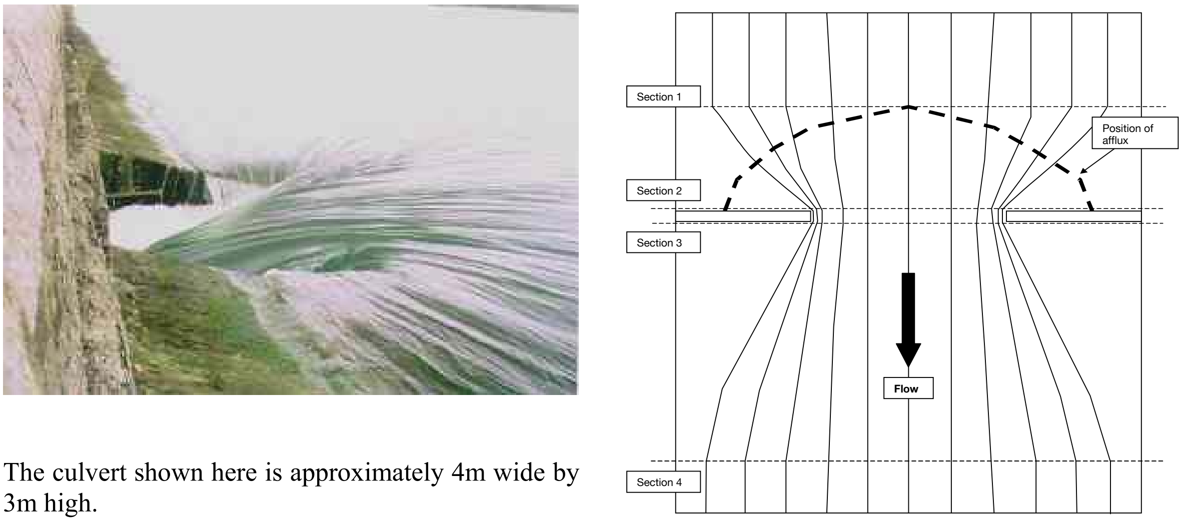
The more general way of calculating afflux or head loss at a structure is to work from the 'energy grade line' (shown in the lower panel of Figure 3.3). This allows the effects of non-uniform flow, varying channel cross section and controls other than normal depth to be taken into account. The energy loss across a structure measured between locations 1 and 4 in Figure 3.3 can be written as

Energy loss (sections 1 – 4) = $\left[H_1 + \frac{\alpha_1 V_1^{2}}{2g}\right] - \left[H_4 + \frac{\alpha_4 V_4^{2}}{2g}\right]$ (3.3)

where

g is the acceleration due to gravity (constant),
V_i is the flow velocity at section i,
H is the water surface elevation,
α is the kinetic energy correction coefficient, which accounts for non-uniform velocity distribution across the channel,

The use of the energy equation (3.3) to compute afflux is discussed in Section 6.2 of this report. The position of the afflux at a structure is usually an arc around the inlet, as shown in the photograph and sketch plan in Figure 3.4. In most practical situations only the afflux along the centreline of the river is estimated.



The culvert shown here is approximately 4m wide by 3m high.

Figure 3.4: Position of afflux at a structure

3.5 Backwater

In the USA, the terms afflux and head loss are rarely used. The preferred US term is 'backwater' which is defined as the rise in the water surface caused by the obstruction compared to 'normal' depth (i.e. the water surface without the obstruction). As the backwater is normally the maximum difference, it is the same as afflux as defined above. Another term that will be seen, usually in the context of culverts and in some of the US Army Corps of Engineers literature, is 'swell head'.

In the UK, the term 'backwater' is generally used to describe the water surface profile upstream of structure – not quite the same as the above definition. Backwater is also used, in the context of 'backwater effect', to refer to the distance upstream of the structure where water levels are raised above normal.

3.6 Which term to use?

Head loss has the advantage over afflux or backwater in that it is directly measurable. Afflux or backwater requires the estimation of the water surface that would be present if the structure were removed, and so cannot be directly observed or measured. However, head loss can be misleading as a measure of the effect of a structure on water levels as it can include other losses such as those due to friction and the difference in bed elevation.

