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Blockage management guide

Guide – SC110005/R1

Flood and Coastal Erosion Risk Management Research and Development Programme

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Foreword

This guide outlines good practice in the assessment and management of blockage risk in watercourses and at inline structures in the UK.

It sits below the 'Channel Management Handbook' (Environment Agency 2015a) and is a sister document to '*Aquatic and Riparian Plant Management'* (Environment Agency 2014a) and '*Sediment Matters'* (Environment Agency 2011). It may be used in parallel with the forthcoming CIRIA *'Culvert, Screen and Outfall Manual'* (Benn et al, 2019), which replaces the *Culvert Design and Operation Guide* (Balkham et al, 2010) and the *Trash and Security Screen Guide* (Environment Agency, 2009).

The guide is aimed at flood risk management practitioners working in a broad range of organisations in the UK. The guide is aimed at asset managers, modellers, mappers and consultants. It may also be of interest to environmental non-governmental organisations, ecologists, fisheries specialists and geomorphologists.

It promotes a risk-based approach to blockage management to reduce the risk of flooding, scour or other hazards. It also advocates a proportionate approach to assessment, with methods ranging from initial appraisal to detailed assessment.

As the title suggests, the methods and tools are guidance, not mandatory. The guide aims to give a balanced view of the issues and options available. It signposts existing guidance where this is recognised, authoritative and accessible, and provides pointers on emerging good practice where methods are new.

It should be noted that methods of assessing debris types and quantities are highly uncertain, and the sources and transport of debris along a watercourse can vary considerably over time. As a result, any mitigation measures should be designed to with this uncertainty and variability in mind.

Although the guide draws on good practice guidance and research from the UK, Ireland, USA, Australia and internationally, blockage assessment remains highly uncertain due to a worldwide shortage of good data. For this reason, professional judgement and common sense are prerequisites for any blockage assessment, and you may wish to undertake sensitivity testing as part of any detailed assessment.

Executive summary

The blockage of watercourses or structures by debris (any material moved by a flowing stream, including man-made materials, vegetation and sediment) reduces flow capacity and raises water levels. The adverse impacts of raised water levels can include an increased risk of flooding, structural failure or breach of earth embankments. Flooding from a blocked bridge or culvert could result in impacts equivalent to a much more serious event than the return period might suggest. Furthermore, debris accumulations can change flow patterns, leading to scour and undermining of structures. They can also obstruct navigation and present a hazard to water users. Nevertheless, some forms of blockages such as woody dams can, restore natural processes, providing flood risk and environmental benefits.

Risk-based management of blockage can reduce the risk of flooding, scour or other hazards. In recent years, the drive to work with natural processes has promoted a move towards more sustainable practices. There is also a need for consistent guidance on the economic appraisal of blockage to allow the preparation of a business case for the full range of management measures from maintenance to capital works.

This guide provides flood risk management practitioners with guidance on the assessment and management of blockage risk. It presents:

Blockage management process	Guidance on setting objectives (including the legal framework and stakeholder engagement), assessing risk, deciding whether to intervene, appraising options, implementation and monitoring.
Management options	Guidance on choosing an approach and options for managing blockage risk including do nothing, reduce debris load, reduce probability and remove.
Initial appraisal	A high-level method using readily-available data to identify potential problem assets, assess risk at a known problem asset, work out what to do (if anything) at a blocked asset and prioritise routine maintenance to reduce risk.
Detailed assessment	A method to support flood risk mapping and assessment, prioritisation of inspections and incident response, design and economic appraisal.

The guide draws on both UK and international research and good practice guidance, including work from Ireland, Australia and the USA. The evidence on which this guide is based is presented in an accompanying science report, including the findings of a literature review, industry consultation and a validation exercise. Other guidance is signposted where this is recognised, authoritative and accessible. The guide provides suggestions for approaches where evidence is emerging or unavailable.

Research and good practice guidance on blockage around the world is limited due to a shortage of good data. As a result, the process of blockage assessment remains highly uncertain. For this reason, professional judgement and common sense are prerequisites for any blockage assessment, and detailed assessment may be accompanied by sensitivity testing.

Contents

1 Introduction

1.1 What is blockage and how can you manage it?

Blockage is the obstruction of a watercourse or in-line structure by debris: man-made material, vegetation (including wood) or sediment.

The right kind of debris in the right place can have benefits for habitat or biodiversity. However, the wrong kind of debris or debris in the wrong place reduces flow capacity and raises water levels. This can lead to flooding, structural failure and embankment breach. Flow acceleration around blockages can scour the bed and banks of the watercourse, undermining foundations. Blockages can also accumulate further debris and sediment, obstruct navigation or present a hazard to water users.

The source–pathway–receptor model is widely used to help conceptualise flood risk (and other types of environmental risks). For a risk to arise there must be a hazard, that is, something that could potentially lead to damage. It can be useful to think of the hazard as having:

- a 'source' which is the physical condition or event that creates the risk – such as the debris
- one or more 'receptors' which suffer the consequences of the risk – such as people, property, infrastructure or habitat at risk of harm
- and a 'pathway', a link between the source and the receptor – such as a mode of transport to a pinch point.

Like the fire triangle of fuel–heat–oxygen, these 3 elements combine to cause a blockage and consequential damage (Figure 1.1). Removing one element, for example, through blockage management, reduces the risk.

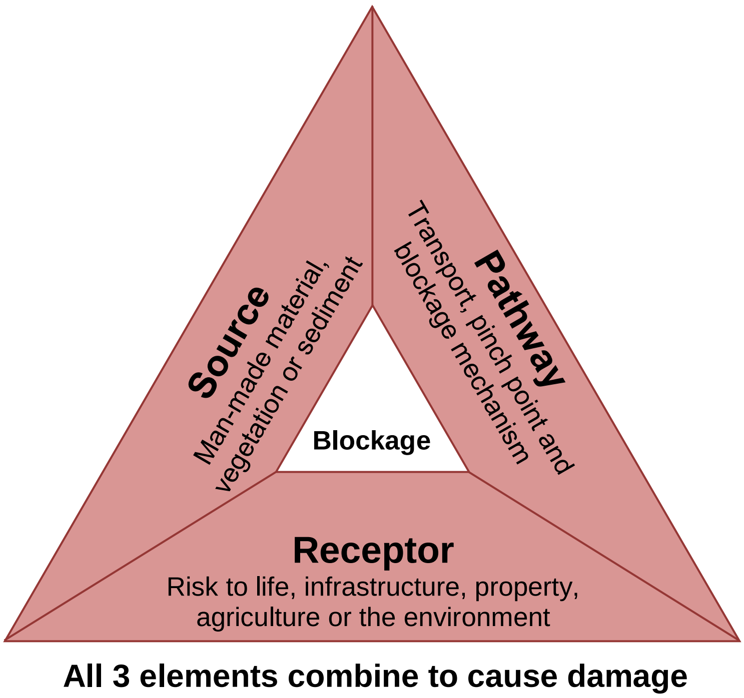


Figure 1.1 Blockage triangle

1.2 Why manage blockage?

Blockage management reduces blockage risk by removing the source of debris, removing the pathway or reducing the consequences.

The legal and policy framework surrounding blockage management has evolved and there is more emphasis on the retention of natural material. The Water Framework Directive imposes a requirement to maintain or improve the ecological status of watercourses and the Floods Directive encourages sustainable flood risk management and working with natural processes.[1]

1.3 Aims of guide

This guide is aimed at flood risk management practitioners in the UK. It is aimed at a broad range of roles: asset managers, modellers, mappers, clients and consultants. It may also be of interest to environmental practitioners, ecologists, fisheries specialists and geomorphologists.

The guide aims to improve understanding of the blockage of watercourses and in-line structures to reduce flood risk, infrastructure failure and scour. It provides an efficient method to:

- identify catchments and systems where blockages increase flood risk
- understand and manage the flood risk from blockages

The guide recommends methods of economic appraisal of blockage to support the preparation of equitable business cases for the full range of management options.

Screens, culverts, bridges, control gates, flap valves, flumes and weirs are covered, but not intake or outfall screens for abstraction or hydropower.

The guide covers variable (or temporary) blockage by man-made material, vegetation (including wood) and to a lesser degree, sediment. It does not cover:

- permanent blockage by a fixtures (such as screen bars)
- ice
- very small material that is unlikely to cause blockage
- debris flows with a high proportion of solids (60–80%) that are characteristic of steep slopes (exceeding 30°)[2]

Throughout the guide, the term ‘debris’ is used for simplicity and does not imply negative connotations.

The guide covers debris classification, blockage mechanisms, how to check for a potential problem and management options. For man-made material and vegetation, it also covers quantitative assessment.

[1] A working with natural processes research framework (Environment Agency 2014c) has been developed by the Joint Environment Agency/Defra FCERM R&D Programme (Project SC130004).
[2] See Section 4.2 of the Scottish Executive’s ‘Scottish Road Network Landslides Study (Winter et al. 2005) for more guidance on debris flows.

1.4 About this guide

This guide sits in a hierarchy below the '*Channel Management Handbook*' (Environment Agency 2015a). It is a sister document to '*Aquatic and Riparian Plant Management*' (Environment Agency 2014a) and '*Sediment Matters'* (Environment Agency 2011).

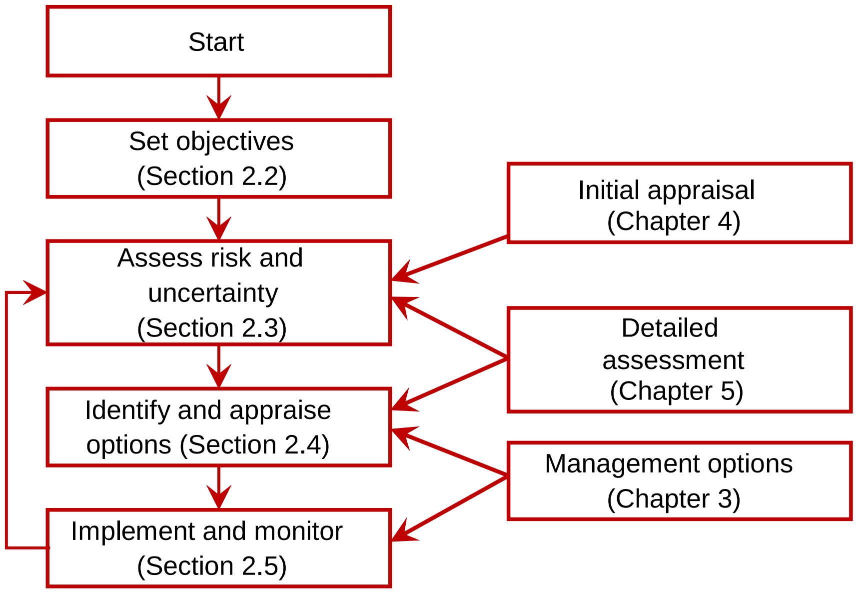
The guide provides guidance rather than mandatory requirements; it is not a rule book. It aims to give a balanced view of the issues and options available; it uses a risk-based approach but is not comprehensive. The guide signposts existing guidance where this is recognised, authoritative and accessible, and provides pointers on emerging good practice where methods are new. It draws upon international research and guidance; a supporting science report covers the findings of a literature review, industry consultation and analytical study. A reader guide is provided in Table 1.1.

Table 1.1 Reader guide

Issue	Relevant sections
I need a quick summary of the blockage management process.	Chapter 2 Blockage management process
What are the legal issues affecting blockage?	Chapter 2 Blockage management process Appendix A Legal framework
How can I comply with the Water Framework Directive?	
What steps should I follow to work out if I should do something at a problem asset or catchment?	Chapter 2 Blockage management process Chapter 4 Initial appraisal
How do I work out what to do (if anything) at a blocked asset?	Chapter 3 Management options
How can I design structures to reduce the risk of blockage?	Section 3.5 Reduce probability
How do I identify potential blockage sites within a catchment?	Chapter 4 Initial appraisal
How do I assess overall risk to inform an asset management plan?	Chapter 4 Initial appraisal
How do I prioritise inspections or interventions at several sites?	Chapter 4 Initial appraisal
What should I do to incorporate blockage into a modelling study?	Section 4.2 Identify pinch points Chapter 5: Detailed assessment
How can I represent blockage in a hydraulic model?	Chapter 5: Detailed assessment
How do I include blockage in an economic appraisal?	Chapter 5: Detailed assessment
How do I quantify risk at a known problem asset?	Chapter 5: Detailed assessment
Are there any worked examples?	Appendix C Initial appraisal Appendix D Detailed assessment Appendix E Multiple assets

> The prediction of blockage is highly uncertain due to the random nature of blockage, numerous influential variables and lack of data. This guide provides results consistent with available evidence. Nevertheless, the results are inherently uncertain and there is a strong case for a programme of systematic data gathering.

2 Blockage management process



2.1 Introduction

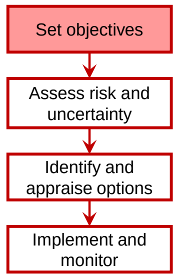
Blockage management involves meeting obligations relating to public safety, the environment and flood risk management, while balancing the costs and benefits of maintenance with the impacts of unwanted flooding or erosion, or environmental benefits. The process may be triggered by a known blockage problem, safety concerns after an inspection, accident or near miss, or a shortfall in structure performance or condition identified during inspection. Alternatively, the catalyst for change may arise from: changes in law or policy; changes in the catchment, watercourse or structure; or a change in maintenance funding.

The process involves: identifying potential problem sites; setting objectives (Section 2.2); and assessing risk and uncertainty (using initial appraisal or detailed assessment) before deciding whether or not to intervene (Section 2.3). If the decision is to intervene, option identification and appraisal (Section 2.4) allows you to choose options before implementation and monitoring (Section 2.5). If you are already aware of a problem site, you can go directly to Chapter 5 detailed assessment. The process can be complex and there is no right or wrong answer. The background to the methods in this chapter is given in the science report.

Table 2.1 signposts readers to relevant sections for the answers to common questions.

Table 2.1 Guide to blockage management

Issue	Relevant sections
How can I identify potential problem sites within a catchment?	Carry out initial appraisal and use the blockage triangle to eliminate low risk sites and identify potential problem sites (Chapter 4).
How can I assess overall risk for asset management planning?	Carry out initial appraisal and use the risk score to indicate the number of problem sites and relative risk at different sites or on different watercourses (Chapter 4).
I want to work out if I could do anything at a problem site.	Carry out initial appraisal and use the blockage risk score to assess whether risk is acceptable or unacceptable (Chapter 4).
How do I prioritise interventions at several sites?	Carry out initial appraisal and use the blockage risk score to compare risk at different sites (Chapter 4).
How do I quantify risk at a known problem asset?	Work through the detailed assessment process to estimate the impacts of blockage (Chapter 5).
How can I reduce the risk of blockage by design?	See Chapter 3 Management options, in particular Section 3.4 Reduce probability.
How can I model blockage?	See Section 5.6 Assess impacts.
How can I incorporate blockage into a modelling study?	Identify pinch points (Section 4.2), assess the debris load (Section 5.2) and blockage type (Section 5.3). Then assess the degree of blockage (Section 5.4) and impacts (Section 5.6).
How do I include blockage in an economic appraisal?	Go through detailed assessment, Steps 1 to 6 (Section 5.2 to Section 5.7). Repeat the process for each option.



2.2 Set objectives

This first step sets objectives for watercourses and in-line structures. This can help to inform risk assessment and the decision to intervene, and to decide which options will give the best outcome. You should consider legal requirements, functional objectives, stakeholder interests and other opportunities (for example, due to adjacent development) (Figure 2.1).

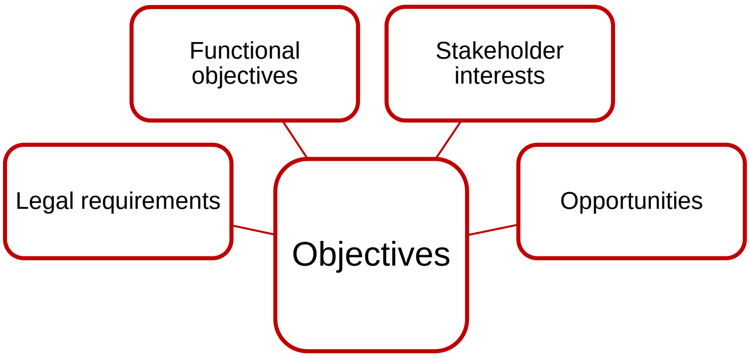


Figure 2.1 Factors informing objectives

Legal requirements imposed by European Union (EU) law and delegated legislation, statute law or case law are broadly similar throughout the UK, though there are some differences. A summary of the legal framework is given in Appendix A. In the case of any uncertainty around what to apply, or how to apply it, relevant legal advice should be sought from an appropriately qualified expert.

Functional objectives are determined by the existing and proposed uses of the watercourse or structure (Table 2.2). Check strategies and plans (for example, local development plans) for proposed uses.

Table 2.2 Prompt list of functional objectives

Function	Objectives
Prevent entry (debris or security screens)	Prevent entry by debris that could cause internal blockage. Prevent access by unauthorised persons.
Structural (bridges, culverts, temporary works)	Support infrastructure above design flood level. Provide adequate freeboard for passage of design flood and any floating debris load. Resist hydrostatic, hydrodynamic and debris impact forces on the structure and any accumulated debris.
Water level management (weirs, flumes, control gates, flap valves)	Control water levels for land drainage, flood risk management and/or ecology. Prevent reverse flow through culverts or pipes at times of high downstream water level. Impound water for navigation, landscape or visual amenity.
Flow measurement (weirs, flumes)	Provide unique stage–discharge relationship for water resource management or flood warning.
Channel stabilisation (weirs)	Dissipate energy to reduce flow velocity and scour.

It is helpful to gather information at an early stage. A prompt list is given in Table 2.3 and a list of useful websites is given at towards the back of this guide. At objective-setting stage, a desk study and site walkover may be sufficient. As a scheme progresses, you may want further surveys or site investigation. It is important to consider the timing of surveys: ecological surveys may be restricted to certain times of the year and water-based recreation may take place outside working hours.

Table 2.3 Prompt list for data gathering

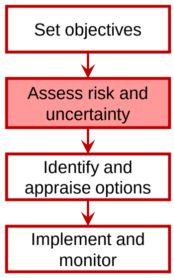
Blockage history, inspection and maintenance records
Function(s) of watercourse and in-line structures
Access routes, weight or dimension constraints
Land ownership and land use (historic, existing and proposed)
River typology, debris load and likely sediment contamination
Environmental constraints and opportunities
Policies, strategies and plans

Stakeholder engagement allows you to identify stakeholder views and to ensure that their interests are taken into account. It can also help you to understand possible unintended consequences of an option or to obtain feedback following implementation. You should engage project partners who are responsible for decision-making, delivery (and most likely funding), statutory consultees and public bodies that support the decision-making process, and other interested parties who may be affected by the work.

Further information

- *Consultation Principles: Guidance* (Cabinet Office 2016)
- *Communication and Engagement in Local Flood Risk Management*, CIRIA C751 (Daly et al. 2015)
- *Aquatic and Riparian Plant Management* (Environment Agency 2014a)
- *Channel Management Handbook* (Environment Agency 2015a)
- *Land Drainage and Flood Defence Responsibilities* (ICE 2016)

2.3 Assess risk and uncertainty



Blockage risk is influenced by many factors: debris type and volume; rate of delivery; transport along the watercourse; interaction with the watercourse or structure; and chance.

Two methods of assessing risk and uncertainty are given in this guide.

Method 1 – Initial appraisal is a quick and simple desk study approach to assess risk using readily available data (Chapter 4). You can use this to identify potential problem sites for strategic or single site assessment of risk, or to prioritise interventions.

Method 2 – Detailed assessment is a more time-consuming approach using more detailed data (Chapter 5). It allows you to estimate quantities of debris and rate of blockage to inform inspection and maintenance, calculate probability and degree of blockage for modelling and mapping, estimate the impacts of blockage on water levels, flood extents and damages (with and without blockage), and determine the benefits of avoiding blockage for economic appraisal and design.

