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Environment Agency

delivering benefits through evidence

Asset performance tools: channel conveyance assessment guidance

Report – SC140005/R2

Flood and Coastal Erosion Risk Management Research and Development Programme

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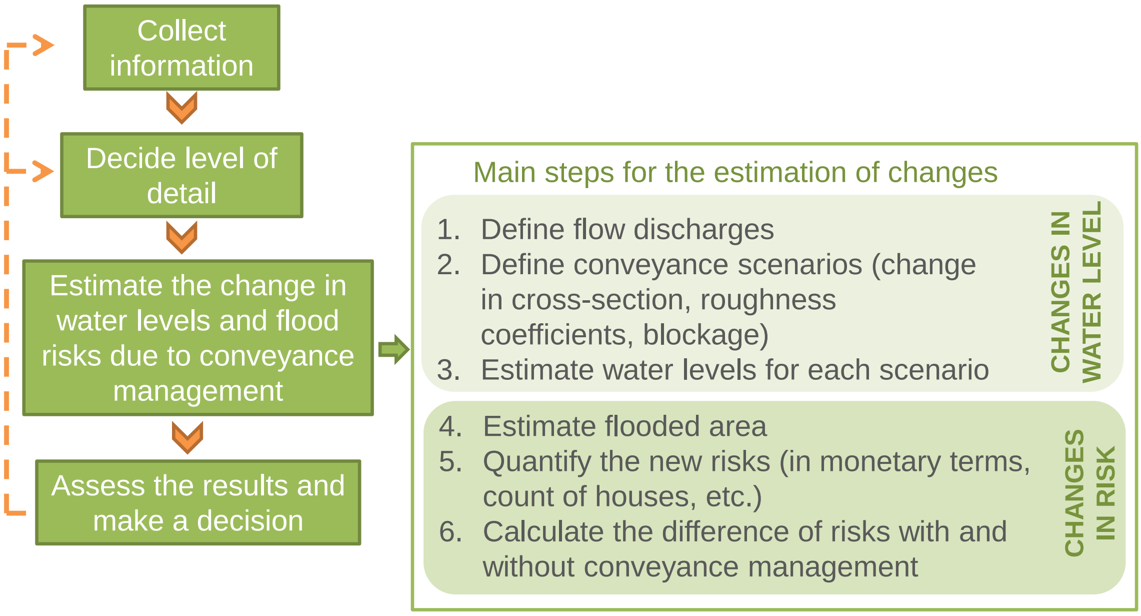
Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

This document describes a structured framework to support decision-making on whether to undertake channel conveyance maintenance works for the purposes of flood risk management. The guidance is developed in the context of the Environment Agency's Asset Performance Tools project. The main steps of the assessment are provided in the figure below.



Main steps of the assessment

Available tools, datasets and workflows are brought together within the context of the structured framework. The tools and datasets described are:

- hand calculations
- Conveyance Estimation System (CES)
- CONVRT-IM (CONVeyance Risk Tool – Intermittent Maintenance)
- National Flood Risk Assessment (NaFRA) and Flood Map products
- Modelling and Decision Support Framework 2 (MDSF2)
- Conveyance key performance indicator (KPI) datasets
- hydraulic models

The guidance does not provide details of all the steps required to use the tools and datasets described, but instead provides the necessary references to obtain that information. Examples of the application of the framework and tools are also provided.

The tools are classified using a tiered approach:

- **Simplified level.** This provides a qualitative assessment. It requires only a general knowledge of the watercourse and access to existing datasets to help to understand the impact of changes in conveyance on flood risk for the particular site of interest.

- **Medium level.** This requires more analysis than the simplified level but provides a quantitative assessment.
- **Detailed level.** This tier is applicable to a relatively small number of maintenance activities where the perceived risks or impacts to receptors are likely to be high.

Application of the guidance will help to justify the undertaking or withdrawal of channel maintenance from a flood risk perspective and will help with communication of the decision.

This guidance does not consider:

- the possible impacts of channel maintenance on geomorphology, environment or habitats
- conveyance management for purposes other than reducing flood risk

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1 Introduction

1.1 Purpose of this guidance

This document describes a structured framework of practical approaches to support decision-making on whether to undertake channel conveyance maintenance works for the purposes of flood risk management. The guidance focuses on available tools, datasets and workflows that are brought together within the context of the structured framework. The aim is to support the estimation of the impacts of conveyance management on water levels and flood risks. This guidance does not deal with the possible impacts of channel maintenance on aspects such as geomorphology, environment and habitat conditions of the channel. These are discussed elsewhere (Environment Agency 2011, 2015a).

Application of the guidance will help to justify the undertaking or withdrawal of channel maintenance from a flood risk perspective and will help communicate the decision. The guidance is consistent with the Asset Performance Tools (AP Tools) framework and provides the performance and risk assessment component of the AP Tools 'propeller' for channel maintenance (Figure 1.1).

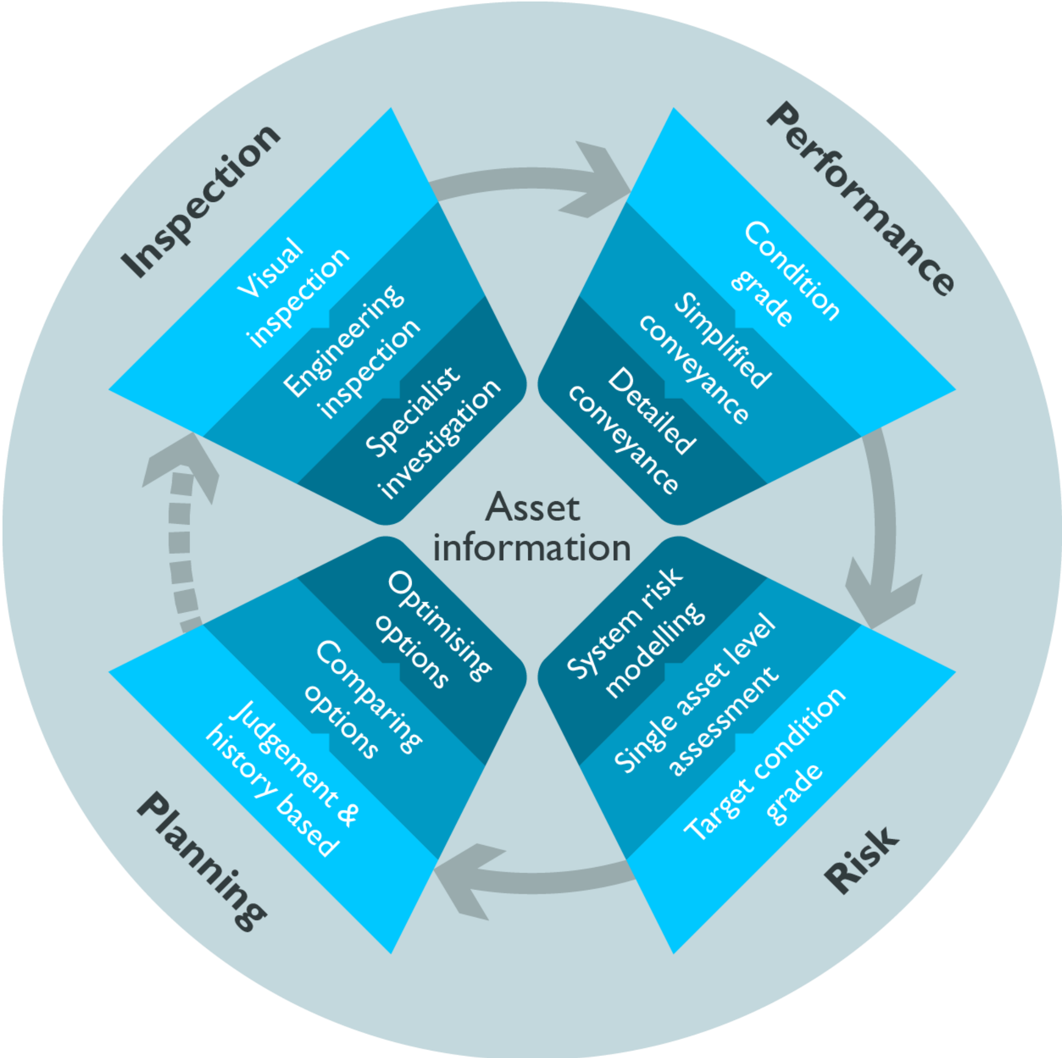

Figure 1.1 AP Tools framework (conveyance)

The conveyance assets considered in flood risk management and included in this guide are natural and engineered open channels and culverts. The performance of these assets is mainly affected by:

- increased roughness caused by vegetation growth
- reduced cross-sectional area through siltation or blockages from natural material, urban debris or structural failure of the culvert/channel

The Adaptive Channel Management Framework presented in the Channel Management Handbook (Environment Agency 2015a) and shown in Figure 1.2 forms a vehicle for the guiding principles of channel management to be used by those seeking to carry out maintenance works to enable a channel to fulfil its desired performance. This guidance supports Stage 3 of the Adaptive Channel Management Framework, aiming to determine whether channel management is (still) required.

This guidance provides links to existing useful material such as:

- Channel Management Handbook (Environment Agency 2015a)
- Aquatic and Riparian Plant Management (Environment Agency 2014a)
- Blockage and Debris Modelling Guidance (project SC110005) (Environment Agency forthcoming)

The purpose of the maintenance works described in this guidance is considered to be to improve, increase or maintain the conveyance of watercourses. It is recognised that watercourses have multiple functions and conveyance management for flood risk is just one. This guidance is not intended to deal with these other functions.

This guidance does not provide details of all the steps required to use the tools and datasets described. It does, however, provide the necessary references and links to find that information.

The range of tools presented includes ones that are used by or have been developed for the Environment Agency. Although some commercial models are named, the guidance does not intend to prescribe any particular tool.