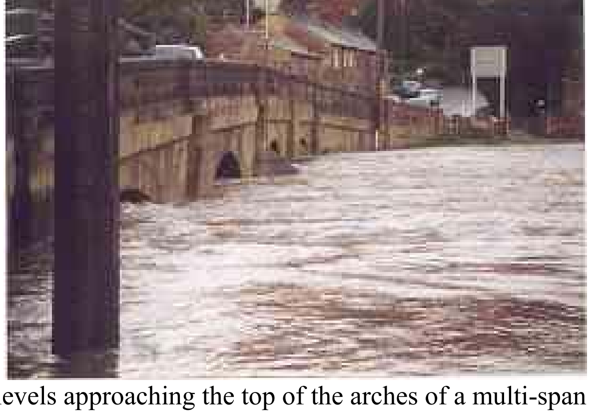
In this report and for the future research, we recommend that afflux (the greatest difference in water levels) as defined in Figures 3.3 and 3.4, and Equation 3.1 for uniform flow, is adopted as the primary measurement, especially for the collection of field data on bridge and culvert losses. The reasons for this are to avoid the multiple interpretations of the term backwater and to clearly differentiate the effects of the structure on water levels from the other effects such as friction and change in channel elevation that would be present without the structure.

3.7 Structure surcharge and overtopping

At extreme flood flows, or when the design capacity of the structure is significantly exceeded, it is possible that the structure becomes surcharged (i.e. the water surface is higher than the soffit) or it is even overtopped or by-passed (Figure 3.5).

Overtopping of a bridge resulting in spill out of the channel and flooding of housing.

Water flowing over a highway bridge deck.



Water levels approaching the top of the arches of a multi-span bridge.

Figure 3.5: Overtopping and surcharging of bridges

A surcharged condition is sometimes a design condition for culverts (which are structurally more capable of withstanding the resulting hydraulic forces acting on the soffit). Bridges are rarely intentionally designed to surcharge, and the preference for dealing with high flows is to allow overtopping of the roadway or embankment before water levels reach the underside of the bridge deck. However, this is often not possible in the conditions that exist where development has encroached over the years onto the floodplain at a river crossing.

3.8 Blockage

Additional blockage of a structure, other than the 'intentional blockage' to flow resulting from the presence of the physical structure, can arise from several causes:

- Collection of floating debris at the abutments/piers or soffit. This is often referred to as 'temporary blockage' because the debris can be removed. Removal more often than not requires human intervention, rather than the floe clearing the debris away.

- Collection of floating ice, referred to as 'ice jams'. This is relatively uncommon in the UK at present.

- Accumulation of bed load at the inlet, outlet, or beneath the structure.

In addition to blockage, other possible effects worthy of note are:

- Bulking — the decrease in the density of water as a result of entrained air in highly turbulent conditions or due to large sediment loads and consequent increase in water levels.

- Local scour — the lowering of bed levels around a structure usually due to the locally increased flow velocities.

For most UK situations, blockage by floating debris and accumulation of sediment at the bed are the most important material considerations (see Figure 3.6). In this study, the effects of both these types of blockage are considered with floating debris as the primary consideration.

The consideration of scour, bulking and ice jams would have involved considerable widening of the scoping study and have not been considered directly, as these are not though to be so important in the UK. Blockage due to the provision of screens is already dealt with in the Manual on Design and Operation of Trash Screens (Environment Agency R&D Report W5A-01).

This study has adopted a consistent approach to blockage. However, the most important point to recognise with blockage is that its occurrence is triggered by a number of different factors and it must be addressed through a risk-based approach.

Complete blockage of Armco culverts by floating debris

Sediment accumulation at the exit of a culvert

Complete blockage of a culvert screen by leaves and twigs

Blockage of a 24m highway bridge span by a raft of timber

Figure 3.6: Examples of blockage

3.9 Other structures

Afflux can also occur at other structures that restrict the flow, such as siphons or sluice gates. Knowledge of afflux at these structures is generally good where their purpose is to control water levels, and hence considerable effort has gone into establishing sound hydraulic design criteria.

Weirs are generally built for the specific purpose of creating an afflux, and they can have a considerable backwater effect. However, as weirs are a well-documented form of control, estimation of their effect on upstream water levels is usually more straightforward. As mentioned in Section 1.2, weirs are considered under the Engineering Theme by a separate research initiative, although their hydraulic analysis is not dealt with in depth.