Data quality and the method of assessment influence uncertainty in the results and the time allocated for assessment. Three levels of detail (or uncertainty) are defined in this guide (Figure 2.2). The level of detail chosen will depend on the nature of the problem, the question being asked, data availability, the level of risk to receptors (including the environment), the likely level of investment and the number of assets assessed. You may choose to use Level 3 for most sites and Level 1 for the most critical sites only.

For a large number of sites, it may be possible to automate some of the steps. Appendix E illustrates how multiple assets have been assessed using semi-automated methods.

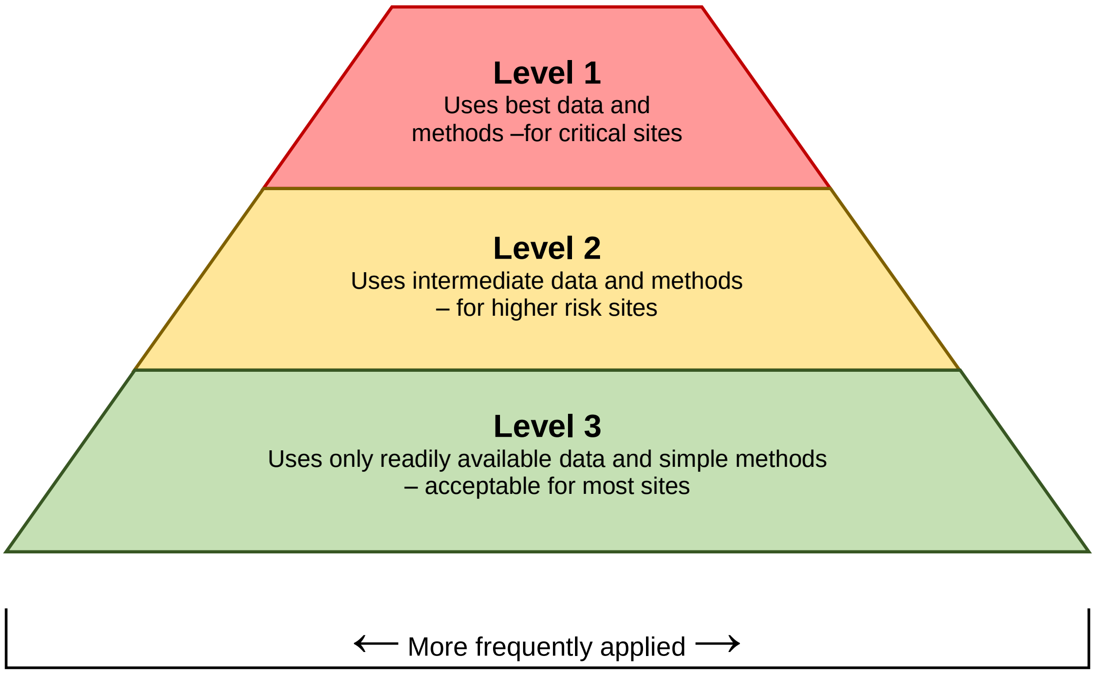
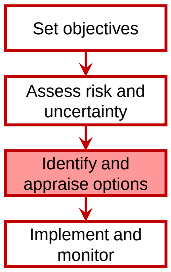


Figure 2.2 Levels of detail for assessment

2.4 Identify and appraise options



If blockage risk is acceptable or there are no receptors, you may choose not to intervene. Doing nothing is a valid approach, especially when empowered with evidence and data on the risks and impacts (Section 3.2).

If the blockage risk is significant enough to cause flooding, structural failure, embankment breach, scour or other impacts, there is an opportunity to intervene.

Options appraisal allows you to identify technically viable options which are environmentally and economically favourable (or achieve regulatory compliance for least cost, depending on the objectives). The process is iterative; the level of detail should be proportionate to the scale of the problem and may increase as a scheme progresses (Figure 2.3).

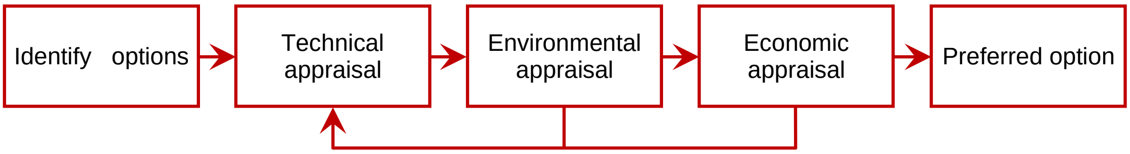


Figure 2.3 Option appraisal process

Once you have identified your potential options, a technical appraisal eliminates unviable options and identifies viable options for environmental appraisal. An appraisal typically starts with high-level options (do nothing and do something), then examines generic options such as reducing sources or reducing probability, before looking at specific measures such as inspection or removal. The benefits of do something are compared with a baseline, typically do nothing or do minimum. See Chapter 3 for more on management options.

Factors to consider include:

- **Site location**: access, operational response time, proximity to roads and power supply, proximity to disposal sites, risk of vandalism or hostile situations
- **Hydrology and hydraulics**: design flood and low flows, catchment response time, channel geometry, impacts on water levels, availability of telemetry, adjacent land use, risk of flooding
- **Geology and geomorphology**: bed and bank material, river typology (whether susceptible to erosion), type and volume of debris
- **Asset management**: function(s) of the infrastructure and watercourse, willingness to accept risk, blockage management approaches at other assets within a portfolio

Environmental appraisal identifies the most beneficial options to take forward to economic appraisal. It identifies environmental constraints and the potential impacts of the options. Depending on the scale of the problem, this may range from a simple desk study and preparation of an environmental constraints plan, to baseline surveys and full Environmental Impact Assessment (EIA). A Water Framework Directive (WFD) assessment may be needed for some maintenance activities to demonstrate that they will not impact adversely on WFD objectives (see Appendix A). Other assessments may be required for designated sites or protected species.

Factors to consider include:

- **Water quality**: nutrients, pollutants, dissolved oxygen, temperature

- **Sediment**: type of sediment, contamination, sediment transport
- **Habitat and ecology**: designated nature conservation sites, protected species, fish and eel passage, breeding birds
- **Biosecurity**: invasive non-native species
- **Cultural heritage**: designated assets, non-designated heritage assets
- **Landscape and visual impact**

Finally, economic appraisal allows you to determine the economic viability of options, compare options or prepare a business case for works, by considering whole-life costs, benefits and risks associated with an option (and outcome measures if applying for Defra flood risk management funding). If the work is for health and safety reasons or for legal compliance, the preferred option is the least cost option that meets the project objectives. Otherwise, the option with the highest benefit–cost ratio (or net present value) and a positive incremental benefit–cost ratio is likely to be preferred.

Issues include uncertainty in the cost of debris management due to uncertainty in timing, nature and quantity of debris that may arrive at an asset. Quantifying environmental impacts can be difficult as there are limited data on the value of intangible benefits such as ecosystem services.

Further information

- *Assessing Environmental Impact: Guidance* (Defra 2013)
- *Flood and Coastal Erosion Risk Management – Appraisal Guidance* (FCERM-AG) (Environment Agency 2010a. 2010b, 2010c)
- *The Green Book. Appraisal and Evaluation in Central Government* (HM Treasury 2003 as amended)

2.5 Implement and monitor

Intervention may range from inspection and maintenance to the improvement or replacement of an existing structure. The issues are wide-ranging and a prompt list is given in Table 2.4, although this is not comprehensive.

Monitoring may be required during or after works as a condition of consent (for example, turbidity monitoring to ensure that work in a watercourse does not cause environmental harm). This is likely to be relatively short-term (that is, the duration of the works or less than a year).

Inspection and monitoring (routine or reactive) can help to keep blockage management appropriate and effective. You may wish to adapt the work according to observations (for example, you could reduce inspection frequency if debris accumulation is consistently low). You may also want to monitor if you have high uncertainty, or to help make future decisions about whether or not to intervene.

Systematic monitoring can identify changes over time and allow you to make informed decisions for the future. It also helps to avoid corporate memory loss. Corporate memory is the data, information and knowledge that has accumulated during the life of an organisation and is stored both in its archives and individuals' memories. Corporate memory loss can lead to the failure to do something (for example, to maintain an asset), with potentially disastrous consequences.

Table 2.4 Prompt list of issues in implementation

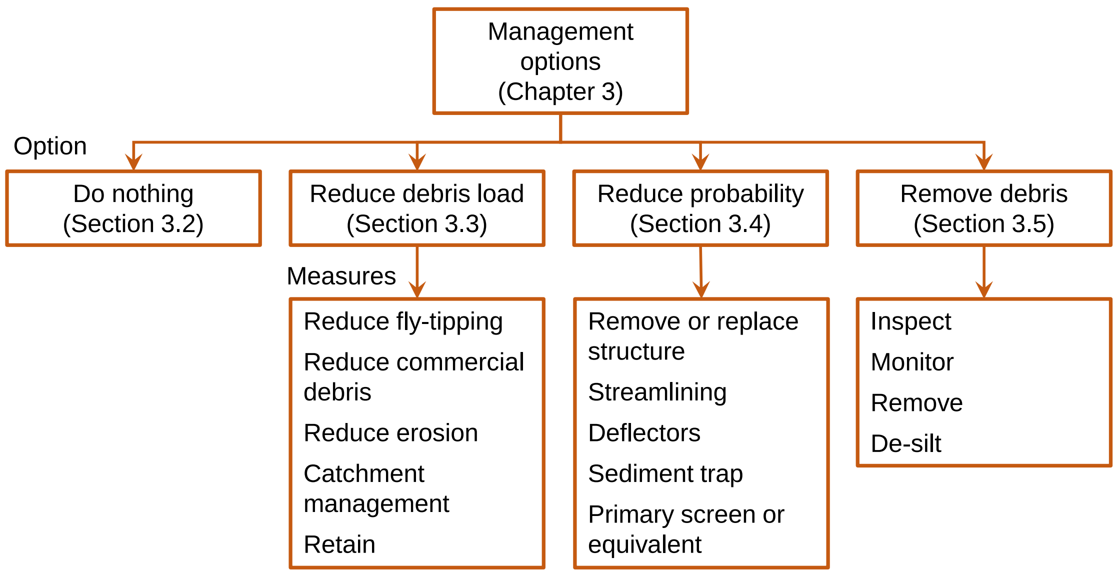
Issue	Notes
Timing	Allowing sufficient time for procurement, funding and design Avoiding site clearance during the bird breeding season Avoiding work in-channel during relevant fish spawning season Working around other site-specific or species-specific timing restrictions Avoiding work in watercourses during high flow conditions Avoiding earthworks during adverse weather
Risk and procurement	Risks to the works (for example, adverse weather, flooding) Allocating risk by selecting an appropriate contract strategy
Access	Safe access for inspection and maintenance (for example, debris removal) Authorised and unauthorised access to the site
Health and safety	Risk assessment and method statements Application of the CDM Regulations
Environment	Avoiding or mitigating for adverse impacts on the environment Opportunities for environmental enhancement Management of silt mobilisation and turbidity
Methods	Selecting debris removal method to suit debris size and location Small, manageable blockages can be removed using hand tools Larger blockages may require specialist contractors and equipment
Disposal of debris	Vegetation may be recycled or shredded on-site and left on river banks Man-made material should be disposed of at a licensed tip Sediment may be returned to the river downstream of structure, or tested for waste acceptance criteria and, depending on result, disposed of at an exempt site or landfill site
Permits	Permits for permanent and temporary works (see Appendix A)

A long-term record of blockage at a wide range of structure types and geographical locations is required to help build a UK-wide dataset on blockage and the impacts of blockage. The supply, transport and delivery of debris is complex and blockage is a random event. Extra data are invaluable in the development of new predictive equations for different structures. This will have strategic benefits for the wider flood risk management community. It is important that monitoring is carried out at regular intervals over the long-term (that is, for several years). The type of information gathered depends on the reasons for monitoring, the type of structure and the impacts of blockage. Guidance is given in Appendix B.

Further information

- *Aquatic and Riparian Plant Management* (Environment Agency 2014a)
- *Pollution Prevention for businesses* (Environment Agency. 2016)
- *Control of Water Pollution from Construction Sites*. CIRIA C532 (Masters-Williams et al. 2001)
- Engineering in the Water Environment: Good Practice Guides:
  - *Temporary Construction Methods* (SEPA 2009a)
  - *Vegetation Management* (SEPA 2009b)
  - *Sediment Management* (SEPA 2010)

3 Management options



3.1 Introduction

This chapter describes the options available to manage blockage risk and is likely to be of interest to asset managers and those involved in options appraisal. Options include:

- doing nothing (Section 3.2)
- proactive options to reduce the debris load at source (Section 3.3)
- proactive options to reduce the probability of blockage along the pathway (Section 3.4)
- reactive options to reduce the consequences of blockage at the structure (Section 3.5)

Your choice of management option depends on the objectives for the site, constraints and opportunities. Influential factors include:

- blockage risk
- rate of blockage and ease of removal during high flow conditions
- ease of disposal of debris
- identification of debris sources and responsible parties
- access to the channel and floodplain upstream
- type of debris

It is preferable to work with natural processes and to address the cause of the problem rather than managing the symptom over the long term. Thus engaging stakeholders to reduce fly-tipping may be better than routine removal of debris.

A decision-making framework to assist with the choice of options is given in Table 3.1, though this is not comprehensive and each option may have advantages, disadvantages and risks (see Sections 3.2 to 3.5). Decision-making may be supported by:

- identification of legal requirements, objectives, constraints and opportunities (see Chapter 2)
- assessment of risk, blockage rate, ease of removal, ease of debris disposal, debris sources and access (see Chapter 4 Initial appraisal or Chapter 5 Detailed assessment)

Option selection may be preceded by initial appraisal (Chapter 4) or detailed assessment (Chapter 5). If you have good knowledge of a problem site, however, you may be able to select suitable options directly.

The background to the management options described in this chapter is discussed in the accompanying science report.

Table 3.1 Decision-making framework

Q1. Is the blockage risk low? (Section 4.6 or Section 5.7)	If yes, you may consider do nothing (Section 3.2). Otherwise, you may consider doing something. Go to Q2.
Q2. Is blockage rapid or difficult to remove during high flow conditions? (Section 4.4 or Section 5.3)	If yes, you may consider proactive options. Go to Q3. Otherwise, you may consider removal and go to Q5.
Q3. Is the disposal of debris difficult (for example due to contamination, volume or haulage distance)?	If yes, you may consider reducing debris load or reducing probability of debris accumulation. Go to Q4. Otherwise, you may consider reducing probability by intercepting debris upstream (Section 3.4).
Q4. Can you identify sources and responsible parties, or gain access to the channel and floodplain upstream?	If yes, you may consider reducing debris load (Section 3.3). Otherwise, you may consider reducing probability of debris accumulation (Section 3.4).
Q5. Which type of debris do you have? (Section 4.5 or Section 5.2)	**Man-made**: remove debris, if practicable (Section 3.5). **Vegetation**: may be retained to minimise impacts on environment (Section 3.4). Remove if necessary to maintain flow capacity or flow measurement, or to prevent erosion (Section 3.5). **Large wood**: may be retained to slow flow, reduce flooding downstream and benefit ecosystems (Section 3.3). Removal is preferable if the debris traps man-made material, creates (or may be transported to a location where it creates) an unacceptable risk to people, property, infrastructure or habitat (Section 3.5). **Fine sediment**: reduce erosion (Section 3.3). **Coarse sediment**: retain (Section 3.3) or reduce probability by design (Section 3.4) if possible. Remove, if practicable and there is an unacceptable risk to people, property, infrastructure or habitat, and no more sustainable options are available (Section 3.5).

3.2 Do nothing

Do nothing is the retention of debris without further intervention.

Suitable applications	Unsuitable applications
No receptors (Section 4.3). Vegetation or sediment (Section 4.5 or 5.2). Low blockage risk (Section 4.6 or 5.7).	Blockage is rapid or removal during high flows is difficult (Section 4.4). Man-made debris (Section 4.5 or 5.2). High blockage risk (Section 4.6 or 5.7).

Large wood: retain or remove?
Large wood (or woody debris) can have a range of potential benefits for watercourses. • **Biodiversity**: varies channel shape and flow patterns, creating habitat for many species of plants, invertebrates and fish. • **Climate change**: provides shade, backwaters and pools, and refuge for fish and invertebrates during drought conditions, improving resilience of river ecosystems to climate change impacts. • **Flood risk**: can cause blockages at structures and increase flood risk, but can also be used to restore floodplain connectivity and increase upstream flood storage. • **Water Framework Directive**: can help achieve environmental improvements and restore rivers to good ecological status or potential. Large wood can be removed, retained, or even installed. **When to remove**: you may remove large wood if there is a risk of unwanted blockage, erosion or flood risk, particularly in urban areas. If large wood is removed, it may be reused in a different part of the catchment or retained for use elsewhere. If this is not possible, it should be disposed of. It may not be necessary to remove all large wood. You can reduce its impact by: realigning it so that it points downstream or is closer to river banks; repositioning it away from culverts and bridges, or away from main flow routes in a channel; and reducing the volume so it takes up less of the channel cross-section. Where wood is removed, you should ensure its removal does not cause harm as defined in the Water Resources Act 1991 (as amended 2009). **When to retain**: you can retain large wood if the material is lower than the river banks and there is no risk of unwanted blockage, erosion or flooding. You may wish to retain debris in rural areas or parkland, but not in urban areas. When retaining material, it is important to establish if it is mobile and could become dislodged. It may be necessary to anchor the structure to prevent it from causing a blockage elsewhere. **When to install**: large wood may be installed to help achieve flood risk-related WFD or other benefits. You should not do this if it will increase unwanted flood or erosion risk. Installing large wood structures in the bed or on the banks of a river may require an environmental permit.

3.3 Reduce debris load

Reducing debris load at source is proactive and can offer wider environmental benefits, particularly if soil erosion or the volume of man-made materials entering the watercourse is reduced. The law supports the control of man-made material; businesses are legally responsible for their waste and have a duty of care to ensure it is stored and disposed of responsibly.

Suitable applications	Unsuitable applications
You can identify sources of debris (Section 4.5 or 5.2). You can identify responsible parties and persuade them to take action. You have good access to the channel and floodplain upstream of structure for debris removal.	You are unable to identify sources of debris (Section 4.5 or 5.2). You are unable to identify responsible parties or persuade them to take action. You have poor access to the channel and floodplain upstream of structure for debris removal.

Methods to reduce debris load

Reduce fly-tipping

Description: provide accessible facilities; raise awareness; encourage reporting of irresponsible practice; and take legal action if advised.

Uses: domestic man-made material

Cost: ££ (medium)

Advantages: proactive

Disadvantages: requires maintenance and disposal

Further guidance:
Fly-tipping: Causes, Incentives and Solutions (Webb et al. 2006)

Reduce commercial debris

Description: store materials away from watercourse. Store securely or install barriers to prevent entry to watercourse (provided no impact on flooding). Inspect and take legal action if advised.

Uses: non-domestic man-made material

Cost: ££ (medium)

Advantages: proactive

Disadvantages: requires liaison with site owner or operator

Further guidance:
Your Rubbish and the Law: A Guide for Business (ENCAMS 2006)

Methods to reduce debris load

Reduce erosion

© Amanda Kitchen

Description: reduce erosion and/or intercept sediment before it enters the channel.

Uses: fine sediment

Cost: £ (low)

Advantages: proactive, protects soils, may reduce pollution

Disadvantages: potential negotiation with many owners or occupiers

Further guidance:
Controlling Soil Erosion (Defra 2005)
Woodland for Water (Nisbet et al. 2011)

Catchment management

© JBA Consulting

Description: remove material from channel or floodplain upstream before it reaches a potential blockage site (like the pictured branches for example).

Uses: man-made materials, vegetation

Cost: £ (low)

Advantages: proactive, man-made debris removal improves environment

Disadvantages: vegetation removal environmentally unfavourable, potential negotiation with many owners or occupiers

Further guidance:
Channel Management Handbook (Environment Agency 2015a)

Retain

© Environment Agency

Description: retain or re-introduce large wood that does not affect structures or water users. Anchor to reduce risk of mobilisation if necessary.

Uses: large wood, vegetation

Cost: £ to ££ (low to medium)

Advantages: varies flow conditions; creates habitat; improves biodiversity and resilience to climate change impacts. Possible flood risk benefits.