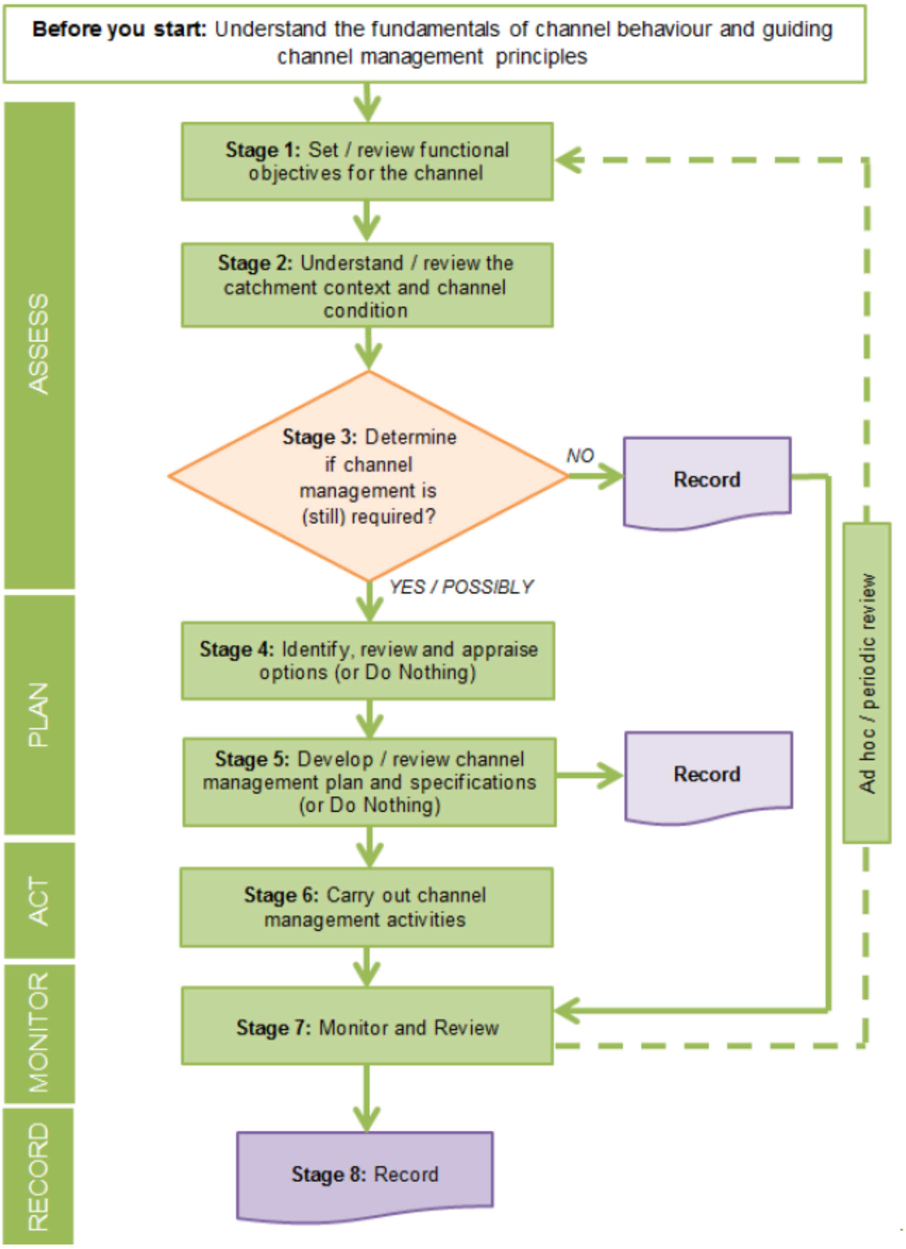

Figure 1.2 Adaptive Channel Management Framework

Notes: Extracted from Environment Agency (2015a)

1.2 Report structure

Chapter 2 presents the concepts of conveyance, maintenance and risk-based approaches.

Chapter 3 describes the framework developed to assess the flood risk management benefits of conveyance management. Three levels of detail are defined, together with the steps to perform the assessment and the available tools and datasets.

Chapter 4 provides further information on each of the tools and datasets presented in Chapter 3.

Chapter 5 presents examples of application of the framework and some of the tools described.

2 Background

2.1 What is conveyance?

Conveyance is a measure of the discharge carrying capacity of a watercourse. It relates the total discharge to a measure of the watercourse slope:

$$Q = K S^{1/2} \quad (2.1)$$

where K (m^3/s) is the conveyance, Q (m^3/s) is the discharge and S is the general watercourse slope. Figure 2.1 shows the relationship between water level and conveyance.

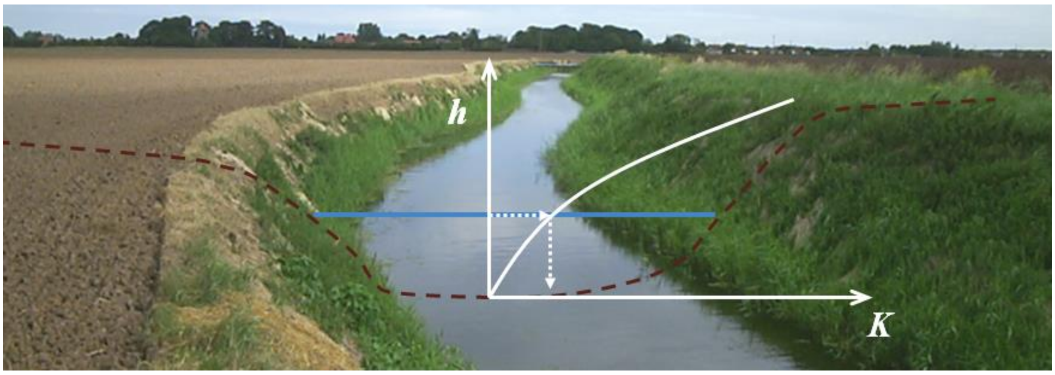

Figure 2.1 Relationship between water level and conveyance

2.2 What influences conveyance?

Conveyance is influenced primarily by:

- the cross-section geometry, which can be modified due to dredging or desilting activities
- the reduction of flow area due to blockages (for example, at bridges and culverts, Figure 2.2)

Conveyance also depends on flow resistance due to vegetation, substrate and channel irregularities.

The Channel Management Handbook (Environment Agency 2015a) summarises the local channel features that influence conveyance as:

- in-channel debris
- surface roughness (may be influenced by excessive vegetation growth)
- sediment deposition (that can occur at local or reach level)
- channel cross-section

Figure 2.2 Example of reduction of flow area due to partial blockage at a culvert

2.3 Why manage conveyance?

The ability of a channel to convey water directly influences water levels, which in turn have an important influence on flood risk (Figure 2.3).

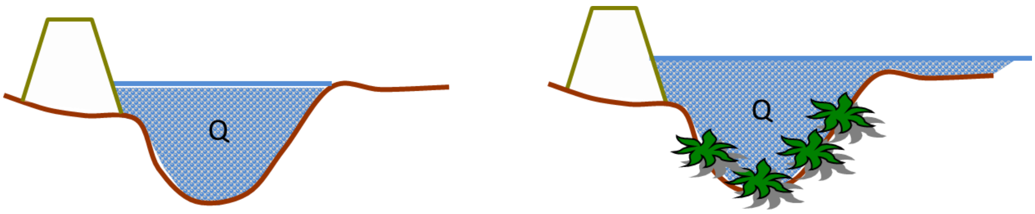

Figure 2.3 Increase of water levels in the channel (right) for the same water discharge due to increased channel vegetation as a result of lack of maintenance activities

Conveyance management can be seen as maintaining or ensuring a certain condition of the channel with the aim of containing a certain water discharge below a certain water level in order to ensure a particular standard of protection.

The appropriate type and frequency of maintenance works can differ from one site to another as they depend on parameters such as:

- type of vegetation
- weather conditions
- maintenance strategy
- objectives of the work

Nevertheless general guidance does exist on the most suitable management options for flood defence maintenance. For example, the Aquatic and Riparian Plant Management Guidance (Environment Agency 2014a) provides a framework to help inform decisions on when and how to manage aquatic and riparian vegetation based on local knowledge of the species present and the watercourse type. The document

‘Delivering Consistent Standards for Sustainable Asset Management’ supports the selection of maintenance options for routine maintenance (Environment Agency 2012).

The impacts of maintenance works on water levels depend on:

- the size and nature of the watercourse
- the type of flood event

For example, the impacts of maintenance are more likely to be high in small or lowland watercourses, which can substantially change their capacity due to intervention works.

In a similar way, the impacts of conveyance management are minor during large events, which inundate large areas of the floodplain; it is not expected that maintenance works in the channel will substantially modify the likelihood of flooding during these large events. Channel maintenance is expected to make a difference during the high probability (smaller) events. These concepts are illustrated in Figure 2.4 where conveyance maintenance has a minor effect during large flood events (slightly reducing water levels) but has a larger impact during medium/low events.

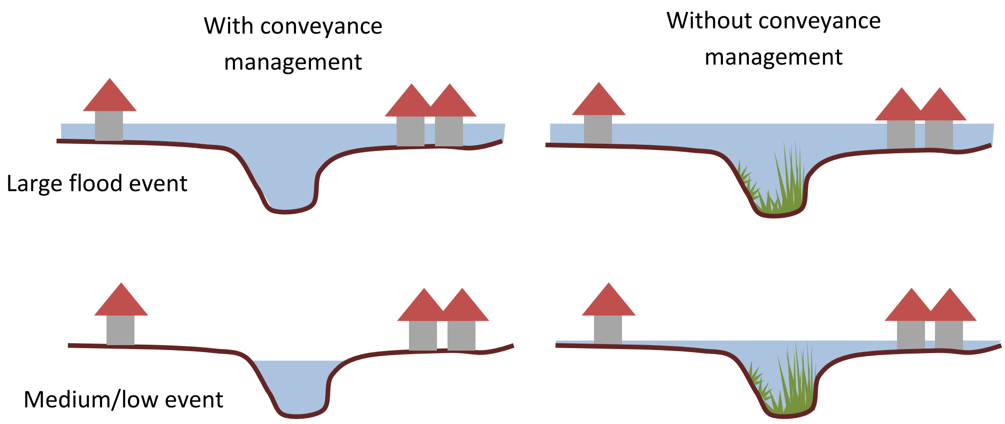

Figure 2.4 Impacts of conveyance management. Top panel: large flood events. Bottom panel: medium to low events. Both panels with conveyance management (left) and without conveyance management (right)

Channel maintenance activities are likely to provide benefits over a limited period of time. Vegetation, debris and sediment will grow, be transported and deposited during the year and depending on the occurrence of flood events. The temporal dimension should also be considered when developing a maintenance plan. In general, the flood risk benefits of channel maintenance are at their maximum just after performing the works and will decrease with time. Such temporal variation is, in general, very case dependent.

The impacts of channel maintenance may apply at local and reach scales. An understanding of the whole system and its connections is therefore needed.

2.4 Why a risk-based approach?

As stated in the Channel Management Handbook (Environment Agency 2015a), the need and level of channel management interventions depends on the level of risk associated with the location. It is essential that the benefits of management, including risk reduction outweigh its costs and other possible impacts. The need to make the most of limited budgets also drives risk-based approaches, which help to identify the areas where it is most worth performing the works.

A risk-based approach to assess the impacts of channel conveyance involves 2 main steps:

- understanding the changes in the discharge capacity of the watercourse, expressed as changes in water levels, in the ‘with’ and ‘without’ conveyance management scenarios (these changes will also have an impact on loading conditions of defences such as embankments)
- understanding how these changes in water levels (with and without maintenance) translate into changes in flood risk

3 Approach to assess benefits of conveyance management

3.1 Levels of detail of the assessment

The level of detail required to make an informed management decision depends on the available data, tools and models, required skills, time and costs, the complexity of the hydraulic situation, the acceptable uncertainty and, perhaps most importantly, the likely level of risk to receptors. Figure 3.1 shows how the different approaches to assess performance and risk align with the 3 tiers (or levels of detail) considered in this guidance – from a detailed, full assessment to a simplified level based on a more qualitative approach.

