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

Afflux at bridges and culverts

Review of current knowledge and practice

Annex 5:
A Review of the Environment Agency S.W. Region Study 'Risk Assessment of Structure Blockage During Flood Flows'

R&D Project Record W5A-061/PR5

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Brian Faulkner, Independent Consultant.

Research Contractor:
JBA Consulting – Engineers & Scientists

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury,
Bristol, BS32 4UD.

Tel: 01454 624400 Fax: 01454 624409 Website: www.environment-agency.gov.uk

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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.

Research Contractor
This document was produced under R&D Project W5A-061 by: Brian Faulkner, Independent Consultant. The research contractor was JBA Consulting – Engineers & Scientists, South Barn, Broughton Hall, Skipton, North Yorkshire, BD23 3AE.
Tel: 01756 799919 Fax: 01756 799449 Website: www.jbaconsulting.co.uk

Environment Agency's Project Manager
The Environment Agency's Project Manager for Project W5A-061 was:
Andrew Pepper, External Advisor, Engineering Theme.

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1 INTRODUCTION

1.1 Terms of Reference

The consultant was appointed to carry out a review of earlier work on blockage risk assessment, which had been undertaken for Environment Agency South West Region in early 1998 [1]. The motivation for the study was that local experience seemed to show that many flood level predictions were underestimated, primarily due to blockage at structures elevating in practice the theoretical flood level.

The study's key output was a practical methodology for assessing the potential for blockage at culverts and bridges. The main elements were:

- a spreadsheet based 'blockage risk model' (BRM) requiring various basic structural, hydrological and debris type attributes, these being allocated various individual probabilities, which were then factored by various user weightings to give an overall single '*Risk of Blockage'* score, expressed as a percentage for any one event. The actual percentage was then more loosely classed into one of three degrees of blockage risk, low (<20%), medium (20-40%), high (>40%) (see Figure 1)

- a decision tree followed, which directed the analyser/modeller to various courses of action depending on the potential for blockage and the consequences of that blockage (mild or severe) (see Figure 2). The blockage model and decision tree combined are referred to collectively as the Blockage Risk Procedure (BRP).

- A guidance manual, which was intended primarily for use in Section 105 flood mapping studies, guiding consultants on the use of hydraulic models (especially HEC-RAS) to model blockage. It was concluded that the actual loss of cross-sectional area in a blockage situation was virtually impossible to quantify, but it was recommended that for culvert flood risk purposes, a 75% loss of cross-sectional area should be assumed, modelled, in the case of HEC-RAS, by means of the vertical blocked obstruction method.

- All of the study output and investigations were placed onto an interactive multi-media type CD for further distribution.

1.2 Publication of Methodology and Further dissemination

The study was the subject of a scientific paper published at the 33rd MAFF Conference of River and Coastal Engineers (July 1998) [2]. Whilst this received some critical interest from practitioners, it was not widely taken up by the Environment Agency, and indeed this review has shown that most regions are still unaware of this project and it potential usefulness. This lack of exposure extends also to a number of the current R&D projects under way in the Environment Agency engaged on risk and performance studies, which did not appear to have unearthed this project even in literature reviews.

The methodology is however standard practice for all flood risk related studies in the Environment Agency South West Region, whereby practioners have to show that they have undertaken a sensitivity analysis on all structures within a flood risk hydraulic model to identify the risk of blockage.

It is regrettable that this methodology did not see wider distribution at an earlier stage, as this might have led to a greater degree of feedback from the users, and improvements might have been implemented at an earlier stage.

1.3 This Review

This review seeks to identify the key areas of the previous study that require improvement and further research IF the concept is to be taken forward within the wider framework of the Environment Agency's current integrated approach to risk assessment and management [3] [4], especially with regard to hydraulic performance of bridges and structures.

The key items that have been reviewed in this assessment are:

- A structured questionnaire issued to known users of the Blockage Risk Procedure (BRP), asking for feedback and comments about how the BRP has performed in practice
- Improvements to the existing method and procedures, based on the questionnaire review and conclusions from the earlier study, focusing on hydraulic modelling, joint probabilities of blockage factors, and more rigorous definition of how blockage factors are quantified
- An exploration of possibilities contained within more advanced risk assessment techniques, in particular Monte Carlo simulation, to improve the predictive accuracy of blockage probability.
- Brief reference to advanced generic modelling techniques as promoted by the Centre for Water Systems at Exeter University, which may be of value in improving the predictive ability of debris (the source of blockage) to move downstream towards a restrictive structure (the mechanism of blockage)
- A concluding summary about how the existing procedures should be revised so as to fit within the Environment Agency's integrated framework for risk assessment and management.

Culvert Blockage Risk Assessment

South West England Version

Version 1.04

January 1998

Help? Version?