Disadvantages: permit may be required for new installations, hazard to boaters, risk of mobilisation and blockage downstream

Further guidance:
FCRM Asset Management – Maintenance Standards (Environment Agency 2012)
Conceptual Design Guidelines: Application of Engineered Logjams (SEPA 2006)
Managing Woody Debris in Rivers, Streams and Floodplains (Mott 2006)

3.4 Reduce probability

Reducing the probability of blockage is proactive and may involve intercepting and removing debris upstream of the structure, or improving flow conditions at the structure to reduce the likelihood of material accumulating.

Suitable applications	Unsuitable applications
You have an opportunity to remove an obsolete structure, design a new or replacement structure, or retrofit an existing structure. You have good access to the watercourse upstream of structure to construct, inspect and maintain an interception structure.	Debris passed downstream could cause blockage at other structures. A primary screen could obstruct fish or eel passage, or sediment transport. You have poor access to the watercourse upstream to construct, inspect and maintain an interception structure.

Methods to reduce probability	
Remove or replace structure	**Streamlining**
 	
Description: remove structure to restore natural channel, upgrade or replace structure with lower impact alternative, relocate infrastructure away from river. **Uses**: structures that can be removed, replaced or relocated **Cost**: £££ (high) **Advantages**: passive, permanent, improves ecological status or potential under Water Framework Directive, reduces long-term maintenance and cost **Disadvantages**: expensive, risk of passing problem downstream	**Description**: avoid obstructions to flow, provide freeboard for floating debris, and streamline any obstructions in flow path. **Uses**: retrofitting existing structures or design of new or replacement structures **Cost**: ££ to £££ (medium to high) **Advantages**: passive, permanent, reduces long-term maintenance and cost **Disadvantages**: expensive, risk of passing problem downstream and debris accumulation during overbank flow **Further guidance**: *Culvert, Screen and Outfall Manual* (Benn *et al*, 2019) *Potential Drift Accumulation at Bridges* (Diehl 1997) *Manual on Scour at Bridges and Other Hydraulic Structures* (Kirby et al. 2015)

Deflectors

Description: install longitudinal or transverse structures to promote change in deposition or accumulation patterns.

Uses: all debris types

Cost: ££ (medium)

Advantages: passive solution

Disadvantages: risk of causing scour or sedimentation elsewhere

Further guidance:
Debris Control Structures (FHWA 2005)
Manual on Scour at Bridges and Other Hydraulic Structures (Kirby et al. 2015)

Sediment trap

Description: install flow control to slow flow and encourage deposition; remove sediment routinely.

Uses: fine sediment

Cost: ££ (medium)

Advantages: limited extent of disturbance

Disadvantages: requires inspection, maintenance and disposal of sediment; addresses symptom not cause; potential impacts on habitat

Further guidance:
Control of Water Pollution from Linear Construction Projects (Murnane et al. 2006, Section 19.2.4)

Primary screen or equivalent

Description: install debris screen, floating boom, surface skimmer or flexible net barrier to intercept debris for removal before it reaches a susceptible structure, where it is easier to manage. Design to retain full height of material and overtop safely.

Uses: man-made materials, vegetation, coarse sediment

Cost: ££ (medium)

Advantages: disturbance during cleaning confined to short reach

Disadvantages: requires inspection, maintenance and disposal of material; disrupts sediment transport, fish, eel and mammal passage and hence affects achievement of WFD targets.

Further guidance:
Culvert, Screen and Outfall Manual (Benn et al, 2019)

3.5 Remove debris

Removing debris from a structure is reactive. It may be routine or carried out in response to trigger events. It can be high risk, particularly if blockage occurs rapidly.

Suitable applications	Unsuitable applications
Man-made debris (Section 4.5 or 5.2). Volume of debris is low and manageable (Section 4.5 or 5.2). Rate of blockage allows timely removal before blockage becomes critical (Section 5.3). Removal during high flows is safe and viable.	Volume of debris is high (Section 4.5 or 5.2). Rate of blockage prevents a timely response (Section 5.3). Blockage removal during high flows is difficult (for example blockage causes water levels to rise well above a structure inlet). Temporary storage or disposal of debris is difficult.

Methods to remove debris

Inspect

Description: inspect and remove debris, routinely and/or in response to trigger events (for example, flood warnings).

Uses: slow blockage

Cost: £ (low)

Advantages: tailor inspection frequency to risk of blockage. Members of the public can provide information.

Disadvantages: reactive, requires resources, unsuited to rapid blockage

Further guidance:
Condition Assessment Manual (Environment Agency 2006)
FCRM Asset Management – Maintenance Standards (Environment Agency 2012)

Monitor

Description: install telemetry or cameras upstream and/or downstream of structure to monitor blockage and trigger inspection and maintenance.

Uses: rapid blockage

Cost: ££ (medium)

Advantages: risk-based inspection

Disadvantages: requires data transmission, risk of vandalism, privacy issues for structures on private land or privately owned, may create expectation of intervention

Further guidance:
Discharge Measurement Structures (Bos 1989)
Local gauging authority

Methods to remove debris

Remove

Description: remove material from structure for reuse, recycling or disposal.

Uses: man-made materials, vegetation

Cost: ££ (medium) (depends on debris type and volume, contamination, opportunities for reuse, proximity to disposal sites)

Advantages: reduces risk to structure or water users

Disadvantages: reactive, potential impacts on ecology, erosion, siltation and flood peaks

Further guidance:
Aquatic and Riparian Plant Management (Environment Agency 2014a)
Channel Management Handbook (Environment Agency 2015a)

De-silt

Description: remove sediment accumulations from above the natural or design bed level of a structure or channel. Selective removal preferable to full removal.

Uses: sediment (fine or coarse)

Cost: ££ (medium)

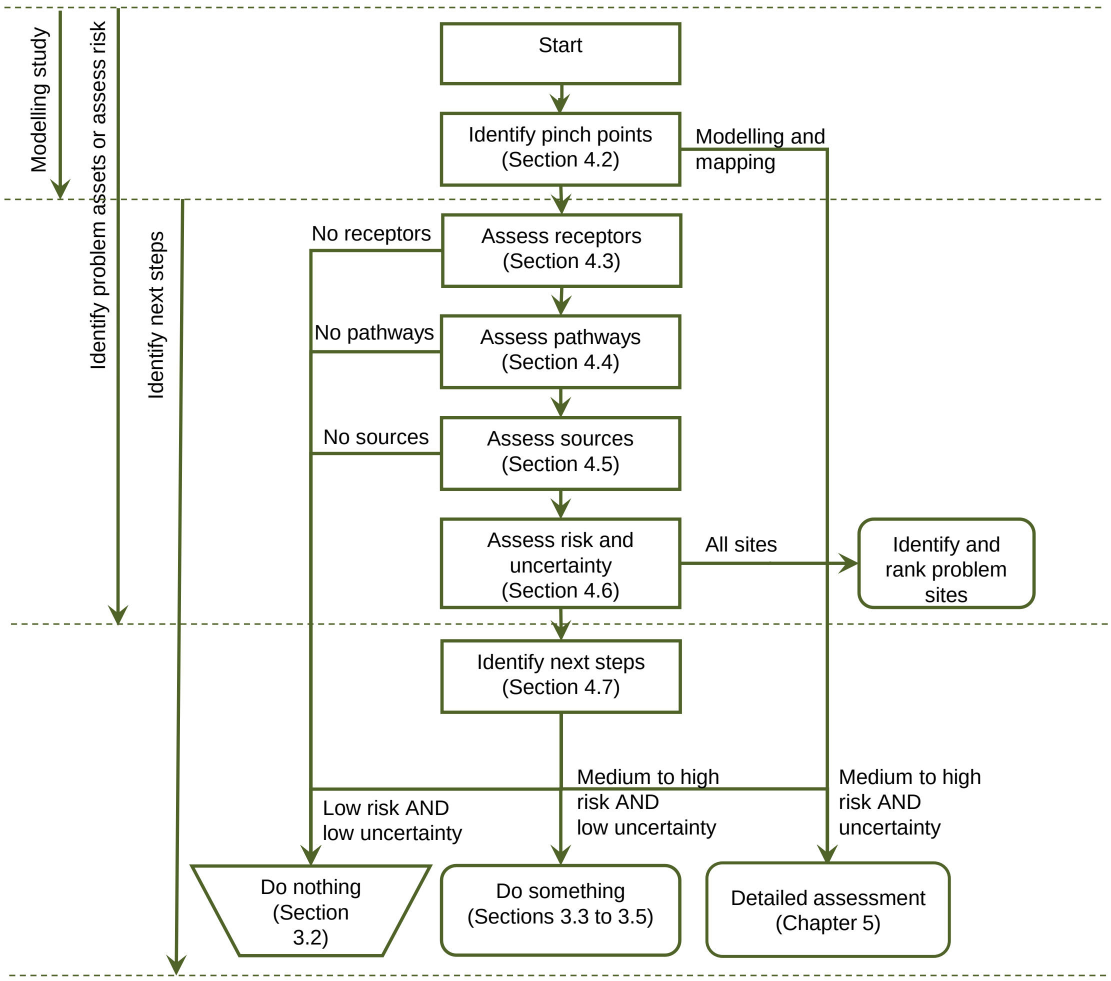
Advantages: may spread fine sediment on land for environmental benefit.

Disadvantages: reactive, loss of habitat and species. Release of fine sediments may smother habitat downstream. May release contaminants.

Further guidance:
Sustainable Management of Dredged Material from Inland Waterways (AINA 2013)
Engineering in the Water Environment: Good Practice Guide. *Sediment Management* (SEPA 2010)

When considering the removal of sediment, you should ensure that this activity will not prevent the achievement of the WFD objectives for the water body.

4 Initial appraisal



4.1 Introduction

Initial appraisal can be used to:

- identify potential problem sites
- assess risk at a single site or within a study area
- prioritise interventions at several sites
- work out whether to do something at a problem site (such as further data gathering, detailed assessment or management interventions)

It is likely to be of use to asset managers, modellers, mappers or engineers involved in options appraisal. You may use this as the first step in blockage assessment, but if you have a known blockage problem, you may go straight to detailed assessment (Chapter 5) or management options (Chapter 3).

The process involves identifying potential pinch points and assessing the 3 elements of blockage risk: **receptors** that are susceptible to flood or scour damage; **pathways** to a receptor; and **sources** of debris (Figure 1.1). It is a quick and simple desk study approach using readily available data. It is likely to take a few hours and can be as simple as looking at maps, studying flood history, or talking to colleagues or partner organisations. It is unlikely to be worth incurring costs (other than staff time) to do this.

Initial appraisal can be carried out at different levels of detail, depending on data quality. This influences the time allocated for assessment and uncertainty in the results. Three levels of detail are defined for data (Table 4.1). You may find that Level 3 is suitable for most sites and that Level 1 is required for the most critical sites only. The background to initial appraisal is discussed in the accompanying science report.

Table 4.1 Levels of detail for initial appraisal

Level of detail	Data quality	Time allocation	Suitable applications
Level 1	Best available data (for example, systematic data gathering at site or similar watercourse, numerical modelling or specialist advice)	Several days to weeks	Good data likely to be available Receptor/s at higher risk Significant capital works Higher certainty is desirable
Level 2	Known deficiencies (for example, empirical methods or professional judgement)	A few hours to several days	Better data likely to be available Receptor/s at intermediate risk Minor works Medium uncertainty is acceptable
Level 3	Gross assumptions (for example, deduced from experience or literature)	A few hours	Little or no data likely to be available Receptor/s at lower risk Revenue expenditure Higher uncertainty is acceptable

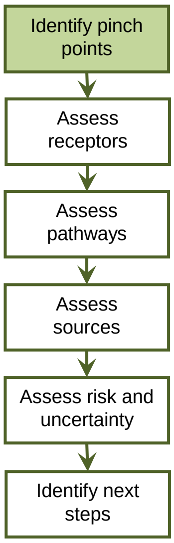
Table 4.2 gives a prompt list of data sources. Appendix C contains a worked example. Appendix E illustrates how multiple assets can be assessed using semi-automated methods.

Table 4.2 Data sources for initial appraisal

Factor	Level of detail		
	3 – gross assumptions	**2 – known deficiencies**	**1 – best available**
Step 1 Identify pinch points			
A Pinch points	Online mapping, aerial or street view images, blockage history, media reports, anecdotal evidence	As-built drawings	Site walkover, channel survey
B Types of impacts		Local knowledge, professional judgement	Specialist assessments
Step 2 Assess receptors			
A Risk to life B Critical infrastructure C Property	Online mapping, aerial or street view images	Visual inspection	Site survey, utilities search, National Property or Receptor Databases (R)
D Environment	Policies, strategies and plans	Desk study	Site walkover
E Other impacts	Local knowledge, media reports, anecdotal evidence	Professional judgement	
Step 3 Assess pathways			
A Catchment response time	Local knowledge, public or media reports	Estimated flow hydrograph	Recorded flows or levels
B Watercourse slope	Online mapping, aerial or street view images, heritage databases	Visual inspection	Channel survey
C Flow depth D Channel width			
E Narrow gaps F Low gaps		Drawings, past inspections, photographs	As-built drawings or structure survey
G Debris dimensions		Site walkover, professional judgement	Monitoring
Step 4 Assess sources			
A Land use B Riverside vegetation	Online mapping, aerial or street view images	Local knowledge	Site walkover
C Fly-tipping D Storage of materials		'Flycapture' database (R) or recorded events	
E River typology F Sediment sources G Sediment deposition	Historic maps	Aerial photographs	
H Length of contributing watercourse J Debris accumulation	Online mapping, aerial or street view images	Professional judgement	

Notes: R = data with restricted access

4.2 Step 1 Identify pinch points



4.2.1 Method

Identify potential pinch points and likely blockage mechanisms (if these are not already known) using Table 4.3.

Identify potential impacts of blockage using Table 4.4.

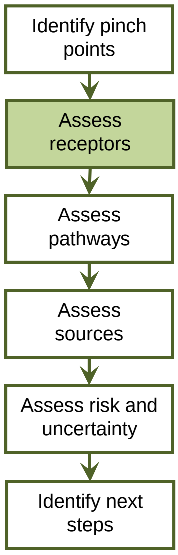
Table 4.3 Pinch points and blockage mechanisms

Blockage mechanism	Control gate	Flapped outfall	Screen	Culvert, bridge or temporary works	Weir, flume or open channel
Debris prevents operation	Yes	Yes	–	–	–
Debris on central obstruction	Yes	–	Yes	Yes	–
Debris on internal obstruction	–	–	–	Yes	–
Debris spans narrow gap	Yes	Yes	Yes	Yes	Yes
Debris spans low gap	Yes	Yes	Yes	Yes	–
Debris trapped on soffit	Yes	Yes	–	Yes	–
Deposition in shallow flow	–	–	–	Yes	Yes
Sedimentation in slow flow	–	Yes	–	Yes	Yes

Table 4.4 Potential impacts of blockage

Type	Cause
Flooding upstream of blocked asset	Flooding, possibly to overflow or relief level upstream (see Section 5.6.1)
Flooding along relief flow path downstream of blocked asset	Overtopping of structure and downhill flow, possibly returning to watercourse
Structural failure (sliding, rotation, uplift or reduced load capacity for arches)	Hydrostatic, hydrodynamic and debris impact forces on structure and any debris accumulations Masonry arch bridges which present a significant obstruction to flow are particularly vulnerable
Embankment breach leading to catastrophic failure of infrastructure and/or flood damages downstream (see CIRIA et al. 2013)	Internal erosion due to surcharging and seepage through embankment that has not been designed as water-retaining External erosion due to overtopping of embankment without scour protection, particularly if trees or protrusions on downstream face
Contraction scour undermining structure or river banks	Flow acceleration around a blockage – applies along the entire length of a blockage, although depth may vary across watercourse
Local scour undermining structure or river banks	Flow acceleration and turbulence at the edge of a blockage

4.3 Step 2 Assess receptors



4.3.1 Method

Identify potential receptors using Table 4.5. For factors A to E, identify the description that best suits the site and circle the corresponding score (where 3 is high, 0 is low). The receptor score is the maximum of scores A to E. Write this in the box at the bottom. If the receptor score is zero, there are no receptors - you can stop and record your findings.

Select a data quality score for each factor that has informed the receptor score. Identify which factors are derived from lower quality data and consider whether these have an impact on the receptor score. Consider whether improving the data would give you greater confidence in the result – sensitivity testing can help you to determine whether the result is sensitive to a particular type of data. If data quality is poor, you may wish to spend more time gathering data either now or at a later stage.

Table 4.5 Potential receptors

Factors	**Score** 0 being low 3 being high	**Data quality score** 1 being best 3 being worst
A. Risk to life (see Note A) Risk of injury or fatality None	 3 0	3, 2, 1
B. Critical infrastructure (see Note B) High impact (for example community severance) Medium impact (for example loss of utilities) Short-term, temporary impact None	 3 2 1 0	3, 2, 1
C. Property (how many properties have the **potential** to be impacted) Many (urban area) Several properties (single community) Single property, agricultural land or gardens None	 3 2 1 0	3, 2, 1
D. Environment (see Note D) Impact on ability to meet legal requirements Impact on environmental targets Impacts on other desirable outcomes None	 3 2 1 0	3, 2, 1
E. Other impacts (see Note E) High impact Medium impact Short-term, temporary impact None	 3 2 1 0	3, 2, 1
Receptor score Take the highest of scores A to E		

4.3.2 Notes on Step 2

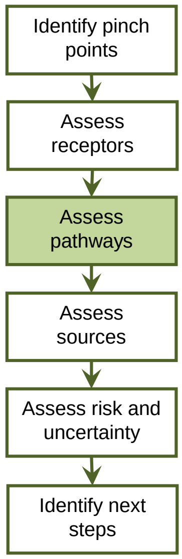
Note A: Risk to life may arise as a result of deep or fast flood flows, catastrophic failure of structure or embankment, or insufficient warning. Risk factors include flash flooding and steep catchments. An embankment breach or structural failure may cause death or injury, either directly due to failure of infrastructure above, or indirectly due to the sudden release of a large volume of water. Defra (2006) gives a method for estimating risk to life.

Note B: Critical infrastructure may include water supply, wastewater, gas, electricity, communications, road, rail or hospitals. Bridges often carry services such as water, gas, electricity or communications cables, and structural failure due to flooding, scour or hydrodynamic forces can lead to loss of the services. Road or railway embankment breach can lead to community severance and considerable disruption, particularly if they provide a sole access route to a remote or island community, or if the diversion route is long. Also consider the potential duration (minutes, hours, days and so on), the potential type of flood (broad categories – such as deep ponding or fast moving) impacting the infrastructure, and what may be impacted by the infrastructure temporarily or permanently failing. You may need to seek further advice.

Note D: Environment may include water quality, geomorphology, habitat, ecology, protected species, designated sites, heritage, landscape or recreation. An accumulation of man-made debris may affect water quality or visual amenity whilst structural failure may affect designated heritage structures. Embankment breach could lead to loss of navigation along a canal or navigable waterway, and the sudden release of sediment may smother downstream gravels.

Note E: Other impacts are included as a catch-all for other types of damage and may include direct damages due to flooding or indirect damages such as due to loss of business or tourism. Here, professional judgement can be used.

4.4 Step 3 Assess pathways



4.4.1 Method

Assess the likelihood of debris transportation and accumulation using Table 4.6. For factors A to F, identify the description that best suits the site and circle the corresponding score (where 3 is high, 0 is low).

The **Transport** score is the highest of scores A to D. Write this in the box at the bottom of the table.

The **Accumulation** score is the highest of scores E and F. Write this in the box at the bottom of the table.

Now calculate the **Pathway** score, which is the mean of the Transport score and Accumulation scores and write the result in the box at the bottom of the table.

Select a data quality score for each of the factors that informs the receptor score.

Identify which factors are derived from lower quality data and consider whether these impact on the receptor score.

Consider whether improving the data would give you greater confidence in the result – sensitivity testing can help you determine whether the result is sensitive to a particular type of data. If data quality is poor, you may wish to spend more time gathering data either now or at a later stage.