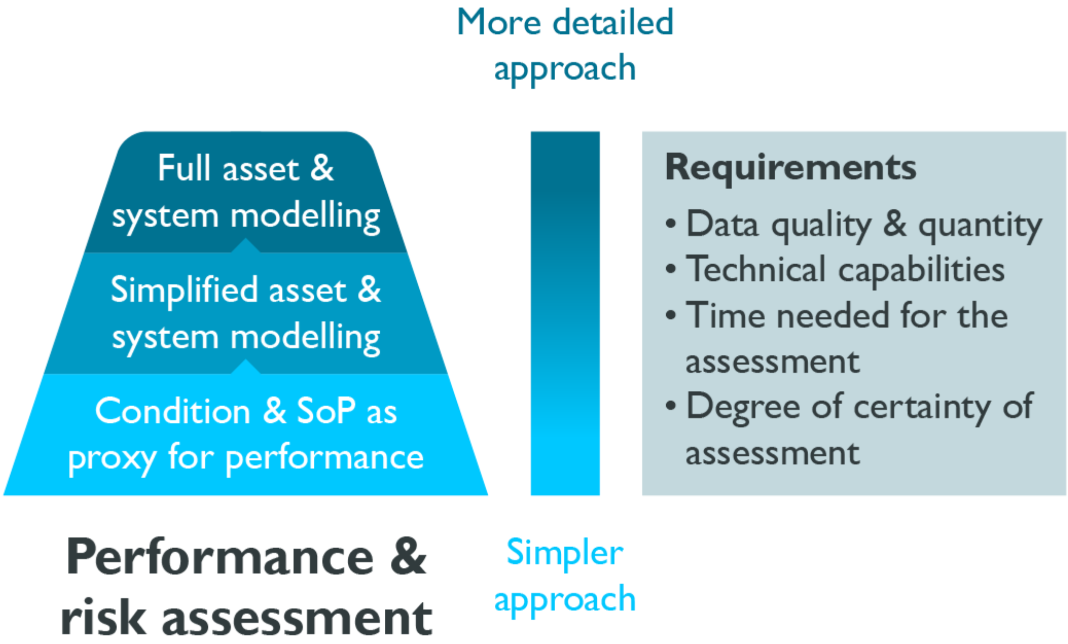

Figure 3.1 Different tiers and requirements for the performance and risk assessment approaches of the AP Tools framework

The more **detailed tier** is applicable to a relatively small number of maintenance activities, where the perceived risks or impacts to receptors are likely to be high. This justifies the investment in collecting more detailed data, the longer time to perform the assessment and the use of higher technical capabilities. This tier helps to reduce the uncertainty of the assessment that is of a quantitative nature. It is appropriate when the simplified and medium tiers do not provide a sufficiently robust analysis. For more information see Section 3.3.3.

The middle or **medium tier** requires a smaller amount of input data, in terms of both quality and quantity, compared with the detailed tier but it still provides a quantitative assessment. For more information see Section 3.3.2.

The simpler, **basic tier** assessment requires only a general knowledge of the watercourse and access to some datasets (such as Flood Maps) to help understand the impact of changes in conveyance on flood risk for the particular site of interest. It provides a qualitative assessment. For more information see Section 3.3.1.

3.2 Main steps of the assessment

The main phases for the assessment of the benefits of conveyance management are shown on the left of Figure 3.2.

The first phase is the collection of available information.

The second phase involves a decision on the level of detail required for the assessment. If there is no previous background information that could support this decision, it is recommended to start at the simplified tier and move to other tiers if further analysis is required to gain sufficient confidence in the decision. If there is enough information and the user is competent and capable of using quantitative approaches, it would be possible to start at the medium tier. The level of detail chosen will be dictated, among other things, by the amount of information available to perform the assessment and the perceived risks. There could be cases where the perceived risks are very high and a detailed assessment is considered from the beginning.

The third phase consists of estimating the changes in water levels and flood risks due to conveyance management using the tools and methods as presented in Section 3.3 and Chapter 4.

In the final phase, the results obtained from the analysis are assessed and the necessary decisions are taken, including moving along the tiers to improve confidence. In some cases, it may be necessary to collect more information to be able to apply more detailed tools. This may involve, for example, carrying out surveys or field visits. This feedback is represented with the dashed arrows in Figure 3.2.

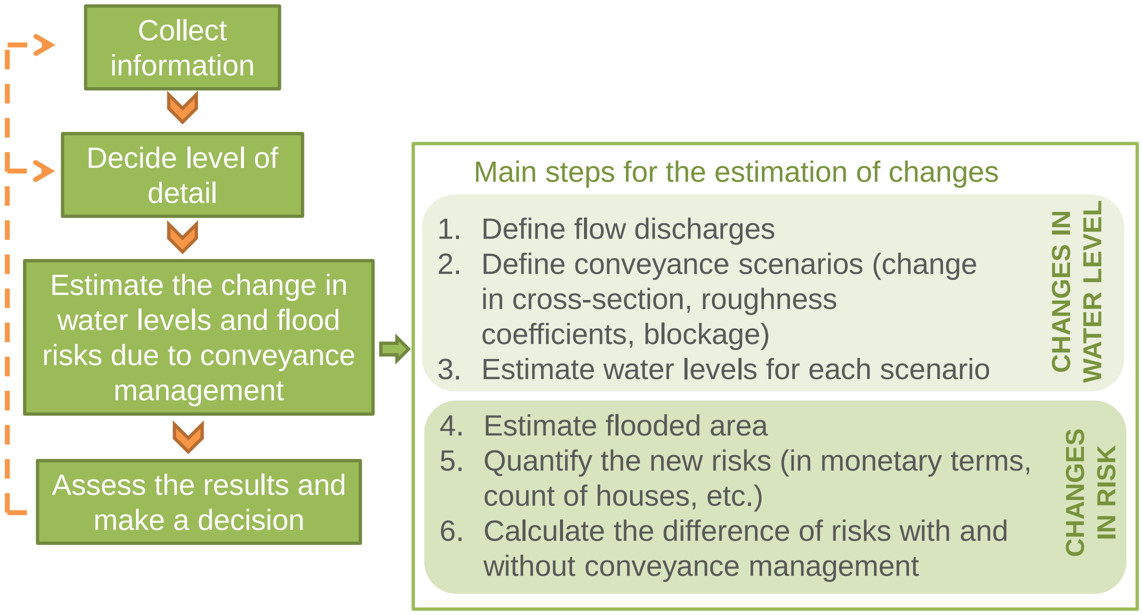

Figure 3.2 Main steps of the assessment

The right side of Figure 3.2 shows the main steps to estimate changes in flood risk due to conveyance management. The detail required and uncertainties related to each step depend on the tier of analysis.

The first step involves the definition of the flood events to be assessed, represented by flood discharges. Water discharges associated with different probabilities of occurrence can be obtained from Flood Estimation Handbook (FEH) studies.[1]

[1] www.ceh.ac.uk/services/flood-estimation-handbook

The second step defines the conveyance management scenarios and how maintenance works change the characteristics of the watercourse. For example, to reproduce the increase in flow area due to dredging or the decrease due to blockage of a culvert, it is necessary to modify the cross-section of the channel. Vegetation management can be simulated by changing the roughness coefficients across the section.

The third step involves applying a tool or looking at an available database to quantify the changes in water levels due to changes in cross-section.

In the simplified tier, these 3 steps are condensed into a single one related to obtaining a better understanding of the possible changes in the behaviour of a channel due to maintenance (see Section 0).

The fourth step involves the use of tools such as hydraulic models (see Section 4.7) to estimate the flooded extent linked to the changes of conveyance capacity of the channel. The risks in the area defined by the inundation models (step 5) can be quantified using different metrics (for example, a count of houses affected by the flooding or the estimated direct property damage of flooding).

Finally, step 6 compares the risks in the 'with' and 'without' maintenance scenarios in order to quantify the benefit associated with the maintenance works.

In the simplified tier, steps 4 to 6 can be substituted by a simplified approach involving estimating areas flooded near the location of the intervention (see Section 0).

Any assessment, independent of the level of detail, should document:

- the data used
- the methodology followed for the assessment
- the decision taken
- the reasons that support this decision

Although this guidance considers only the available tools and datasets to quantify the benefits of conveyance management, there is also the need to think about the whole system when planning any maintenance intervention. It should be considered whether maintenance could have a negative or beneficial impact elsewhere in the catchment. For example, upstream improvements in conveyance could increase flow velocities (and/or increase volumes) and thus cause more flooding downstream. In addition, downstream dredging on a tidal river could mean more tidal flow to upstream areas of the system.

3.3 Available tools and datasets

Estimating channel conveyance performance involves understanding:

- the changes in river conveyance capacity (that is, in water levels)
- the changes in the consequences of flooding (that is, in flood risk)

A number of methods and tools are available to estimate those changes, based on the level of detail required. These are summarised in Table 3.1 and the levels of detail explained below. Further information on each tool and method is given in Chapter 4.

Table 3.1 Summary of tools and datasets for estimating channel conveyance performance

Tool	Level of detail[1]	National /local[2]	Dataset	Method	Estimates changes in:	
					Water levels	Flood risk
Qualitative assessment	S	L	–	✓	✓	–
NaFRA	S	N	✓	–	–	✓
Flood Maps	S	N	✓			✓
CES	M	L	–	✓	✓	–
Hand calculations	M	L	–	✓	✓	–
Conveyance KPI Tool	S/M	N	✓	–	✓	✓
CONVRT-IM	M	L	–	✓	✓	✓
Culvert blockage lookup tables	M	L	✓		✓	✓
Hydraulic models	D	L	–	✓	✓	–
MDSF2	D	L	–	✓	–	✓
GIS tools	D	L	–	✓	–	✓

Notes: [1] D = detailed; M = medium; S = simplified
[2] L = local; N = national
CES = Conveyance Estimation System; GIS = geographical information system; KPI = key performance indicator; MDSF2 = Modelling and Decision Support Framework 2; NaFRA = National Flood Risk Assessment

3.3.1 Simplified tier

The results of this assessment are qualitative. The assessment can be done based on a minimum of input data and making use of information from previous guidance and existing databases.

The input data required for this assessment are:

- the location of the reach of interest
- the general characteristics of the river (approximate width, depth and slope)
- the location of receptors
- the likely flooded area

To assess whether conveyance may have any impacts on flood risk, one option is to examine existing assessments such as NaFRA and Flood Map products (see Section 4.4), which provide information about flooded areas. For example, Flood Map products show the likely areas affected by flooding with a different probability of occurrence per year.