Finally, discrete and short narrowings in a river channel such as that resulting from embanking or construction of channel walls may generate afflux if the available flow area is sufficiently restricted. If the narrowing is discrete, afflux calculations should be used. If however the channel changes occur over several cross sections, then the hydraulic effects are best considered within general water level calculations for non-uniform flow along the river channel of varying cross section.

3.10 Chapter Summary

This chapter has introduced some of the basic definitions and concepts used in bridge and culvert hydraulics relevant to afflux estimation.

The amount of afflux for a given structure varies with flow rate and will also differ depending on the location within and along the channel. For most engineering purposes, it is the maximum value that is required.

It is important when undertaking hydraulic calculations that the afflux effect of a structure is identified separately to other effects and that the location of afflux is correctly identified. Particularly care is required in the location of the points of calculation either side and through the structure.

As the primary concern for flood management is the effects of bridges and culverts on water levels at high flows, it is necessary to also consider, under the umbrella of afflux estimation, the possibility of surcharge and overtopping.

In a similar manner, the proposed future development of an Afflux Estimation System would be planned in such a way as to readily interface with standard river models.

4 POTENTIAL 'USERS' AND THEIR NEEDS

4.1 Introduction

Flood management activities can be considered under five main headings:

1. Regulation
2. Improvements
3. Strategic Planning
4. Flood Warning
5. Operations and Maintenance (including Incident Management)

The Environment Agency is seeking to introduce nationally consistent tools and procedures within its areas of operation. The EA also concurs with the views expressed by the ICE Presidential Commission on Flooding in their report 'Learning to Live With Rivers' (ICE, 2001). This emphasises the critical importance of estimation of flood water level in all aspects of flood risk management.

4.2 Needs in regulation and Development Control

The influence that the EA and other operating authorities exert on infrastructure and residential/industrial developments through the planning process and the statutory consent procedures of the Water Resources Act and the Land Drainage Act is significant. The prevention of inappropriate and unsustainable developments ensures that floodplain capacity is maintained. The current 'norm' is to require that any new structure over or in a watercourse has zero afflux at a defined flood magnitude (usually the 100-year event), or can be demonstrated to have negligible (adverse) influence on flood risk. If the proposals are considered to have an impact and they cannot be modified easily, mitigation measures (such as raising of flood defences) may be considered.

It is common for designers of new structures or consultants undertaking flood risk assessments to estimate afflux by computer modelling – usually using a software package. In practice it is not possible (and arguably it is not the role) of development control officers to check or verify these calculations, although they should have a knowledge of the methods approved by the EA and be able confirm the correct magnitude. There is therefore an important issue of 'confidence building'. Is it possible to quickly and unambiguously assess whether an appropriate method has been used and that the estimated afflux is realistic? There are 'back stop' measures that are often applied (for instance insisting on a minimal blockage or opening ratio for any new structure, in addition to minimal afflux) and in some cases these are appropriate. However, these can be difficult to defend if challenged.

While no consent/regulation regime can always be entirely effective, the benefits of improved design procedures and design knowledge should benefit all developments, whether consented or unconsented.

4.3 Needs in flood risk mapping

Defra and the EA and have several on-going initiatives in flood risk mapping including the Section 105 flood risk mapping programme, the Indicative Flood Risk Maps (IFM) for

England and Wales, Catchment Flood Management Plans (CFMPs), mapping of the extent of major flood events (post event surveys), and the Extreme Flood Outline project. To varying degrees, all these initiatives (except perhaps the post-event flood mapping) rely on the estimation of afflux and blockage risk, with the Section 105 programme being the most dependent.