If the pathway score is zero and you have confidence in the data quality, there are no pathways - you may wish to stop and record your findings. Otherwise, you may continue to Section 4.5.

Table 4.6 Transportation score

Type	Factors	Score 0 being low 3 being high	Data quality score 1 being best 3 being worst
Transport	**A. Catchment response time** (see Note A) Rapid (lead time rainfall to flood <6 hours) Slow (lead time rainfall to flood >6 hours)	3 0	3, 2, 1
	B. Watercourse slope (see Note B) Steep (steeper than 1%) Intermediate (slope 0.1–1%) Mild (0.1% or milder)	2 1 0	3, 2, 1
	C. Flow depth (see Notes D and G) Flow depth exceeds debris draught Flow depth similar to debris draught Flow depth smaller than debris draught	2 1 0	3, 2, 1
	D. Channel width (see Notes E and G) Channel width exceeds debris length Channel width similar to debris length Channel width smaller than debris length	2 1 0	3, 2, 1
Accumulation	**E. Narrow gaps** (see Notes E and G) Screen area <3 times culvert area Culvert barrel area <3m^2 Structure opening width <6m Gap narrower than debris length Gap similar debris length Gap wider than debris length	3 3 3 2 1 0	3, 2, 1
	F. Low gaps (see Notes F and G) Gap lower than debris height Gap similar to debris height Gap higher than debris height	2 1 0	3, 2, 1
Summary	**Transport score** Take the highest of scores A to D.		
	Accumulation score Take the highest of scores E and F.		
	Pathway score Mean of Transport score and Accumulation score		

4.4.2 Notes on Step 3

Note A: Rapid response catchments react quickly to heavy rainfall, producing flash flooding that poses an extreme threat to life. Flash flooding can destroy buildings, roads and bridges, uproot trees, and mobilise debris, boulders and vehicles, increasing blockage risk and leading to rapid blockage of structures. The EA Rapid Response Catchments register identifies catchments with potential for extreme flash flooding.

Note B: Watercourse slope upstream of the pinch point influences flow velocity and mobilising capacity of the flow, particularly for sediment, which may be transported as suspended load or bed load. You can estimate watercourse slope along the length of contributing watercourse using online maps for larger watercourses.

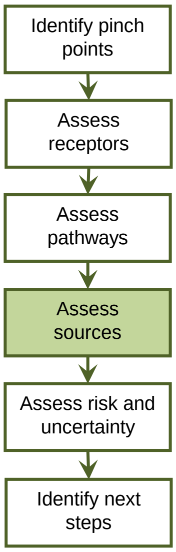
Note C: Flow depth relative to debris draught (submerged depth) influences the transport of floating debris. Shallow flow is insufficient to float and transport debris. Intermediate flow will float the debris but portions may be in contact with the bed, reducing its velocity relative to the flow. Deep flow will transport debris at the flow velocity without any substantial contact with the bed. Flow depth can be estimated using local knowledge or by applying regime equations for gravel bed rivers in the UK (Sear et al. 2003, Table 2.5). You may estimate floodplain flow depth by comparing flood zone maps with known or surveyed topography. Consider the viable range of flow depths, from normal flow to bankfull flow and flood flows.

Note D: Channel width relative to debris length affects the transport and accumulation of floating debris. In smaller streams, debris that is longer than channel width is mobilised during high flow events only, whereas in larger streams, debris that is shorter than the channel width is mobilised more easily. Regular flushing of small pieces reduces the frequency of accumulations.

Notes E and F: Narrow gaps and **low gaps** are more likely to trap floating debris by bridging if they are smaller than the debris – although there is an element of chance. For narrow gaps, debris length relative to opening width is influential and, for low gaps, it is debris height relative to opening height.

Note G: Debris dimensions – you can determine debris type from land use type, local knowledge or professional judgement, and the size of the larger debris pieces likely to approach the structure (see Table 5.4 for a guide to debris classification and sizes). You can estimate debris draught from its volume and density, or using professional judgement.

4.5 Step 4 Assess sources



4.5.1 Method

Assess potential sources of debris and debris volume using Table 4.7.

For factors A to J, identify the description that best suits the site and circle the corresponding risk score. At the bottom of the table, determine the vegetation, man-made debris and sediment scores. Add these to the blank boxes near the bottom of the table. The scores that are greater than zero indicate the likely types of debris.

Determine the **Debris** score (the maximum of scores A to G) and **Volume** score (the maximum of scores H and J) and write these in the blank boxes. Calculate the source score which is the mean of the Debris score and Volume score, and add your score to the table. If the **Source** score is zero, there are no sources and you may stop and record your findings. Otherwise, you may continue to Section 4.6.

Select a data quality score for each of the factors that informs the source score. Identify which factors are derived from lower quality data and consider whether these impact on the source score. Consider whether improving the data would give you greater confidence in the result – sensitivity testing can help you to determine whether the result is sensitive to a particular type of data. If data quality is poor, you may wish to spend more time gathering data either now or at a later stage.

Table 4.7 Source score

Type of debris	**Factors**	**Score** 0 being low 3 being high	**Data quality score** 1 being best 3 being worst
Vegetation	**A. Land use** (see Note A) Woodland, arable land (producing straw or hay, baled or unbaled), timber operations or felled timber awaiting collection Urban areas (areas with a high density of human construction; residential, commercial or industrial areas) Suburban open (for example, parks, golf courses) Pastoral or rural	 3 3 2 0	3, 2, 1
	B. Riverside vegetation (see Note B) Large mature trees Small trees or bushes Small vegetation (see Table 5.4)	 3 1 0	3, 2, 1
Man-made	**C. Fly-tipping** (see Note C) History of fly-tipping, suburban land use (with dwellings) or urban land use Vehicle access or private gardens adjacent to channel None of the above	 3 1 0	3, 2, 1
	D. Storage of materials (see Note D) Adjacent to watercourse with no barrier In floodplain or within 100m of watercourse None	 2 1 0	3, 2, 1

Table 4.7 Source score (continued)

Type of debris	Factors	Score 0 being low 3 being high	Data quality score 1 being best 3 being worst
Sediment	**E. River typology** (see Note E) Plane bed or wandering Active single thread Passive single thread Other types	 3 2 1 0	3, 2, 1
	F. Sediment sources (see Note F) Stores of sediment within channel Heavy sediment load due to catchment topography, soil, land use or channel use None of the above	 3 2 0	3, 2, 1
	G. Sediment deposition (see Note G) Transition from steep to mild bed slope Sudden constriction on bed rock river Sudden expansion in cross-section None of the above	 3 3 3 0	3, 2, 1
Volume	**H. Length of contributing watercourse** (see Note H) Long (500m or more) Intermediate (250m) Short (100m or less)	 3 2 0	3, 2, 1
	J. Debris accumulation (see Note J) Extensive debris accumulation Little debris accumulation None	 3 1 0	3, 2, 1
Debris types	**Vegetation** (highest of scores A and B)		
	Man-made (highest of scores C and D)		
	Sediment (highest of scores E to G)		
Summary	**Debris score** Highest of scores A to G		
	Volume score Highest of scores H to J		
	Source score Mean of Debris score and Volume score		

4.5.2 Notes on Step 4

Note A: Land use along the contributing length of watercourse and in the floodplain influences the type and quantity of debris with potential to enter the watercourse (see Table 5.4). Debris may be generated on the floodplain and mobilised during flood conditions, or blown into the watercourse from nearby land during high winds. Consider land use adjacent to the watercourse and on the floodplain (or up to 100m from the watercourse if no floodplain).

Note B: Riverside vegetation can be mobilised by bank erosion. Mortality and breakage of trees in the floodplain can produce large logs which may be transformed into smaller material by decay and loss of branches, twigs or bark. Seasonal grass or vegetation cutting in arable or rural areas can generate straw or hay (baled or unbaled) and loose vegetation, all of which can be effective in blocking channels and major bridges, and are difficult to remove and dispose of. Late summer floods can mobilise straw bales of up to 0.5 tonnes or more. Small vegetation generally has a minimal impact on blockage unless the length of contributing channel is significant, although small material can build up on a screen to create an impermeable blockage (the 'beaver' screen effect).

Note C: Fly-tipping is a major source of man-made materials. Risk factors include a history of fly-tipping, vehicular access to the bank of a watercourse and private gardens backing onto a watercourse. Urban or suburban land use also contribute. Culvert removal (or daylighting) removes an obvious pinch point, but may increase fly-tipping along the open length depending on the land use before and after daylighting.

Note D: Storage of materials near a watercourse can lead to materials falling, running off or being blown into the watercourse during heavy rainfall or high winds. Risk sites include distribution depots, construction sites, supermarkets or sites where packaging, building materials, trolleys, sediment or other materials are stored. The risk is greater if they are lightweight, stored immediately adjacent to the watercourse, and there is no fence between the stockpiles and the watercourse. You can identify sites using local knowledge, maps or aerial photographs, the latter preferably recent, high resolution and verified by inspection on the ground.

Note E: River typology indicates river activity and sediment load. A river that exhibits lateral movement is also more likely to generate vegetation and woody material due to bank erosion. River typology can be assessed by examining historic maps, aerial photographs or site walkover. Guidance is available in *Aquatic and Riparian Plant Management* (Environment Agency 2014a) or *Channel Management Handbook* (Environment Agency 2015a).

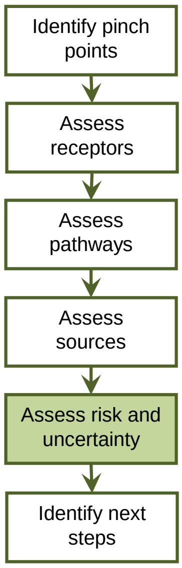
Note F: Sediment sources include stores of loose sediment within the channel which are likely to move during high flows. A heavy sediment load may be related to the catchment geology, erodible soils, steep slopes or topography, heavy rainfall, high winds, land use, channel modifications or function, or misconnections between foul and surface water sewage network. Note that road run-off may be contaminated by hydrocarbons. Guidance is given in *Sediment Matters* (Environment Agency 2009).

Note G: Sediment deposition may occur if there is a sudden reduction in velocity, either due to a transition from steep to mild bed slope, a throttle on the watercourse or a sudden expansion in the cross-section. Replacement of an engineered channel with a meandering natural channel reduces bed slope and may encourage deposition.

Note H: Length of contributing watercourse influences the volume of debris and is measured upstream of the asset to a location at which no more debris can enter the watercourse, or at which debris is prevented from moving downstream (for example, a lake or a screen). Research suggests that the length of contributing watercourse is limited due to the time taken for debris to travel downstream towards a structure, although there is insufficient data for this distance to be defined at present (Allen et al. 2015).

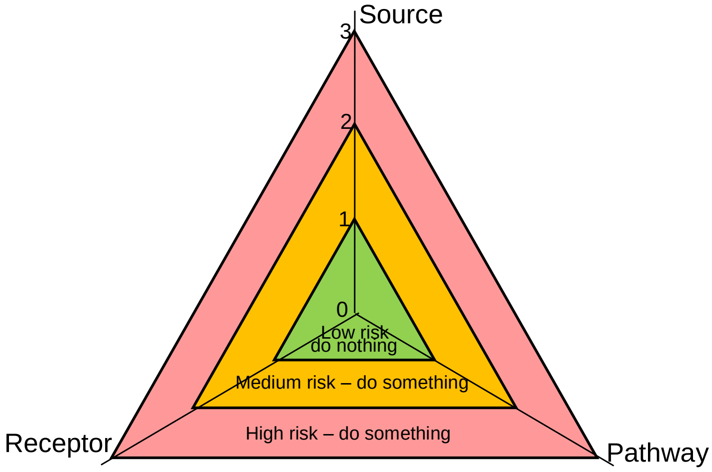
Note J: Debris accumulation within the channel and/or floodplain influences the debris load available for mobilisation and is determined by the frequency of debris generation, higher flows and catchment management. Adverse weather conditions such as heavy rainfall or high wind can break branches and carry man-made materials towards the watercourse or floodplain. Regular debris management between events, and previous flood events that reduce the debris available by transporting it downstream, will reduce debris load. The debris load and hence degree of blockage experienced at a structure during a flood event is lower if the flood is preceded by a smaller flood event that clears the catchment of some available debris, than if there are no recent significant flow events.

4.6 Step 5 Assess risk and uncertainty



4.6.1 Step 5A Identify problem sites

Next identify potential problem sites by plotting the source, pathway and receptor scores onto the blockage triangle below. If all 3 scores are less than one (in the green zone), the site is very low risk and you may stop. Otherwise, you may proceed to Step 5B below.



4.6.2 Step 5B Assess risk and uncertainty

Calculate the blockage risk score for each problem site using the equation below and the source, pathway and receptor scores; it should be between 1 and 9. You can use this to assess catchment-wide risk, rank sites, prioritise interventions at multiple sites or work out your next steps.

$$Risk\ score = \left(\frac{Source\ score + Pathway\ score}{2}\right) \times Receptor\ score$$

Next you can determine data quality scores (DQS) for source, pathway and receptor for each problem location if you want to identify where data improvements might have the most impact. These are built up in the same way as the risk scores, using the factors that are influential and ignoring the data quality scores for factors that are not influential.

So, if the receptor score was derived from a risk to property, you can use the DQS for property. If 2 or more factors have been chosen, you can use the mean DQS for those factors.

The Pathway DQS is the mean of the Transport DQS and Accumulation DQS. The Source DQS is the mean of the Debris DQS and the Volume DQS. The results can be tabulated (see Table 4.8). Appendix C contains an example.

You can review the DQS against contributing scores; or use the equation below to calculate an overall score to help prioritise data gathering between multiple sites; it should be between 1 and 3.

$$Data\ quality\ score = \left(\frac{DQS_{Source} + \mathrm{DQS}_{Pathway} + 2DQS_{Receptor}}{4}\right)$$

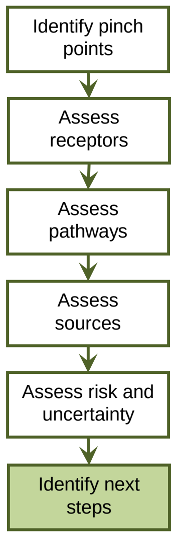
Table 4.8 Data quality score

Score	Influential factors	DQS values	Chosen DQS
DQS receptor			
DQS pathway			
DQS source			
Data quality score			

Identifying which scores are derived from lower quality data allows you to consider whether these impact on the risk score and whether improving the data would give you greater confidence in the result – sensitivity testing can help you to determine whether the result is sensitive to a particular type of data. If data quality is poor, you may wish to spend more time gathering data either now or at a later stage.

Blockage prediction is inherently uncertain due to a lack of systematic data gathering on the nature and impacts of blockage.

4.7 Step 6 Identify next steps

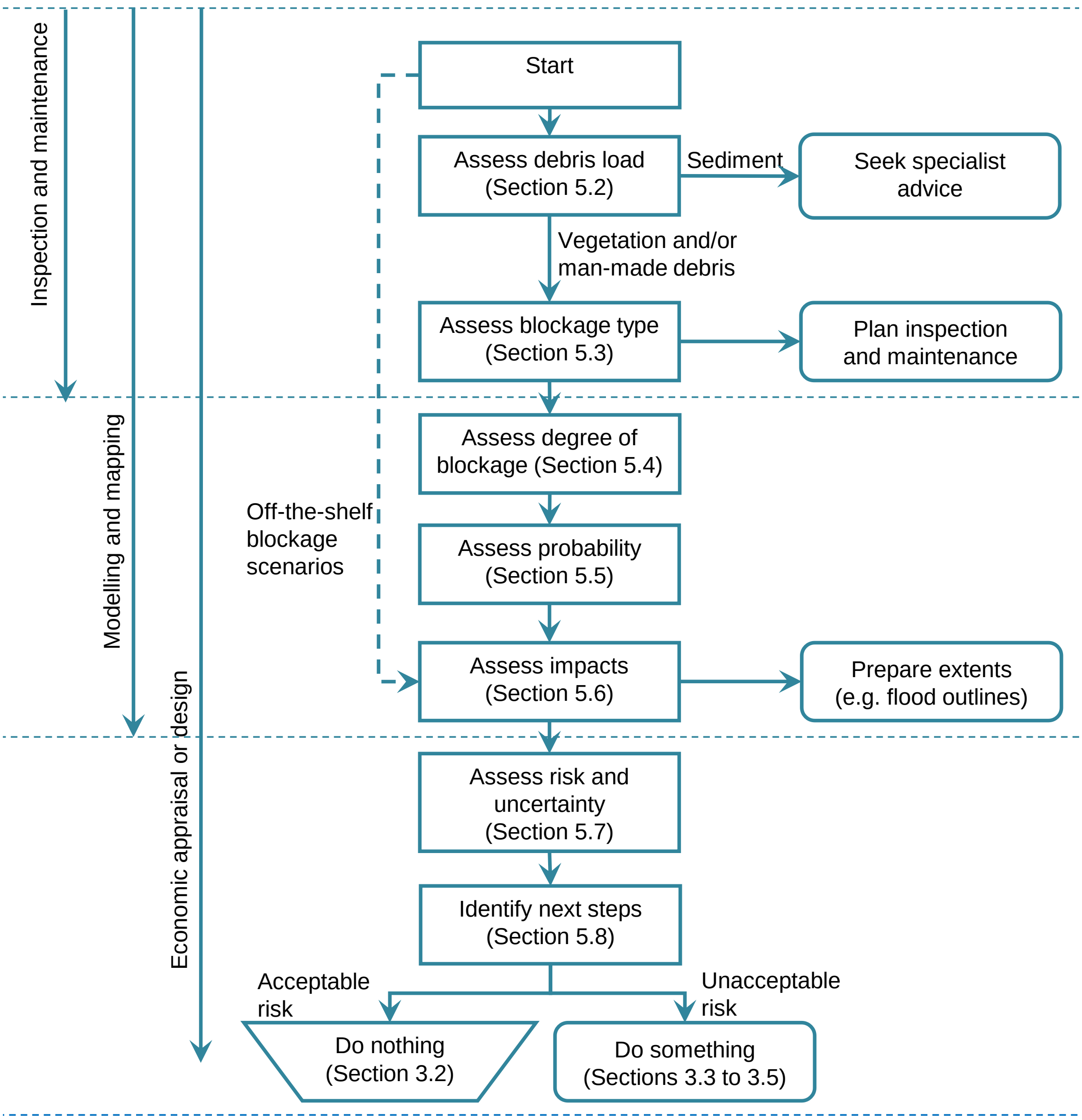


Finally, you can circle the appropriate risk score and the data quality score which best reflects your choice of data in Table 4.9. You can decide what action to take based on whether blockage risk is low, medium or high and the data quality.

Table 4.9 Next steps

Data quality score	Risk score		
	Low (1 to 1.75)	**Medium (2 to 4.5)**	**High (5 to 9)**
1 – best available	Do nothing (Section 3.2)	Do something (Chapter 3) (which may involve detailed assessment, Chapter 5)	
2 – known deficiencies			
3 – gross assumptions	Further data gathering or detailed assessment (Chapter 5)		

5 Detailed assessment



5.1 Introduction

Detailed assessment can be used to help plan inspection and maintenance, assess risk for known risk sites or where you have significant uncertainty, model and map flooding and other risks, or inform economic appraisal and design. It is likely to be of interest to asset managers, modellers, mappers or those involved in options appraisal.

It is likely to be preceded by initial appraisal, but if you know you have a blockage problem, you may wish to start here or go straight to management options (Chapter 3).

An assessment involves quantifying blockage risk, starting with an estimate of **debris volume** and **rate of blockage**, which can be used to inform inspection and maintenance. It allows you to calculate **probability** and **degree of blockage**, which can inform modelling and mapping. Finally, you can estimate the **impacts** on water levels and/or flood extents (with and without blockage), **damages** (with and without blockage) and the **benefits** of avoiding blockage for economic appraisal and design.

Detailed assessment uses more detailed information and methods than initial appraisal (Chapter 4). It can be carried out at different levels of detail – determined by the data quality and the choice of methods (Table 5.1); this influences the time allocated for assessment and the uncertainty in the results.