Some of the available resources on possible impacts on flood risks of conveyance management such as the Conveyance KPI datasets (see Section 4.6) are available only for internal use by the Environment Agency.

A general knowledge of the type of watercourse can provide some qualitative indications about possible changes in the behaviour of a channel due to maintenance. The Channel Management Handbook (Environment Agency 2015a) and the Aquatic and Riparian Plant Guidance (Environment Agency 2014a) provide tables and flowcharts to help to define the channel typology. They include descriptions of the most important geomorphological features and the possible impacts expected from different management options.

3.3.2 Medium tier

At this tier, a quantitative assessment of the impacts of channel management on water levels is possible with some simple tools. Hand calculations or simple tools like the Conveyance Estimation System (CES) (see Section 4.2) can be used to estimate water levels at different management scenarios (Step 3 in Figure 3.2).

The estimates are made at a representative cross-section of the watercourse for each management scenario (Step 2 in Figure 3.2). Each scenario considered is represented by a particular:

- geometry of the cross-section – this may vary if dredging works are performed or blockage occurs near a culvert
- roughness coefficient – this depends on the vegetation type and growth

The comparison of water levels as a function of discharge, obtained for different management scenarios, provides an understanding of the impacts of maintenance.

Pre-calculated lookup tables related to the blockage of culverts also provide quantitative assessments of the impacts.

When considering dredging works, it is assumed that a certain change of the cross-section geometry will occur. It could be assumed that the decrease in water levels due to dredging is similar to the decrease in bed levels. Significant tidal, backwater effects or other local features may, however, have an influence and a more detailed assessment with hydraulic models (detailed tier) is typically advised.

The amount of material to dredge (and where to dredge) should be supported by detailed assessment. It is vital that sediment-related management is planned and implemented based on an underlying understanding of the dominant natural processes at the location. Existing guidance provides information about different aspects to consider when managing sediment:

- Channel Management Handbook (Environment Agency 2015a)
- Key Recommendation for Sediment Management (Environment Agency 2011)
- Sediment Matters (Stone and Shanahan 2011)

Managing vegetation implies a modification of roughness coefficients. Information about roughness coefficients for different types of vegetation and at different stages of growth can be found in the Roughness Advisor of CES – see Section 4.2 and the example shown in Figure 3.3. Information is also available in many references from the literature such as Defra's Roughness Review (Fisher and Dawson 2003), Open-channel Hydraulics (Chow 1959) and the Channel Management Handbook (Environment Agency 2015a).

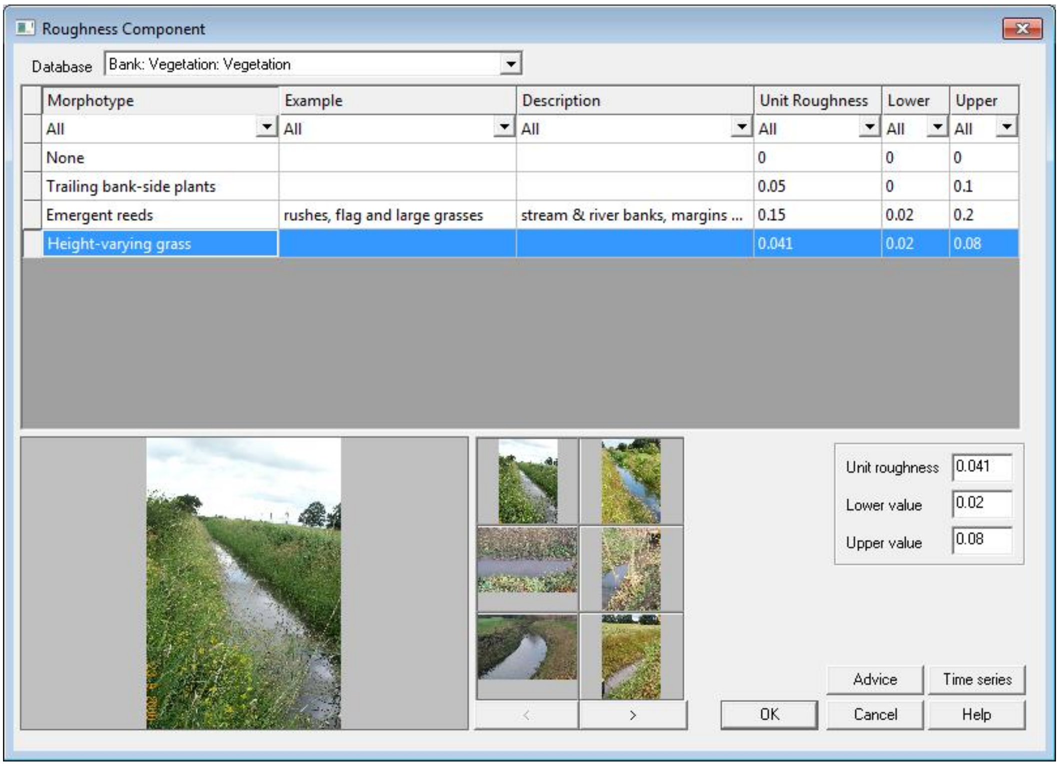

Figure 3.3 Example of roughness information in the CES Roughness Advisor

At this level, CONVRT-IM (see Section 4.3) provides an estimation of both changes in water levels and the impacts of these changes on the risk of flooding.

The results from the Conveyance KPI tool (see Section 4.6), which was developed for the Environment Agency, provide an initial assessment of impacts associated with different conveyance management options. The impacts are expressed as the increased number of properties at risk of flooding.

At this level, it is also possible to consider a semi-quantitative approach, where the changes in water levels are quantified as explained above, using hand calculations or CES, and the possible benefits on risks (for example, properties affected) are estimated from simplified approaches (see Section 0).

3.3.3 Detailed tier

This level involves the use of more sophisticated tools which have higher requirements in terms of input data and technical capabilities of users. The steps to be followed in the assessment are the same as those detailed in Figure 3.2. As an example, the workflow below describes those steps to assess the impacts of culvert blockage using more detailed tools.

- Step 1: Calculate river discharge for a range of return periods.
- Step 2: Estimate culvert capacity based on culvert dimensions and type.
- Step 3: Estimate how much flow will not go through the culvert for different assumptions of blockages (for example, 100%, 60%, 30% and 0%).
- Step 4: Use hydraulic models to estimate the flood area associated with each discharge.
- Step 5: Calculate the impacts of flooding as number of properties, property damage and so on for each scenario.

- Step 6: Calculate the increased impacts (compared with the 'no blockage' scenario).

The use of hydraulic models to estimate water levels provides a more detailed assessment of hydraulic parameters along the reach than those from the medium tier toolset because the models are applied to a stretch of the watercourse and not just to a single cross-section. This implies a more realistic definition of the watercourse geometry represented by several cross-sections or by a digital terrain model (DTM). Hydraulic models consider backwater effects caused by:

- structures such as bridges
- water level changes due to maintenance
- the blockage of culverts

They can also calculate the flooded areas and flood depths for particular management scenarios.

The translation of water level changes to changes in flood risk requires an understanding of the changes in flood extent and the number of properties affected. This can be inferred with inundation models combined with GIS tools or with specific tools that estimate the change in risks such as MDSF2 (see Section 4.5).

4 Description of tools and datasets

This chapter provides detailed descriptions of the tools and datasets introduced in the previous chapter. It includes tools and methods to estimate changes in water levels due to maintenance works and the likely impacts of these changes on flood risk.

4.1 Hand calculations

Hand calculations are based on fundamental equations that can be easily applied using a calculator or a spreadsheet. Two equations are presented here:

- Manning's equation to calculate water discharge or level in a channel (Section 4.1.1)
- a method to estimate the increase of water levels due to blockage (Section 4.1.2)

4.1.1 Use of Manning's equation

Manning's equation is a well-established method of calculating the discharge in a channel, Q (in m^3/s):

$$Q = \frac{1}{n}\frac{A^{5/3}}{P^{2/3}}S_e^{1/2} \qquad (4.1)$$

where A is the cross-sectional area of flow (m^2) and P is the length (m) of the wetted perimeter of the channel corresponding to a given water level Z (m above Ordnance Datum, OD) at which the depth of flow to the lowest point in the invert of the channel is Y_{MAX} (m) (Figure 4.1). The hydraulic resistance of the channel is defined in terms of Manning's coefficient n. S_e is the energy gradient along the channel, which can often be approximated by the general slope of the watercourse.

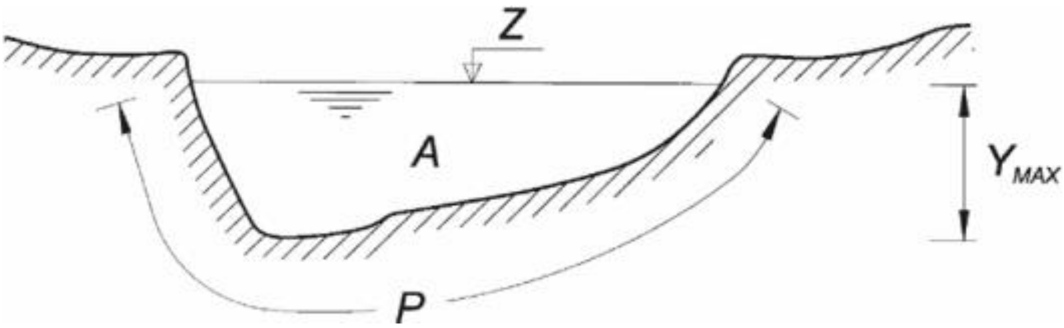

Figure 4.1 Schematic of a channel cross-section

Source: Kirby et al. (2015)

If the water discharge (Q) is known, the calculation of water level (Z) or water depth (Y_{MAX}) requires an iterative process using Equation 4.1.

To estimate the changes in water levels due to maintenance, Manning's equation is applied to 2 scenarios, that is, before and after maintenance. Each scenario will be characterised by a different roughness coefficient if vegetation maintenance is performed and/or a change in cross-section if dredging or desilting is performed.

Comparison of the water levels for the 2 scenarios provides an understanding of the likely impact of the management scenarios for a range of discharges.

More details about the application of Manning's equation are given in:

- Manual on Scour at Bridges and Other Hydraulic Structures (Kirby et al. 2015)
- Channel Management Handbook (Environment Agency 2015a)
- Aquatic and Riparian Plant Management (Environment Agency 2014a)

An illustrative example of the application of Manning's equation in a hand calculation is given in Section 5.4.