Name of Structure:	Type location here	Grid Ref:	EEEE NNNN
Hydrometric Code and Area :	xx	MAF :	5.00 m3/s

Flood Growth Curve		MAF	Q5	Q10	Q25	Q50	Q100
	1	5.0	6.2	7.5	9.2	10.6	12.1

Structure Details					
Upstream Invert Level	2	100.00	m AOD		
Downstream Invert Level	3	99.90	m AOD		
Barrel Length	4	15.0	m		
Bed Slope	5	0.007	m/m 1 in 150		
Shape Code	6	1			0%
Span or Diameter	7	2.000	m	*Barrel Flow Area (m2)*	2.00
Rise	8	1.000	m	*BarrelWetted Perimeter(m2)*	6.00
Number of openings	9	1	m	*Barrel Compound n*	0.014
Barrel 'n'	10	0.012		*Barrel Full Velocity (m/s)*	2.84
Bed 'n'	11	0.018		*Structure Full Capacity (m3/s)*	5.68
Trash screen fitted?	12		No		

Structural Factors		Value	Category	Potential
Multiple openings in structure	13	N/A	Single	
Poor entrance conditions	14	10%	Good	*0.3%*
Poor exit conditions	15	10%	Good	*0.1%*
Poor barrel condition	16	10%	Good	*0.1%*
Poor river approach	17	10%	Good	*0.4%*
Aspect ratio (span < rise)	18	N/A	Broad	

Flood Hydrology Factors		Value	Category	Potential
Capacity relative to target flood	19	10%	Low	*9.5%*
Proximity of design flow to soffit	20	100%	High	*9.7%*
Frequency of flash flooding	21	50%	Medium	*3.3%*
Frequency of long slow rise floods	22		None	

River Condition Factors		Value	Category	Potential
Level of urbanisation near structure	23	20%	Low	*1.6%*
Evidence of tipping into river	24	15%	Low	*0.8%*
Density of bankside growth (large)	25	15%	Sparse	*0.4%*
Density of bankside growth (small)	26	50%	Medium	*1.3%*
Amount of loose bankside material	27	15%	Low	*1.9%*

Maintenance Factors		Value	Category	
Frequency of maintenance visits	28	50%	Medium	*3.7%*

Risk of Blockage in Flood Event	29	Medium	*33%*

Figure 1 – Existing Blockage Probability Model

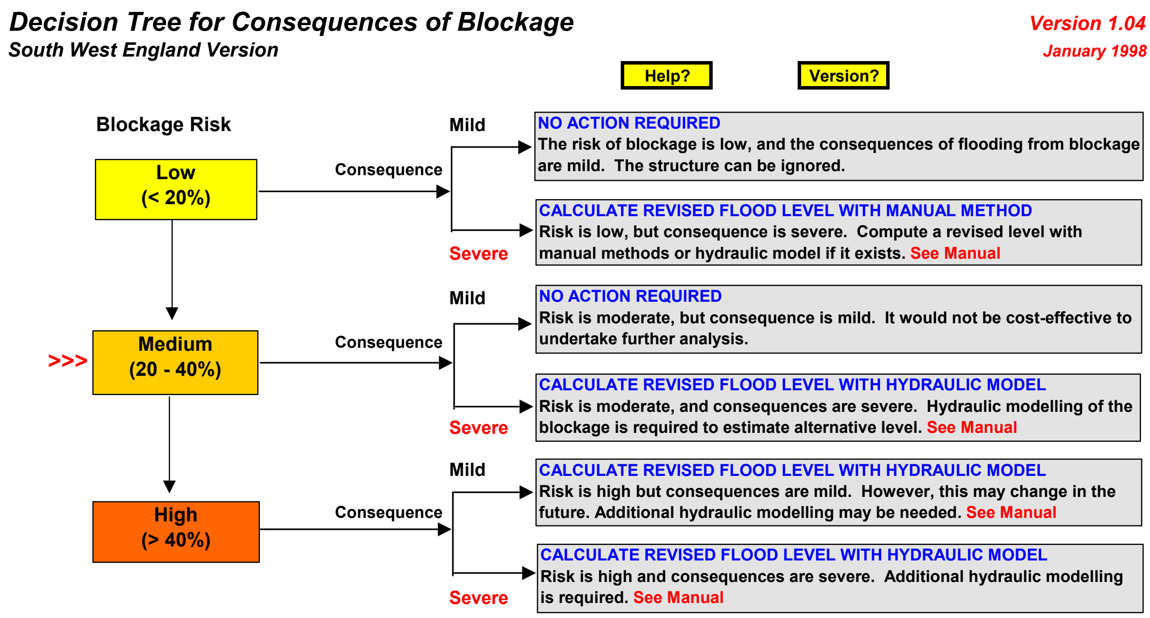


Figure 2 – Decision Tree

2 QUESTIONNAIRE REVIEW

2.1 Questionnaire Format

A short structured questionnaire was issued during September/October 2001, sent to 8 organisations (all consultants) with experience of applying the BRP. The questionnaire is listed in Appendix A.

The intention was to identify the main strengths and weaknesses of the Blockage Probability Model (BRM) as seen by the users. The importance of this feedback should not be overlooked by DEFRA and the Agency, as this is a practical and robust method that has seen application 'in the field', and thus has relevance to practioners who require simple, straightforward guidance on flood risk procedures without the complication of convoluted, more academically based methods.

In the main, simple yes/no type answers to allow a simple visual summary of the questionnaire results. These have been summarised in Figure 3.

2.2 Questionnaire Analysis

The majority of interviewees as expected had applied the method in the South West Region, one consultant in the North West.

All consultants had applied the method to large (>2.7 m span) box culverts, but only 35% had applied it to arch structures. 75% had not used the BRP for other structures such as weirs and sluices.

With regard to the ease of use of the current model, there was a 100% confirmation of the understanding of how to set up and apply the model.