The level of detail will depend on: the nature of the problem; the question being asked; areas of uncertainty identified during initial appraisal; data availability; the level of risk to receptors (including the environment); the likely level of investment; the number of assets assessed; and the degree to which the process can be automated. You may find that Level 3 is suitable for most sites and choose Level 1 for the most critical sites only.

It may be worth purchasing data and Table 5.2 gives a prompt list of potential data sources. Table 5.3 gives a guide to detailed assessment and the background to the methods is discussed in the accompanying science report.

Avoid spending more on analysis than it would cost to address the problem.

Table 5.1 Levels of detail for detailed assessment

Level	Data quality or methods	Time allocation	Suitable applications
Level 1	Best available data (for example, monitoring data, numerical modelling or specialist advice)	Several days to weeks	Good data likely to be available Receptor/s at higher risk Significant capital works Lower uncertainty is acceptable
Level 2	Known deficiencies (for example, empirical methods or professional judgement)	A few hours to several days	Better data likely to be available Receptor/s at intermediate risk Minor works Medium uncertainty is acceptable
Level 3	Gross assumptions (for example, deduced from experience or literature)	A few hours	Little or no data likely to be available Receptor/s at lower risk Revenue expenditure Higher uncertainty is acceptable

Table 5.2 Data sources for detailed assessment

Factor	Level of detail		
	Level 3 (worst)	**Level 2**	**Level 1 (best)**
Step 1 Assess debris load			
Land use	Online mapping	Aerial or street view images	Site walkover
Debris type and size	Online mapping or aerial images	Photographs	Site walkover and measurements
Debris volume	Not applicable	Professional judgement	Monitoring
Step 2 Blockage type			
Blockage location and type	Local knowledge	Professional judgement	Inspection or monitoring
Blockage timing		Empirical method (Section 5.3.2)	Real-time monitoring
Step 3 Degree of blockage			
Structure dimensions	Local knowledge, online mapping or aerial images	Site walkover Inspection reports Professional judgement	Structure survey
Design log length (or bed material type and size)			Monitoring
Degree of blockage	Not applicable	Not applicable	Monitoring
Step 4 Probability of blockage			
Contributing upstream channel length	Online mapping, aerial or street view images	Professional judgement	Site walkover
Channel slope			Digital Terrain Model
Income Domain Score or Multiple Deprivation Measure	National statistics		
Land use	As Step 1 above		
Step 5 Assess impacts			
5A Impacts on water levels			
Design flows	Professional judgement	Hydrological assessment	Gauged flows
Modelled water levels	Historic water levels	Flood risk mapping levels	Bespoke modelled levels
Relief level	Professional judgement	As-built drawings or visual inspection	Site survey
5B Impacts on receptors			
Ground levels	Online mapping	Online height data (contours)	Digital Terrain Model
Flood extents	Historic flood outlines	Flood Zones	Modelled outlines
Property thresholds	Professional judgement	Digital Terrain Model	Surveyed
Property types	Online mapping, aerial or street view images	Site walkover	National Property or Receptor Databases (R)
Likelihood of scour	Geological maps, photographs	Bed and bank sediment type	Bed and bank sediment size
Structure or embankment design	Professional judgement		Ground investigation

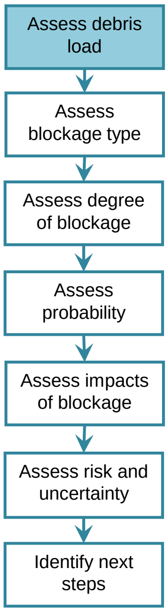
Notes: R = data with restricted access

Appendix D gives an example of detailed assessment for a single site. Appendix E shows how multiple assets have been assessed using semi-automated methods.

Blockage prediction is inherently uncertain due to a lack of systematic data gathering on the nature and impacts of blockage.

Table 5.3 Guide to detailed assessment

Issue	Suggested approach and guidance
Does detailed assessment take a deterministic or probabilistic approach?	This guide covers deterministic assessment. Probabilistic assessment is discussed in the science report.
Does detailed assessment require lots of data?	No. Level 2 or 3 methods use little or no data; Level 1 methods use systematic blockage records.
Which structure types can I assess?	Bridges, control gates, culverts, flap valves, flumes, open channels, screens and weirs
Which debris types can I assess?	Man-made materials and vegetation Sediment is covered only briefly; for more see Sear et al. (2003) or consult a geomorphologist.
How can I quantify risk of blockage?	Assess the blockage risk using Sections 5.2 to 5.7.
How can I work out what to do (if anything) at a blocked asset?	Assess the blockage risk using Sections 5.2 to 5.7 and determine whether this is acceptable or unacceptable.
How can I plan inspection and maintenance?	Estimate the blockage risk and prioritise sites according to risk (Sections 5.2 to 5.7).
How can I determine the required operational response time?	Assess debris load and estimate the blockage timing (Sections 5.2 and 5.3).
How can I size a new or replacement screen so that operatives can mobilise to clear debris before complete blockage occurs?	Assess the debris load, blockage timing and degree of blockage (Sections 5.2 to 5.4). Then size the screen to suit the response time and maintenance regime; see also *Culvert, Screen and Outfall Manual* (Benn et al. 2019).
How can I represent blockage in a hydraulic model?	Assess the debris load, blockage timing and degree of blockage (Sections 5.2 to 5.4).
How can I assess or map the impacts of blockage?	Assess the debris load. Then estimate the degree and impacts of blockage (Sections 5.2 to 5.5).
How can I determine the benefits of intervention?	Estimate the degree of blockage. Then assess the impacts of blockage with and without blockage (Sections 5.4 and 5.5).
How can I design structures to reduce the risk of blockage?	Assess the blockage risk for different options and compare the damages of each (Sections 5.2 to 5.7).



5.2 Step 1 Assess debris load

5.2.1 Step 1A Assess debris type and size

You can determine the type and size of debris likely to arrive at a structure using Table 5.4. If you have vegetation or man-made debris, you may use the quantitative assessment methods in this chapter. If you have a significant sediment source, you may wish to seek advice from a geomorphologist.

Table 5.4 Debris classification, sources and risk factors

Vegetation (floating)  	**Classification** Small (shorter than 150mm): leaves, twigs, cuttings, garden waste Medium (150mm to 3m long): branches, shrubs, mats of weeds Large (longer than 3m): large branches, trees, logs **Sources**: seasonal leaf shedding, decay, breakage, floodplain vegetation, gardens, local run-off, wind action, wind-throw or collapse, bank erosion **Risk factors**: steep or wooded catchment, high winds, heavy rainfall, land management, maintenance, human action
Man-made (floating or non-floating)  	**Classification** Small domestic: bags, packaging, containers, newspapers, magazines Large domestic: furniture, mattresses, carpets Large non-domestic: shopping trolleys, ladders, pallets, straw bales, cars **Sources**: fly-tipping, commercial and industrial sites **Risk factors**: vehicular access to channel, urban land use, social deprivation, restricted access to waste disposal or recycling sites, waste disposal charging regime, high winds, deep or fast flow, flooding
Sediment (non-floating)  	**Classification** Fine (<20mm): silt, sand, fine to medium gravel Coarse (20–200mm diameter): coarse gravel, cobbles Very coarse (>200mm): boulders **Sources**: bed and bank erosion, collapse of banks or walls, sheet or gully erosion, slope failure, landslips, catchment changes **Risk factors**: steep catchment or watercourse, unstable watercourse, land use, agricultural practices, deforestation, climate change

5.2.2 Step 1B Assess debris volume

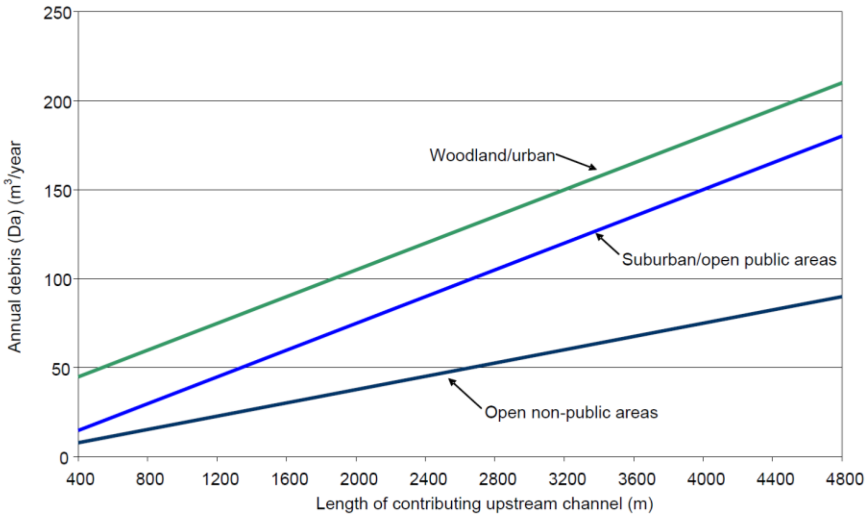
The volume of debris can be estimated using a method from Table 5.5.

Table 5.5 Methods for debris volume

Level of detail	Vegetation or man-made		Sediment
	Floating	Non-floating	
Level 1	Monitoring at site or similar watercourse (see Appendix B)		Consult a geomorphologist.
Level 2	Empirical method (see box below)	None	Sear et al. 2003
Level 3	Known land use and likely rate of debris production and mobilisation.		

Level 2 Empirical method for floating debris

Estimate the annual debris load using the graph below. For lengths of contributing upstream channel with varying land use or different land use on the left and right bank, either take the predominant land use type, or pro-rata on the length of each land use type along each bank. This method may over-estimate so you may wish to examine the effect of applying a 40% multiplier. The length of contributing upstream channel may be limited due to the time taken for debris to travel downstream during high flow conditions, although lack of data does not allow this to be defined at present (Allen et al, 2015).



The debris volume in m^3/year is:

$$V = Da \times F$$

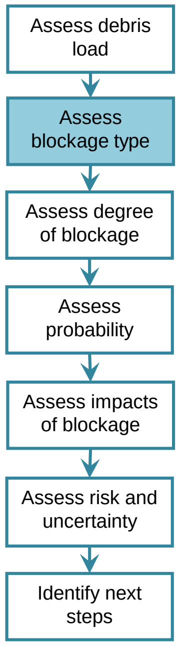
where:

Da = annual debris load (m^3/year) (from graph above)

F = stream slope adjustment factor (from table below)

Average gradient (S1085)	Milder than 1 in 1000	1 in 500 to 1 in 1000	1 in 250 to 1 in 500	Steeper than 1 in 250
Stream slope adjustment factor, F	0.25	0.50	0.75	1.00

5.3 Step 2 Assess blockage type



5.3.1 Step 2A Blockage type

You can estimate the likely blockage type from the debris type and asset type using Table 5.6.

Consider the ease of removal during flood conditions and distance to disposal sites – this depends on debris type and size, debris volume and likelihood of debris contamination. Add your findings to the summary table in Section 5.7 (Table 5.21).

Table 5.6 Blockage types

Asset type	Debris type		
	Floating	Non-floating	Sediment
Screen	Top-down	Bottom-up	Bottom-up
Bridge or culvert: narrow or low gap	Debris bridges gap	Unlikely	Bottom-up
Bridge or culvert: mid-stream obstruction	Debris trapped on obstruction	Unlikely	Unlikely
Control gate or flap valve	Debris prevents operation: blocked open or closed		Bottom-up
Flume	Debris bridges gap	Bottom-up	Bottom-up
Weir or open channel	Bottom-up	Bottom-up	Bottom-up

5.3.2 Step 2B Blockage timing

Determine the likely blockage timing using a method from Table 5.7. Add your findings and your choice of method (3, 2 or 1) to Table 5.21 in Section 5.7.

Table 5.7 Methods for blockage timing

Level	Method
Level 1	Monitoring at site or similar watercourse (see Appendix B).
Level 2	Empirical method applicable to all debris and structure types, including open channels and overland flow (see the following box).
Level 3	Knowledge of hydrology, hydraulics, geomorphology or blockage.

Table 5.8 Methods for blockage timing (continued)

Level 2 Empirical method for blockage timing

First, determine type of debris delivery using the table below.

Debris type	Likely timing of peak mobilisation
Floods infrequently	Pulsed delivery
Reeds and aquatic vegetation	Progressively during rising limb of a hydrograph with peak mobilisation coinciding with peak in-bank flow
Grass and garden mulch	At commencement of overland flow, especially in rural areas
Man-made materials	Progressively during rising limb of a flood hydrograph, once overland flows develop
Man-made materials: urban	During periods of significant overbank flow, when depth × velocity ≥ 0.3 along overland flow paths
Man-made materials: building	Often pulse-like delivery once significant overbank or overland flow develops
Sediment	During rising limb of flood hydrograph, around bankfull discharge Peak deposition normally on falling limb as velocity drops

Then determine blockage timing using the table below.

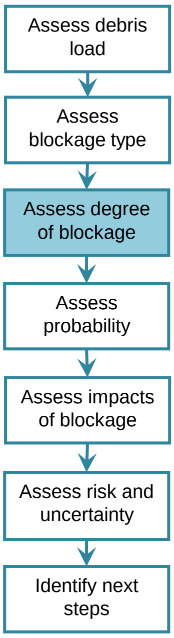
Dominant material	Delivery and type	Blockage locations			
		Inlet	Barrel	Outlet	Handrails
Floating	Progressive (top-down)	0 at T_P to A_b at T_{soff}	Unlikely	Unlikely [1]	A_b throughout structure surcharging
	Pulse (porous plug)	A_b at T_{Source}	Not applicable	Not applicable	
Non-floating	Progressive (bottom-up)	0 at T_{Source} to A_b at T_P			Unlikely
	Pulse (porous plug)	Unlikely [2]	Not applicable	Not applicable	Unlikely

where:
A_b = predicted area of blockage (m^2) (see Section 5.4)
T_P = time at which water level peaks immediately upstream of the structure
T_{soff} = time when water level drops back to soffit level of structure
T_{Source} = time when flow that first overtops stream banks at source reaches structure

Notes:
1. Unlikely, but could occur if inlet is open and outlet grated.
2. Unlikely, but could occur if upstream bed/banks are unstable and/or prone to scour.

Adapted from *Guidelines for Culverts and Small Bridges* (Engineers Australia 2015).

5.4 Step 3 Assess degree of blockage



You can estimate the degree (or dimensions) of blockage using a method from Table 5.9.

The degree of blockage is likely to vary with the magnitude of a flood event. If a variable degree of blockage for different flood magnitudes is required, you may wish to conduct sensitivity testing to examine the influence of flow on depth and velocity, and hence the type and volume of debris that is mobilised, the size of the debris, its size relative to structure opening, and hence the probability and degree of blockage. These methods for estimating degree of blockage are not linked to flood magnitude because available blockage data are insufficient to provide this level of detail.

Table 5.9 Methods for degree of blockage

Level	Asset type		
	Screen	Bridge	Other types
Level 1	Inspection and monitoring at site or similar watercourse (Appendix B)		
Level 2	Empirical methods (Table 5.10)		
Level 3	Local knowledge of site or similar sites		Industry practice (Table 5.11)

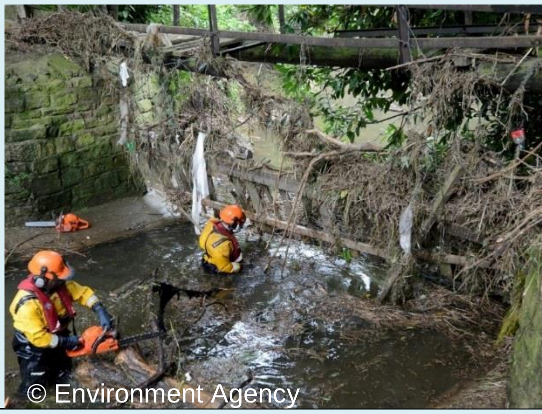
Table 5.10 Level 2 methods for degree of blockage

Screen (blinding or pseudo-weir)

Impermeable barrier from surface to bed (for example, large objects or natural debris accumulates over time)

Screen (blockage)

Permeable debris over full height of screen (for example, screen receives little debris or is cleaned regularly)



For sloping screens (more than 20° from horizontal) and land use exceeding 3% suburban, blocked area in m^2 is given by:

$$\ln A_b = 7.41 + 2.69\log SB - 3.27\log SA - 0.21\log LO$$

where:

SB = screen bar spacing (m)

SA = screen angle from horizontal (degrees)

LO = suburban–open land use along contributing length of watercourse, within 100m of watercourse (%)

This method can give a blockage area in excess of screen area so cap the blocked area at the screen area. It can also under- and over-predict (continued overleaf).

If an existing screen is considerably larger than the recommended range above, the blocked area should be multiplied by a size factor, taken as the ratio between the cross-sectional area of the screen and the mean cross-sectional area of the screens assessed in the study ($4.0m^2$).

If residential property or essential infrastructure would be at risk of flooding if the screen was to block, blocked area should be multiplied by a safety factor, with a suggested value of 2.0 to 4.5.

If blocked area is less than two-thirds of the screen opening area for a security screen and 50% of the opening area for a debris screen, then blocked area should be rounded up to 67% or 50% respectively.

Table 5.11 Level 3 methods for degree of blockage

<table>
<tr>
<td>Bridge or culvert: low gap


If design log length* exceeds height of gap, then:
Blockage dimensions = width of gap × height of gap</td>
<td>Bridge or culvert: narrow gap

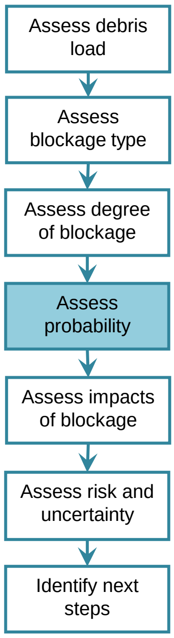

If design log length* exceeds width of gap, then:
Blockage dimensions = width of gap × smaller of flow depth and height of gap</td>
</tr>
<tr>
<td colspan="2">* Design log length is the lesser of upstream channel width and the maximum length of sturdy log that can bridge the gap without breaking.</td>
</tr>
<tr>
<td>Bridge or culvert: mid-stream obstruction

</td>
<td>If pier is in main channel, then floating rectangular raft forms below water level:
Depth = 1.2m
Width = average of adjacent spans, up to 20m
Blockage potential depends on upstream channel sinuosity, pier shape and location. For more information, see Potential Drift Accumulation at Bridges (Diehl 1997).</td>
</tr>
</table>

Table 5.8 Level 3 methods for degree of blockage (continued)

Screen  	For a security screen, assume 75% blockage. For a debris screen, assume 67% blockage.
Bridge or culvert  	**Masonry arch** Treat as low opening where height of opening is mean arch opening height. **Multiple openings** Not all openings may block to same degree. For spans within debris transport zone: treat as single opening For spans outside debris transport zone: assume half the blockage
Culvert	For top-down (porous plug) blockage, examine 33%, 67% and 100% blockage.
Control gate or flap valve	If debris dimension exceeds gate or valve opening dimension, or slow flow downstream of outlet permits sediment accumulation, then assume gate or valve blocked open or closed.
Weir, flume or open channel  	If debris draught exceeds flow depth, then take blockage dimensions as design log length times estimated log diameter. If debris bridges gap, treat as bridge with narrow gap.

5.5 Step 4 Assess probability



You can estimate the probability of blockage using a method from Table 5.11 and add your findings to Table 5.21. Recommendations for probabilistic modelling are given in the accompanying science report.

