1 Design of works in the fluvial environment

1.1 Scope of the guide

The scope of this guide is generally limited to what can be termed 'interventions' in the fluvial environment. This includes hard engineering and soft engineering as well as maintenance interventions such as de-silting and vegetation control. The fluvial environment includes not only the watercourse (bed and banks) but also the floodplain and immediate hinterland.

The guide is intended primarily for situations where flood risk management or land drainage is an important driver. It aims to support delivery of fluvial design in line with government policy as set out in *Making space for water* (Defra, 2005).

The fluvial system is illustrated in Figure 1.1. Although interventions in the fluvial system have greatest impact on the river channel itself, the wider impacts on the channel margins and floodplain must also be taken into account.

The impact of fluvial interventions extends beyond the physical environment to cover a wide range of uses of the fluvial system such as navigation, angling, walking, water supply and wildlife. In addition, the full extent of the fluvial system – as encompassed by the catchment – has a direct impact on the hydrology, geomorphology and ecology of the river – all of which are important inputs to the fluvial design process.

The guide covers all of these elements, though its primary focus is inland flood risk management. It does not stray into issues of land use management or surface water drainage in the catchment. At the downstream end of the fluvial system, the guide deals with issues of tidal influence, but does not cover saline water ecology, or waves in estuaries or on the coast.

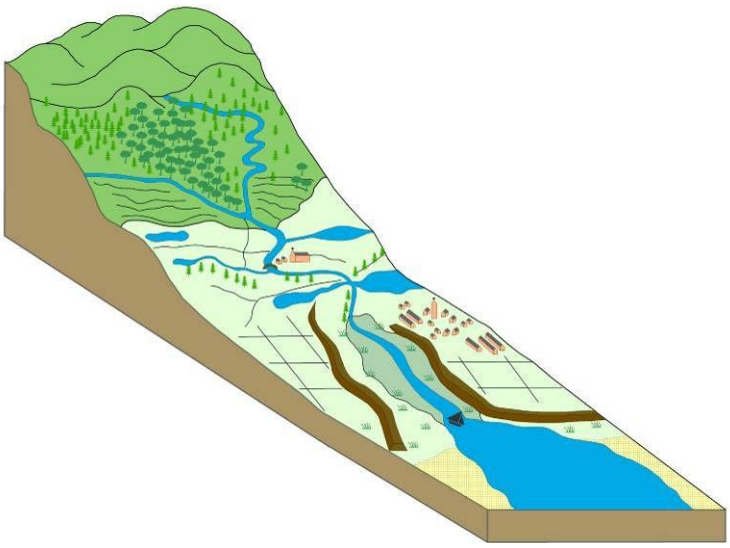


Figure 1.1 The fluvial system

From source to sea, the fluvial system includes drainage channels and rivers, lakes, floodplains and washlands, and all the associated ecology and landscape.

The system also includes the flood risk management infrastructure, together with the infrastructure associated with other uses of the river, such as navigation locks.

The fluvial system is dynamic and changes with time. Understanding this is fundamental to the fluvial design process.

1.2 Design and asset management

It is helpful at this stage to define what we mean by design. But first it is necessary to define the term 'asset' in the context of flood risk management (the focus of this guide). The term is used here to describe an engineered or natural component of the fluvial system that performs a flood defence or land drainage function (for example, a floodwall, a sluice structure, a river channel or a revetment to prevent erosion). An asset forms a part of an asset system that includes a number of interdependent assets working together to provide a flood protection, drainage or other function. The design of assets therefore needs to be carried out in the context of their associated systems (see Section 1.4.2).

It is also useful to explain the term 'function' as it is used in this guide. All assets have a primary function, which defines their main purpose. Thus, the primary function of a culvert is 'to convey drainage flow under an obstruction without undue restriction'. Although the primary function of many of the assets described in this guide relates to flood risk management, some assets have other primary functions. These include structures such as navigation locks and fishpasses, though these are also likely to have an impact on flood risk management. All such assets require management throughout their lifecycle, as illustrated in Figure 1.2.

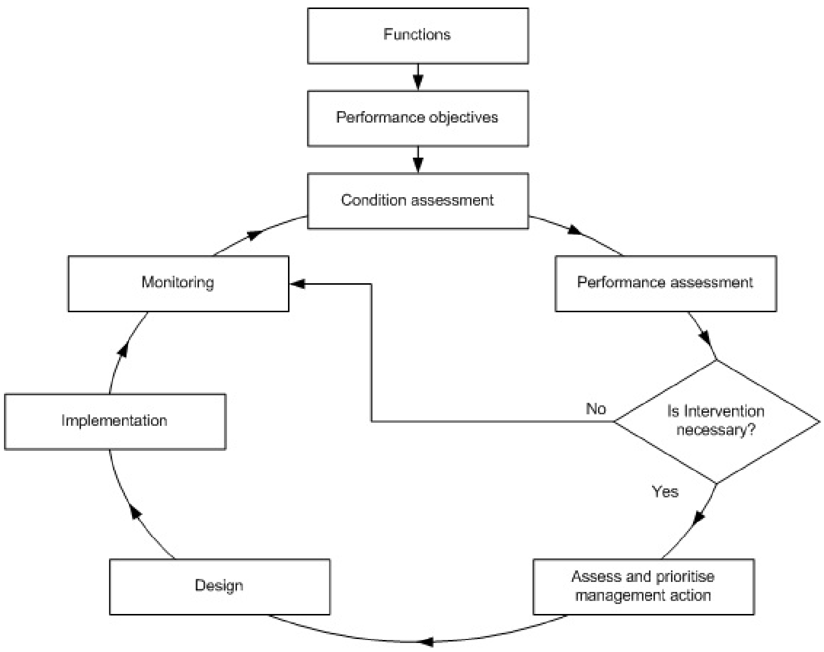


Figure 1.2 Asset management lifecycle

This diagram illustrates the role of design in the lifecycle of an asset.