Table 4.1: Summary of Flood Risk Mapping Initiatives in England and Wales

Flood Risk Map	Coverage	Risk Level Mapped	Comments
Flood Risk Map of England and Wales (IH 130)	All of mainland England and Wales and Isle of Wight	1% fluvial.	First attempt at national flood risk mapping. Data was used in the production of the IFM maps.
Indicative Flood Risk Maps	All of England and Wales	1% fluvial, 0.5% tidal Undefended. No account for blockage (effect of structures largely ignored).	1: 10,000 mapping scale. Original (1999) version largely based on IH 130 dataset (see below). Updates issued in 2000, 2001, 2002, 2003. The IFM maps also include S105 map and post event flood data where available.
Section 105 Mapping	Coverage of defined 'hot spots'. Intended to identify floodplains on main rivers and in major urban areas of known flood risk.	1% fluvial, 0.5% tidal plus other levels (usually lower) as appropriate. In some cases, the effects of culvert blockage on water levels are considered.	Based on detailed hydrological and hydraulic modelling. 1:2,500 scale urban; 1:10,000 scale rural.
Post Event Flood Maps	Recent events mapped include the Midlands/Wales floods of Easter 1998, the Yorkshire Derwent floods of 1999 and the North East and South East floods of 2000.	Varies according to severity of event. Includes afflux and blockage effects where recorded.	Tend to be plotted at 1:10,000 or 1:2,500 scale.
Extreme Flood Outline	All of mainland England. Decision yet to be taken on Wales.	0.1% fluvial and tidal. Structures and blockage not considered.	1: 10,000 mapping scale. Exact method of analysis yet to be determined. Project expected to be completed by March 2003.
Catchment Flood Management Plans	Intended to cover all major river catchments in England and Wales by March 2007.	Various but 1% fluvial will be included in all studies. Possible climatic change considered.	Largely to be undertaken using the MDSF methodology based on flow routing. Unlikely to explicitly include afflux except in very specific cases. Fluvial equivalent of Shoreline Management Plans.
Note: Indicated mapping scales are the recommended scale for printing. Most floodplain/flood risk data is available digitally and can be plotted at any scale.			

The exceedance probabilities (or return periods) used in Section 105 mapping is generally 1% (100 years) for fluvial flood risk and 0.5% (200 years) for tidal flood risk. The Extreme

Flood Outline will consider the 0.1% (1000 year) fluvial and tidal flood risk. At such flows many structures are likely to be overtopped. Table 4.1 provides a summary of the flood risk maps produced under the auspices of Defra and the EA.

The Indicative Flood Maps (which contain information from the more detailed Section 105 maps and historical events) increasingly influence other areas of the EA's business. The IFM maps are issued to local planning authorities and are an important tool for deciding on which planning applications are referred to the EA. The maps in a slightly lower resolution form are also publicly available through the EA's website. The IFM data is also used in the delineation of the EA's flood warning areas and also in identifying Critical Ordinary Watercourses under the Defra High Level Targets initiative.

At a local level, the accuracy with which afflux is estimated can have a significant impact on the flood outline, particularly at flows in or around bankfull. Blockage of structures can have an even greater impact on flood risk areas.

Currently flood risk mapping commissioned by the EA is being produced under a national framework agreement, with an Alliance Board to promote partnering between the EA and the four consortia of framework consultants. The Alliance co-ordinates the methodologies used in the mapping process through a detailed written specification (National Flood Risk Mapping Specification, Issue 4, November 2001), and the advisory role of a Technical Group consisting of representatives from the EA and the Consultants.

The National Flood Risk Mapping specification currently requires afflux to be assessed using 'appropriate methods' and the ISIS, MIKE-11 and HEC-RAS programmes are suggested as appropriate modelling tools. The Agency's National Survey Specification (Environment Agency, 2002) also provides guidance on appropriate survey techniques and advises on the positioning of cross-sections around structures. The specification includes the option to consider the effects of blockage on structures, and one region of the EA in particular (South West) routinely incorporates this in to its flood plain mapping commissions. It would be logical if consistent approaches were adopted by all regions.

Flood risk maps are also produced as part of more strategic studies such as the Catchment Flood Management Plans (CFMPs), and in capital strategy planning. These sometimes need to map to a level of detail where the effects of afflux and blockage would be discernable. In CFMPs, there can be a need for some consideration of afflux where flooding is known to be related to constrictions at particular structures.

4.4 Needs in Operations and Maintenance

Operations and maintenance staff of the EA and other operating authorities carry out important tasks of removing debris, vegetation trimming and general channel maintenance. They have to balance flood defence needs with those of conservation, fisheries, aesthetics and the available resources. With the development of a risk-based approach to maintenance, the need to target work on critical areas is becoming increasingly important. Such targeting would take into account the impacts of the work (on flood levels and the environment) and acknowledges the inherent uncertainty in the assessment process. The approach to specification and provision of these improved measures is being developed under the PAMS initiative (see Section 1.2.1).