4.1.2 Estimating the impact of blockage on water levels

The Blockage and Debris Modelling Guidance (project SC110005) (Environment Agency forthcoming) has developed a quick method to estimate the change in water level due to blockage of a culvert. The method is based on Equation 4.2, which gives the increase in water level, ΔWL, as a function of the flow velocity through the structure without blockage, U (in m/s) and the areas of the unobstructed flow, A (in m^2) and of the debris blockage, A_b (in m^2):

$$\Delta WL \approx 1.5\frac{U^2}{2g}\frac{A^2-1}{\left(A-A_b\right)^2} \tag{4.2}$$

The flow velocity, U, can be estimated as Q / A, where Q is the flow discharge.

4.1.3 Information requirements

The minimum information required to apply hand calculations is:

- the geometry of a representative cross-section
- the general slope of the watercourse
- the likely roughness coefficients associated with different types of vegetation
- an estimation (or assumption) of water discharges

In the case of blockage of culverts, it is necessary to assume the likely area obstructed.

Information about roughness coefficients corresponding to different types of vegetation can be found in:

- the Roughness Advisor of CES (see Section 4.2)
- references from literature such as:
  - Defra's Roughness Review (Fisher and Dawson 2003)
  - Open-channel Hydraulics (Chow 1959)
  - Channel Management Handbook (Environment Agency 2015a)

4.2 Conveyance Estimation System (CES)

The CES is a software tool that enables the user to estimate the conveyance or carrying capacity of a channel; thus it estimates site-specific stage-discharge curves. It was developed by the Environment Agency to reduce the uncertainty associated with flood level prediction.

CES has 3 main components:

- **Roughness Advisor**. This provides roughness advice based on channel descriptions, photographs and grid references (Figure 3.3). The roughness values are based on the findings of an extensive literature review (Fisher and Dawson 2003). Information is included on surface materials, vegetation morphological types, vegetation categories due to human intervention (for example, grass and hedges) and irregularities. The Roughness Advisor provides total unit roughness values comprised of up to 3 component roughness values (surface material, vegetation and irregularities). Mid, upper and lower total unit roughness values are provided based on the mid, upper and lower unit roughness values for each component. This range of roughness values reflects what is expected within these natural systems.
- **Conveyance Generator**. This module calculates the conveyance capacity of the channel. It requires a description of the representative cross-section geometry and of the roughness coefficients.
- **Uncertainty Estimator**. The uncertainty in water level for a given flow rate is represented in CES through upper and lower bands. These bands represent the 'soft' boundaries within which the 'true' value is likely to occur.

CES is free standalone software. The software and associated documentation are available to download from the dedicated CES website (www.river-conveyance.net). The software does not require any installation.

4.3 CONVRT-IM

CONVRT-IM (CONVeyance Risk Tool – Intermittent Maintenance) is a tool developed for the Environment Agency to estimate the benefits of conveyance activities at local level (for example, those defined as intermittent activities by the Environment Agency). Figure 4.2 shows an example screen from the tool.

The local parameters of the watercourse and details of the activity are required as inputs to the tool. The user is asked to enter the type of works and its length.

The information about type of works (whether it is grass, tree or weed clearance, desilting or dredging) is recorded in the output file, although it does not influence the calculations.

The length of works is a fundamental input to estimate the total length of influence of works and to define the areas where information about consequences needs to be provided.

The user needs to provide a relationship between water levels and return periods in normal conditions without any influence from maintenance activities. The source of the data – whether numerical model, visual estimations and so on – is flagged in the results file to assess the quality of provided water levels.

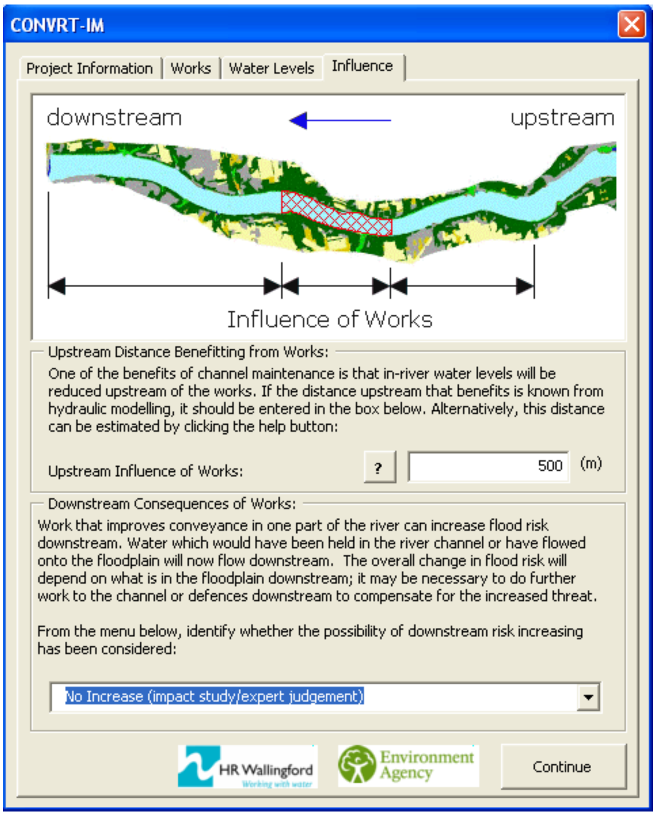

Figure 4.2 Example screen from the CONVRT-IM tool

The user is also required to input the reduction in water levels induced by the activity. This should be entered as a set of values related to different return periods. This is a fundamental input to calculate the benefits of conveyance activities. If information on water level changes due to the activity is not readily available, the user is advised on the use of CES to estimate water levels before and after the activity. A detailed guide to perform these calculations is provided in HR Wallingford (2013). CONVRT-IM can also generate the file inputs needed to run CES (see Section 4.2).

Another set of information required is related to the defence types at both banks and along the reach length influenced by the works.

The consequences of flooding or breaching are evaluated as the number of residential properties within the area of inundation. Advice is provided about the area in which the user of the tool should estimate the number of properties at risk.

The main output of the tool is the Expected Annual Households Flooded before and after the activity. The difference between both describes the benefits of the activity.

CONVRT-IM is a spreadsheet-based tool available within the Environment Agency. The tool is designed to minimise the data or modelling requirements, with the data used embedded within the tool itself. The tool provides guidance to the user about the required inputs and is designed to be used with minimum training.

4.4 NaFRA and Flood Map products

NaFRA estimates the likelihood of flooding at a national scale based on a 50m × 50m grid. NaFRA outputs support the development of Environment Agency Flood Map products. Flood Map shows the risk of flooding from rivers and sea in England. This information supports the understanding of the areas likely to be flooded. Figure 4.3 shows an example of a Flood Map from Oxfordshire.

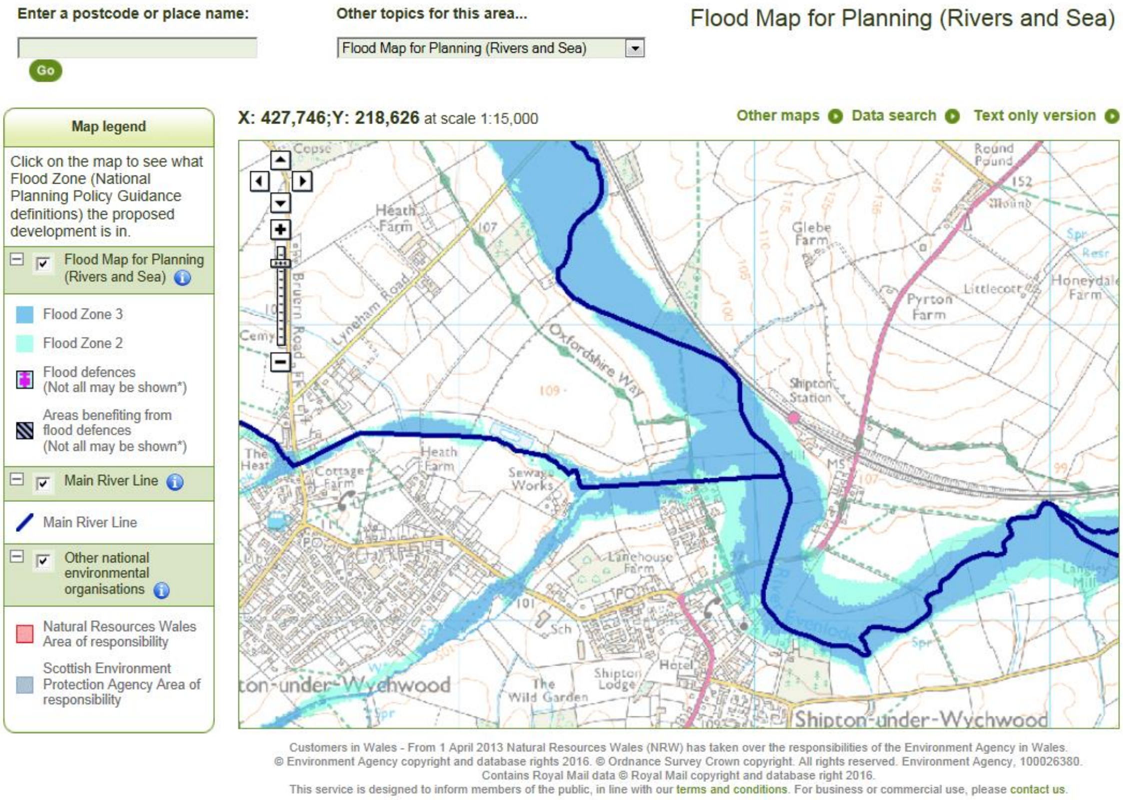

Figure 4.3 Flood Map example showing the area at risk of flooding (Flood Zone 2 and 3)

The standard NaFRA scenario provides residual risk for current conditions. Two additional scenarios were also produced for System Asset Management Plans assuming no defences and no conveyance maintenance.

The risks in the 'no conveyance maintenance' scenario were estimated by increasing water levels in the channels to allow for reduced vegetation management and/or reduced desilting/dredging. The increase of water levels was calculated at national level based on the available knowledge of:

- the type of vegetation and substrate
- related roughness coefficients
- the cross-sectional shape of watercourses

4.5 MDSF2

MDSF2 is a decision support toolset developed for the Environment Agency which quantifies the probability of flooding and the economic and social impacts of flooding and coastal erosion. It incorporates a system-based risk assessment allowing for the integration of the multiple relationships that exist within the flooding system.

MDSF2 is used by the Environment Agency to create the national flood risk maps and to assess flood risk management strategies. MDSF2 can therefore be used to assess the flood risk impacts of changes in water levels due to conveyance management (water levels need to be calculated using another tool).

Further information about MDSF2 can be found in Evaluating MDSF2 for Flood Risk Management Strategies (Environment Agency 2015b).