Respondents were asked to rate the three most important and least important factors affecting blockage probability, in their experience. In the main most of these respondents were not part of the original major questionnaire issue of the earlier study, so these responses, albeit a small sample, can be compared to the earlier data for consistency.

Table 2.1 – Top Ranked Factors from Questionnaires

	Most important factor for blockage		Least important factor for blockage
1	Presence of trash screen	1	Poor hydraulic exit conditions
2	Poor hydraulic entrance conditions	2	Culvert or bridge 'n' value
3	Insufficient span	3	Barrel (waterway) length
4	Proximity of design flood to soffit	4	Poor river approach

The presence of a trash screen was considered the single most important factor to influence blockage probability. In the earlier study, the statistical analysis showed the trash screen factor second only to '*Presence of loose bank side material'*.

Poor hydraulic entrance rated second in this survey, but only 14th of 28 in the earlier study, an inconsistency. Insufficient span rated third, comparable to the 6th from 28 in the first review.

Proximity of flow to soffit rated 4th, somewhat inconsistent with the earlier rating of 17th from 28.

With regard to the least important factors causing blockage, this review identified poor hydraulic exit conditions (comparable to the earlier 23rd of 28), followed by barrel 'n' value, barrel length and river approach (skewness) as equally unimportant. These responses were comparable to the previous study, where none of the above were considered significant.

In response to the usefulness of the Blockage Procedure, 100% thought it a useful and practical approach to identifying blockage probability. All thought that it was best used as a relative approach i.e. to identify the sensitivity of various design and or operating factors on blockage potential, rather than an absolute (and deterministic) assessment of probability.

However, some 60% of respondents thought that the predictive output of the BRM was actually quite realistic as a deterministic figure, although there were no calibration data to support this. A single probability for blockage was considered useful by 85% of respondents, especially as this single factor is diluted by categorising into a low, medium or high band immediately after in the decision tree process.

Opinion is divided as to whether a refinement of the single percentage measure i.e. by quoting a probability distribution, is actually useful. This is a key output of a Monte Carlo type approach, so development along these lines will have to take into account its relevance in the day to day methods of working of most practioners.

Not surprisingly, the majority of consultants had not followed up any of the specific structures analysed with actual field based calibration material, a key recommendation of the first study.

2.3 Questionnaire Summary and Future Directions

As a pointer to future R&D direction, both studies highlight trash screens as major problem for blockage.

Poor inlet conditions (which might include for example badly aligned wing-walls, zones of ineffective flow, and piers or other 'obstructions') all seem to be influential factors in blockage.

Anecdotal evidence from both studies also suggests that whilst absolute size of structure is important (obviously a very large opening is less prone to blockage, AND the result of blockage is less noticeable with regard to e.g. afflux), there is also a relative aspect to blockage with regard to the ratio of the capacity of the culvert in relation to its design flow e.g. 1 in 100 year return period.

For example, a large open structure may appear to have negligible blockage potential, but a large hydraulic load imposed on this structure by a comparably large flood (with associated large debris etc.) may create conditions for a comparably large blockage problem. Thus the risk associated with this structure (defined as *likelihood x consequence*) where likelihood may be low but undesirable consequence is high, may be the same as for a smaller structure where the likelihood is high(er) and consequence is low(er).

The extent to which high flows at or near the full capacity of the structure influence blockage probability is not well understood or quantified at present, but it seems an important area for further research. Intuitively, this must be a critical scenario, since at these levels of flows, any blockage is likely to have a rapid and marked influence on the headwater afflux, and hence flood potential or consequence. Similarly, low flows, even with a high degree of blockage, are very much less sensitive in terms of afflux, and hence (flood) risk.

These conclusions are supported by the results of the South West study whereby a systematic sensitivity analysis of low and high flows through a theoretical 'standard' culvert (2.5 x 2.0) was carried out in HEC-RAS. Figure 5 of the MAFF paper [2] shows clearly how the ratio of % increase in water level to % increase in blockage is near linear with a gradient of 1 for low flows, whereas in high flows, the ratio becomes more of a power function, where a 50% blockage creates a 100% increase in headwater.