A key factor in any targeted programme of maintenance for bridges and culverts (which will mainly relate to the control and removal of blockages) is whether the blockage is significant in flood defence terms. In some cases the negative visual/public impression given by debris blockages can be greater than any actual impact on flood risk. However, the maintainer requires a rational and consistent assessment procedure in order to underpin the maintenance regime adopted (in other words, can the procedures be justified if challenged). Another important consideration is that many temporary blockages occur during flooding where the feasibility of removal is more limited. This is discussed further in the Trash Screens Design Manual (draft report published by Environment Agency, R&D Project W5A-01, June 2003).

4.5 Needs in new works design

The Environment Agency and other operating authorities have major interests in improvement works to rivers, both for environmental considerations and for flood defence. Afflux and blockage are important considerations in many of the pre-feasibility, feasibility, detailed design and post-project appraisal of such schemes, especially in urban areas. Even relatively small changes in the stage/discharge relationship of a structure can have significant impact on the effectiveness and economic appraisal of improvement schemes. There are also wider benefits to UK Consultants working overseas and for others.

Some feasibility and design work is undertaken for the EA by Consultants, and a proportion is also undertaken in-house. Since 1999 major flood defence schemes have come under the remit of the EA's National Capital Programme Management Service (NCPMS) and since November 2000 much of the design work is being undertaken under the EA's NEECA Framework Agreement with leading Engineering Consultancy firms.

The benefits of more accurate level estimation in scheme design are two-fold. If afflux/blockage risk is underestimated then the scheme may be under-designed and the risk of flooding will be higher than assumed. On the other hand if afflux is overestimated then inappropriate works may be undertaken. In the context of structures such as bridges and culverts, even minor works to existing structures can be costly and highly disruptive.

Designers of new works include the IDB and local authority staff and specialist and non-specialist consultants. It is important to note that much new urban infrastructure is undertaken with one designer undertaking the road, foul and surface water drainage as one package. The designer may or may not be a specialist in open channel hydraulics, and the common design tools used (MicroDrainage and HydroWorks) are not necessarily the most appropriate for assessing the impact culverts and bridges may have on channel water levels.

4.6 Needs in Hydrometry

Flood discharge is a key parameter in flood defence planning and forecasting. Bridges and culverts can often play an important role in flow gauging as they can act as controls and help to contain the flow. Historically bridges were often used as locations for spot gaugings although the use of cableways and ultrasonics is now generally favoured. Improvements in the estimation of afflux could help in the planning of new gauge sites (in particular in avoiding inappropriate locations) and in generating theoretical ratings for ungauged locations. The results of the afflux research project may have relevance and a cross-linkage with the EA Water Resource Function's R&D project W6-061 on 'Extension of Rating Curves using Hydraulic Models'. In this respect, the need in hydrometry is for consistent and appropriate methods for estimating afflux at all ranges of flow. The Agency's other needs are much more focused on the higher flows where flow is approaching or exceeding bankfull.

4.6 Needs in Flood Warning

The role of afflux and blockage estimation in flood warning has already been mentioned in the discussion of flood risk mapping, operations and hydrometry, all of which are important inputs into the flood warning systems being used by the EA. As increasing use is made of models for flow forecasting, so the benefit from improvements in afflux and blockage estimation will become more pronounced. The effect that afflux has on river levels needs to be assessed in order that the observed and predicted flows can be properly interpreted. In a flood warning context, this assessment needs to take place in real time or shortened timescales.

4.7 Users outside the Flood Defence operating authorities

On the 'Client' side, the users of information on afflux and blockage include:

- Local Authority Development Control/Planning Departments
- Highway Authorities and the Highways Agency
- Navigation Authorities (e.g. British Waterways, Harbour Authorities)
- Railtrack
- British Railways Property Board
- Water Companies
- Developers of new infrastructure.

Many structures of interest to Flood Defence operating authorities are also considered by one or more of the above groups. No estimate was available of the number of structures involved in these sectors. Initial consultation has revealed that Railtrack alone has responsibility for something in the region of 21,000 bridges over water and probably at least double that number of culverts (although it should be noted that the railway industry uses a definition of a culvert that includes any structure with a span between 6 feet (1.8m) and 18 inches (0.45m) which is different to the definition used here). These structures are predominately more than 100 years old and the hydraulic design criteria are unknown and highly variable. The owner of these assets is also not an expert on flood risk or hydraulics and relies heavily on existing guidance.

However the railway, navigation and highways sectors do have an existing regime of technical guidance and are subject to independent audit. There is therefore an existing mechanism for improved guidance on afflux to be disseminated and adopted.