For new assets, the cycle starts with the assessment that an asset or system is not achieving its stated or implied performance objective.

For existing assets, a programme of monitoring, condition assessment or performance assessment often identifies the need for remedial works or change to the standard of service

In both cases, the design has to take account of the functions the asset is intended to perform.

So in the context of this guide, 'design' activities address the management of the asset throughout its whole lifecycle. The term design therefore encompasses:

- **New design** – often the easiest design activity and one for which the designer starts with a clean sheet.
- **Design for refurbishment or change of performance** – design for the adaptation, upgrading, rehabilitation or decommissioning of assets within existing fluvial systems, following an assessment of their condition and performance. The constraints imposed by the existing system and its wider environment will have a strong influence on the achievement of the design objectives. This is the more common context for fluvial design.
- **Design for operation and maintenance** – for example, to address cracking in a masonry wall.

All these design activities may require the design of temporary works (for example, cofferdams and stream diversions) as part of the construction process.

The outputs from design activities can be wide-ranging and may include:

- design notes;
- calculations (including computer analyses);
- output from a mathematical model;
- specifications;
- drawings;
- operation and maintenance (O&M) guidance and manuals.

All these are needed in different proportions to define the design concepts and to convey them to those carrying out the physical works on the site during the construction period and throughout the functional life of the asset.

It is essential that designers of works in fluvial systems appreciate the extent to which the works can impact on the wider environment and thereby affect other users of the system. Consideration of these impacts is an essential part of producing sustainable designs – and in identifying opportunities for enhancements to the environment – as well as recognising the constraints they impose.

In the particular context of flood risk management, recent developments have led to the adoption of the 'source–pathway–receptor' conceptual model to improve the understanding of flooding mechanisms. These terms are defined in the glossary and the concept is illustrated in Figure 1.4. This fluvial design guide deals principally with the source and pathway elements. It does not address the design of local measures to protect individual properties against flooding.

1.3 Fluvial design process

1.3.1 Overview

The fluvial design process is objective-led. The need for design is usually identified from an inadequate standard of performance, operational inefficiency or an asset reaching the end of its life. The design process commences by:

- understanding and defining the performance objectives of the asset;
- identifying an optimum solution for achieving these objectives;
- presenting these in such a way that the asset can be built and managed over its design life (see Section 1.4.4).

Once the design objectives are clearly defined, the nest step is to assess the current and expected future performance of the system in the light of these objectives. This may involve surveys, investigations and assessment of historic records. If the need for intervention to achieve a new performance standard is identified, options for achieving this are then developed and assessed to identify the preferred solution. The preferred option is then designed in sufficient detail to enable its implementation. Although the design process finishes before the implementation, it must provide information to:

- allow the asset to be constructed;
- guide its operation, maintenance, future upgrading and decommissioning.

Designing in the fluvial environment involves interaction with many people who have varied interests concerning the natural, managed and built environments. Understanding their needs and incorporating these into the process is crucial to achieving solutions that are appropriate and acceptable. The supporting consultation, risk and data management processes are discussed further in Section 1.3.3.

1.3.2 Achieving the design product

To achieve a successful design within this challenging environment, the following important aspects need to be managed properly:

- performance objectives;
- design development;
- design outputs.

These three aspects are covered in more detail in Box 1.1.

Box 1.1 Important aspects in fluvial design

Performance objectives Once the need for intervention is identified, it is important to capture this in a set of performance objectives (if they do not exist already) that set the higher level focus of the design decisions and outputs, and the benchmark against which the implemented solutions will be evaluated. Examples of these for a new sluice structure could include the ability to pass a particular flow for a given head and the facility to allow migration of particular fish species.	
Design development This aspect is an iterative process of identification of approaches and the development of the preferred solution. It involves three main processes (see right). The design development process requires an appropriate balance between fact-finding, analyses, value engineering and associated iterations on the one hand, and moving towards a preferred solution on the other. The defining principle here is obtaining enough information to enable design decisions to be made with an acceptable level of certainty.	▪ Option identification and screening. The mindset needs to be open to ensure all the relevant disciplines (hydraulics, engineering, ecology, operational, geomorphology, landscape, etc) are involved. The purpose is to identify realistic options that can achieve the performance objectives. ▪ Identification of the preferred option – further investigation to find the optimum solution to meet the performance objectives. ▪ Consolidation – development of the preferred solution, with all important aspects defined and the underlying assumptions, principles and outcomes captured in a design note or report.

Design outputs The focus of the detailed design should be the development of the design in enough detail to facilitate its construction and, as much as possible, to inform and direct the future operation, maintenance, adaptation, rehabilitation or decommissioning works. Design outputs are summarised on the right. Where performance specifications are used (as is often the case for structures such as sluices and pumps where the final design is left to the supplier of the plant), particular care should be taken to ensure the design concepts and performance objectives are described clearly. This should be supported by an unambiguous testing and approval programme.	▪ Design note or report to document the design decisions, assumptions, principles and choices. ▪ Design calculations (whether a formal output or not) should be clear and accessible. ▪ Construction works information including specifications and drawings. ▪ Construction support information such as residual risk information (including health and safety and environment), consent information and conditions. ▪ Whole life operation, maintenance and performance monitoring requirements, and residual risk information. ▪ Information to inform adaptation, rehabilitation or decommissioning.

1.3.3 Managing the design process

This section deals with the three inputs into the design process outlined in Section 1.3.1. Stakeholder consultation is covered in Section 1.4.1.

Risk identification and assessment

Designing in the fluvial environment has its particular challenges and constraints. Any interventions in the existing system need to take account of – and work with or around – the various other interests. These include existing development, stakeholder interests, and environmental interests and designations. Addressing the needs of all of these interests may involve difficult decision-making, particularly where there is adverse interaction between interests (with regard to meeting performance objectives) which may lead to higher costs, delays or other unwanted outcomes.