4.6 Conveyance KPI datasets

The Conveyance KPI project developed national datasets for the Environment Agency that reported the flood risk benefits (at national level) of maintaining channel conveyance. The datasets provide information about:

- changes in-channel conveyance (in-channel discharges and water levels)
- associated risks for different assumed maintenance options

The risks are expressed as the number of houses at increased risk of flooding due to different management strategies. The results provide a quantified comparison of changes in risk for the different scenarios considered. An example output is shown in Figure 4.4.

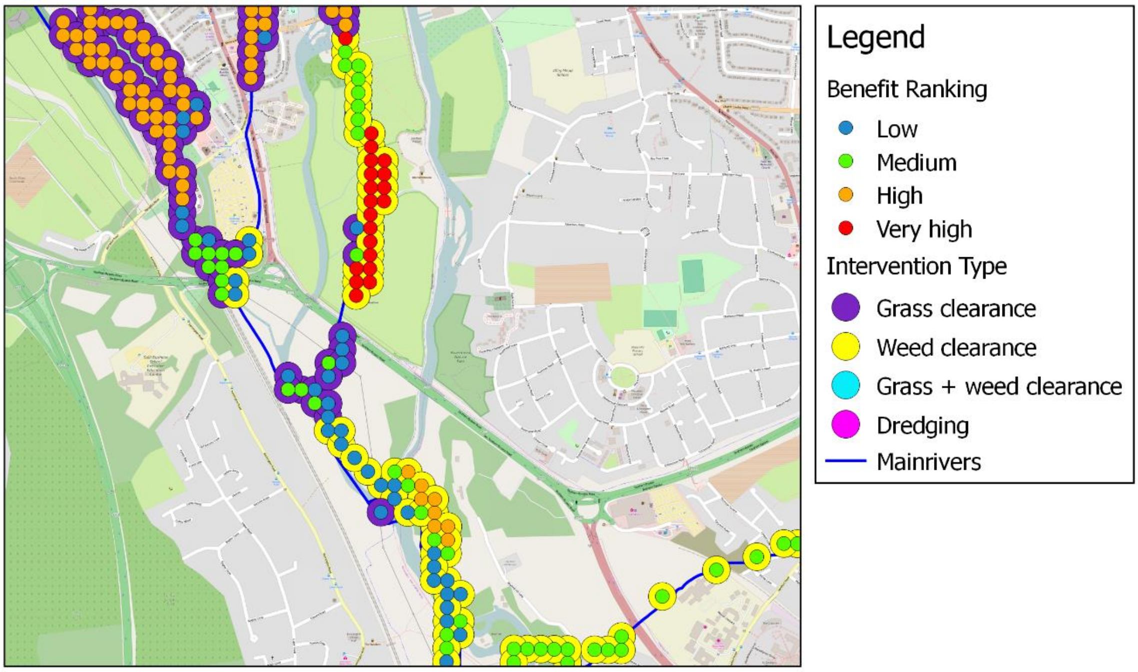

Figure 4.4 Example of Conveyance KPI project results showing the benefits (small circles) at each location linked to a particular management intervention (large circles)

The tool is also applied to identify the strategically important watercourses where conveyance-related works produce the greatest benefit. This is done by:

- identifying watercourses where maintenance works may have a potential to keep or increase conveyance capacity (potential important maintained watercourses)
- identifying watercourses where the attribution of benefits is important (potential important benefitting watercourses)

The tool assumes that any conveyance maintenance activity produces either a change of roughness across the sections where the activity is performed (for example, due to vegetation removal) and/or a change of the shape of the cross-section geometry (for example, dredging or removal of sediments). Therefore, each maintenance scenario has different water levels associated with the same water discharge.

Water levels at each maintenance scenario are estimated using the CES (see Section 4.2) and by considering the following characteristics of the watercourses:

- geometry, cross-section and slope
- type of substrate and vegetation

Further details of the methodology are given in HR Wallingford (2016).

National datasets such as the River Habitat Survey (www.riverhabitatsurvey.org) are used as input for the calculations. Note that this information may not be accurate in some areas.

Some of the tool's outputs are used to support the Environment Agency's Asset Information Management System and the Creating Asset Management Capacity programme.

4.7 Hydraulic models

Hydraulic models are mathematical representations of the physics of water flow solved numerically by computers. They provide estimations of water levels, flow paths, velocities and inundation extents. They can be used to:

- calculate the flows and water depths both in the channel and on the floodplain
- map the risk of flooding associated with a particular conveyance management scenario

Hydraulic models commonly used for flood risk analysis can be categorised as either one-dimensional (1D) or two-dimensional (2D). In the UK, 1D models are generally used for channel flow and 2D models for flood inundation (though both types can be used in both situations). It is common for linked 1D–2D models to be used for river flood studies. The 1D and 2D elements of models can be applied at a range of spatial and temporal scales.

Hydraulic models require a description of the area of study – both river channel and floodplain. This can be obtained from surveys, Ordnance Survey MasterMap data, LIDAR (light detection and ranging) data and so on.

The models also require the setting up of boundary conditions – mainly water discharges upstream and water levels downstream. Water discharges associated with different probabilities of occurrence can be obtained from FEH studies.[2]

As explained in Section 3.2, to simulate the conveyance management scenarios with hydraulic models, it is necessary to either modify the cross-section in the model (to reproduce the increase of flow area due to dredging or the reduction of area due to blockage of a culvert) or the roughness coefficients (to reproduce the management of vegetation).

Many open source and commercial hydraulic models are available to simulate water level variations and flood extents, including HEC-RAS, Flood Modeller, InfoworksRS, MASCARET, JFlow, TELEMAC and TUFLOW.

4.8 Culvert blockage lookup tables

For some channels in England, the Environment Agency has generated lookup tables which show the impacts of differing degrees of culvert blockage in terms of potential

[2] http://www.ceh.ac.uk/services/flood-estimation-handbook

property inundation and economic loss. An example of the data that has been generated at these sites is shown in Table 4.1.

Additional outputs typically include interactive PDF documents that display the flood extent and most important impacts for a user-selected combination of flood event and percentage blockage. These outputs can help with incident management decision-making as well as supporting channel maintenance decisions.

Table 4.1 Example of culvert blockage lookup table showing the predicted flooded property count for 3 degrees of blockage for 6 rainfall amounts

	Block_30%	**Block_60%**	**Block_100%**
Rain_10mm	500	640	828
Rain_20mm	943	987	1,017
Rain_30mm	1,090	1,109	1,128
Rain_40mm	1,171	1,186	1,210
Rain_50mm	1,254	1,269	1,341
Rain_60mm	1,434	1,447	1,456

A typical methodology for generating the data sets is provided below.

1. Obtain data on culvert locations and dimensions, DTM, receptors (properties) and hydrology.
2. Perform a standardised hydrological analysis to provide estimates of flows at the culvert entrances.
3. Estimate the flow capacity of the culvert with no blockage.
4. Estimate the flowrate/volume of flow that will not be conveyed by the culvert (*Q*) for each combination of hydrological event and blockage.
5. Build a 2D inundation model covering the culvert entrance and potential overland flow routes from the entrance.
6. Run the 2D inundation model with the flow Q ‘inserted’ at the location of the culvert entrance and generate maximum flood depth grids.
7. Count the number of properties potentially flooded and event property damages and other impact metrics (such as annualised damages and economic benefits of keeping the culvert blockage free).

In order to generate the data for many culverts efficiently, high degrees of automation are usually applied. It is also possible to perform the steps above ‘manually’, for example, using the FEH hydrology, 2D flood spreading and property damage modules in Flood Modeller.

5 Examples of application

This section provides examples of the application of the approach outlined in Chapter 3 and the results obtained with some of the tools described in this guidance. Table 5.1 presents a summary of the examples.

Table 5.1 Summary of examples

	Example	Tier	Tools used
1	Assessment of maintenance options in Great Eau	Detailed	Hydraulic model (Flood Modeller) and MDSF2
2	Dredging activities in the River Kent in Cumbria	Medium/Detailed	CES and hydraulic model with mobile bed
3	Effectiveness of additional dredging on the Somerset Levels and Moors	Simplified to screen sites, then Detailed	Hydraulic models (Flood Modeller and TUFLOW)
4	Application of hand calculations for backwater analysis	Simplified	Manning's equation

5.1 Assessment of maintenance options in Great Eau

5.1.1 Area of study

Great Eau in Lincolnshire is a predominantly fluvial and rural catchment, with almost all the land dedicated to agriculture. It therefore has many drainage channels and ditches. The study covers approximately 15km of the Great Eau River from the river mouth in Saltfleet to Withern. The study also includes the Long Eau River from Manby to the confluence with the Great Eau River (about 8km). Flood defences in the area are mainly turf-protected embankments.

5.1.2 Aim of the study

The aim of the study was to estimate the influence of different maintenance scenarios (Table 5.2) on the risk of flooding, primarily as a result of their impact on river conveyance. The study was part of the Performance-based Asset Management System (PAMS) project (Defra and Environment Agency 2009) commissioned to develop, test and document a suite of methods and tools that could deliver step-by-step improvements in the way the Environment Agency and others manage their flood and coastal defence assets.

5.1.3 Tools used

The study used a hydraulic model, ISIS (now Flood Modeller), to quantify the changes of water levels in the channel and MDSF2 type tools to estimate the risks and economic damages involved with the different maintenance scenarios considered.

5.1.4 Results obtained

The study followed the steps defined in Figure 3.2.

Ten management scenarios were defined (Table 5.2) and analysed with the hydraulic model, calculating water levels associated with different return periods. As an example, Figure 5.1 presents water levels obtained from the hydraulic model for some of the scenarios.