Table 5.9 Methods for estimating blockage probability

Level	Screens	Other types
Level 1	Systematic observations at site or similar watercourse (Appendix B)	
Level 2	Empirical methods (see box below)	Scoring system in *Culvert, Screen and Outfall Manual* (Benn et al. 2019)
Level 3	Local knowledge of blockage frequency at site or similar watercourse	

Level 2 Empirical methods for probability of blockage at screens

Flood Risk Management Research Consortium Phase 2 (FRMRC2) method (Wallerstein and Arthur 2012), suitable for:

- man-made materials and vegetation
- upstream network lengths exceeding 900m (apply to shorter lengths with care)
- catchments with agricultural or rural land use exceeding 3%

The probability of blockage P_b (%) is:

$$P_b = \frac{e^p}{(1+e^p)}$$

where the power p is given by:

$$p = -1.14 + (0.28\ logCL) - (0.19\ logLR) - (0.24\ logLA) + (1.12\ ID)$$

where:

CL = length of contributing upstream channel (m)

LR = rural land use within 100m of watercourse (%)

LA = agricultural land use within 100m of watercourse (%)

ID = Income Domain Score, one of 6 indices used to determine index of deprivation in the UK

Wallerstein method (Wallerstein et al. 2013)

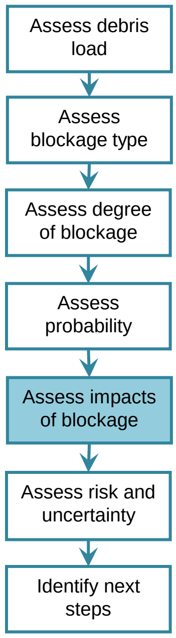
Suitable for gaps up to 150mm wide, debris up to 350mm long and debris length/span ratios up to 2.0

Can be applied to narrow gaps at larger structures with care in the absence of other methods.

Estimate the ratio between debris length and span, L/S. If L/S is ≤2.0, the probability of blockage (%) can be taken as 17.5–20 times the ratio (L/S).

These methods are highly uncertain and you may wish to carry out sensitivity tests (see Section 5.7).

5.6 Step 5 Assess impacts



5.6.1 Step 5A Impacts on water level

You can determine the impacts of blockage on water levels, velocities and flow patterns using a method from Table 5.13. Assessing the impacts on flow patterns may require professional judgement.

Table 5.10 Methods for impacts on water level

Level	Method
Level 1	Numerical modelling of water levels (Table 5.13)
Level 2	Overflow or relief level (see box below).
Level 3	Quick method (see box below).

Further information

- *Culvert Screen and Outfall Manual*. CIRIA (Benn et al. 2019)
- *Debris Control Structures* (FHWA 2005)
- *Debris Forces on Highway Bridges* (Parola et al. 2000)

Levels 1, 2 and 3 Dealing with multiple structures

At any one structure, the blockage may vary from ‘all clear’ to the design blockage, but at multiple structures, assuming that each acts independently, there are many possible scenarios involving different degrees of blockage at different structures. To define and model each scenario would require a large amount of work and is not recommended. In practice, blockage at multiple structures is not independent. Blockage at an upstream structure will reduce the debris load passing downstream, reducing the probability of blockage at a downstream structure.

A suggested approach is to define the best case scenario by modelling all structures as ‘all clear’, then define the worst case scenario by modelling all structures with the design blockage, and finally, define a series of likely combinations of blocked and clear, taking account the likely reduction in debris load downstream of a blockage.

Table 5.11 Level 1 Numerical modelling of water levels

Type	Blockage type	Description
By debris type	Floating debris (vegetation, some man-made material)	Apply top-down blockage from water level downwards.
	Non-floating debris (some man-made material, sediment)	Apply bottom-up blockage from bed upwards and increase hydraulic roughness if appropriate (Table 5.15).
	Permeable debris ('porous plug')	Reduce effective opening width, increase contraction and expansion loss coefficients. (Table 5.16).
	Impermeable debris (sediment, vegetation mats)	Add in-line weir immediately upstream of structure.
By blockage location	Top-down	Reduce structure soffit level, model opening as an orifice, increase expansion and contraction coefficients (Table 5.16).
	Bottom-up at inlet	Reduce cross-sectional area immediately upstream or add an in-line weir or sluice gate, change inlet efficiency (Table 5.16). For weirs, raise part of crest and increase discharge coefficient (Table 5.17). Reducing cross-sectional area throughout a structure changes wetted perimeter and over-estimates friction loss.
	Bottom-up throughout structure (for example, long culvert or wide bridge)	Reduce cross-sectional area throughout structure and increase hydraulic roughness (Table 5.15).
By asset type	Bridge (debris on single pier)	Increase pier width from water surface to bed; increase expansion and contraction coefficients (1:1 contraction rate upstream, 1:4 expansion rate downstream) (Table 5.16); designate ineffective flow areas.
	Bridge (debris spans 2 adjacent piers)	As above, but increase pier widths from water surface to bed such that piers touch.
	Control gate or flap valve blocked open or closed	Amend opening dimensions, invert level or gate level, amend orifice or head loss coefficient.
	Screen with permeable blockage	Apply permeable debris over full height of screen.
	Screen with impermeable blinding	Apply impermeable blinding from the waterline to the bed over the full width of the screen.

Level 1 Numerical modelling
Modelling blockage simply by increasing roughness is not ideal. The impact of blockage on water levels is not just a friction effect but includes energy losses due to contraction and expansion around debris, and increased turbulence.

Hydraulic roughness coefficient (Manning's *n*) is used to estimate friction loss and is dependent on many factors (see Table 5.15 for typical values). A high coefficient gives high energy loss. It should not be used to model the impact of loss of cross-sectional area caused by blockage. Values in excess of those given in Table 5.15 cannot be justified.

Table 5.12 Hydraulic roughness coefficient (Manning's *n*)

Sediment type	Minimum	Normal	Maximum
Clay (<2µm)	0.018	0.020	0.023
Silt (2–60µm)	0.020	0.022	0.025
Sand: fine (0.6–0.2mm)	0.010	0.012	0.016
Sand: medium (0.2–0.6mm)	0.017	0.020	0.025
Sand: coarse (0.6–2mm)	0.026	0.028	0.035
Gravel: fine (2–6mm)	0.020	0.024	0.028
Gravel: medium (6–20mm)	0.028	0.030	0.035
Gravel: coarse (20–60mm)	0.022	0.035	0.040
Cobbles (64–256mm)	0.040	0.055	0.070

Contraction and expansion coefficients represent the energy lost as flow contracts and expands around an obstruction (see Table 5.16 for typical values). High coefficients equate to high energy loss. During flood conditions, flow changes with time and the hydraulic condition can change from subcritical to supercritical then back to subcritical again. In this instance, the coefficients should be chosen for the design flow – typically the peak flow.

Table 5.13 Contraction and expansion coefficients

Asset type	Contraction	Expansion	Contraction	Expansion
No transition loss	0.0	0.0	–	–
Gradual transition/minor blockage	0.1	0.3	–	–
Typical bridge section	0.3	0.5	0.01	0.03
Abrupt transition/major blockage	0.6	0.8	0.05	0.2
Screen	0.5–0.9	1.0	–	–

Discharge coefficients for orifice and weir flow represent the energy loss due to entrance or exit conditions or flow over a weir (see Table 5.17 for typical values). A low coefficient correlates to low efficiency – and greater energy loss.

Table 5.14 Discharge coefficients

Asset type	Transition	With blockage
Control gate or flap valve	Free or submerged orifice flow	Blockage ratio <0.36: use 1.9. Blockage ratio 0.36–0.77: use 3.6–3.1BR Blockage ratio >0.77: use 1.4BR to 1.4
Weir	Broad-crested weir	33–67% of original coefficient over blocked length; use higher values for high flows

Level 2 Overflow or relief level

Overflow or relief level influences the impact of blockage and is usually, but not always, found close to the structure. It is frequently the level of the road or railway crossing the watercourse, although more complicated situations can exist where a watercourse passes below larger areas of land, particularly in urban areas.

You can determine the relief level, relief flow path and consequences of blockage during a site walkover. The relief flow path may include temporary storage areas that would fill before water continues downstream. It should take into account any flood relief arches, bypass culverts or weirs or a preferential overland flow routes allowing the safe passage of overtopping flow when structure capacity is exceeded.

Level 3 Quick method

This method estimates head losses due to expansion and contraction around the structure and debris, but ignores friction.

It is suitable for:

- channels where width does not change much with elevation or water depth
- channels where water remains in-bank after blockage occurs
- subcritical flow
- initial assessment of point assets or short assets

It is not suitable for:

- 100% blockage
- supercritical flow
- long, linear assets
- sites where channel width increases considerably with elevation (for example structure is highly blocked, soffit level is similar to river bank level, water overtops river banks and floodplain is much wider than the river channel width)

Water level increase due to blockage is:

$$\Delta WL = Afflux(blocked) - Afflux(Unblocked)$$

This can be approximated by: $\Delta WL \approx 1.5\frac{U^2}{2g}\left[\left(\frac{A}{A-A_b}\right)^2 - 1\right]$

where:

U = flow velocity through structure without blockage (m/s)

A = flow area before blockage (m^2)

A_b = flow area blocked by debris (m^2)

If you have out-of-bank flow, consider the proportion of flow on the floodplain. This can be estimated either by hydraulic modelling or manually – a method suitable for hand calculation is given in *The Assessment of Scour and Other Hydraulic Actions at Highway Structures BD 97/12* (Highways Agency 2012).

5.6.2 Step 5B Impacts on receptors

You can assess the physical impacts on receptors of the predicted change in water level, flow velocity or flow pattern using methods from Table 5.18. Add your findings to the summary table in Section 5.7 (Table 5.21).

Table 5.15 Methods for impacts on receptors

Level	Type of impact			
	Flooding	**Structural failure due to hydrodynamic forces**	**Embankment breach due to internal or external erosion**	**Contraction or local scour**
Level 1	Estimate flood outlines with and without blockage using modelled water levels and surveyed ground levels.	Consult a structural engineer.	Consult a geotechnical engineer.	Consult a hydraulic engineer.
Level 2	Project the relief level upstream of asset to estimate flood risk area; estimate flow path downstream of asset to estimate extent of flooding (see Section 5.6, Level 2 methods).	Estimate mobilising and resisting actions on structure; see *Manual on Scour at Bridges and Other Hydraulic Structures* (Kirby et al. 2015)	Assess resistance to internal or external erosion – see Chapter 8 of *The International Levee Handbook* (CIRIA 2013).	Estimate scour depth and compare with foundation depths; see *BD97/12* (Highways Agency 2012) and *Manual on Scour at Bridges and Other Hydraulic Structures* (Kirby et al. 2015).
Level 3	Estimate likely change in flood extent from ground slope and impact on receptors.	Professional judgement	Assume at risk unless designed as water-retaining structure.	Visual inspection and professional judgement. Rule of thumb: maximum local scour depth twice the width of obstruction.

5.6.3 Step 5C Impacts on damages

You can estimate the impacts on damages with and without blockage using a method from Table 5.19, and determine the benefits of intervention (the difference between the damages with and without blockage), then add your findings to Table 5.21 in Section 5.7.

Table 5.16 Methods for impacts on damages

Level	Method	Applications	Description	Further information
Level 1	Cost-benefit analysis (CBA)	Quantitative assessment to compare options.	Monetised method using benefit–cost ratio, net present value or internal rate of return.	*Multi-Coloured Manual* (FHRC 2016), *Multi-Coloured Handbook and Data* (FHRC 2014), *Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG)* (Environment Agency 2010a)
	Cost-effectiveness analysis (CEA)	Works to achieve regulatory compliance at least cost.	Monetised method to determine least cost option that will achieve the objective(s).	
Level 2	Scoring and weighting	Initial appraisal or to supplement other methods, or if intangible impacts are significant.	Score and weight options against a list of objectives to generate implied values.	*FCERM-AG: Guidance on applying the scoring and weighting methodology* (Environment Agency, 2010c)
	Ecosystem approach (ESS)	Policies or projects that are expected to an impact on the environment.	Scoring and weighting, or quantitative assessment of changes to ecosystem services provided by the natural environment.	*Accounting for environmental impacts: Supplementary Green Book guidance* (HM Treasury 2012); *Ecosystem Services and Flood and Coastal Erosion Risk Management* (Rouquette 2013)
Level 3	Appraisal summary table	Screening	Describe, quantify and value impacts (if possible) and who might be affected.	*FCERM-AG: Supporting document for the Appraisal Summary Table* (Environment Agency 2010b)

A prompt list of costs, damages and benefits (damage avoided) is given in Table 5.20. An environmental assessment or WFD assessment will help to identify the impacts of blockage (see NIEA 2012 for guidance). Whole-life costs and benefits are generally discounted to present value when considering damages over the appraisal period (HM Treasury 2003, as amended).

Table 5.17 Prompt list of costs, damages and benefits

Type	Description	References
Whole-life costs	Construction (including access, temporary works or water management) Inspection and maintenance (for example, debris removal, processing materials, reuse or disposal to landfill) Cost of decommissioning	*Long-term Costing Tool* (Environment Agency 2015b)
Land drainage	Change in soil saturation or surface inundation affecting agricultural productivity	*Multi-Coloured Manual* (FHRC 2016) and *Multi-Coloured Handbook and Data* (FHRC 2014)
Flooding	Change in water level, frequency and severity of flooding due to blockage	
Embankment breach or structural failure	Damage to canal, road, rail or other infrastructure	*Multi-Coloured Manual* (FHRC 2016)
Scour	Change in flow velocity or flow patterns, leading to bed and/or bank erosion, loss of land or damage to infrastructure	*Manual on scour at bridges and other hydraulic structures* (Kirby et al. 2015)
Safety	Change in hazard leading to change in injury rates or loss of life	*Costs to Britain of workplace fatalities and self-reported injuries and ill health* (HSE 2014)
Habitat	Change in flow variability, habitat and climate change resilience due to retention or management of large wood	*Flood and Coastal Erosion Risk Management: Economic valuation of environmental effects* (Eftec 2010), *Multi-Coloured Manual* (FHRC 2016)
Fisheries and ecology	Improved or impaired fish and/or eel migration	*An Estimation of the Benefits of Enhanced Regulations for Fish Barrier Management* (Eftec 2014)
Income from the use of debris	Reuse of timber for structural purposes, shredding wood for landscaping or management within channel to improve the environment for wildlife, flood risk and people. Recycling of sediment as construction aggregate.	None

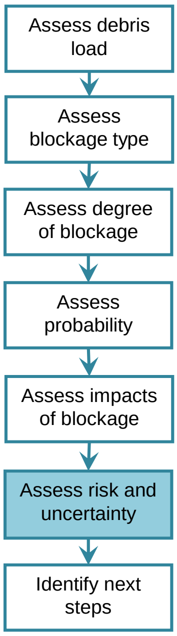
Level 1 Method for flood damages

Estimate flood damages for at least 3 flood events using flood outlines, flood depths and standard depth-damage data.

Level 2 Method for flood damages

Estimate the number of properties at risk for the 1% Annual Exceedance Probability (AEP) (100-year return period) flood. Scale down the number of properties at risk for smaller floods and apply estimated weighted annual average damages for each return period (FRHC 2014).

5.7 Step 6 Assess risk and uncertainty



5.7.1 Step 6A Assess risk and uncertainty

You can assess blockage risk by taking the product of with-blockage impacts (from Step 5) and annual probability (from Step 4) – a simple estimate of annual average damages - and add your results to Table 5.21.

You can assess uncertainty by looking at the level of detail used to calculate each variable and the data quality scores for your chosen data. This identifies which variables have been derived using lower levels of detail or low quality data.

Consider whether these would impact on the receptor score and whether improving the data or assessment methods would give you greater confidence in the result – sensitivity testing can help you to determine whether the result is sensitive to a particular type of data (see Section 5.7.2). If so, you may wish to spend more time gathering data either now or at a later stage.

Table 5.18 Summary of detailed assessment

Variable	Value	Level of detail (3 worst, 1 best)
Step 1 Assess debris load (from Section 5.2)		
Debris type	Vegetation/man-made/sediment	
Debris volume (m^3)		
Step 2 Assess blockage type (from Section 5.3)		
Blockage type		
Onset of blockage (hours)	……hours	
Peak blockage (hours)	……hours	
Ease of debris removal		
Distance to disposal site		
Step 3 Assess degree of blockage (from Section 5.4)		
Blockage location		
Blockage dimensions (m)		
Blockage area (% or m^2)		
Step 4 Assess probability (from Section 5.5)		
Probability		
Step 5 Assess impacts (from Section 5.6)		
Impact on water level (m)		
Nature of impact	Flood/breach/failure/scour/other	
Impacts for 'all clear' (£)		
Impacts with blockage (£)		
Benefits of avoiding blockage (£)		
Step 6 Assess risk and uncertainty		
Blockage risk (impacts × probability)		

5.7.2 Step 6B Sensitivity testing and verification

Consider sensitivity testing to assess the impact of uncertainty on the results. Focus on variables that are both influential and uncertain, and impacts that contribute a significant proportion of costs or benefits. Test variables one at a time. Suggested ranges are given in Table 5.22.

Table 5.19 Suggested ranges for sensitivity testing

Variable	Level of detail		
	Level 3	Level 2	Level 1
Step 1: Debris load	Volume × 40%		Volume ±20%
Step 2: Blockage timing	Double and halve timing		
Step 3: Degree of blockage	Double and halve degree of blockage		Degree of blockage ±20%
Step 4: Impacts of blockage	Viable ranges of water level, velocity, flow pattern and nature of impacts		
Water level	Viable ranges of hydraulic roughness, expansion and contraction coefficients and/or discharge coefficients.		
Damages	Sensitivity testing – see *Flood and Coastal Erosion Risk Management Appraisal Guidance* (Environment Agency 2010a) If using an ecosystems approach, consider how much a benefit would have to fall or a cost would have to rise to make an option unviable (switching analysis).		
Costs	Optimism bias	Contingency sum	Risk register or optimism bias

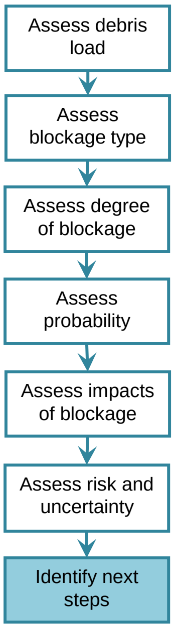
You can verify your findings by comparing predicted blockage and observed blockage – if data are available (for example, blockage history, observations or photographs). Check for consistency of:

- debris type and volume
- blockage mechanism (location, type and timing)
- degree of blockage
- frequency of overtopping or flooding
- head loss across the structure
- impacts of blockage

Blockage prediction is highly uncertain as there is a lack of systematic data gathering on the nature and impacts of blockage.

In practice, blockage probability depends on a range of factors, including debris length and buoyancy, location and alignment of the debris in the channel, flow depth and velocity, and flow patterns both upstream and at the structure. This is in addition to the impact of debris management, which is not considered by these methods.

5.8 Step 7 Identify next steps



Decide whether the blockage risk is significant enough to do something. Otherwise, you can stop and record your findings.

To prioritise reactive inspection and maintenance, consider the blockage timing (from Step 1).

To plan debris removal or size a screen, consider the debris volume (from Step 2).

To select a modelling approach, consider the degree of blockage (from Step 3) and the nature and extent of blockage impacts (from Step 5).

To assess blockage risk across a portfolio of assets, consider the monetary value of blockage risk (from Step 6).

To decide whether risk attributed to an asset is significant enough and whether you intervene, consider the monetary value of blockage risk (from Step 6).

To compare options and identify the economically most favourable option (or the option that meets legal requirements for least cost), you may wish to repeat Steps 1 to 6 for different options.

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Useful websites

All websites listed were accessed in May 2019. This is not a definitive list. The Environment Agency accepts no responsibility for the content of other websites.