Early assessment of the potential impacts and opportunities is an integral part of the design process to enable the avoidance or management of potential negative impacts and the realisation of optimum enhancement opportunities. Risk assessment and management processes relating to these – including stakeholder engagement, health and safety and environmental impact assessment (EIA) processes – are described in Sections 1.4.1, 1.4.5 and 1.4.6 respectively.

Factors that can affect the achievement of design objectives give rise to risks. The complex nature of these risks means that it is good practice to use a well-defined process to support better decision-making through identifying, assessing and responding to the risks. This process is called ‘risk management’. Risk management aims to lessen or remove risks, by reducing the probability of occurrence, or by mitigating the consequences, or a combination of both. The management plan also needs to address any residual risk.

To provide a transparent trail of risk management, it is important that identified risks, together with the actions taken to manage them, are recorded and kept up-to-date in a risk register. This also provides risk information to the next stage of the design process and ultimately to the implementation stages. Risks associated with the design of particular types of fluvial structures and their management are described in Chapters 8 to 11.

Data collection and analysis

Design choices and decisions need to be based on proper analyses of relevant information. Getting this right is vital to the quality of design decisions as well as the time taken for the design process.

Supporting information normally includes:

- what is needed to establish how the system works;
- historical management and associated performance;
- potential impacts of options for management;
- legal or other requirements.

For fluvial design, information on historical performance under various hydraulic loading conditions is particularly important. Analysis of these conditions should take account of expected future trends including climate change effects.

There is likely to be a minimum level of information needed for design below which any design decisions would be based on nothing but 'heroic assumptions'. On the other hand, it is unlikely that an ideal amount of information would ever be available. The effort and cost of obtaining additional information needs to be balanced against the added value to the decision-making process. The need to obtain further supporting information should therefore be based on an analysis of the information available and comparison with that required to make the design decisions with the requisite level of confidence.

It is also important to record the sources of the information obtained, the data attributes and the assumptions made in their use. These metadata provide a valuable record of the data used and their provenance, allowing anyone revisiting the design to understand fully the quality of the data on which it was based. Further guidance on assessing data requirements, data quality and recording information about data through a metadata system developed for flood and coastal management is available in *Improving data and knowledge management for effective integrated flood and coastal erosion risk management – a guide to good practice* (Robinson et al, 2007).

1.4 Basic concepts

This section sets out some of the basic information that a designer needs to know and understand when designing for the fluvial environment. In line with the character of this chapter, it covers issues relevant to fluvial design as a whole. Subsequent chapters describe crucial aspects of the basic concepts in further detail.

It is important to recognise that in fluvial design in general – and flood risk management in particular – a full understanding of the historical context greatly assists the development of appropriate solutions. This not only relates to the history of flooding problems (past events, mechanism of flooding, records of flows and levels, significance of blockages, loss of floodplain, for example) but also to the morphological, environmental and anthropomorphic history associated with the river system.

1.4.1 Roles and responsibilities

Legal framework

The legal basis for flood risk management in England and Wales is set out principally in the Water Resources Act 1991, the Environment Act 1995 and the Land Drainage Act 1991. Further information on these and other acts, and those organisations with responsibilities or powers under them, is given in *Land drainage and flood defence responsibilities* (ICE, 1996). These acts describe the roles and responsibilities of the operating authorities and form the basis for their operational, supervisory, regulatory and executive powers to do work in the fluvial environment. With respect to flood risk management, the operating authorities are primarily the Environment Agency for all main rivers, the Internal Drainage Boards (IDBs) for their respective internal drainage districts, and local authorities for non-main rivers.

The new European Union Directive on the assessment and management of flood risks (EU Floods Directive) will require the production of flood risk management plans and maps as part of a strategic planning framework for fluvial flood risk management (see 'Strategic planning framework'). In the context of flood risk management in England, Defra's policy document *Making space for water* (2005) sets out the aims and objectives, constraints and opportunities for the future.

The environment and human use of the river system can be both driver and constraint for fluvial works. Legislation of particular importance to the fluvial environment includes:

- The Conservation (Natural Habitats, &c.) Regulations 1994 – otherwise known as the Habitats Regulations – which implement the EU *Habitats Directive* in the UK;
- *Water Framework Directive* at the European level;
- various other acts and regulations at the national level including those relating to strategic environmental assessment (SEA) and environmental impact assessment (EIA).

The EIA screening process is particularly important, as it often highlights other legislative requirements. Further information on these requirements and their implications for fluvial design is provided in Chapters 4, 5 and 6.

It is a fundamental requirement of any works in the fluvial environment that the rights and responsibilities of the riparian owner and all other involved parties are understood and accepted prior to, or during, the design process. In particular, it is essential that those parties who will be responsible for the operation and maintenance of any asset or intervention are fully aware of these responsibilities and accept them throughout the life of the asset.

Stakeholders and consultation

Designing in the fluvial environment involves the development of management interventions to alter or support the workings of the fluvial system. As a result, it is necessary to ensure effective consultation with the stakeholders in the design process, primarily for two purposes:

- early input to the planning and design process to identify all relevant information, issues and constraints and to exploit any 'win–win' opportunities;
- feedback of emerging plans to the various stakeholders, explaining how their inputs have affected the outcomes, identifying any outstanding issues and encouraging wider acceptance and ownership.

Three main types of organisation are particularly relevant in the context of carrying out works in the fluvial environment. These are:

- those with operational responsibilities or powers to manage or carry out works to maintain the functional performance of the fluvial systems;
- those that regulate aspects of the systems;
- those that are directly affected by management activities.