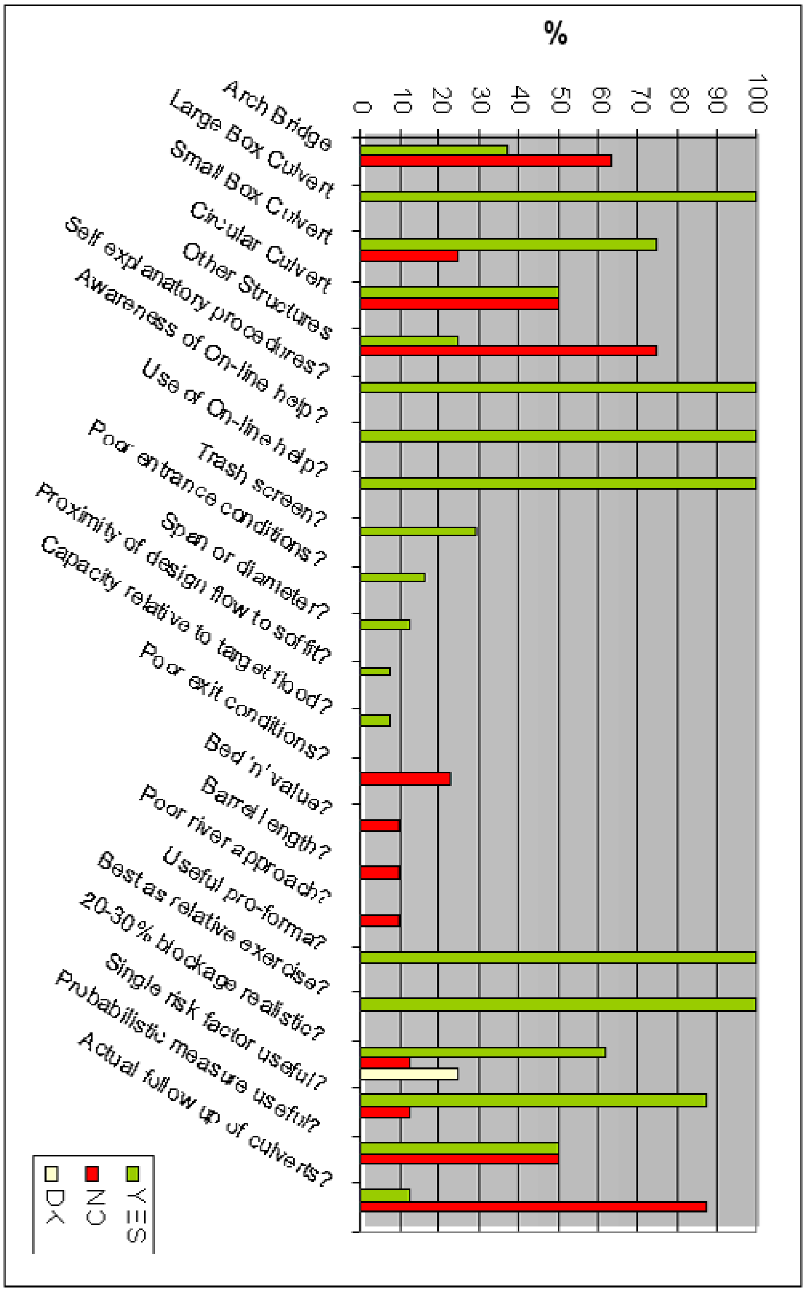


Figure 3 – Histogram summary of questionnaire responses

3 IMPROVEMENTS TO THE EXISTING MODEL

3.1 Current Structure

The current model identifies six key areas that are deemed to influence blockage, namely culvert dimensions, hydraulic controls, flood hydrology, river debris condition and maintenance frequency.

These areas are sub-divided into a further 28 attributes, identified from a comprehensive questionnaire review sent out as part of the South West study. Respondents were asked to rank the attributes in order of importance, and allocate an 'importance score' for each. Some simple statistical weighting was then carried out on the database of attributes to identify in very simplistic terms the frequency of 'blockage occurrence' due to that one attribute as if occurring in isolation.

Thus the presence of a trash screen, assuming all other conditions to be ideal, might cause blockage in 9% of the occurrences of a major (i.e. bankfull) event. The presence of a significant amount of loose bankside material near to the culvert/structure was deemed to create a 10% possibility of blockage.

The current probability approach in the model is:

1. that these attributes are independent,
2. that they can be summed to provide a total probability,

hence, the presence of a large amount of loose debris + trash screen might create a 19% (1 in 5) chance of blockage in a significant flood event.

Clearly, not all attributes will operate at 100% of their potential in each event, so a refinement of the probabilistic model is included which allows practioners to specify a further weighting on most attributes e.g. if observation has shown that debris upstream is minimal, and that regular maintenance of a trash screen is carried out, then the attribute blockage probability (9%) is simply factored down by a user specified weighting of that attribute (normally a percentage). Thus if the user suggests that at the structure in question only modest amounts of bankside debris may be present in a flood event (suggested weighting 50%), then the adjusted probability is in fact 0.5 x 9% i.e. 4.5% for the debris attribute in isolation.

Again the user defined weightings are somewhat arbitrary, although the range and distribution of possible weightings did take account of the minimum, maximum and standard deviations of the attribute database, so there is some statistical basis for them.

3.2 Estimation Improvements of Independent Blockage Factors

Whilst the severe lack of observation data and time constraints in the South West study meant that this kind of pseudo-quantitative approach was the only one feasible, and in practice the combined factors do appear to give reasonably plausible probabilities, there are essential improvements needed to the model structure.

First, some more rigorous definition of the blockage creating potential of key attributes is required. Currently the model attributes are based on nothing more (valuable though it is) than anecdotal information and engineering judgement from a range of practioners.

The problem has been and still is that virtually no long-term records are available from the field of specific structures propensity to blockage, the frequency of this blockage and the degree of associated loss of cross-sectional area and or afflux in sufficient quantity as to be useful in probability determinations.