Table 5.2 Scenarios considered in the hydraulic model

Scenario	Vegetation management	Other management works
1	Business As Usual	–
2	Business As Usual	Lowering of 300mm in Great Eau
3	Business As Usual	Increase of 20% in capacity of pumps
4	Business As Usual	Increase of embankment crest in some reaches of Great Eau
5	Do Nothing	–
6	Do Nothing lower tidal reach	–
7	Increased Maintenance	–
8	Increased Maintenance in the upper reach, considering 2 cuts per year at 80%	–
9	Business As Usual	Lowering of 300mm in Great Eau + neap tide as boundary condition
10	Business As Usual	Raise of 300mm in Great and Long Eau
11	Business As Usual	– (same as scenario 1 but using neap timed as boundary condition)

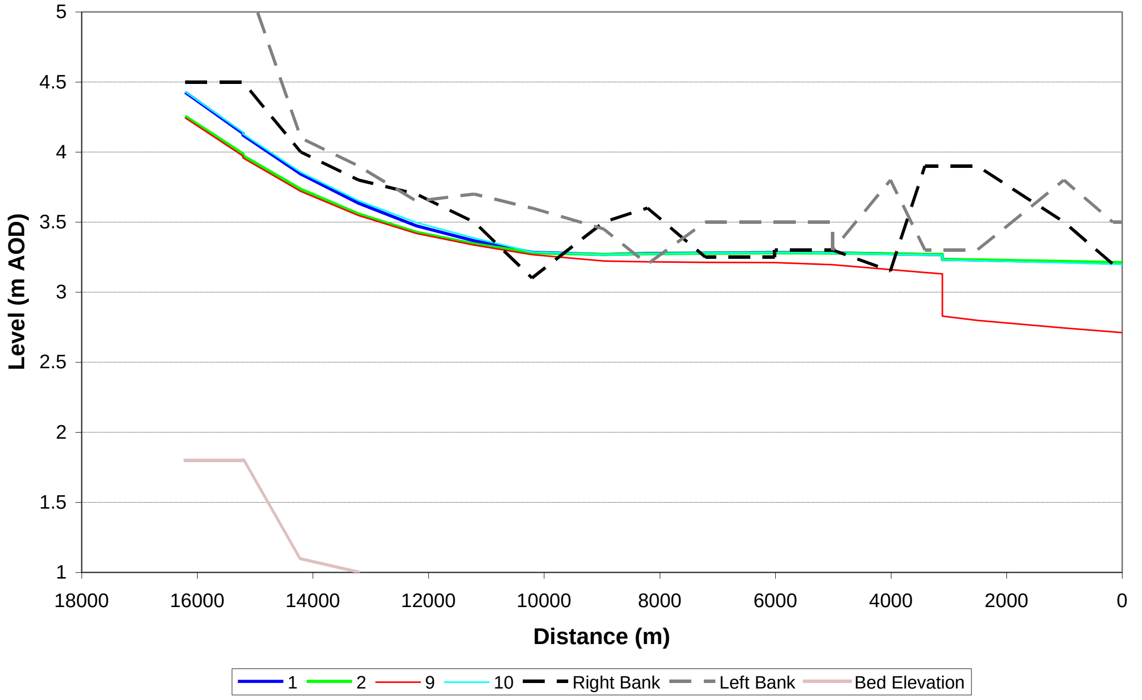

Figure 5.1 Water levels for the 100-year return period event for the Business as Usual (option 1) and different dredging options (2, 9 and 10)

Notes: m AOD = metres above Ordinance Datum

Probability of inundation maps (Figure 5.2) and estimated annual damages (EAD) maps were produced. The results from the latter are summarised in Figure 5.3.

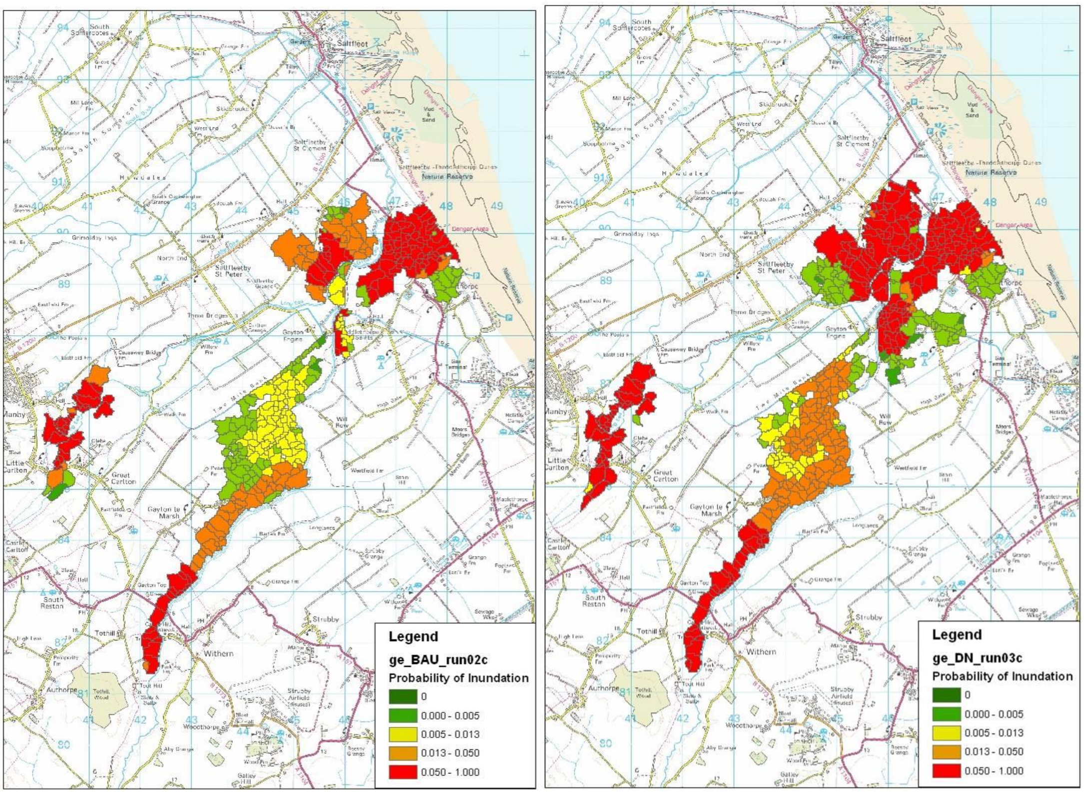

Figure 5.2 Probabilities of inundation in the Business as Usual (left) and Do nothing (right) scenarios

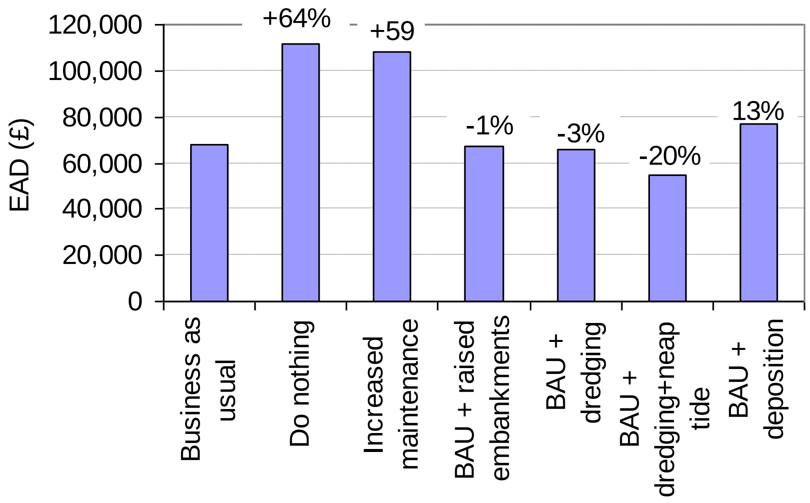

Figure 5.3 Comparison of EAD for the different management scenarios

5.1.5 Assessment of the approach

Use of the detailed tier tools was necessary to capture the complexity of the Great Eau system. They were able to appropriately describe the 'flow-dominated' upper reaches of the watercourse, where conveyance management had a much bigger impact than in the lower reaches, which were 'storage and tidal dominated'.

The results highlighted the strong interaction between the upper and lower reaches, and the possibility of transferring flooding problems from one area to another due to variations in the maintenance strategy. This finding emphasised the need for a system-approach rather than an assessment based on tools applied at local level.

The estimation of probabilities of inundation with a MDSF2 type tool was extremely useful to assess the influence of boundary conditions (spring and neap tide levels) on channel capacity.

The use of these tools required expert knowledge and resources.

5.2 Dredging activities in the River Kent in Cumbria

5.2.1 Area of study

The River Kent in Cumbria is a gravel bed river. It is heavily modified through:

- mining in the upstream sections
- weirs and other control structures in the middle and lower reaches
- a flood alleviation scheme in the town of Kendal

As a result of high coarse sediment loads, shoals develop frequently in the flood alleviation scheme in Kendal (Figure 5.4) and are routinely removed.

Figure 5.4 Large gravel shoal in the River Kent

5.2.2 Aim of the study

The study was part of the River Sediments and Habitat Project. This aimed to improve the understanding of the interaction between sediments, habitats and channel management actions (Environment Agency 2011). The study assessed the impacts of sediment removal on flood risks.

5.2.3 Tools used

The study used a 1D hydraulic model with mobile bed capability and the CES, which provides more detailed information on the lateral variation in flow depths and velocities.

5.2.4 Results obtained

The hydraulic model provided an understanding of the variations in water depth, flow velocity and shear stresses over an annual cycle. The maximum, 75th percentile, mean, 25th percentile and minimum values were determined for each variable (including the standard deviation of the variables) (Figure 5.5).

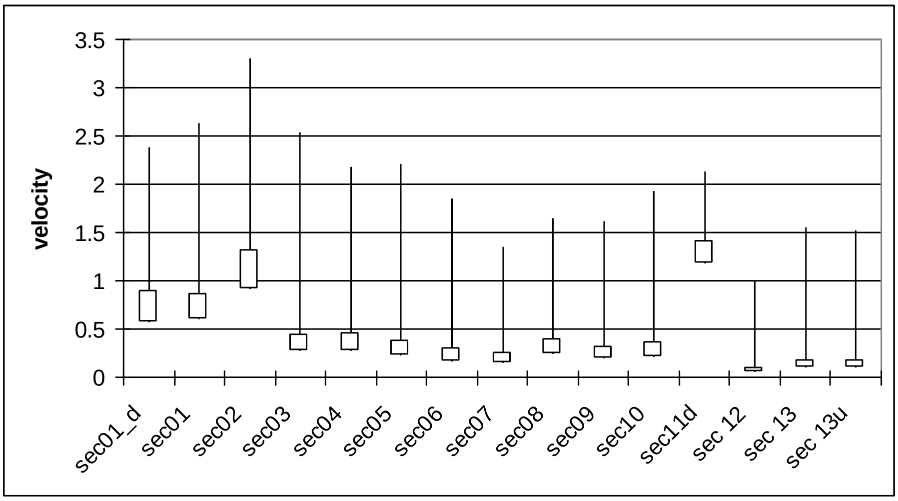

Figure 5.5 Longitudinal variation in velocity along the different cross-sections of the River Kent

Notes: From upstream section 13 to downstream section 01

The hydraulic modelling, supported by field observations and monitoring, showed that bar growth within the channel does reach a point where it becomes self-regulating without compromising the standard of defence of the flood alleviation scheme. However, this was dependent on sufficient high flows occurring to reduce the onset of vegetation colonisation.

5.2.5 Assessment of the approach

Sensitivity tests using hydraulic sediment modelling were useful to define an adaptive management routine. In this case, partial sediment removal at key points was considered to see whether this would provide an opportunity to achieve a balance between improved ecological status, while maintaining the standard of defence and ensuring the integrity of flood defences in downstream reaches.

5.3 Effectiveness of additional dredging on the Somerset Levels and Moors

5.3.1 Area of study

The Somerset Levels and Moors is a large low-lying area in south-west England. Following the major flooding in 2013 to 2014, 8km of the rivers Tone and Parrett were dredged. Further dredging is being considered as part of the 20 Year Flood Action Plan (Environment Agency 2014b).