The main organisations relevant to fluvial design works in England and Wales include:

- Natural England, Countryside Council for Wales, English Heritage and Cadw (the historic environment service of the Welsh Assembly Government) – in relation to the regulation and protection of the natural and historic environment;
- regulatory functions of the Environment Agency – for issues affecting fisheries, ecology, recreation, pollution prevention, waste, water resources and flood risk management;
- local planning authorities – in relation to requirements for planning or other consents;
- navigation authorities such as British Waterways and the Environment Agency;
- landowners, occupiers and local population potentially affected by the design works, including by access to works;
- managers or regulators of other utilities or major infrastructure networks such as county councils (highways and public rights of way), Network Rail (railway infrastructure), Transco (gas pipelines) and the relevant electricity and telecommunications companies;
- local conservation and recreation interests such as wildlife trusts, angling and boating clubs.

The success of the consultation process relies on:

- having a clear consultation plan;
- ensuring adequate records are kept;
- making genuine efforts to take on board feedback while maintaining the primary objective of the design.

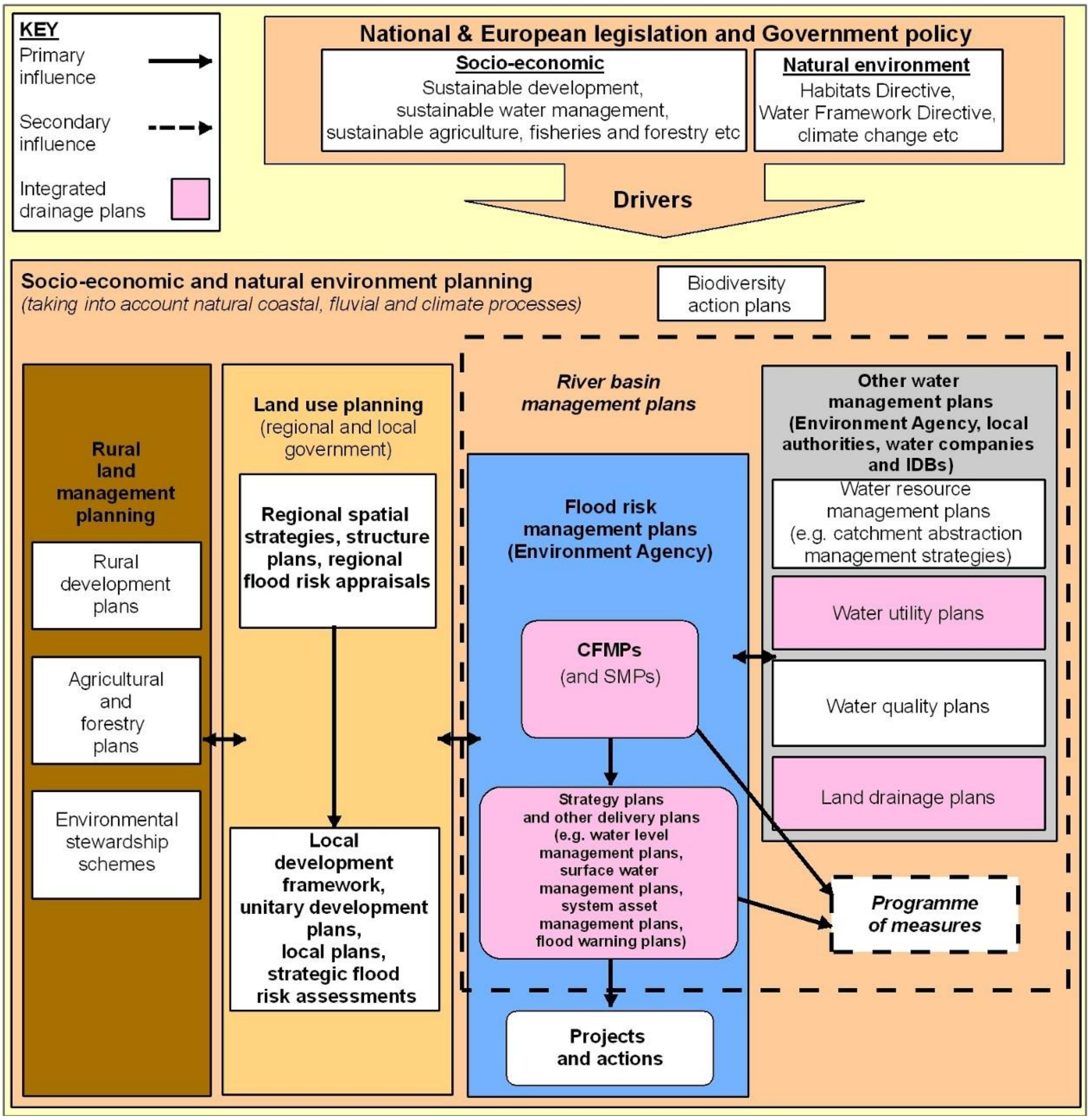
Advice on appropriate consultation approaches is available in *Sustainable flood and coastal erosion risk management* (Wade *et al*, 2007).

Strategic planning framework

Within flood risk management, this guide supports the implementation of design and management solutions developed through delivery plans, which are typically strategy plans or system asset management plans (SAMPs). Where these delivery plans exist, they are in turn based on policy as set by catchment flood management plans (CFMPs) and shoreline management plan*s* (SMPs).

The strategic planning framework is illustrated in Figure 1.3. In particular, it shows how this guide (represented by the two boxes closest to the bottom right corner) fits into the framework, as well as how flood risk management planning fits into the wider development planning framework.

Figure 1.3 Strategic planning framework for flood risk management



The starting point of any intervention within the fluvial environment is ensuring a clear understanding of the higher level policies, strategies and plans that relate to the associated system. It is then important to develop appropriate management solutions in line with the wider strategic approach.

1.4.2 The fluvial system

Overview

In theory, the fluvial system is made up of all land (whether or not it is formally recognised) that conveys or manages water, or where water is naturally stored, runs off, or infiltrates to the strata beneath. Water enters the fluvial system:

- following rainfall;
- from coastal inundation;

- from springs and rising groundwater;
- from infrastructure systems such as dams and piped drainage networks.