Some more reliable method must be found to provide more quantitative measurement of blockage probability. The obvious two options are:

3.3 Flume based model studies of blockage

Flume scale model simulations of representative box and arch culvert structures, tested against a range of flows and blockage creating conditions is recommended. Specifically, a typical set of scale model scenarios to be simulated might include the following:

1. five standardised types of structures, including say box culvert (with and without trash screen) , arch, multiple arch and bridge on piers
2. 2 flow conditions, say 75% of opening depth, and full depth + 25% (i.e. near soffit and surcharge conditions)
3. randomised sequence of scaled blockage material types introduced to flume, including say model equivalents of tree trunk, branches, matted leaves, with a fixed quota introduced in each run.
4. at the end of each sequence, the extent of cross-sectional loss is estimated, and the afflux also measured. This latter measurement would provide invaluable additional data on the wider question of the significance of afflux in general. (The loss of cross-sectional area could in fact be precisely back calculated from the afflux measurement).
5. each scenario or class must then be repeated *n* times, sufficient to arrive at statistically significant differences between the experimental classes

Whilst actual deterministic type data can emerge from a flume study such as this, its principal output is primarily stochastic, i.e. probabilistic. Provided enough simulations are carried out, the real value added is a robust and statistically significant data set identifying the propensity and frequency of certain structures to accumulate blockage. The actual amount of blockage is also a figure that emerges, but this is dependent to some extent on how much debris is carried towards the structure, another major random component of the process, and other judgements may have to be made about this.

A study such as this might reduce the current blockage model of 28 no. factors down to a much simpler (but statistically more reliable) model of perhaps only 5 or 6 factors, key factors perhaps being ratio of discharge to capacity of structure, type of structure, debris potential from upstream, hydraulic efficiency of approach, and maintenance frequency.

A further benefit of this probabilistic approach is that by standardising the simulated flow in relation to structure capacity, the output probabilities might reasonably be assumed to apply to any size of structure of a certain type i.e. by placing emphasis on flows rates of say 75% and 125% of capacity, and assuming that the modelled debris scale also remains proportionate. Thus it is not actually necessary to simulate a 2m, 3m and 5m box culvert, as the ‘scaled blockage potential’ is probably similar for each type of structure, irrespective of actual size.

3.4 Observation and calibration of real structures

The second approach is to identify a few specific known problem culverts in the field, and monitor these intensively, within a structured reporting and quantifying framework, over a period of several years.

In practice, the former method is likely to yield far more useful, consistent data in a shorter period of time. The latter would be quite demanding of time, and involves many logistical problems.

To conclude on this sub-section, it must be recognised that the actual probability of blockage rests simply on two fundamental processes:

1. the duration and frequency of debris arriving at a structure. This process is probably highly stochastic in nature, although some techniques are possibly available to model this (see below)

2. once subjected to a debris load, what is the probability of a certain type of structure trapping this material to such an extent that there is significant loss of conveyance, and thence afflux?

It is in the latter process that scaled model studies will provide essential data, data which simply are not available at present.

Whilst the current model has value as a relative exercise, and as an approximate indicator of blockage potential, it must be understood that there is little statistical reliability to the attribute probabilities and user defined weightings, as they have been derived only from a limited sample of 'quantified' opinions.

3.5 Improvements to the Joint Probabilities of the Current Model

As discussed above, the current 28 no. attributes are all considered independent, and capable of individually adding to the blockage probability.

It is however very likely the case that several of these attributes are inevitably closely related i.e. there is collinearity amongst the variables, which makes any valid statistical interpretation near impossible.

For example, it is highly likely that the attributes '*Evidence of Tipping into River'* and *'Level of Urbanisation near Structure'* are closely related, but in the model they are assumed independent, each with an individual attribute probability.

It is clear therefore that significant 'double counting' is taking place in the model, and the best approach may be to simplify greatly the number of attributes included, as discussed in 3.2., whilst ensuring that the remaining attributes are indeed statistically independent.

Doubt has been expressed (HR Wallingford team engaged on the Risk, Performance and Uncertainty review) as to whether individual attribute probabilities can be meaningfully added in this way to arrive at an overall blockage probability. Normally, independent events when combined assume a multiplicative sum, but in this case there is a complex combination of some 'fixed' attribute probabilities e.g. span of culvert and/or problematic entrance, plus a stochastic component e.g. amount of debris in the river. Further research on the statistical methodology is needed to establish the best way of combing these attribute probabilities.

3.6 Wider application of the Blockage Risk Procedure to other uses

Currently the BRP has been used exclusively for Section 105 type flood studies. In practice however, there are two further important areas of application for which the BRP could be used. These were addressed and described in the MAFF paper, but have not been taken up by the Environment Agency.

3.6.1 Applications in new design

The blockage model has considerable potential for design of new structures. Basic geometry can be entered, and various blockage attributes pertaining to its locality can be tested. If it transpires that blockage risk (likelihood x consequence) is seen to be unacceptably high, then this may in fact require a redesign of the culvert itself e.g. wider span, no trash screen etc, in order to reduce the blockage probability. Because the process is numeric, it is possible to objectively compare different scenarios.

3.6.2 Applications in maintenance

An efficient maintenance programme could be devised by e.g. Highways Authority or Environment Agency that assessed all structures within an area. Even without prior evidence of blockage, the model could be used to identify in advance those culverts most likely to carry the greatest risk, and hence a targeted, prioritised, preventative maintenance programme could be devised in a systematic objective way,

In the light of new Environment Agency initiatives on risk and performance, it is strongly recommended that the BRP or its subsequent variation should be assessed either by Environment Agency staff or their various R&D contractors to see if it can be incorporated into mainstream design and operational standards.

In this context, the HR Wallingford team on Risk, Performance and Uncertainty felt that a valuable addition to the Decision Tree part of the procedure would be to provide additional similar trees for the design and maintenance uses.