Bing Maps: online mapping, aerial photographs and street view images (www.bing.com)

British Geological Survey: solid and drift geology maps (www.bgs.ac.uk/data/maps/home.html)

British Listed Buildings: online database of listed buildings including bridges, culverts and weirs (www.britishlistedbuildings.co.uk)

Environment Agency: including catchment-scale flood risk and water quality management such as:

- Catchment Abstraction Management Strategies (CAMS) www.gov.uk/government/collections/water-abstraction-licensing-strategies-cams-process
- Catchment Flood Management Plans (CFMPs) www.gov.uk/government/collections/catchment-flood-management-plans
- River Basin Management Plans (RBMPs) www.gov.uk/government/collections/river-basin-management-plans-2015

Environment Agency LiDAR (OpenData) (https://environment.data.gov.uk/searchresults;query=LiDAR;page=1;pagesize=20;orderby=LastModified)

FEH Web Service: guidance on rainfall and river flood frequency estimation in the UK (https://fehweb.ceh.ac.uk)

Google Maps: online mapping, aerial photographs and street view images (www.google.co.uk)

National Heritage List for England (NHLE): register of all nationally protected historic buildings and sites in England. Including bridges, culverts and weirs (https://historicengland.org.uk/listing/the-list/)

Met Office Integrated Data Archive System (MIDAS): rainfall data (http://catalogue.ceda.ac.uk) (Search for MIDAS)

National River Flow Archive (NRFA): hydrometric data from gauging station networks across the UK (http://nrfa.ceh.ac.uk/peak-flow-data)

Office for National Statistics: Income Domain Score or Multiple Deprivation Measure for the UK – via gov.uk data portal (http://data.gov.uk)

OpenStreetMap: Community built online open data mapping service and data (www.openstreetmap.org)

Side-by-side maps/aerial photos/historic maps from the National Library of Scotland, but also covering England, Wales and Ireland (http://maps.nls.uk/geo/explore/sidebyside.cfm)

Social media: Facebook, LinkedIn, Twitter and so on

StreetMap.co.uk: street and road map for Great Britain, including Ordnance Survey mapping (www.streetmap.co.uk)

List of abbreviations

AEP	Annual Exceedance Probability
BIM	Building Information Modelling
Defra	Department for Environment, Food and Rural Affairs
DQS	Data quality score
EIA	Environmental Impact Assessment
FCERM	Flood and Coastal Erosion Risk Management
FRMRC2	Flood Risk Management Research Consortium Phase 2
FEH	Flood Estimation Handbook
LiDAR	Light detection and ranging
mAOD	Metres above Ordnance Datum
MDM	Multiple Deprivation Measure
OS	Ordnance Survey
SEPA	Scottish Environment Protection Agency
TPO	Tree Preservation Order
WFD	Water Framework Directive

Glossary

Asset	A man-made or natural object that performs a function and may be at risk of blockage. Something of cultural heritage value.
Asset register	A record of fixed assets of interest to an organisation.
Bar	An elevated feature in a watercourse caused by sediment deposition. Specific types of bar include mid-channel bars, point bars (on the inside of meander bends) and mouth bars (in estuaries).
Blinding (pseudo-weir)	A temporary accumulation of impermeable debris on the lower part of a screen to create a 'weir' effect, reducing flow area and increasing upstream water levels.
Blockage (permanent)	A permanent fixture that reduces the flow area of a channel, culvert, screen or other structure (e.g. screen bars).
Blockage (variable)	A temporary accumulation of debris or sediment in a watercourse that reduces flow area and potentially leads to flooding, scour or other impacts.
Breach	The loss of material from an earth embankment which allows the passage of water.
Channel	The path of a stream, river or waterway that conveys water some or all of the time. A natural channel will typically convey water up to a 50% annual probability flood, after which water will spill onto the floodplain.
Coarse woody debris	Accumulations of branches, twigs and leaf litter (smaller than large woody debris).
Control gate	Undershot, overshot, side-hinged, vertical or radial gate installed on a watercourse to control flow and water levels for flood risk management, navigation or abstraction.
Culvert	A covered channel or pipe that prevents the obstruction of a watercourse or drainage path by an artificial construction (Flood and Water Management Act 2010).
Debris	Any solid material moved by a flowing stream, including natural and man-made material, and sediment.
Debris screen (also known as Trash screen)	A structure installed at a culvert inlet to trap debris and prevent internal blockage that might be difficult to remove.

De-silting	Removal of sediment accumulations above the natural or design bed level of a channel or culvert, generally as a maintenance activity. See also Dredging.
Dredging	Removal of bed material below the natural or design bed level of a channel or culvert, normally involving underwater excavation. See also De-silting.
Ecosystems approach	Option appraisal method that takes account of the value of the supporting, provisioning, regulating and cultural ecosystem services provided by the natural environment.
Flap valve	Non-return valve designed to close when downstream water level exceeds the upstream water level. Typically fitted to culverts or drainage outfalls into tidal waters and rivers to prevent reverse flow.
Flume	Open channel structure with a narrow throat, and sometimes a raised bed, typically used for flow measurement or control.
Fluvial geomorphology	A branch of geomorphology that describes the characteristics of river systems and examines the processes sustaining them.
Fly-tipping	The illegal disposal of controlled waste.
Geomorphology	The scientific study of the evolution and configuration of landforms.
Hydromorphology	A term used in the Water Framework Directive to describe the physical form and physical processes that occur in a water body such as flow patterns, width and depth of river channels, features such as pools and riffles, sediment availability/transport; and interaction between the river and its floodplain.
Initial appraisal	A process of sorting structures into those with a potential risk of blockage and those with little or no risk of blockage.
Invasive non-native species	A non-native animal or plant that can spread and damage the environment, the economy, our health and the way we live.
Large woody debris (or large wood)	Trees, roots, trunks, logs, branches and other large pieces of wood that are no longer attached to the ground, typically defined as exceeding 0.1m in diameter and 1.0m in length.
Open channel	A natural or artificial conduit capable of conveying water with a free surface.
Pathway	In the “source-pathway-receptor” concept, the route that allows a hazard to travel from a source to a receptor. A pathway must exist for a hazard to reach a receptor and may be constrained to mitigate risk.

Receptor	Something, such as a person, property, infrastructure or habitat, that is susceptible to the impacts of blockage, due flooding, structural or geotechnical failure or scour.
Refuse	Waste or rubbish, including household and commercial waste, and can include fly-tipped waste.
Scour	The removal of erodible bed or bank material due to flowing water or wave action.
Security screen	A screen with closely-spaced bars that is designed to prevent unauthorised or accidental access to a conduit or other hydraulic structure, and reduce the risk of someone coming to harm.
Sediment	Natural granular or cohesive material, from clay to boulders that can be transported by flowing water and settle in areas where the flow slows down.
Source	Areas with the potential to supply debris to a watercourse.
Structural failure	Inability of a structure to perform its intended function due to cracking, movement or collapse.
Vegetation	Natural material such as leaves, twigs, garden waste, small branches, plants, trees, large branches, shrubs, mats of weeds.
Water users	People who use a watercourse for transport or recreation, including boaters, canoeists, rowers and open water swimmers.

Appendix A: Legal framework

This appendix deals with the law as it applies in England. Other nations within the UK have different (although often similar) legislation. The context of this appendix is not exhaustive and the law is changing all the time, so readers are advised to seek independent advice. For a comprehensive description of legal requirements, see Appendix A of *Aquatic and Riparian Plant Management: Technical Guide* (Environment Agency 2014b).

Table A.1 Overview of legal framework

Type	Statutory instrument	Overview
Brexit	European Union (Withdrawal) Act 2018	Converts all existing EU-derived law into UK law. In this guide, relevant EU Directives are quoted using their EU names and at the time of writing remain in force. With time these Directives may be amended or repealed.
Health and safety	EU Health and Safety Directive and delegated legislation (including CDM Regulations 2015)	Aim to protect people from health and safety risks arising from construction work through systematic management. Places duties on clients, designers and contractors during design and construction projects.
	Health and Safety at Work etc. Act 1974	Aims to secure the health, safety and welfare of people at work, and to protect others from health or safety risks in connection with the activities of people at work. Places duties on both employers and employees.
	Occupiers' Liability Act 1957 and 1984	Defines the liability of occupiers to people or things that are present on land or property (whether lawfully or unlawfully), for injury or damage that results from things that are either done or omitted.
	Corporate Manslaughter and Corporate Homicide Act 2007	Defines corporate manslaughter, a criminal offence that organisations may be found guilty of when serious management failings result in a gross breach of duty of care leading to fatality.
Flood risk management	EU Floods Directive and delegated legislation	Aims to reduce and manage the risks to people's health, the environment, cultural heritage and economic activity posed by flooding. Imposes duties on members to prepare flood risk maps and flood risk management plans.
	Water Resources Act 1991	Consolidates provisions relating to the National Rivers Authority (now Environment Agency) and imposes powers and duties relating to abstraction and impounding, pollution, flood defence and fisheries.
	Land Drainage Act 1991	Aims to consolidate provisions relating to internal drainage boards and local authorities in relation to land drainage.

Table A.2 Overview of legal framework (continued)

Type	Statutory instrument	Overview
Flood risk management (continued)	Flood and Water Management Acts 2010 and 2015	Aims to improve flood and coastal erosion risk management, and to implement some of the proposals in Making Space for Water and the Pitt Review. Places duties on the Environment Agency, Regional Flood and Coastal Committees and lead local flood authorities.
Environmental protection and enhancement	EU Water Framework Directive and delegated legislation	Aims to protect and improve the water environment, promote sustainable water use, reduce pollution and mitigate the effects of floods and droughts. Sets targets for good chemical and ecological status (or potential) in water bodies such as rivers. Imposes duty on the EA and NRW to assess whether activities impact on a water body and support those targets.
	Environment Act 1995	Aims to address a wide range of environmental issues. Established the EA and SEPA, and places duties on them to protect or enhance the environment and to contribute towards sustainable development (subject to and in line with other legal provisions and taking into account costs).
	Countryside and Rights of Way (CROW) Act 2000	Provides public access to open country and registered common land. Places duties on relevant authorities to conserve and enhance the natural beauty in areas of outstanding natural beauty in exercising or performing their functions.
	Natural Environment and Rural Communities (NERC) Act 2006	Aims to conserve, enhance and manage the natural environment for the benefit of present and future generations, thereby contributing to sustainable development. Places duties on Natural England and public bodies to conserve and enhance biodiversity where consistent with their functions.
	Environmental Damage Regulations 2009	Aims to protect natural habitat and resources. Places duties on operators to take practicable steps to prevent environmental damage to protected species, habitats, water bodies or land (for example, by causing pollution).
Nature conservation	EU Habitats Directive and delegated legislation	Aims to conserve rare or threatened flora and fauna, and natural habitats, including Special Areas of Conservation (SACs), Special Protection Areas (SPAs) and Ramsar sites. Places duties on nature conservation bodies and public authorities.

Table A.3 Overview of legal framework (continued)

Type	Statutory instrument	Overview
Nature conservation (continued)	EU Birds Directive and delegated legislation (see also Wildlife and Countryside Act 1981 below)	Aims to protect all wild bird species and to preserve, maintain or re-establish sufficient diversity and area of habitat. Resulted in the designation of Special Areas of Conservation (SACs) and Special Protection Areas (SAPs).
	Wildlife and Countryside Act 1981 (as amended)	Aims to protect wild birds, animals, plants and habitats, and to prevent the establishment of invasive non-native species. Makes it an offence to capture, kill, disturb or trade in birds, eggs or their nests, or to intentionally kill, injure or take wild animals. Places duties on landowners and conservation bodies to protect nature conservation sites such as Sites of Special Scientific Interest (SSSI).
	Salmon and Freshwater Fisheries Act 1975	Aims to protect fish stocks. Makes it an offence to cause direct mortality or habitat degradation, obstruct or impede migration, or allow harmful matter to enter watercourses.
	European Eel Regulation	Aims to recover eel stocks and makes it an offence to cause mortality or obstruct eel passage. Places duties on abstractors to exclude eels from abstraction or discharge points, and on anyone impounding water or constructing, altering or maintaining a structure in or near water, to provide for the free passage of eels.
	Infrastructure Act 2015	Aims to control invasive non-native species. Empowers environmental authorities to compel landowners to take action, or to enter land to take action on invasive non-native species.
Waste	Landfill Directive and delegated legislation	Aims to reduce impacts on the environment by introducing stringent requirements for waste and landfills. Places duties on those sending waste to landfill and landfill operators.
	Waste Framework Directive and delegated legislation	Aims to ensure waste is managed without harming human health or the environment, or causing nuisance. Encourages re-use and defines waste management hierarchy (prevent, reuse, recycle, recover, dispose). Places duties on those who produce or manage waste and environmental permitting authorities.

Table A.4 Overview of legal framework (continued)

Type	Statutory instrument	Overview
	Environmental Protection Act 1990	Aims to improve the control of pollution to air, water and land by regulating the management of waste, emissions and material containing invasive non-native species. Places duty of care on those involved in handling waste.

Table A.2 Prompt list of permit and consent requirements

Type	Requirements	Overview
Work in watercourses	Flood risk activity permit	Applies to activities in, over or under a main river, in its floodplain or affecting a designated flood defence. Applies to permanent and temporary works.
	Ordinary watercourse consent	Applies to works to erect, alter or repair a structure or obstruction on an ordinary watercourse. IDB bylaws apply to work in an Internal Drainage Board (IDB) area.
	WFD assessment (to assess whether a flood risk activity impacts on a water body and supports WFD targets)	Applies to flood risk activity permits for some activities on main rivers (e.g. culverts, sediment management).
Debris management	Permission for felling or lopping trees	Applies to trees protected by a tree preservation order (TPO), trees sited in a conservation area or nature conservation site, or trees used by roosting bats. Does not apply to trimming vegetation, minor tree works, or removing wood or fallen trees.
	Waste exemption for use of waste	Applies to waste (e.g. silt, dredgings) spread to benefit land or reused in construction.
	Waste exemption for disposal of waste	Applies to waste (e.g. silt, dredgings) deposited along a watercourse.
	Waste environmental permit	Applies to waste disposed of to landfill. Waste may need to be treated first (e.g. contaminated silt may be de-watered to reduce volume).

Appendix B: Inspection and monitoring

B.1 Inspection frequency

Inspection can be carried out routinely and/or in response to trigger events (for example, weather forecasts).

For routine inspection, it is advisable to choose an inspection frequency to suit the blockage risk (probability and consequences). Indicative inspection frequencies (the number of inspections per year) for different asset types and levels of blockage risk are given in Table B.1. You can estimate blockage risk using the initial appraisal methods in Chapter 4 or detailed assessment methods in Chapter 5.

Table B.1 Indicative inspection frequencies

Frequency (number per year)	Blockage risk		
Asset type	**Low**	**Medium**	**High**
Screen or control gate	1 to 4	6 to 12	12 to 26
Flapped outfall	1 to 6	6 to 12	12 to 26
Other types	1 [1]	1 to 4	4 to 12

Notes: [1] Before flood season.

Avoid underwater inspection in the vicinity of blockages. The hazards presented by unexpected currents, turbulence and poor visibility increase the risk of becoming snagged, trapped underwater or struck by moving debris.

B.2 What to look for

Inspection aims to pick up simple information about the structure, the nature and extent of blockage, and any evidence of scour or structural damage due to debris impact or blockage. A prompt list is given in Table B.2.

Table B.2 Prompt list for inspection

Type of data	Description
Structure	Photograph of upstream face and any blockage
	Opening dimensions or area (m or m^2)
Debris	Volume, type and dimensions (see Table 5.2)
Blockage	Blockage mechanism: location, type and timing
	Degree of blockage (m, m^2 or percentage of opening area)
	Number of blocked gates, whether a gate is blocked open or closed (if applicable)
Impacts of blockage	Increase in water level due to blockage
	Flooding, structural failure, embankment breach, scour or other

It is advisable to inspect the watercourse at least 50m upstream of the asset and assess the potential for further debris recruitment from the watercourse and floodplain upstream.

If blockage is present at the time of inspection, you can advise on:

- whether maintenance is required to remove the debris
- the urgency of the work
- whether the maintenance frequency could be changed

You may wish to record any remedial works that have been undertaken.

During low to medium flows, you can estimate blockage dimensions by scaling from known structure dimensions or using a theodolite. During high flow conditions, most debris is likely to be below water level. Floating debris tends to accumulate from the water surface down to bed level.

Beware that blockage may vary as flood subsides. Floating debris may drop to the bed and either wash through the structure or block an inlet fully – even if full blockage did not occur during a flood. Non-floating material tends to accumulate and blockage may increase. Beware that debris may be removed before you can inspect for blockage.

B.3 Photographs

Dated photographs of the structure and watercourse can be used for reference during the current assessment and for comparative purposes during future assessments, ideally taken from the same position every time.

Taking 2 photographs as a minimum, including a view of the upstream face of a structure including the waterline and any blockages, and a view of the watercourse upstream of the structure, allows any changes in regime to be identified. For short structures such as bridges or weirs, it can be useful to take an additional photograph of the downstream face of the structure.

B.4 Inspection process

It is good practice to conduct inspections methodically (for example, upstream to downstream, left to right, or top to bottom). For future Building Information Modelling (BIM) compliance, you may divide a large asset spatially and give each section a standard two-letter code (for example, S1 first panel, S2 second panel) (BSI 2007). River left and river right are conventionally described facing downstream.

B.5 Asset management systems

You can use an asset register or asset management system to store and analyse blockage data, manage inspection frequency, and to prioritise and plan interventions. A single asset management system accessible by many users is more economical and consistent than several local databases. Cloud storage allows collaboration and access by multiple users from different sites.

You may use interoperable software packages to avoid the need to convert or re-enter data. Spreadsheets are BIM compliant and can be used to store data, perform calculations and link to other data such as photographs. It is helpful if new data is capable of being searched and for this reason, it is preferable to avoid scanning hard copies unless archiving historical data such as drawings.

Appendix C: Example – initial appraisal

This example shows how to assess risk at individual and multiple assets in order to prioritise inspections and emergency responses, and may be of interest to asset managers. It is based on real assets but some details have been changed.

Step 1 Identify pinch points

A local authority wishes to prioritise inspections at 3 of its 120 screens. Table C.1 summarises the characteristics of these 3 screens.

Table C.1 List of screens

Asset ref	Screen 7	Screen 40	Screen 119
Watercourse	–	–	–
Asset location	–	–	–
Easting	–	–	–
Northing	–	–	–
Picture			
Screen area	3.4m^2	2.3m^2	1.4m^2
Culvert	750mm diameter (0.44m^2)	750mm diameter (0.44m^2)	750mm diameter (0.44m^2)
Watercourse slope	Steep (0.04 or 1 in 25)	Moderate (0.01 or 1 in 100)	Steep (0.0125 or 1 in 80)
Length of upstream contributing watercourse	415m	320m	70m
Land use	Industrial, woodland and public open space	Suburban	Suburban
Other factors	–	–	Vehicular access to watercourse

Step 2 Identify potential receptors

The checklist for receptors shows that all 3 screens would have similar impacts on properties. Screen 7 has a higher environmental impact, as flooding would have an additional impact on amenity in the surrounding park.

The data quality score for the most influential factors (property and other impacts) varies from 1 to 3 (Table C.2), as data were determined from a range of online mapping, professional judgement and visual inspection. Therefore, there is scope for improving data at a later stage.

Table C.2 Potential receptors

Factors	Screen 7	Screen 40	Screen 119	Data quality score
A. Risk to life Risk of injury or fatality None	3 ⓪	3 ⓪	3 ⓪	3, 2 ①
B. Critical infrastructure High impact Medium impact Short-term, temporary impact None	3 2 ① 0	3 2 ① 0	3 2 ① 0	3, ②, 1
C. Property Multiple properties, urban area Several properties (single community) Single property, agricultural land or gardens None	3 ② 1 0	3 ② 1 0	3 ② 1 0	3, 2, ①
D. Environment Impact on ability to meet legal requirements Impact on environmental targets Impacts on other desirable outcomes None	3 2 ① 0	3 2 1 ⓪	3 2 1 ⓪	③, 2, 1
E. Other impacts High impact Medium impact Short-term, temporary impact None	3 ② 1 0	3 ② 1 0	3 ② 1 0	③, 2, 1
Receptor score Highest of scores A to E	2 (C or E)	2 (C or E)	2 (C or E)	

Step 3 Assess pathways

All 3 screens have high transport scores because they are in rapid response catchments and high accumulation scores due to culvert barrels with areas <3m^2. As a result, all 3 pathway scores are high.

The data quality score for the most influential factors (catchment response time and narrow gaps) varies from 2 to 1 (Table C.3), being determined from local knowledge, structure survey and professional judgement. This is adequate for initial appraisal, but could be improved at a later stage if the structure proved to be high risk.