Unless prevented by a mechanical means such as pumping, once water collects on a surface in sufficient quantities, it flows downhill from its source and is transported overland or by natural or man-made conveyance systems through natural and built areas en route to the sea. Water may also spread out as it makes its way downstream, depending on the volume of flow, the conveyance capacity and the topography. The extent to which water spreads out during its passage downstream depends on the topography and constrictions along its length such as dams and culverts, and across its width such as embankments, walls and buildings within the floodplain.

The effect of the water once it leaves the normal waterway through a flood pathway depends on the type of receptors in the inundated area. This is illustrated by the source–pathway–receptor model in Figure 1.4.

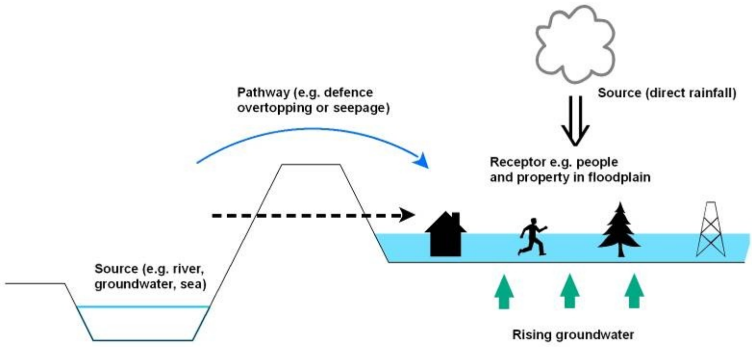


Figure 1.4 Sources, pathways and receptors of flood risk

The source–pathway–receptor model is a useful tool for understanding flood risk and flooding mechanisms.

System interactions

The hydraulic behaviour of a fluvial system is interactive, with the conditions or characteristics of one part of the system having effects on the flows and levels within other parts. For example, a constricted part of the system reduces the conveyance through it, thereby affecting the water levels upstream. These changes may also affect the transport of sediments and debris within the system. Such changes could lead to sediment deposition and associated loss of conveyance in some areas and sediment starvation or riverbank scour in others.

The effect of constrictions becomes marked at larger flows and even more significant if the constriction is surcharged or restricted by blockage. The extent of the impact on upstream levels depends on the backwater effect, while its significance depends on the effect of the raised water levels on the potential pathways into the receptor area. These effects can range from the direct effect of water level and waves leading to overtopping of the riverbank or flood embankment, to increased water forces leading to piping, structural damage or a breach of the defences (see Section 1.4.3).

The interactive nature of a fluvial system demands the assessment of the performance interventions and management interventions applied to it at a system scale, with the extent of the system or subsystem being determined by the relevant area of hydraulic or other influence. See Chapter 7 for more detailed information about hydraulic analysis.

1.4.3 Flood risk management

Flood risk management within the fluvial environment often requires management of the engineering performance of fluvial systems such as the conveyance capacity. This can take the form of occasional major improvement works to achieve a significant step change in engineering performance or increased maintenance activities, or sometimes both.

Management of flood risk normally involves the reduction of either the probability of flooding (through management of sources and pathways) or the consequence of flooding (through management of the receptor), or both. This guide is primarily concerned with managing the probability of flooding. Consequence management is addressed in other publications including:

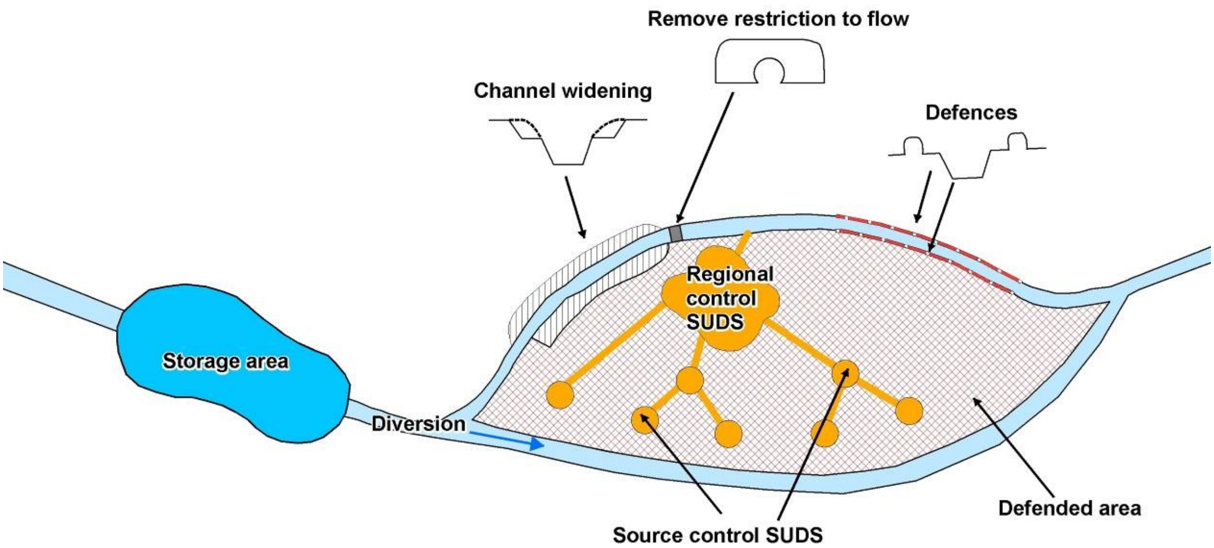
- *Planning Policy Statement 25: Development and flood risk* (CLG, 2006) and its practice guide published by Communities and Local Government (CLG);
- various guides on property-level flood resistance and resilience published by CIRIA, the Environment Agency, CLG and Defra.