4.8 Research and training

The academic community uses the concept of afflux for teaching and research, but would not be classed as an end user in any practical sense. However, it will be essential to engage with, and obtain the support of, the academic community for delivery of the benefits of this research programme as they influence the education and training of future practising engineers, managers and modellers.

The EA also has a structured professional development programme for its staff and is increasingly looking to identify and demonstrate 'core competences'. Afflux and blockage awareness should be one aspect of this programme for its flood defence and development control staff. The Association of Drainage Authorities is a focus for identification and dissemination of best practice for IDBs and will have interests in the dissemination of the findings of the afflux research project to this sector.

4.9 Typical target users for the research

As a result of the consultation process (see Appendix 2 for details), an impression has been gained of the range of 'users' of information on afflux and blockage. In order to assist in the identification of research needs general 'categories' of users have been identified.

The categories have not been based on existing sectoral/institutional structures but rather on the likely resources and technical requirements. Four categories are suggested:

1. The Manager/Asset Maintainer
2. The Flood Defence Professional
3. The (non-specialist) Designer
4. The River Modeller

There is of course an obvious further category of the specialist hydraulic designer/researcher and software developer. However, it is assumed that such professionals will already be familiar with the key issues and will be able to assimilate the results of this research without having the material specifically targeted for them.

Each of these user categories is considered in further detail below.

4.10 The Manager/Asset Maintainer

Groups that would typically fall into this category would be engineers and managers in charge of asset maintenance outside the river engineering sector – e.g. those working for highway authorities, the railway industry and developers. These practitioners need to understand the aspects of the assets they are concerned with that effect afflux.

Likely Needs:
- A non-technical definition of afflux and its causes.
- Tools for easy identification of when to consider afflux/blockage, probably as a trigger to determine when 'expert' or 'outside' help is required.

This category of user is highly unlikely to be a hydraulics expert or to have access to specialised design software. Afflux will be one of many other considerations they need to take into account. There may be little existing awareness of afflux or its effects both as a design and a management consideration.

4.11 The Flood Management Professional

Groups that would typically fall into this category are flood defence and development control engineers in the Environment Agency, IDB staff and local authority drainage staff.

Likely Needs:
- A non-technical definition of afflux
- A summary of the causes/indicators of afflux and blockage
- Tables showing the range of afflux/blockage that can be expected at 'typical' structures.
- Guidance on suitable methods of estimating afflux/blockage and how to specify this to others.
- Quick 'vetting' procedures for calculations submitted by others.
- Design tables/nomographs to estimate afflux/blockage.

This category of user is unlikely to be a hydraulics expert or to have access to or the time/training to use specialised software.

4.12 The (non-specialist) Designer

Groups that would typically fall into this category would be engineers working for consultancies and client design teams.

Likely Needs:
- Clear guidance on the selection of appropriate design criteria.
- Clear (prescriptive) guidance on the appropriate methods of assessing afflux and blockage.
- Case studies.
- Advice on the limits of existing methodology and where more specialist analysis is required.

This category of user is unlikely to have a specialist background in hydraulics but is likely to be a graduate with some knowledge of open channel and pipe flow.

A heavy reliance on software in design work would be expected, although access to specialist river/drainage models will be limited (most likely to be HEC-RAS or MicroDrainage).

4.13 The River Modeller

Groups that would typically fall into this category are the EA staff and technical members of Consultant's teams working on NEECA and Flood Risk Mapping projects for the EA, and undertaking flood risk assessments for developers.

Likely Needs:

- In depth appraisal of the methods of estimating afflux and blockage and their limitations.
- Critical advice on using existing modelling packages to estimate afflux and blockage.
- Easy access to other expert practitioners and the latest research.
- How to accommodate afflux and blockage on a catchment scale.

For this user it is important that any advice is integrated with existing guidance such as the EA's National Flood Risk Mapping Specification and Modelling Guidance.

This category of user may not have a background in hydraulics but is likely to be a university graduate or postgraduate. A noticeable trend in the sector is for the use of personnel from disciplines other than civil engineering as a result of recent increases in demand and the broader base from which such staff are now drawn. Typically university degrees are geography, environmental science and GIS.

A heavy reliance on software is typical, usually a river modelling package (ISIS, HEC-RAS, MIKE-11 and HYDRO).

The benefits of improved afflux and blockage estimation are discussed in Section 11.