Table C.3 Pathway score

Factors	Screen 7	Screen 40	Screen 119	Data quality score
A. Catchment response time Rapid Slow	 ③ 0	 ③ 0	 ③ 0	3, ②, 1
B. Watercourse slope Steep (steeper than 1%) Intermediate (slope 0.1–1%) Mild (0.1% or milder)	 ② 1 0	 2 ① 0	 ② 1 0	③, 2, 1
C. Flow depth Flow depth exceeds debris draught Flow depth similar to debris draught Flow depth smaller than debris draught	 ② 1 0	 ② 1 0	 ② 1 0	③, 2, 1
D. Channel width Channel width exceeds debris length Channel width similar to debris length Channel width smaller than debris length	 ② 1 0	 ② 1 0	 ② 1 0	3, ②, 1
E. Narrow gaps Screen area <3 times culvert area Culvert barrel area <3m^2 Structure opening width <6m Gap narrower than debris length Gap similar debris length Gap wider than debris length	 3 ③ 3 2 1 0	 3 ③ 3 2 1 0	 3 ③ 3 2 1 0	3, 2, ①
F. Low gaps Gap lower than debris height Gap similar to debris height Gap higher than debris height	 2 ① 0	 ② 1 0	 ② 1 0	3, ②, 1
Transport score Highest of scores A to D	3 (A)	3 (A)	3 (A)	
Accumulation score Highest of scores E and F	3 (E)	3 (E)	3 (E)	
Pathway scores Mean of Transport and Accumulation scores	3	3	3	

Step 4 Assess sources

All 3 screens have sources of vegetation due to woodland land use and mature trees along the watercourses upstream (hence A and B score 3). At screens 40 and 119, vehicle access to the watercourses provides an opportunity for fly-tipping, although there is no history (hence C scores 1). At screen 7, materials are stored adjacent to the watercourse (hence D scores 1). Screen 119 has a lower source score due to a shorter length of contributing watercourse and lack of debris accumulation.

The maximum score for each type of debris shows that vegetation is likely at all 3 screens, with some man-made debris, but little or no sediment.

The potential debris volume is assessed in Table C.4. The highest volume is likely at screens 7 and 40, which have longer lengths of contributing watercourse. Screen 7 also has some debris accumulation in the channel and floodplain upstream.

The source score is taken as the mean of the Debris and Volume scores. It can be seen that screens 7 and 40 have higher source scores than screen 119 due to the length of contributing watercourse and debris accumulation.

The source data were obtained from a site walkover and hence the data quality score was taken as 1 (best available) throughout.

Table C.4 Source score

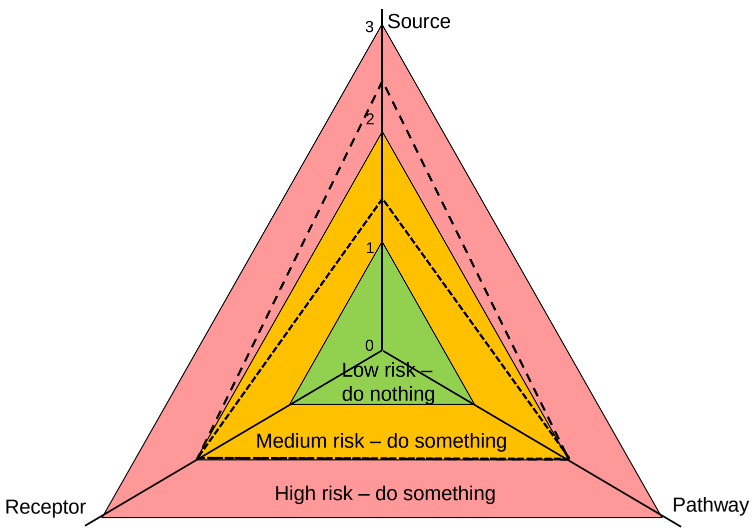
Factors	Screen 7	Screen 40	Screen 119	Data quality score
A. Land use				3, 2, ①
Woodland, arable producing straw or hay (baled or unbaled), timber operations or felled timber awaiting collection	③	③	③	
Suburban open (for example, parks, golf courses)	2	2	2	
Pastoral or rural	0	0	0	
B. Riverside vegetation				3, 2, ①
Large mature trees	③	③	③	
Small trees or bushes	1	1	1	
Small vegetation	0	0	0	
C. Fly-tipping				3, 2, ①
History of fly-tipping, suburban (with dwellings) or urban land use	3	3	3	
Vehicle access or private gardens adjacent to channel	1	①	①	
None of the above	⓪	0	0	
D. Storage of materials				3, 2, ①
Adjacent to watercourse with no barrier	2	2	2	
In floodplain or within 100m of watercourse	①	1	1	
None	0	⓪	⓪	
E. River typology				3, 2, ①
Plane bed, wandering	3	3	3	
Active single thread	2	2	2	
Passive single thread	1	1	1	
Bed rock, anastomosed and so on	⓪	⓪	⓪	

Table C.4 Source score (continued)

Factors	Screen 7	Screen 40	Screen 119	Data quality score
F. Sediment sources Stores of sediment within channel Heavy sediment load due to catchment topography, soil, land use or channel use None of the above	3 2 ⓪	3 2 ⓪	3 2 ⓪	3, 2, ①
G. Sediment deposition Transition from steep to mild bed slope Sudden constriction on bed rock river Sudden expansion in cross-section None of the above	3 3 3 ⓪	3 3 3 ⓪	3 3 3 ⓪	3, 2, ①
H. Length of contributing watercourse Long (500m or more) Intermediate (250m) Short (100m or less)	3 ② 0	3 ② 0	3 2 ⓪	3, 2, ①
J. Debris accumulation Extensive debris accumulation Little debris accumulation None	3 ① 0	3 1 ⓪	3 1 ⓪	3, 2, ①
Vegetation score (highest of A and B)	3	3	3	
Man-made score (highest of C and D)	1	1	1	
Sediment score (highest of E to G)	0	0	0	
Debris score Highest of scores A to G	3	3	3	
Volume score Highest of scores H and J	2	2	0	
Source score Mean of Debris and Volume scores	2.5	2.5	1.5	

Step 5 Assess risk and uncertainty

The blockage triangle shows that for all 3 sites are potential blockage sites with medium to high risk.



The risk score was calculated for each screen. For Screen 7:

$$Risk = \left(\frac{Source + Pathway}{2}\right) \times Receptor = \left(\frac{2.5 + 3}{2}\right) \times 2 = 5.5$$

Table C.5 gives the risk scores for all 3 screens. Both screens 7 and 40 have scores above 5 and are high risk. Screen 119 has a score below 5 and is medium risk. The relative risk was consistent with the local authority inspection records.

Table C.5 Risk scores for the screens

	Screen 7	Screen 40	Screen 119
Receptor score	2	2	2
Pathway score	3	3	3
Source score	2.5	2.5	1.5
Risk score	**5.5 (High)**	**5.5 (High)**	**4.5 (Medium)**

The data quality score (Table C.6) was estimated from the source, pathway and receptor data quality scores given in Tables C.2, C.3 and C.4 respectively.

The Receptor DQS could be derived from C Property (DQS 1) or E Other impacts (3), and so the mean of these data quality scores was taken.

The Pathway DQS is the mean of the Transport DQS and Accumulation DQS. A value of 1.5 was derived from A Catchment response time (DQS 2) and E Narrow gaps (1).

The Source DQS is the mean of the Debris DQS and the Volume DQS. A value of 1.0 was derived from the mean of A Land use (DQS 1) or B Riverside vegetation (1) for Debris, and H Length of contributing watercourse (1) for Volume.

Although the overall aim of the data quality score is to identify areas for improvement, the overall score can be useful to prioritise data gathering. An overall data quality score reflecting the overall approach was 1.6 (slightly better than known deficiencies) and was the same for all 3 screens as the same data sources were used. This indicated reasonable confidence in the results.

Table C.6 Data quality score

Screen	Influential factors	DQS values	Chosen DQS
DQS Receptor	C Property E other	1 3	2
DQS Pathway	A Catchment response E Narrow gaps	2 1	1.5
DQS Source	A Land use or B Riverside vegetation H Length of contributing watercourse	1 1 1	1
Data quality score			$\left(\frac{1+1.5+2\times2}{4}\right)$ = 1.6

Sensitivity testing was carried out to assess the impact of factors that were most uncertain such as watercourse slope, storage of materials, debris accumulation and relative flow velocity. These factors did not affect the risk scores.

Step 6 Identify next steps

Finally, the next steps were determined using the risk and uncertainty scores. All 3 screens have a medium to high risk score and known deficiencies in the data

(Table C.7). Hence the asset owner could progress to 'do something' management options (Chapter 3), possibly with detailed assessment to provide a business case for the work.

Table C.7 Next steps

Data quality score	Risk score		
	Low (1 to 1.75)	Medium (2 to 4.5)	High (5 to 9)
1 – best available	Do nothing (Section 3.3)	Do something (which may involve detailed assessment) (Chapter 3)	
2 – known deficiencies			
3 – gross assumptions	Further data gathering or detailed assessment (Chapter 5)		

Appendix D: Example – detailed assessment

This example shows how to quantify risk at an individual asset in order to support modelling, economic appraisal or project appraisal, and may be of interest to modellers, mappers or engineers involved in options appraisal. It is based on a real site but some details have been changed. A sketch map of the site in shown in Figure D.1

A 675mm diameter concrete pipe culvert carries an A road over a steep watercourse. The relief level is the road, 6m above the culvert (Figure D.2). Historic flood records and site inspection show that, when the culvert surcharges, surplus water flows across the road and downhill towards the valley bottom, closing the road and affecting residential and commercial properties. One property is at risk upstream, slightly above relief level. Historic maps show that the watercourse immediately upstream of the road was originally used as a storage reservoir for a mill.

Data and results are given in Tables D.1 and D.2 with commentary below.

Figure D.1 Sketch map of site

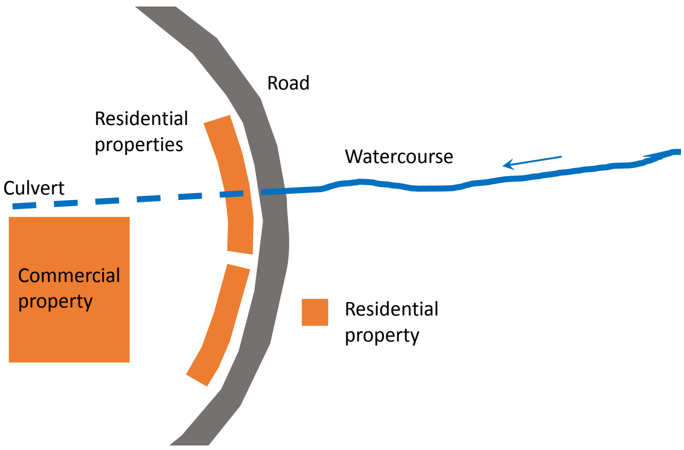
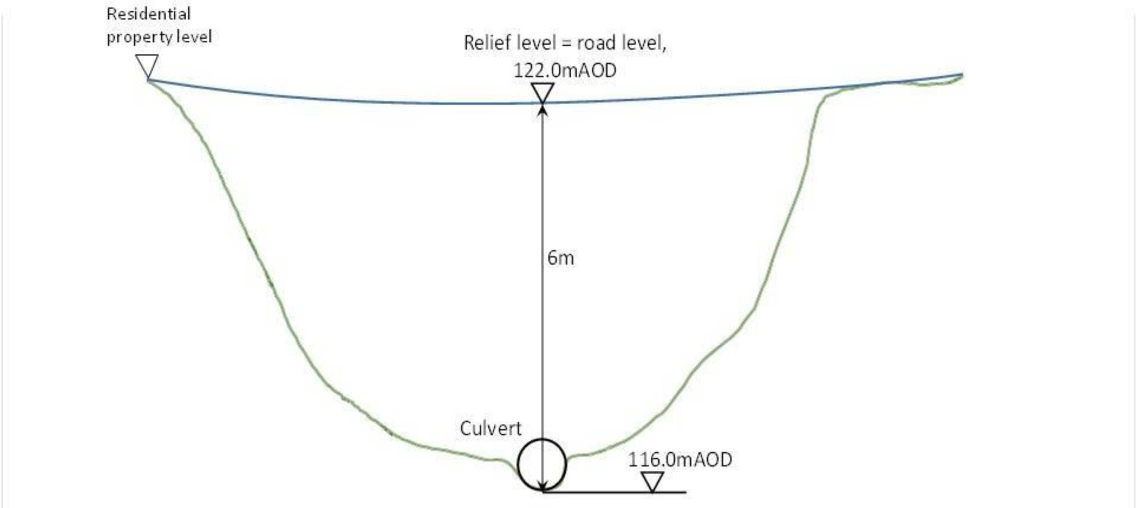


Figure D.2 Relative heights of culvert and relief level)



Notes: mAOD = metres above Ordnance Datum

Step 1 Assess debris load

For woodland (Table D.1), the debris type is likely to be large woody vegetation. From the empirical method, the volume for a 400m length of contributing channel in woodland is estimated to be 45m^3/s per year.

Step 2 Assess blockage type

From Section 5.3.1 (Step 2A), the likely blockage mechanism is bridging by floating debris. From Section 5.3.2 (Step 2B), blockage at the culvert inlet by floating vegetation is predicted to be progressive. The predicted onset of blockage is T_P, 2.5 hours and maximum blockage at T_{soff}, 4.25 hours. Removal of material during flood conditions is difficult as the culvert inlet would be submerged. Woody debris is likely to be shredded on-site, so transport to a disposal site is not considered.

Step 3 Assess degree of blockage

Based on Table 5.11 the degree of blockage is estimated to be 67% as the design log length exceeds the culvert diameter and is capable of bridging the culvert and trapping further debris. Sedimentation is unlikely to occur as the watercourse is steep.

Step 4 Assess probability

From the Wallerstein method, the probability of blockage is estimated to be 17.5–20 times the ratio between debris length and structure opening span. The debris length L is 1.0m and the span of the opening is 0.675m, giving L:S ratio of 1.48. Thus the probability of blockage during any event is 25%. However, this is very uncertain.

Step 5 Assess impacts

Manual calculations show that the culvert operates under inlet control and that the 1% AEP (100-year return period) flood of 4.3m^3/s will overtop the embankment and water level will be similar to road level (122.0mAOD).

Hydraulic modelling is used to estimate the increase in water level due to blockage. The blockage is represented as a porous plug, based on large woody debris bridging the inlet and accumulating further debris. This predicts that blockage will increase flows and water levels over the road, by 0.12m from 122.0mAOD to 122.12mAOD.

Flooding is the primary impact of blockage. Since the watercourse upstream of the road was used as a mill storage reservoir, the road embankment is thought to be a water-retaining structure and unlikely to breach. The modelled water levels and a Digital Terrain Model are used to generate flood outlines with and without blockage for a 1% AEP event.

Flood damages are estimated using the Multi-Coloured Manual weighted annual average damage method, based on the modelled 1% AEP water levels and flood outlines for the 'with blockage' and 'all clear' scenarios. Damages include direct damages to 16 residential properties and 2 non-residential properties.

Step 6 Assess risk and uncertainty and Step 7 Identify next steps

The blockage risk is high as blockage occurs rapidly and it is difficult to intervene during a flood due to submergence of the culvert inlet. Thus proactive management options are preferable, such as reducing debris load by catchment management, or reducing blockage probability by replacing the culvert or installing a screen.

Economic appraisal is performed for installing a debris screen with long-term inspection and debris management. For an appraisal period of 50 years, the whole-life present value damages are £4 million and the whole-life present value cost of doing something is £500,000 (£350,000 capital and £150,000 inspection and maintenance). Thus the benefit–cost ratio of doing something is 9 to 1.

Uncertainty is related to the data quality and choice of method. The most uncertain data are relief level and flow depth. Sensitivity testing shows that the viable range of values gives a robust benefit–cost ratio. If the benefit–cost ratio was marginal, there would be merit in more data gathering to confirm the business case.

Table D.1 Data for detailed assessment

Factor	Values	Source	Data quality score
Contributing upstream channel length	400m to next culvert	Site walkover	1
Land use	Woodland	Site walkover	1
Channel slope	0.1 or 1 in 10	OS 1:25,000 map	2
Mean daily rainfall	–	–	–
Income Domain Score	Not applicable	National statistics	1
Design log length	1.0m	Site photographs	2
Structure dimensions	675mm diameter	Site survey	1
Flow depth	1m	Professional judgement	3
Time to peak/overtop	2.5 hours	Flow hydrograph	2
Relief level	122.0mAOD	OS MasterMap	3
Ground levels	116.0mAOD	Digital Terrain Model	1
Flood water levels	122.0mAOD	Bespoke modelling	1
Flood extents	Varies	Modelled outlines	1
Property thresholds	Varies	Digital Terrain Model	2
Property types	Residential A road	National Property and Receptor Databases	1

Table D.2 Summary of detailed assessment

Variable	Value	Method used
Step 1 Assess debris load (from Section 5.2)		
Debris type	Large woody vegetation	1
Debris volume (m^3)	45 m^3/year	2
Step 2 Assess blockage type (from Section 5.3)		
Blockage location and type	Inlet screen, top-down	1
Onset of blockage (hours)	2.5 hours	2
Peak blockage (hours)	4.25 hours	2
Ease of debris removal	Difficult	2
Distance to disposal site	0 (shredded on-site)	2
Step 3 Assess degree of blockage (from Section 5.4)		
Blockage dimensions (m)	0.240m^2	2
Blockage area (% or m^2)	67%	2
Step 4 Assess probability (from Section 5.5)		
Probability	25%	2
Step 5 Assess impacts (from Section 5.6)		
Impact on water level (m)	+0.12m flow depth over road	1
Nature of impact	Flooding	1
Impacts for 'all clear' (£)	£13,000	1
Impacts with blockage (£)	£551,000	1
Benefits of avoiding blockage (£)	£538,000, benefit–cost ratio = 9:1	1
Step 6 Assess risk and uncertainty		
Blockage risk (impact × probability)	£135,000	

Appendix E: Example – multiple assets

This example describes detailed assessment of blockage impacts at 600 culverts using semi-automated procedures and may be of interest to asset managers, modellers or mappers. The impacts of complete blockage were assessed using a two-dimensional flood model. Inputs were *Flood Estimation Handbook (FEH)* catchment descriptors, a Digital Terrain Model and the National Property Dataset. Outputs were:

- indicative flood extents
- depth, hazard and velocity grids
- housing equivalents at risk for critical infrastructure, residential and non-residential properties

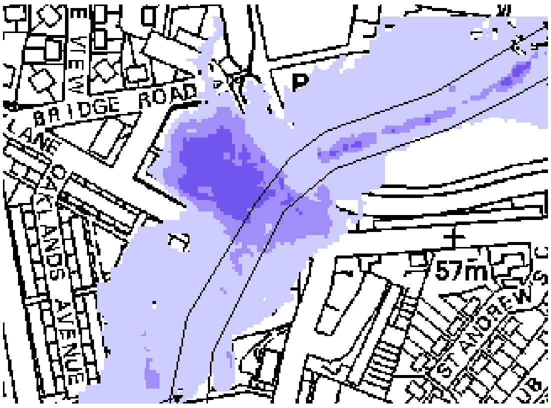
Hydrology

FEH catchment descriptors were extracted for flow estimation points at the inlet of each culvert. Design hydrographs were estimated for 3 user-defined events (20%, 4% and 1% AEP or 5, 25 and 100 year return period) using the FEH statistical method for peak flows and ReFH for hydrographs, which were then scaled up to peak flow. This process was semi-automated using in-house software. For quality assurance, catchment descriptors were checked and flow estimates were prepared for other flow estimation points for benchmarking against other studies.

Hydraulic modelling

Indicative flood outlines and depth, hazard and velocity grids were generated using a two-dimensional numerical model (see example depth grids in Figure E.1). This used a Digital Terrain Model derived from 2m light detection and ranging (LiDAR) infilled with 5m NextMap. This was edited to remove buildings, raised flood defences and channel sections at in-line structures (other than the culvert in question), and to ensure that modelled watercourses flowed downhill. Channel capacity was set at zero so that all flow was out-of-bank and hydraulic roughness (Manning's n) was 0.1 throughout. The results were checked and model runs amended where appropriate.

Figure E.1 Example depth grids



Impacts

Critical infrastructure, residential and non-residential properties intersecting the flood extents were determined using the National Property Dataset. Housing equivalents were calculated and used to determine the benefits of doing something.

Finally, a report containing the flood extents, property counts, property types and housing equivalents was generated automatically for each culvert.

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