In the broadest sense, approaches for reducing the probability of flooding to a desired level of flood risk typically include one or more of the following:

- Holding back water and releasing it at a reduced rate, thereby reducing peak flows and lowering peak water levels. This includes surface water management measures, for example as provided by:
  - sustainable drainage systems (SUDS; see Woods-Ballard *et al*, 2007);
  - the provision of flood storage reservoirs (see Chapter 10);
  - bringing previously lost areas of the floodplain back to functional use.
- Lowering the flood levels within the channel. This typically involves:
  - channel deepening;
  - channel widening;
  - dredging;
  - weed-cutting;
  - removal of blockages and constrictions;
  - removal or lowering of weirs.
- Provision of raised defences to block the pathways of flooding. This approach includes the use of floodwalls, embankments, and temporary or demountable flood protection systems.
- Diversion of the water away from areas at risk – including flood relief or diversion channels.

These approaches are illustrated in Figure 1.5. This diagram illustrates local runoff control measures within a defended area, but the same approach is also applicable upstream. Chapters 8 to 11 cover the most relevant types of intervention in more detail.

Figure 1.5 Four ways to manage the probability of flooding



1.4.4 Asset management

Performance and reliability of assets

Asset management is a process that seeks to manage continuously the performance, risk and whole-life cost of the associated infrastructure. As explained in Section 1.3, performance objectives are set at the start of a project. These give rise to performance requirements for the associated assets or components. It is therefore important that the designer takes account of the mechanisms that can lead to failure of the asset to perform as intended.

Performance is the extent to which an asset fulfils its intended function; reliability is the probability that the asset does not fail. *Risk, performance and uncertainty in flood and coastal defence – A review* (Sayers *et al*, 2003) is the primary reference and source of definitions and concepts of flood risk and associated performance, reliability and uncertainty. Note that some have been updated in a subsequent report from the joint Defra/Environment Agency flood and coastal erosion risk management R&D programme (Buijs *et al*, 2007).

The performance requirements and associated failure mechanisms can be different for each asset type. For example, a flood defence or reservoir has to act as a barrier, so the failure mechanisms concern overtopping, breach or seepage. In contrast, a watercourse has to convey water, so the failure mechanisms concern blockage or increased resistance. Chapter 9, for example, identifies the specific failure mechanisms for the main asset types in fluvial design. In addition, the other functions of an asset (for example, improving a habitat) impose their own performance requirements for that function, together with associated failure modes.

The performance of a fluvial system depends on how the individual assets within it perform individually and interact as a system. Fluvial design should always consider performance requirements for a whole range of loadings on the system, including the maintenance of ecological, heritage or social functions where these are defined objectives. For example, a channel may be designed to ensure that average summer flows are contained within a smaller channel to maximise flow velocities and minimise siltation, with further flows being contained within a flood defence up to a specified probability of occurrence.

Aspects of performance requirement during extreme events may include a serviceability requirement (such as limiting overtopping of some footpath or road to a maximum rate of overtopping for a specified probability of occurrence) or a requirement for safe overtopping up to some higher flow.

The continued performance and reliability of assets and their associated systems are affected by uncertainties and deterioration over time. These aspects and how they can be managed or accounted for in design are discussed below.

Uncertainty

Every design process has to deal with uncertainty. It can be helpful to distinguish different types of uncertainty, as this determines the best way to handle it:

- **Uncertainty in nature** – caused by the huge complexity of interaction inherent to natural systems. An example of this is climate change and its likely impact on flood risk.
- **Knowledge uncertainty** – resulting from limitations in our knowledge of the state of a physical system, and our ability to measure and model it. Two types of knowledge uncertainty can be distinguished:
  - **Statistical uncertainty** – for example, the uncertainty in determining the severity of an extreme discharge resulting from the extrapolation of a limited dataset and from the selection of the probability distribution.
  - **Process model uncertainty** – for example, the uncertainty caused by the fact that numerical models are not perfect, including the uncertainty about climate change.

More detailed guidance on types of uncertainty is provided in *Risk, performance and uncertainty in flood and coastal defence – A review* (Sayers *et al*, 2003).

The best way to analyse uncertainty in fluvial design depends on the type of uncertainty under consideration. In a general sense, it is important to make uncertainty explicit: it is good practice to go through the design process using the best estimate of each parameter, while keeping track of all the uncertainties that are encountered along the way. It is also important that the uncertainties are clearly communicated as part of the design outputs.

Where uncertainties are explicitly allowed for (for example, by the inclusion of freeboard in a defence height), the assumptions made should be clearly recorded. This will enable future design and operational decisions to be based on a full understanding of the original design. For example, how the information on uncertainty is used in designing trigger levels for evacuation during a flood warning may differ from how uncertainty is used when determining the design crest level for a flood defence.

A specific way to understand the effect of uncertainty on the robustness of the design solution is by using sensitivity or scenario analyses – as is typically used to take into account the process model uncertainty related to climate change. The end result of this analysis should be, for each relevant design input parameter, a best estimate plus an understanding of the uncertainty.

There are two principal approaches to dealing with uncertainty during fluvial design:

- the precautionary approach (conservative design);
- the managed/adaptive approach (flexible design).

The approach in conservative design is to increase the certainty of performance. A typical simple example is to design a defence with a higher crest than the design water level through the addition of a freeboard. This approach is generally suitable for managing uncertainty in nature (natural variability).

The other approach is flexible design. For uncertainties with time components such as climate change, this means ensuring the designs can easily be adapted over time as circumstances change or knowledge improves. Examples include accommodating future raisings of crest level by designing a floodwall with stronger foundations, or a flood embankment with a wider crest than currently required.

Where uncertainties can directly impact on performance (such as statistical uncertainty about extreme discharges), flexible design can involve resilience measures such as crest and landward slope protection with a view to reducing the risk of catastrophic failure.