In all cases, some correction of terminology is needed to agree with the definitions as set out in Report SR 587. The currently referred to *'Risk of Blockage in Flood Event'* in the Blockage Probability Model is more correctly defined as '*Probability of Blockage'*.

On the Decision Tree page, the heading '*Blockage Risk'* should in fact be '*Blockage Probability'*. Some expansion and refinement of the tree is needed that describes various consequences as at present, and then describes risk, most suitably in a common term such as flood damage cost.

4 APPLICATION OF ADVANCED RISK ASSESSMENT PROCEDURES

4.1 Probability distributions

During the previous study, it was realised that the use of deterministic type single values for blockage probability, whether for a single attribute or an overall combined probability is not particularly realistic, when the overall process has a highly stochastic nature.

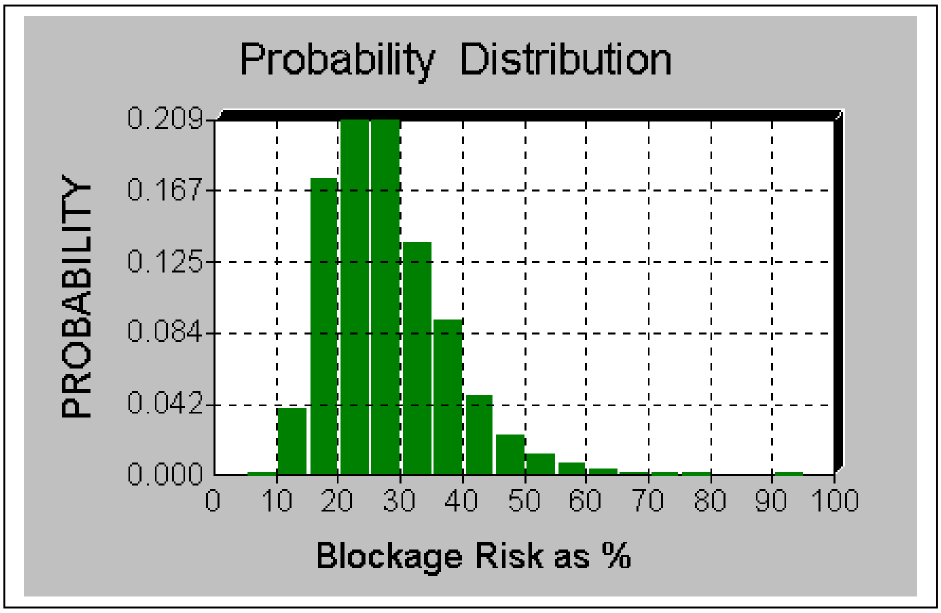
Powerful tools are available on the market which are precisely designed to formulate models where the inputs are uncertain, but where some idea of the probability distributions is known.

Tools such as *@RISK* (version 4) integrate seamlessly into spreadsheets such as EXCEL, and add considerable power to the spreadsheet capability [5]. Rather than specifying a specific probability for a particular attribute (which is likely to be an approximate and uncertain value), a probability distribution can be specified that describes the range and shape of the probability for that one attribute. Different distributions can be specified for all such attributes in the model. An enhanced *@RISK* version of the current BRM was developed but not reported on in the earlier study, although it was a key feature of the MAFF paper [2].

Through the process of Monte Carlo simulation, these distributions are sampled n'000 times within the spreadsheet, each output contributing to a final probability density.

The output then becomes a probability density function itself, rather than single blockage probability value as at present, as shown in Figure 4.

Figure 4 – Monte Carlo based blockage probability



The above output shows, taking into account all uncertainties (distributions) of all variables in the model, that there is a 42% chance (21% + 21%) of the blockage probability lying between 20 and 30% in this case.

4.2 Natural variability

In the new framework of uncertainty and risk assessment, this kind of output may well be a superior form of quantitative measure. Report SR587 devotes a full section to the importance of defining uncertainty in the risk assessment process.

'Consideration of uncertainty within the decision-process attempts to quantify our lack of sureness, and thereby provide the decision maker with additional information on which to base a decision … Given this additional information, a more informed, better substantiated decision can be made …' SR 587, p.61.

Monte Carlo outputs such as above give precisely this kind of information. Granted, this type of output is more difficult to understand, but then the whole risk environment is also more complex, and will require more expertise and judgements about uncertainty than is the case at present amongst water engineering professionals.

The clear advantage of introducing Monte Carlo simulation into a spreadsheet model is that the highly uncertain nature of the input variables, which involves both **Natural Variability** and **Knowledge Uncertainty** can be quantified. Providing that the probability density functions for various blockage causing attributes can be reasonably defined (e.g. via statistical outputs from flume scale models, field calibrations), then all of this variability is actually accounted for in the final output.