5.3.2 Aim of the study

The Environment Agency carried out an assessment of the effectiveness of dredging at 10 potential locations in order to:

- better understand the benefits of further dredging
- be able to prioritise any further dredging

The 10 sites were selected using a simplified tier approach based on expert judgement and stakeholder views on where a lack of dredging was thought to be a direct cause of increased flood risk (Environment Agency 2014b). A detailed tier assessment was then undertaken for the 10 sites.

5.3.3 Tools used

The main tools used for the detailed assessment were linked 1D (Flood Modeller) and 2D (TUFLOW) hydraulic models. A rapid assessment was possible because hydraulic models already existed for most of the required sites. ‘With’ and ‘without’ dredging simulations were made for the historic event and design events. Results were extracted for the impact on both in-channel water levels and flood extents.

5.3.4 Results obtained

The impact of the simulated dredging at the 10 sites was assessed in terms of:

- flood risk benefits (properties not flooded and change in flood duration)
- water level management benefits

- environmental benefits

An effectiveness ranking was derived for each site based on impacts and expected costs. This information is shown in Table 4.9 for 5 highest priority sites.

Table 5.3 Example assessment impacts of further dredging

Site	Scale	cost	Flood risk benefits		Water level management benefits	Increased risk of flooding	Environmental Benefits	Effectiveness
			Properties	Duration				
Parrett: North Moor Pumping St to M5 bridge 3.2km)	small/med	med/high	up to 20 properties	reduced duration of up to 20 days for 25 -35 properties	Reduced duration of floods - may reduce agricultural damages (particularly applies to spring/summer floods in this area as experienced in 2012) Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	low/medium	medium	1
Tone: Ham to Hook Bridge (6.9km)	large	high	fewer than 5 properties	reduced duration of up to 2 days in some moors, properties and A361	Reduced duration of floods - may reduce agricultural damages (particularly applies to spring/summer floods as experienced in 2012) Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	low	low	2
Parrett: Langport to Tone confluence (7.8km)	large	high	no change	reduced duration up to 2 days at Westover Trading Estate and Thorney properties	Reduced duration of flooding in some moors - may reduce agricultural damages. Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	medium	medium	3
Glastonbury Millstream (4.3km)	small	low	no change	no reduction to duration of property flooding	Potential benefits for improved summer water supply/drainage to adjacent agricultural land. Funded by IDB precept.	low	low	4
Parrett: Thorney to Langport (6.2km)	small	medium	no change	reduction in duration up to 2-4 hours for properties at Westover Trading Estate	Increased capacity of channels may allow earlier pumping. Maintenance dredging will enable compliance with WLMP/Favourable Condition status to achieve required seasonal levels.	low	low	5

5.3.5 Assessment of the approach

The approach involved an initial screening of locations using a simplified approach, followed by a detailed approach which made use of existing 1D and 2D models.

The assessment of benefits, negative impacts and costs was made at a high level using available information and expert judgement and was appropriate to prioritise the sites. Further analysis would be necessary to support detailed design.

5.4 Application of Manning's equation hand calculations for backwater analysis

5.4.1 Area of study

This example was developed for illustrative purposes and is not based on a particular location.

5.4.2 Aim of the study

Understanding the impact of flood risk from a watercourse often involves the need to assess water levels along it over a distance upstream from some known point or structure. Where this information is not readily available and hydraulic modelling is not feasible, knowing how to assess water levels through a backwater analysis can be very useful. This example illustrates how the hand calculations using Manning's equation described in Section 4.1.1 can be carried out.

5.4.3 Tools used

Backwater analysis is used to calculate upstream water surface level, starting from a given downstream water level.

The starting downstream level has to be determined separately. Often it is related to the known level in a receiving watercourse to which the one of interest is discharging. In other cases, the downstream water level is derived from a hydraulic calculation for flow over an outfall weir or sluice.

The backwater analysis commonly uses Manning's equation for steady state (that is, constant rate) flow. The equation provided below is similar to the Equation 4.1 in Section 4.1.1.

$$Q = \frac{1}{n} A R^{2/3} S_e^{1/2} \qquad (5.1)$$

where:

Q = discharge in a channel (m^3/s)

A = cross-sectional area of flow (m^2)

R = hydraulic radius (m) (defined as the area divided by the wetted perimeter of the channel)

S_e = energy gradient along the channel (can often be approximated by the general slope of the watercourse)

n = Manning's coefficient

5.4.4 Results obtained

The steps below demonstrate how Manning's equation can be applied to obtain the water levels in a channel upstream of a weir with a crest level of 11.0m OD, a length of 3.0m and a flow of $10m^3/s$.

Step 1: Estimation of downstream water level for a particular flow

Consider a channel whose downstream cross-section is as shown in Figure 5.6.

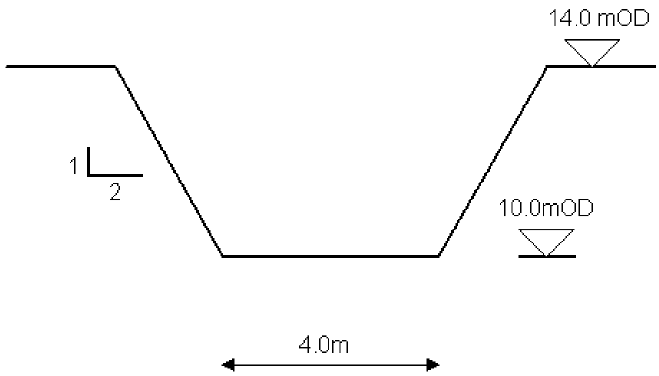

Figure 5.6 Geometry of downstream cross-section

Use is made of the broad-crested weir formula:

$$Q = 1.7 \times b \times H^{3/2} \qquad (5.2)$$

where:

b = length of weir (m)

H = vertical distance from level of crest of weir to water surface

In this example, Q = 10.0m^3/s and b = 3.0m.

Therefore, 10.0 = 1.7 × 3.0 × $H^{3/2}$ and H = 1.56m.

The downstream water level is therefore 11.0 + 1.56 = 12.56m OD.

The bottom of the channel is at 10m OD (Figure 5.6) and so the channel depth is 2.56m.

Step 2: Assessment of channel flow cross-section and roughness properties at 12.56m OD

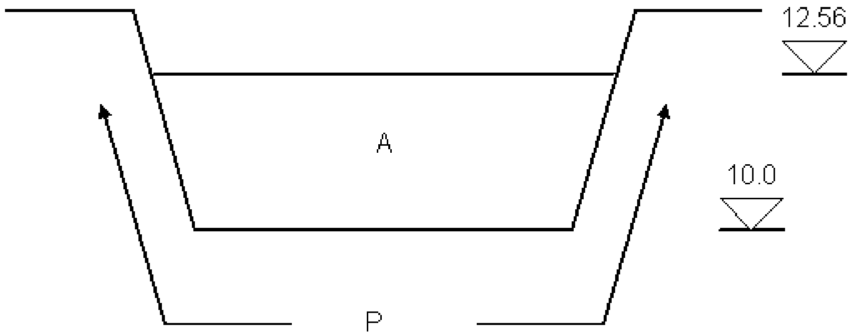

Figure 5.7 Geometry of channel flow cross-section

At 12.56m OD for the channel depicted in Figure 5.7:

Cross-sectional area of flow (A) = 23.3m^2

Wetted perimeter (P) = 15.4m

Hydraulic radius (R) = A/P = 23.3/15.4 = 1.51m

Manning's coefficient (n) = 0.05 (based on actual channel roughness characteristics)

Step 3: Assessment of the surface water slope (S) at the downstream section

To calculate Manning's equation can be transposed to give:

$$S^{1/2} = \frac{Q\,n}{A\,R^{3/2}} \quad (5.3)$$

Therefore, at the downstream channel section:

$$S^{1/2} = \frac{10.0 \times 0.05}{23.3 \times 1.51^{3/2}} \quad (5.4)$$

Hence the surface water slope at the downstream section S = 2.66 × 10^{-4}.

Step 4: Assessment of the water levels at 100m intervals upstream of downstream section

On the basis that the slope will not change rapidly with distance upstream, the water level at the next channel cross-section (say 100m) can be projected from the slope at the downstream section.

The rise in level over 100m = 100 × 2.66 × 10^{-4} = 0.0266m, which rounds to 0.03m.

Therefore, the calculated water level at 100m upstream = 0.03 + 12.56 = 12.59m OD.

With a channel bed level of 10.3mOD, the new channel depth is 12.59 – 10.3 = 2.29m.

The procedure can now be repeated for the next 100m to give:

A = 19.6m^2

P = 14.2m

R = 1.38m

n = 0.05 (same value as above because similar roughness to previous 100m)

New surface slope S = 4.23 x 10^{-4}

The rise in level over the next 100m is therefore 0.04m.

The water level at (+200m) becomes 0.04 + 12.59 = 13.63mOD

This process can be repeated for many more times going upstream.

5.4.5 Assessment of the approach

Backwater analysis is based on the hydraulic concept of 'normal depth', that is, that there is a natural depth of water in a stream or river and that the water level along a watercourse will try and achieve this 'normal depth'.

At normal depth, the water surface slope will be at the same gradient (or slope) as the channel. If the water depth becomes too great (for example, if water is held up by an obstruction), the water surface gradient will flatten upstream until normal depth is again achieved. Likewise, if the water depth becomes too little (for example, if water can freely spill out over a weir), the water surface gradient will steepen upstream until normal depth is achieved. As a result, structures that affect the channel size (for example, bridges and/or culverts) or give sudden changes in the bed (for example, drop at weir) need to be taken into account. In each case, an individual calculation of the effect on the water level from downstream to upstream needs to be made. Backwater analysis can then continue upstream.

Sections can be taken at greater spacing than 100m, although close spacing gives better stability to the answer if the water surface gradient is steep. Drawing a longitudinal profile of the results will show whether the calculated gradient has fluctuated wildly; if it has, the section spacing should be reduced.

The channel can be any shape and can include flow on the floodplain outside the main channel. The channel geometry as surveyed can be approximated to calculate the geometric properties.

The method is for subcritical flow and steady flow conditions only. The method is limited to application in single reaches with no branches, confluences, junctions or loops.

The process lends itself to spreadsheet calculation. Where system becomes complex, hydraulic modelling is advisable.

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List of abbreviations

AP Tools	Asset Performance Tools
CES	Conveyance Estimation System
DTM	digital terrain model
EAD	estimated annual damages
FEH	Flood Estimation Handbook
GIS	geographical information system
KPI	key performance indicator
m AOD	metres above Ordnance Datum
MDSF2	Modelling and Decision Support Framework 2
NaFRA	National Flood Risk Assessment
OD	Ordnance Datum

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