Staged design and construction can also be used where the analyses of the sensitivities or future scenarios show that different solutions or parts of solutions are appropriate for each one. This allows aspects of work to be carried out now that meet the current need, but without preventing the implementation of future approaches when trends become clearer. With such an approach, it is important to understand the points in time at which the next design decisions have to be made in order to allow enough time for scheme development and implementation. These approaches are particularly appropriate for managing knowledge uncertainty.

In reality, the optimum solution is usually a combination of these different methods; a certain level of freeboard to take account of statistical uncertainty, with resilient designs and provisions to make later improvements practicable. The decision about this balance should be based on whole-life considerations, including the feasibility and costs of major improvement.

Deterioration

Design has to take account of the whole life of the assets, including how they deteriorate. Deterioration includes any physical process that the asset undergoes and which impairs its performance.

Deterioration of an asset's flood risk reduction function is directly related to its failure modes. For example, lowering of the defence crest through settlement can cause overtopping at lower water levels than intended, resulting in larger overtopping flows than expected and perhaps causing a breach. Animal infestation can increase the probability of piping, which can again lead to a breach. Similarly, siltation of a watercourse or blockage of a culvert can reduce conveyance capacity, leading to higher water levels than expected for a given flow.

The consideration of deterioration in design typically leads to two types of design criteria:

- minimising deterioration by the choice of materials and structure types;
- taking deterioration into account by considering the expected design life and the need for (and ease of) inspection and repair.

An example of the choice of materials would be the use of imported high quality rock for a revetment rather than locally available poor quality stone that would break down quickly under hydraulic forces. An example of allowing for deterioration would be increasing the thickness of steel in a sheetpile wall to allow for corrosion over the life of the structure (30 to 50 years). Both of these have cost implications, but the savings in future costs and disruption make the extra initial investment worthwhile.

1.4.5 Management of health and safety

The health and safety of all users and managers of the fluvial environment should be a vital consideration when designing in the fluvial environment.

The Construction (Design and Management) Regulations 2007 (CDM) detail the procedures and roles required for all construction projects. The aim of the Regulations is to ensure that, as far as is reasonably practicable, all foreseeable health and safety risks are identified, removed if possible or managed to an acceptable level, as part of the design process, with residual risks identified and documented. Further information on the application of the CDM Regulations is available from the Health and Safety Executive (HSE, 2007) together with supporting guides.

It is essential that designers evaluate the risks for:

- construction workers;
- operatives carrying out maintenance work;
- members of the public who make use of, or gain access to, the completed works.

The early involvement of operational staff in this process is vital. For example, the design of the crest width and slopes and the specified frequency of maintenance of a flood embankment should take account of the requirement for safe access for operation and maintenance such as grass cutting and inspection. Similarly, fluvial designs should avoid the need for access to unsafe areas, such as over or within the watercourse. Examples include making sure that facilities for operating mechanical structures are positioned where they can be accessed and operated safely. For structures over or within watercourses, the use of durable and low-maintenance materials and finishes can reduce the need for operational access, and thus reduce the exposure to risk. Where the need for access is unavoidable, the design and specification should ensure safe operation.

The selection of fluvial works that create confined spaces should be avoided wherever possible; otherwise they should be designed to limit the need for operational access. Interventions to existing systems should also consider the removal or improvement of such conditions. Opportunities for this include ‘daylighting’ of culverts (demolishing at least the crown of a culvert, to re-create an open channel), or the provision of adequate ventilation, access and escape facilities.

Designers should ensure that operators of the works do not have contact with contaminated water if this can be reasonably avoided. This should reduce health risks such as leptospirosis (Weil’s disease).

In general, the management of the health and safety risk should be underpinned by the general risk management principles and approaches set out in Section 1.3.3.

See Chapter 8 (Section 8.8) for further information about health and safety aspects of work in river channels.

1.4.6 Environmental impacts

In line with the government’s sustainable development strategy, the design of works in the fluvial environment should ensure that we live within certain environmental limits and respect the sensitivity of the planet’s environment to change (Wade *et al*, 2007).

To achieve these objectives, fluvial design needs to ensure that it works with the natural systems, and that it identifies and takes account of the wide range of interests that could be affected by any proposed intervention, through the use of environmental impact assessments. Within the fluvial system, these interests often include:

- fish;
- birds;
- bats;
- invertebrates and macrophytes;
- recreational and social features;
- cultural heritage including areas of historic or archaeological importance;
- landscape setting.

Proper consideration of these interests requires an understanding of the baseline conditions, constraints and opportunities, and the development of design solutions with these in mind. This is discussed in more detail in Chapters 3 to 5. The Water Framework Directive sets out important legislation with respect to the ecological status of water bodies, and places strict limits on what are the acceptable impacts of river works. Fluvial design works should always aim to enhance the overall ecological status of the affected watercourses.

Wider impacts such as climate change and energy use should also be considered. It is already clear that anthropogenic carbon dioxide emissions are leading to climate change. The management options we choose, and how they are designed, have a significant impact on the carbon footprint associated with their implementation and whole-life management.

The role of the options appraisal and the design process in reducing such impacts cannot be overemphasised. Subsequent stages, in which the chosen design solutions are being implemented, generally afford less scope for reduction. A good example of this is given in Chapter 9, where the use of compressed tyre bales in a flood embankment reduced the need for imported earth fill and avoided thousands of tyres going to landfill.

Design can be used to:

- reduce energy use;
- make operation and maintenance activities more efficient;
- make better use of materials (including minimising the use of primary materials and aggregates, and the waste generated);
- facilitate eventual decommissioning.

The planning and design process needs to include an understanding of the local availability of materials and sustainable construction and operational processes, and to design around them as much as practicable. Approaches to realising environmental opportunities, reducing environmental impacts and improving the sustainability of flood risk management, including case studies, can be found in *Sustainable flood and coastal erosion risk management* (Wade *et al*, 2007).

1.5 Principles of fluvial design

Box 1.2 sets out some of the principles to which good practice fluvial design should adhere. Further details and basic information to underpin these statements are provided in Section 1.4.