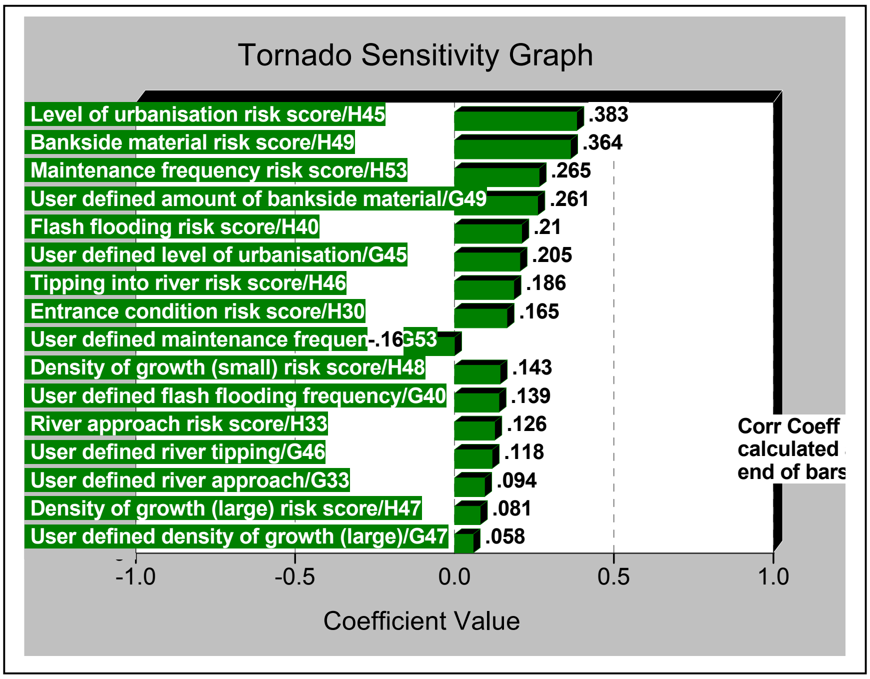
Many near random natural processes are potentially at work in the causation of a blockage problem at a structure. It is almost certain that these processes cannot be described deterministically, so a probabilistic approach seems inevitable. This natural variability is best described by Monte Carlo simulation.

4.3 Knowledge Uncertainty

The second key area of uncertainty within a procedure such as a Blockage Probability Model involves the modelling process itself, incorporating both *statistical uncertainty* (extrapolation from small data sets) and *process model uncertainty* (incomplete description of the model factors). It is obvious that the current model contains considerable knowledge uncertainty.

The Monte Carlo simulations of *@RISK* contain another powerful output that can be used to measure in a quantitative way this actual uncertainty. It does not overcome the need to reduce this uncertainty, but it does allow identification of those variables that contribute most to the probabilistic output. Figure 5 shows a sensitivity 'tornado graph' from a typical Blockage Probability simulation.

Figure 5 – Monte Carlo uncertainty and sensitivity output



During the Monte Carlo simulation, *@RISK* runs a multiple regression on the output dependent variable (in this case the combined blockage probability) and all other inputs as 'independent' variables from every pass of the model.

What emerges graphically is a representation of the exact effect or degree of influence of each variable on the overall outcome. Factors are ranked according to either the correlation coefficient or the stepwise regression coefficient R^2.

Depending on whether that input is part of the natural variability discussed above (e.g. amount of debris in the river) or process uncertainty (e.g. exact influence of trash screen as assumed in model), the most influential model attributes can be identified.

In the current Blockage Model, 'user defined weightings' are identified in spreadsheet column G, whereas inbuilt 'process' probabilities fixed within the model are defined in column H.

For example, in Figure 5, *level of urbanisation* attribute (cell H45 in the model) has the biggest single influence on this blockage probability, and explains some 38% of the variance in the output. Thus it is a highly important and sensitive factor. This attribute is defined within the model, not by the user, so is an example of process uncertainty. The output clearly identifies this as a key factor for further research to improve (i.e. reduce) the uncertainty or probability range of this variable.

Conversely, *User defined amount of bankside material* (cell G49) is a user defined weighting of the attribute *Bankside material*, and is identified as the fourth most important variable. As a user defined input, this is a case of knowledge uncertainty. Thus, the user must be aware of the sensitivity of this input, and must ensure that his weighting of this attribute is accurately measured.

It will be obvious that tornado sensitivity graphs such as the above are a most powerful way of identifying natural and process uncertainty within any model that can have probability distributions attached to it. This kind of output is relatively easy to interpret, and it is recommended here as a useful tool for many flood risk uncertainty applications.

It is recommended that the Monte Carlo derived 'tornado' approach is applied to the current model to identify all those variables that are most influential in blockage risk. This will require the simulation of a wide range of structures and operating conditions, and a statistical analysis carried out on the results.

An advanced technique such as Principal Components Analysis could also prove highly effective in identifying the collinearity amongst input variables, and reducing down the 28 no. attributes to a more manageable 5 or 6 key components.

4.4 Genetic algorithms for debris accumulation

Another key issue not resolved in the earlier study is the knowledge uncertainty associated with the amount of debris likely to arrive at a structure. It follows that irrespective of the flow rate, the inadequacy of the culvert entrance or presence of a trash screen for example, if there is no debris material in the river, then the probability of blockage will be zero.

Thus some improved modelling or empirical technique may be useful in order to model the potential for debris to arrive at a structure. (The current model simply assumes that in every major flood event sufficient debris will arrive at the structure so as to create the potential for blockage, but this may not always be the case). To some extent this has been approximated for in the model by allowing the user to specify weightings for the amount of debris likely to be encountered (in effect a calibration), but there is little quantitative data available to support the currently recommended factors. The process still remains essentially random however. Use of Monte Carlo techniques improves this uncertainty still further, by allowing a probability distribution for amount of potential debris. In its simplest form, this probability function can be of triangular shape with the parameters minimum, most likely and maximum.