Box 1.2 The eight principles of fluvial design

1 Fluvial design must be **sustainable.** It must aim to work with natural processes and meet the needs of the present without compromising the ability of future generations to meet their own needs. Consequently, all fluvial design work must aim to:

- avoid negative impacts to the river system and users of it;
- be efficient in its use of resources;
- maximise opportunities for win–win scenarios.

2 Fluvial design must consider all stages in the **lifecycle** of the intervention – not only its primary role during its operational life, but also the construction stage at the beginning, its operational and maintenance requirements, and the decommissioning stage at the end.

3 Fluvial design must include engagement with all **stakeholders** from the early stages of a project. This allows early identification of project opportunities and risks. It also helps to ensure that nothing is overlooked, reduces the risk of conflicts arising, and promotes 'ownership' of the project, which may be important once when the scheme is in operation.

4 Fluvial design must adopt a **systems approach**. It has to look at the complete river system insofar is it can be affected by, or may have an impact on, the proposed interventions. This includes potential interaction with surface drainage systems.

5 Fluvial design must be **performance-based**. It has to take account of the mechanisms that can cause failure of the assets to perform as intended. This is relevant for defence assets and their function to defend against flooding, but also for watercourses and their function to convey water. It is also relevant for other functions such as facilitating navigation or improving aquatic habitat.

6 Fluvial design must consider the **full range of loading conditions** that the asset is likely to meet in its design life. Traditionally the practice has been to adopt a design condition such as the 1% annual probability flood and to focus exclusively on this. Such an approach is no longer acceptable and the designer must examine both lower flow conditions (which are much more likely to occur) and extreme floods beyond the design event, in order to reduce the risk of catastrophic failure and other adverse impacts.

7 Fluvial design must be **flexible** and **adaptable.** We cannot accurately predict the future, particularly in terms of global climatic change. Designs should therefore be flexible and adaptable so that changes can be made readily at a later date, if necessary, rather than fully designing now in an attempt to meet an uncertain future requirement.

8 Fluvial design must take account of the inherent **uncertainty** associated with natural events and our understanding of them. Designs should be **robust** and **resilient**, so that they provide the required level of service now and in the future.

Key references

Health and Safety Executive (2007). *Managing health and safety in construction. Construction (Design and Management) Regulations 2007. Approved code of practice*. HSE.

This approved code of practice provides practical advice on how to comply with the duties set out in the CDM Regulations, including that of a designer. Advice within the code can help ensure health and safety is integrated into the whole life management of fluvial design from the start, and not an afterthought or bolt-on extra. This enables early identification of hazards, so they can be eliminated or reduced at the planning and design stages.

Robinson, A, Ogunyoye, F, Guthrie, G, Burgess, T, Brown, C, Chatterton, J and Rickard, C (2007). *Improving data and knowledge management for effective integrated flood and coastal erosion risk management - A guide to good practice.* Defra/Environment Agency R&D Technical Report

FD2323/TR5. Defra. Available from: http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD2323_6150_TRP.pdf

This document provides a framework, guidance and tools to support objective-led data management. In particular, it provides information on establishing the design objectives and data, in assessing the adequacy of available data, and the value or otherwise of obtaining additional data.

Sayers, P B, Gouldby, B P, Simm, J D, Meadowcroft, I and Hall, J (2003). *Risk, performance and uncertainty in flood and coastal defence – a review,* Defra/Environment Agency R&D Technical Report FD 2302/TR1. Defra. Available from: http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD2302_3433_TRP.pdf

This document provides a fundamental understanding of risk, performance and uncertainty as they relate to flood and coastal risk management. It provides information on the variety of methods and tools for assessing risk, performance and uncertainty in the design and associated processes, together with management approaches for addressing them.

Wade, S, Simm, J, Cornell, S, Green, C, Ogunyoye, F, Stark, H, Wallis, M, Asmerom, K, Howe, J and White, I (2007). *Sustainable flood and coastal erosion risk management – Part 1,* Defra/Environment Agency R&D Technical Report FD2015/TR1. Defra. Available from: http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD2015_6140_TRP.pdf

Wade, S, Simm, J, Bowker, P, Wallis, M, Asmerom, K, Ogunyoye, F, Budd, M, Brew, D, Howe, J, Green, C, Cornell, S and Nicholls, A (2007). *Sustainable flood and coastal erosion risk management. – Part 2: Case studies report,* Defra/Environment Agency R&D Technical Report FD2015/TR2. Defra. Available from: http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD2015_6141_TRP.pdf

These documents provide a framework for sustainable flood risk management and management principles. It can help to ensure that opportunities for achieving more sustainable design solutions are identified early and to avoid unsustainable design practices.

Other references

Buijs, F, Simm, J, Wallis, M and Sayers, P (2007). *Performance and reliability of flood and coastal defences,* Joint Defra/Environment Agency Flood and Coastal Erosion Risk Management Research & Development Programme, R&D Technical Report FD2318/TR1. Defra. Available from: http://sciencesearch.defra.gov.uk/Document.aspx?Document=FD2318_5925_TRP.pdf

Communities and Local Government (2006). *Planning Policy Statement 25: Development and flood risk.* The Stationery Office. Available from: http://www.communities.gov.uk/publications/planningandbuilding/pps25floodrisk.

Department for Environment, Food and Rural Affairs (2005). *Making space for water. Taking forward a new Government strategy for flood and coastal erosion risk management in England. First Government response to the autumn 2004 'Making space for water' exercise*. Defra. Available from: http://www.defra.gov.uk/environ/fcd/policy/strategy/firstresponse.pdf.

Institution of Civil Engineers (1996). *Land drainage and flood defence responsibilities*, 3rd edition. Thomas Telford.

Woods-Ballard, B, Kellagher, R, Martin, P, Jefferies, C, Bray, R and Shaffer, P (2007). *The SUDS manual*, Report C697. CIRIA.