The consultant has been in contact with Professors Savic and Walters at the Centre for Water Systems, Exeter University who have experience in developing so called genetic algorithms capable of modelling such natural variability in a much more sophisticated way.. It may be the case that such refined techniques are considered too complex and impractical to be of day to day use, but these experts could be asked for their detailed comments.

5 SUMMARY AND RECOMMENDATIONS

The Blockage Probability Model and Decision tree developed for use in the Environment Agency South West Region has been used by a number of consultants over the last 2 – 3 years.

It is considered practical, useful and easy to use. However, it is known that there is considerable model process uncertainty and natural variability within the model output which will require addressing with further targeted research.

The current model and its concept actually fit closely within the overall proposed framework of risk, performance and uncertainty as set out in HR Wallingford Report SR 587, even though the Blockage Probability Model predates the HR report by some 3 years. Specifically, the main recommended method (see below) uses a technique identified in that report as a Tier 3 Detailed Methods technique, namely Monte Carlo analysis.

The Blockage Probability Model already embraces an understanding of knowledge uncertainty, and techniques have been considered that can improve this [6]. The current model can relatively easily be considerably enhanced with the introduction of Monte Carlo simulation and is likely to be a useful risk analysis and performance tool in the future, coinciding with wider Environment Agency initiatives. More reliable data and consideration of joint probabilities is needed prior to this stage however.

The current model has been used exclusively for flood analysis of existing structures, but there is considerable potential to apply the existing and improved models especially to the fields of culvert design and operations and maintenance.

Little statistical data on culvert blockage frequency or mechanisms are available, and it is likely that these data will be very difficult to collect in the field. Consequently it is recommended that probability distributions of blockage are established by means of scale model studies. With sufficient simulations, actual frequencies can be arrived at that could be applied within risk based models such as the BRM, greatly improving the statistical reliability of the model.

The use of standardised culverts and bridges and standardised flow rates in the scale model(s) avoids the problem in the field that every real observation culvert will be unique, and therefore of limited use in providing data for wider statistical application.

The current spreadsheet based model carries out only a very basic form of hydraulic capacity check but this could be greatly improved to provide a simplistic but reliable headwater computation that could be used by any practioner who does not have access to more sophisticated models such as ISIS or HEC-RAS. This could be developed within the existing model, and the output used either to assess afflux or blockage impacts for existing or proposed culverts or other structures.

There is a danger that further research into afflux and blockage becomes academically over-involved. Practical, basic but reliable tools (spreadsheets and nomographs in particular) are what are needed by the industry to consistently check the flood risk effects of afflux and or blockage.

The current BRM needs considerable refinement with regard to the treatment of joint probabilities, and the specification of the value of the individual attribute probabilities.

The Decision Tree process needs to be expanded to incorporate additional trees for design procedures and operations and maintenance. The Blockage Probability Model and the Decision Trees could be written to CD or made available via the Environment Agency web site in one convenient guidance manual package.

The current model currently uses single deterministic type values for 28 attributes with potential for blockage. It is likely that there is considerable collinearity between some of the variables, but this has not been statistically assessed. In order to remove this collinearity, and perhaps simplify the BRM data input, it is thought likely that perhaps no more than 6 attributes in total would be sufficient to adequately describe blockage probability. More data and further research is needed here.

With regard to the overall approach to afflux and blockage effect, it is recommended that a standardised approach be employed wherever possible. This means that studies and techniques should not be restricted in scale, and should be applicable regardless of culvert or bridge dimension. Obviously for a small culvert there is greater likelihood of blockage with the same absolute size of debris as for a large culvert.

However, this would imply that larger culverts/bridges rarely encounter blockage and its associated afflux. This may be the case, but it seems possible that larger scale debris might also be more apparent in a larger river (more transportable), so assuming a consistent scale between size of structure and size of debris conveniently allows scale model derived blockage frequencies in theory to be applicable to any size of structure. Particularly useful outputs would include for example:

- nomograph type tables that indicated blockage probability given the ratio median debris size D_{50} to size of culvert.
- increase in afflux due to blockage, given a ratio of cross-sectional loss to culvert full area

Two hydraulic conditions seem important in physical and computational assessment of afflux and blockage, namely when the structure is running near full bore, and when the structure is in surcharge. Flows at significantly less than these conditions are unlikely to generate blockage and or afflux that is problematic. Incorporation of a simple headwater hydraulic calculation into the existing BRM would allow sensitivity testing of any flow rate however.

6 REFERENCES

1. A Guidance Manual for the Assessment and Modelling of structure Blockage During Flood Flows, Environment Agency South West Region 1998 – Consultants B L Faulkner and Kennedy & Donkin.

2. Faulkner B.L. & Waller S.J., A Risk Assessment Approach to the Prediction and Modelling of Structure Blockage During Flood Flows, *Proceedings of the 33rd MAFF Conference of River and Coastal Engineers, Keele University, July 1998*

3. Risk, Performance and Uncertainty in Flood and Coastal Defence – A Review, Volume 1 (draft), HR Wallingford, Report SR 587, September 2001

4. Environment Agency R&D Project W5-029 – Failure On Demand of Flood Defence Scheme Components – contract to be awarded

5. Winston W.L. *Simulation Modelling Using @RISK*, Duxbury Press 1996

6. G Koller *Risk Assessment and Decision Making in Business and Industry* CRC Press 1999